

**Persistent Workplace Energy Savings and Awareness
through Intelligent Dashboards:**
Monitoring, Advice, Comparison, Control and Automation

Ph.D. DISSERTATION

Ray Yun

Computational Design
Center for Building Performance and Diagnostics
School of Architecture
Carnegie Mellon University

Advisory Committee

Vivian Loftness, School of Architecture, CMU (Chair)
Azizan Aziz, School of Architecture, CMU
Peter Scupelli, School of Design, CMU
Ramesh Krishnamurti, School of Architecture, CMU

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ABSTRACT

Commercial buildings consume at least 18% of the total electrical energy used in the United States. Over 2.8 billion dollars are wasted every year due to computers being left on during the night and weekend. Yet up to 40% of the plug-load energy consumption can be reduced by behavior change. In the field of Human Computer Interaction (HCI), recent intervention studies have identified that monitoring and controls can motivate more environmentally-focused behavior in residences, where the occupants also have a financial interest. These studies, however, have not adequately addressed behavior in office environments, neither been thoroughly quantified for impact nor fully explored control strategies. This dissertation addresses these limitations through the development of an Intelligent Dashboard for Occupants (ID-O) that provides diverse feedback (self-monitoring, advice, comparison) and control (remote and automated control) features. With an ID-O, through a variety of interventions, one can explore 1) energy conservation, 2) energy awareness, and 3) persistent energy savings. Three intervention strategies are considered in this dissertation in the following order:

- Feedback;
- Feedback and on-line control;
- Feedback, on-line control and automated control

The first two give rise to the following expectation, namely, that there is an increase in energy conservation, energy awareness and persistent energy savings, even after the intervention has been removed. The third strategy suggests that it will (relatively) provide the greatest increase in energy conservation with a (relative) reduction in energy awareness and persistent energy savings, after the intervention has been removed. These then are the hypotheses that underlie this dissertation.

To thoroughly investigate the effectiveness of feedback and control interfaces, the ID-O dashboards were deployed in a large office building over a period of nine months. Eighty employees were recruited and their baseline data was collected for fourteen weeks. With four groups of 20 employees, three different configurations were tested alongside one

control group – one with only feedback (self-monitoring, advice, and comparison), one with feedback and on-line control, and one with feedback, on-line and automated control. The dashboards were in place for thirteen weeks, and then removed for eleven weeks, allowing for measurements of user electricity consumption before, during and after the availability of an Intelligent Dashboard.

During the interventions, the more features that were offered, the greater savings that were achieved. After the interventions were removed, all dashboard groups persistently saved energy with only a slight decrease in savings. Surveys were conducted at the end of the pre, during and post interventions. Between the during- and post-interventions, the biggest awareness increase was found for the group with only feedback and the group with feedback and on-line control. A relatively low increase was measured for the group with feedback, on-line and automated control. The following results were demonstrated:

- Provision of feedback (self-monitoring, advice, and comparison) through energy dashboards increases 1) energy conservation, 2) energy awareness, and 3) persistent energy savings, even after the intervention has been removed.
- Introduction of feedback and on-line controls have greater 1) energy conservation, 2) energy awareness and 3) persistent energy savings, even after the intervention is removed.
- Added intervention by automated calendar controls demonstrated the highest energy savings, after the interventions had been removed. As expected, there is reduced energy awareness, but not reduced persistent energy savings.

Beyond its main contribution on energy conservation, awareness and persistent savings, this dissertation contributes to the increasing field study literature on HCI interface choices specifically focused on energy and behavioral impacts. It also adds to the expanding breadth of existing HCI intervention studies in office environments with greater participant numbers over a longer duration; and provides quantified energy savings from technology-specific plug load management in offices through behavioral change.

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1. INTRODUCTION

Office buildings consume 18% of the total electrical energy in the United States (EIA, 2011). US office workers annually waste 2.8 billion dollars due to computers that are not shut off when the workers leave the office (IEPC, 2009). By not turning off their computers, a large company with 10,000 computers wastes \$260,000 and contributes 1.871 tons of CO₂ to climate change. People's habitual behaviors waste considerable resources and seriously damage the environment. In a study by the New Buildings Institute, monitoring the energy consumption for computers and monitors alone can lead to over 50% energy savings from these devices (Figure 1). In addition to turning off their devices when not in use, other control tools - power management, timers, brightness controls and occupant control can reduce all workstation plug loads up to 40% (NBI, 2012, Figure 2).

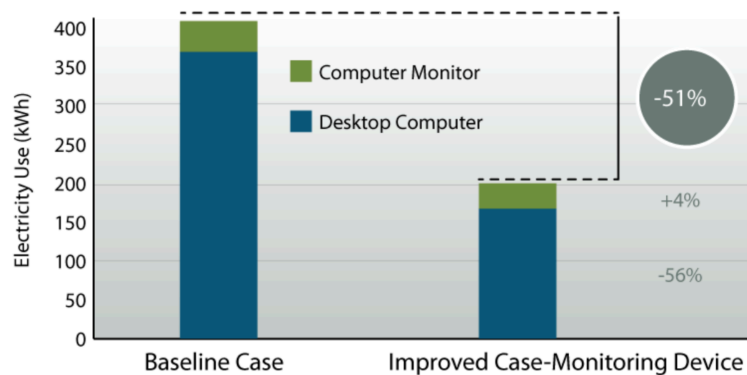


Figure 1. Energy saving from monitoring devices in office buildings (NBI, 2012)

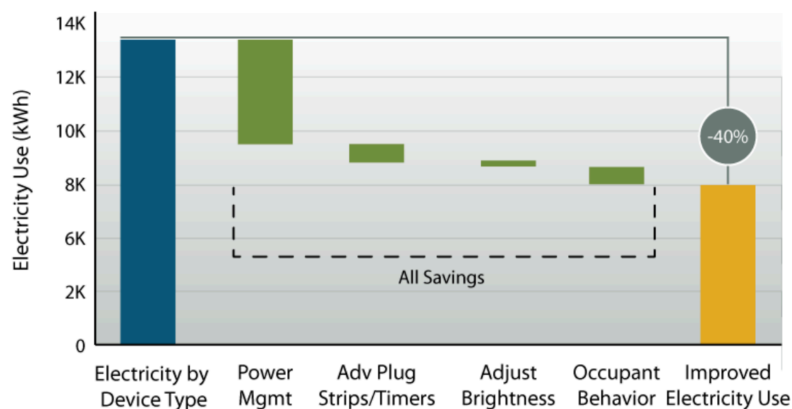


Figure 2. Energy saving from smart control devices, appliance settings, and occupant behavior change in office buildings (NBI, 2012)

Human-Computer Interaction (HCI) researchers have been developing interfaces to promote sustainable behavior including web/mobile energy dashboards (Granderson, 2010; Bartram et al., 2011; Alrowaily et al., 2012; Gamberini et al. 2012), computer games (e.g., Bang et al., 2007; Shiraishi et al., 2009), ambient displays (e.g., Kuznetsov et al., 2010; Kim et al., 2010) and eco-art/visualization (e.g., Holmes, 2007).

These studies have three major limitations. First, many of the studies target household energy use (e.g., Ruijten et al., 2012; Gamberini, et al., 2012), with few studies focused on the domain of the workplace. Unlike domestic users, office workers are not typically responsible for paying for electricity and tend to care little about saving energy in their workplace (Lehrer et al., 2011; Foster et al. 2012).

Second, many of the studies are not thorough in terms of the methods, number of participants, and the length of the study. Froehlich et al. (2010) pointed out that most HCI studies measured behavior change effectiveness from system interventions without having a control group and baseline data (out of 27 studies, none were found that had a control group and baseline data). Moreover, while the average number of participants tested in environmental psychology is 210 and the average study length is 15.5 months, HCI studies on energy behavior have an average of 11 participants and a study length of 2.5 weeks.

Third, strategies of on-line control intervention from a user interface have not been studied in depth. This strategy is an approach to conserve energy by providing individuals with easy ways to control their energy consumption. Fogg (2009) pointed out that the addition of this type of intervention to the traditional interventions (e.g., monitoring, advice, peer comparison) can increase target behaviors. However, on-line controls are a recent development and have not been thoroughly studied yet (Yun et al., 2013a) since this requires “smart” plugs that both monitor and control electricity.

To address the limitations of the currently-published studies, the following hypotheses were established:

- User interfaces (UI) for energy effectiveness in the workplace have been inadequately studied and developed.
- Interfaces with communication alone will not inspire persistent energy savings or increased awareness.
- Interfaces that offer communication and on-line control will inspire energy savings and increased awareness, with significant contribution to individual and organizational sustainability.

The next chapters explore the hypotheses as follows. Chapter 2 reviews the theories and strategies for behavior change and also provides an overview of current dashboard studies and design strategies to display energy feedback. Chapters 3 and 4 provide the overview of the Intelligent Dashboard for Occupants (ID-O), outline the pilot study, and examine the usability of the dashboard. Chapter 5 describes the long-term evaluation of how the strategies affected office workers' energy consumption and Chapter 6 discusses users' perceived sustainability level measurement. Chapter 7 then presents the usability, engagement and perception that dashboard users experienced. Chapter 8 concludes the research and presents the findings, as well as the limitations that should be addressed in future research.

2. DASHBOARDS & BEHAVIOR CHANGE: LITERATURE REVIEW

To understand and investigate user interface (UI) interventions for energy effectiveness, the background literature was reviewed as follows. The review begins at the broadest theoretical level to understand the behavior change process in general. The review then moves to intervention strategies to understand the factors that affect behavior change that leads to energy savings. Then, it reviews the dashboard studies that employed the selected strategies to understand the strategy application. The review ends with the focused design choices used to display energy feedback.

2.1. Review of Behavior Change Theories

Behavior-change researchers develop strategies and investigate intervention effectiveness in terms of improving health, decreasing environmental degradation and exploring other benefits. There are a number of theories and approaches that explain the causes, processes, methods and barriers that influence behavioral change (e.g., Fogg, 2002; Pajares, 2002; Stern et al., 1987; Skinner, 1965). Among other theories, stage-based, behavior-change models are widely employed to explain the process of behavior change. The main idea is that behavior change occurs by progressing through a series of stages. For example in healthcare, the Transtheoretical Model (TTM), also known as the Stages of Change Model, involves five stages (i.e., pre-contemplation, contemplation, planning, action, maintenance) (Prochaska, 1997). In health related studies on stress management, smoking cessation, weight management, adherence to lipid-lowering drugs and the like, surveys were used to identify study participants' stage of change (e.g., Prochaska et al., 1988; O'Connell et al., 1988). Unfortunately, there is limited research on stages of change for sustainability-related behavior, although notable exceptions include (Mair et al., 2013). This chapter discusses about the measurement of sustainability-level changes in combination with the different interventions illustrated in the last chapter.

Previous research (Yun et al., 2013) and Valente (2002) review various behavior change models and five stage-based models were found – TTM (Prochaska et al., 1997), Diffusion of Innovations (Rogers, 1995), Piotrow's Steps to Behavior change (1997),

McGuire's Hierarchy of Effects (1989) and Geller's model (2002). Table 1 illustrates the comparison of the stages of the behavior change models. TTM explains the process of health-behavior change in five stages (Precontemplation – Contemplation – Preparation – Action – Maintenance), Rogers' Diffusion theory demonstrates five stages in the adoption process (Awareness – Persuasion – Decision – Implementation – Confirmation). Piotrow et al. and McGuire expanded the stages of behavior change into a more specific hierarchy for health promotion evaluation as illustrated in Table 1. Geller's model demonstrates four performer behavior stages (unconscious incompetence, conscious incompetence, conscious competence, unconscious competence).

These models contain a similar behavior change process. For example, people do not perform the target behavior at first, because they do not know the value of it. If they realize the value, they move onto the next stage. Even if people know the value of the behavior change, they may not act on that knowledge immediately because they need time to process and assimilate the new information before making decisions. After they decide to change, people perform the target behavior and reach the next stage. The last stage is where people continuously perform the target behavior to the point where it has become habitual.

There are three distinctions among the models. First, Diffusion theory was initially derived from studies on knowledge adoption, whereas the rest of the theories focus on behavior adaption. Second, the TTM model was initially developed to understand the process of quitting bad habits (e.g., quitting smoking), however the rest focus on the process of adopting a new behavior (Valente, 2002). Third, the first four models are associated with health behavior change whereas the last one focuses on environmental behavior change. Geller's model clearly explains the stages of behavior change and more importantly, it focuses on sustainability, therefore his model was employed for the study to investigate an individual's sustainability level.

Table 1. Comparison of Stages behavior change (adapted from Valente, 2002)

Diffusion of Innovations (Rogers, 1995)	Hierarchy of effects (Mcguire, 1989)	Steps to behavior change TTM (Piotrow et al., 1997)	TTM (Prochaska et al. 1992)	Behavior Change for Sustainability (Geller, 2002)
			1. Pre-contemplation	1. Unconscious incompetence
1. Knowledge	1. Recalling message 2. Liking message 3. Comprehending message 4. Knowledge of behavior	1. Recalls message 2. Understands topic 3. Can name source of supply	2. Contemplation	2. Conscious incompetence
2. Persuasion	5. Skill acquisition 6. Yielding to it 7. Memory storage of content	4. Responds favorably 5. Discusses with friends/family 6. Thinks others approve 7. Approves oneself 8. Recognizes that innovation meets need		
3. Decision	8. Information search and retrieval 9. Deciding on basis of retrieval	9. Intends to consult a provider 10. Intends to adopt 11. Go to provider	3. Preparation	
4. Trial	10. Behaving in accordance with decision	12. Initiates use 13. Continues use	4. Action	3. Conscious competence
5. Adoption	11. Reinforcement of desired acts 12. Post-behavior consolidation	14. Experiences benefits 15. Advocates that others practice behavior change 16. Supports practice in the community	5. Maintenance	4. Unconscious competence

One of the limitations of Geller's model is that it focuses on the level of the individual, whereas in the office environment, individual behavior is shaped by a larger context that includes at least the workgroup and organization. The Bioecological Systems Theory by Bronfenbrenner includes such dimensions (Figure 3, 2005). This theory identifies the four layers of environment that affect human development: Microsystem (e.g., family members), Mesosystem (e.g., family gatherings), Exosystem (e.g., family's financial status), and Macrosystem (e.g., law). Later, Chronosystem was added to this model to

explain how humans and the environment change over time (the Process-Person-Context-Time model). With this model, possible factors that influence an office worker's environmental behavior change such as work peers (Microsystem), work meetings (Mesosystem), company campaigns (Exosystem), and company policy (Macrosystem) can be understood.

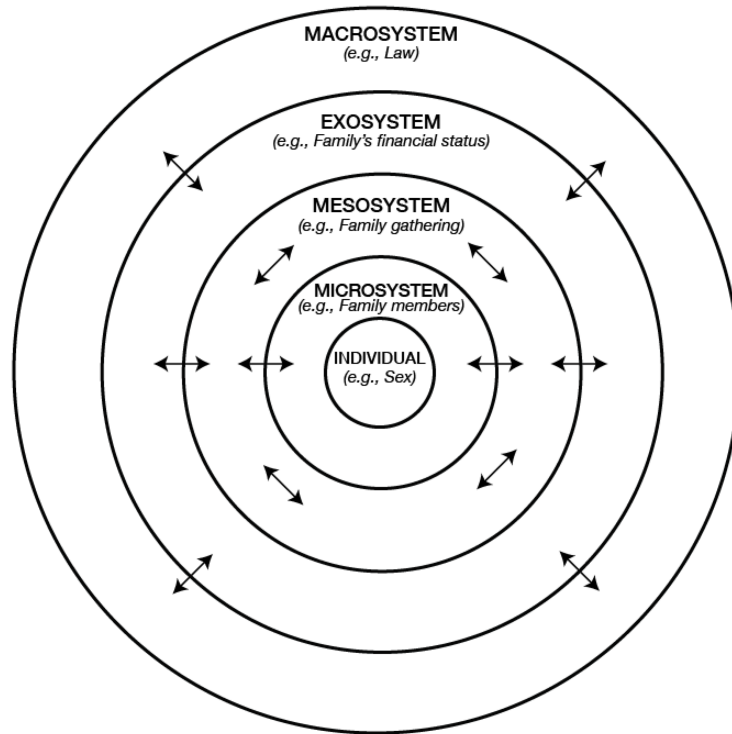


Figure 3. Ecological systems theory by Bronfenbrenner

2.2. Review of Intervention Strategies for Environmental Behavior Change

Motives for human behavior have been widely studied in the field of Psychology. Freud (1915) initially argued that all human motivation is derived from instinctive urge for sex and pleasure. Physiological necessities such as food and drink were also studied as the basis of human motivation (Ryan et al., 2000). Study domain on motivation have been broader since 1960s to safety (e.g., Cunningham et al, 1975), esteem (e.g., Imparato, 1972), work achievement (e.g., Fineman, 1975), exercise (e.g., Dishman et al., 1980), learning (e.g., Gottfried et al., 1996) and many others, and scales for effective motivation measurement were studied and developed (Mayer et al., 2006). The following sections

discuss intervention strategies to motivate energy behavior based on Geller's behavior theory.

2.2.1. Geller's Behavior Change Model

Geller's behavior change model apparently demonstrates the connection between the stages of environmental behavior change and types of interventions. This section adapts Geller's model to explain the nine intervention techniques. Geller calls people that encounter an intervention "performers."

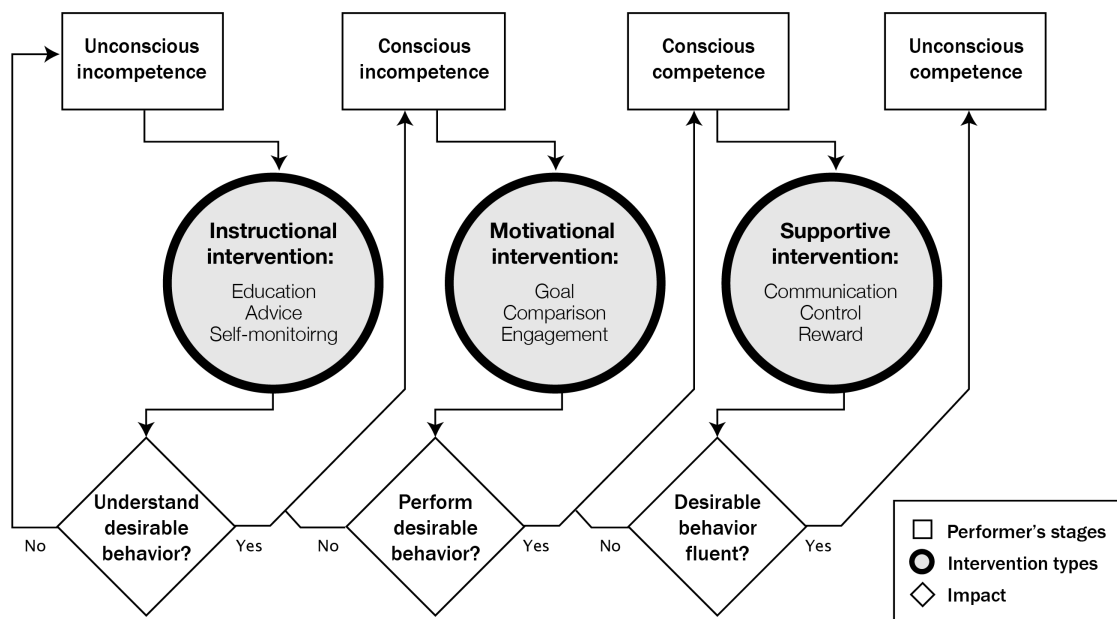


Figure 4. Behavior change model for sustainability (simplified), adapted from Geller (2002).

This demonstrates the four performer's stages and three types of interventions that help a performer move onto the next stage.

Geller's behavior change model consists of four stages of performers and three types of interventions, which help performers move to a next stage (Figure 4). First, unconscious incompetence is the stage where people do not behave in a sustainable way because they do not know how to do it. People in this stage can learn what they could do and/or why it is important. If they understand it, they move to the next performer stage, conscious incompetence. If not, they go back to the first stage. Even if people know what to do,

they may not do it immediately because they need motivation. With the aid of motivational intervention, people can adopt pro-environmental behavior more easily and move to the next stage, conscious competence. In this stage, the person has now acquired environmental knowledge and performed a target behavior, but the goal of behavior change is to make this a habitual behavior. Supportive intervention can help people repeatedly perform the behavior and move to the goal stage, unconscious competence, once the pro-environmental behavior has become routine.

There are three assumptions in Geller's model: the first is that people move linearly from one stage to the next, the second is that they do not relapse, and the third is that people fully understand desirable behavior as a binary state, yes or no. Based on the literature, these are contentious assumptions to make. People oscillate between understanding at a surface level to really understanding in depth, and they progress and regress. If someone answers no to any question they can conceivably move back to any stage, not just to the previous one. Although the assumptions are unproven, Geller's model still clearly demonstrates a performer's behavior change stages in the domain of sustainability. Of the components in the model, this survey focuses on the intervention techniques. Figure 4 shows nine techniques linked to the three primary interventions. Nine techniques are defined and divided them into three groups based on their main characters and functions, but note that they are not mutually exclusive. The following sections discuss the nine techniques in more detail in the context of the workplace.

2.2.2 Instructional Interventions

The techniques for helping people realize they do not have pro-environmental habits include education, advice and self-monitoring.

Education. According to Geller's model, education intervention can allow people with no background information about sustainability (unconscious incompetence) to understand why they should perform sustainable behaviors (conscious incompetence).

In environmental psychology, Winett et al. (1982) studied watching educational videos that demonstrate that sustainable behaviors (e.g. turning down a thermostat) can reduce up to 28% of electricity consumption. Bandura et al (1977) argued that demonstrating desired behavior works better than simply describing the behavior. Fogg (2002) also argued in his book that if a system guides users through a process, it can have greater persuasive power.

Recent research (NEEFUSA, 2009) states many companies are not completely certain how to educate and engage employees to behave in a sustainable way. Forty-nine percent of the 1300 survey respondents in the report said their companies have no or a not-advanced sustainability education program. Leading companies recently put significant effort into building websites that provide online training, run internal campaigns, and share information to improve companies' sustainability (GreenBiz, 2009).

Advice. This approach is to give people suggestions about what they can do to reduce energy consumption. According to the “Sustainability in the Workplace” report (2011), one of the biggest barriers in the workplace that prevents pro-environmental behavior is a lack of ‘how to’ information (unconscious incompetence) Since office workers typically are not the ones who purchase and manage the appliances, written manuals about effective ways to use each appliance (e.g., how to setup the power management for their computers and monitors) will be helpful for them to understand how to save energy (conscious incompetence). There are various methods to convey advice: emails, mobile instant messages, an agent's dialogue messages (e.g., Al Mahmud et al., 2007), icons on a mobile telephone (Froehlich et al., 2009), facial expressions (Yun et al., 2011), missions in a game (e.g., Bang et al., 2007; Shiraishi et al., 2009), and many others.

Fischer (2008) introduced Mosler and Gjutscher's study (2004) that shows how advice intervention can reduce home electricity consumption. In this study, they provide participants with advice on how to reduce electricity usage. As a result, the group that received advice shows a difference of a 14% reduction from the control group with no advice. To design effective advice intervention for the workplace, designers should think

of two aspects: personalized advice and the timing of the advice. To design personalized advice, the system should know the user's context (e.g., what devices individual users have in the office) (Adomavicius et al., 2011). Harrigan, et al. (1994) argues that providing individualized and personalized information can help motivate and guide people's energy consumption. Moreover, if the system knows what time they typically use a device, and what time they leave the office, the system can provide the advice at the appropriate time (e.g. sending a message to turn-off the device before the user leaves the office).

Self-monitoring. This allows people to observe their behavior performance, learn their energy consumption pattern, and explore where they could save energy (conscious incompetence). In environmental psychology studies, monitoring alone can contribute to some energy conservation. For example, Winett et al. (1979) taught participants how to read electricity meters at home and asked them to read and plot the consumption daily. As a result, they showed a 7% reduction compared with the control group.

The literature argues that self-monitoring can be more powerful and lead to bigger energy savings if it provides real-time information, shows appliance-specific data, and compares current data with historic data. For example, energy efficiency-related studies (Fogg, 2002; Fischer 2008; Fitzpatrick et al, 2009) argue that real-time feedback improves interaction between the user and the system (Ehrhardt-Martinez, 2010) and helps motivate the user. Self-monitoring with appliance-specific data is also useful because it allows people to see how or where they could improve their energy conservation (Fischer, 2008). Historic data can be helpful as well because users can better learn about their consumption pattern. Wilhite et al. (1999) argues that providing a historic comparison with last year's data reduced energy consumption by 4%.

According to Foster's research (2012), office workers would prefer a monetary value for monitoring their energy consumption, because it may be more useful and makes the resource more tangible. Various units such as dollars, CO₂, or hamburgers can be used depending on who the users are (e.g., Lucid's Building dashboard).

2.2.3. Motivational Interventions

Even if people learn what to do to improve sustainability via instructive intervention, they may not do it. In this case motivational intervention is needed to stimulate people to make pro-environmental changes. (This turns “conscious incompetence into conscious competence.”) The specific techniques for this type of intervention are goal-setting, comparison, and engagement.

Goal-setting. This intervention is a strategy to motivate people by challenging them to achieve their aim. This strategy has been studied in psychology for a relatively long time. For example, Van Houwelingen et al. (1989) assigned a 10% reduction goal to one group of households and no goal to another group, and showed a 12% energy savings difference (natural gas) when compared with the control group.

In considering goal-setting, previous research suggests that there are several factors in setting a good goal. According to Foster et al. (2012), many office workers feel frustrated when the company assigns unrealistic or unachievable sustainability goals. Shiraishi et al. (2009) argues that a too-challenging and long-term goal may make people unmotivated. To set good goals, companies can quantify and visualize each employee’s performance and assign short-term personal goals to individuals so that they can see their achievement in real-time (FEEFUSA, 2009).

Comparison. This is a strategy to show people their performance and others’ performance to motivate them to change their behavior. Foster et al (2012) showed that office workers could be effectively motivated to perform pro-environmental behaviors when they realize what others do for sustainability (turning conscious incompetence into conscious competence).

Siero et al. (1996) show the comparison intervention can help motivate employees to conserve energy. They provide different information to two units in a metallurgical company. Employees in the first unit received information about their energy consumption and assigned goal, and the second unit received additional information

about the performance of the other unit. As a result, the second unit who received comparative information achieved more energy savings.

To use the comparison strategy in the workplace, comparison targets should be carefully selected. For example, people with similar a jobs and work environments can make relatively fair comparisons. If compared subjects are not similar, e.g., divisions that have different numbers of people, comparisons can be made with converted units such as energy consumption reduction rate per month, or average consumption per person.

Engagement. This is a strategy to appeal to people's emotion or curiosity, and motivate them to perform a pro-environmental behavior. Engagement has not been considered as a primary intervention for motivating energy conservation in environmental psychology. In the HCI community, however, it has been commonly used as a motivational factor by many researchers and designers. The genres are various: Interactive agent/avatar (e.g., Yun et al., 2011, Ruijten et al., 2012), ambient display (e.g., Kuznetsov et al., 2010; Kim et al., 2010), eco-art or eco-visualization (e.g., Holmes, 2007), game (e.g., Bang et al., 2007; Shiraishi et al., 2009) and many others. With an engaging manner, the system can naturally influence behavioral change. For example, virtual characters such as a polar bear (Froehlich et al. 2009), coral (Kim et al., 2010), or human (Yun et al., 2011) can make users feel empathy and perform desired behaviors to keep the character alive or happy. Watkins et al (2000) pointed out that visual attractiveness is a powerful factor for persuasion and Bang argued (2007) that game characters and agents can be more persuasive if they look visually appealing. A recent report (GreenBiz, 2009) states that an eco-art installation in the workplace (which contains a message about sustainability) can easily draw employees' attention, help raise their awareness of sustainability and motivate them to perform desirable behavior turning (unconscious incompetence into conscious incompetence and conscious competence via the engagement intervention).

As stated above, various approaches have been used; however, it is still questionable whether engagement can motivate users for a long time. This intervention alone may be insufficient

for long-term behavior change, so one way designers can think of it is to harness engagement with supportive intervention so that users can be motivated continuously.

2.2.4. Supportive Interventions

Instructional interventions make users aware of their energy usage and ways to reduce their energy consumption. Motivational factors have been shown to be effective in supporting pro-environmental behavior, but are often temporary. However, the desired results are to sustain these new behaviors for the long-term. The techniques for sustaining environmental change are called supportive interventions and consist of communication, control and reward.

Communication. This strategy is to conserve energy in the workplace by providing a communication tool with people with the same interests (social network) or people who have the authority to change facilities. Social network systems are now common and allow people to easily share information, comments and testimonies. Froehlich et al. (2010) argues that social network systems (e.g. Facebook, Twitter) are a good place for social sharing and public commitment about sustainable behavior. Mankoff et al. (2007) argue social networks can increase continuous participation in a social movement. Social networks in the workplace can be beneficial to motivate people in their daily life and can be a good supportive tool to encourage each other in the community for the long term (turning conscious competence into unconscious competence). To harness this strategy for the workplace, however, designers should be aware of the business' culture because the use of social media during the work hours may be allowed in some organizations (e.g. universities) but not in others (e.g. typical offices in companies) (Foster et al., 2012).

Additionally, methods that allow communication with people who manage facilities in the workplace may increase sustainability. Typically people who are in charge of devices in workplace are not office workers but people in the facility management department. When office workers self-monitor their plug loads and realize a certain item consumes too much energy, they can report this and ask their facility manager to fix it or replace it with a more energy-efficient product. Oinas-Kukkonen et al. (2008) also pointed out that if a system

equips with social network and support communication between users, they will more likely use it for persuasive purposes.

Control. This technique is an approach to conserving energy by providing individuals easy and simple ways to control their energy consumption. For example, a system interface can provide a button that controls users' devices based on their settings, and they can press a button to turn on or off a group of devices at once when they come into or leave the office. This transforms the target behaviors into ones that can be achieved more easily and simply, and users can be motivated to do it. This is similar to Fogg's reduction principle (Fogg, 2002). Reducing complex behavior into simple tasks increases the cost/benefit ratio of the behavior and motivates users to perform it (conscious competence) and to repeat it to get the benefit continuously. Although this approach has huge potential for motivating sustainable behaviors, it has not been thoroughly studied yet.

One study (Mercier et al., 2011) has looked at this technique. They demonstrate that advanced controls for office appliances such as remote control plug strips or timer plug strips can reduce respectively up to 55% and 43% of electricity consumption in the office building. This study shows the importance of the use of hardware for control. However it does not explain the impact of the use of user interface for remote control or automated control so further research still needs to be done.

To employ this strategy in the persuasive system, designers should consider the technical challenges of making everything controllable by a single system. Currently, however, at least plug loads (electricity) can be easily controlled with many commercial products such as Plugwise (<http://plugwise.com>) or Enmetric (<http://enmetric.com>). These are small devices that can be connected between an outlet and an appliance's power cord, and give users not only control but also real-time consumption data so that people can easily monitor and control their plug loads. Soon it is expected there will be individual controls for other devices within the office that consume energy such as lighting, heating, cooling and ventilation systems.

Reward. A reward is a prize for the performance of target behavior. Unlike other elements that are designed for “before behavior,” this element occurs “after behavior.” B. F. Skinner (1965) categorized it as a consequence intervention. Because this intervention results from the performer’s behavior and the performer gets motivated by it to perform the behavior again, we categorize it as a supportive intervention.

Environmental psychology studies show that reward intervention can motivate people to conserve energy. Kohlenberg et al. (1976) showed that monetary payment can reduce energy usage. They gave different rewards according to people’s energy savings. (e.g., 5 - 10%: \$2/week, 10-15%: \$3/week, 15-20%: \$5/week). They found that the reward group showed a reduction of 15% compared with the control group.

The reward must be carefully selected for people to consider it worthwhile and also for it to be manageable for companies. Fosters’ study (2012) shows that office workers think about what the potential benefit will be when they are asked to perform a sustainable behavior. Effective rewards that they suggested included saving funds for a Christmas party or receiving coupons for free food in the cafeteria, both relatively realistic and tangible. Other studies (Whilhite et al. 1978; Stern et al., 1987) also show that the larger the reward offered, the better people perform pro-environmental behavior, and a low incentive does not affect people’s behavior. In the field of HCI, virtual rewards (Shiraishi et al., 2009), and emotional rewards (Froehlich et al., 2009; Kim et al., 2010) were introduced but there are not many studies on how virtual or emotional rewards can motivate people and actually contribute to energy conservation.

2.3. Review of Existing Energy Dashboards

Of the nine suggested intervention strategies, this research focuses on the most commonly used informational intervention strategies (Fischer, 2008; Torning et al., 2009) - self-monitoring, advice, comparison - and a relatively new approach, control intervention strategy (Yun et al., 2013). This section reviews the literature focusing on dashboard systems for energy saving that employ these strategies.

Table 2 provides an overview of the relevant studies, the intervention techniques used, and the resulting energy savings. All the studies in the Table 2, employed the self-monitoring technique, and advice and comparison were relatively less commonly used.

Table 2. Summary of dashboard research in households (Note: advanced features - d: distributed monitoring, p: personalized advice, a: automated control)

Studies	Intervention types				Electricity Saving	Number of participants	Study Duration
	Self-monitoring	Advice	Comparison	Control			
Pruitt et al. (2005)	✓	✓			13%	2,600	12 months
Ueno et al. (2006)	✓	✓			9%	19	9 months
Petersen et al. (2007)	✓	✓	✓		32%	Dormitories	5 weeks
CurrentState (2008)	✓			✓a	Not measured	--	--
Foster et al. (2010)			✓		17% (Estimated)	8	18 days
Bartram et al. (2011)	✓d		✓	✓	Not measured	--	--
Weiss et al. (2012)	✓d	✓p			Not measured	--	--
Alrowaily (2012)	✓				4%	9	10 weeks
	✓		✓		15%		
Gamberini et al. (2012)	✓d	✓p			11%	10	4 months

The studies summarized in Table 2 have limitations based on their methodology and domain. The CurrentState system (2008) provides a proof-of-concept idea about the scheduled control but was not implemented. Bartram et al. (2011) and Weiss et al. (2012) introduced advanced features for self-monitoring and advice such as distributed items monitoring and personalized advice, but did not conduct field studies. Several studies measured significant energy savings from their system intervention, however these studies were done on residential areas.

Table 3. Summary of dashboard research in the workplace (Note: advanced features - d: distributed monitoring)

Studies	Intervention type				Electricity Saving	Number of participants	Study Duration
	Self-monitoring	Advice	Comparison	Control			
Granderson et al. (2010)	✓				18 – 35%	2 companies, 2 universities	2 years
	✓				7%		
Carrico et al. (2010)		✓			2%	24 buildings in a university	8 months
	✓	✓			8%		
Building Dashboard (2010)	✓		✓		31% (estimated)	72 buildings in a university	7 weeks
Mercier et al. (2011)	✓d				31%	30	2 months
				✓	36–55%		

The four studies summarized in Table 3 below focus on the four intervention strategies in the domain of workplace. Granderson et al. (2010) conducted the case studies on the energy dashboard for two to three years targeting commercial buildings. This web-based dashboard displays real-time electricity consumption for the whole building and motivates the office workers to save energy. They measured an 18-35% reduction of

energy consumption. The study shows the importance of data displays for the whole building.

Carrico et al. (2010) compared feedback and advice strategies. To provide feedback they emailed the university faculty and staff about the energy performance in messages like, "Smith Hall achieved 12% of electricity saving this month. Keep up the good work!" To provide advice they emailed monthly tips on how to save energy. They conducted this study for eight months (including four months as a baseline study) targeting 352 faculty and staff of a university. The result showed feedback and advice contributed 7% and 2% energy savings respectively and the combined strategy (feedback and advice) showed 8% energy savings. The second study shows the importance of email use about the performance of the whole building.

Lucid's Building dashboard (2010) studied the dashboard that contains two features: self-monitoring and comparison. The web-based dashboard displays the real-time energy consumption of the building the user is in (self-monitoring) and other buildings as well (comparison). This study was conducted in fifty-four buildings on a university campus for seven weeks targeting faculty, staff and students. The result shows \$14000 was saved after the dashboard intervention. This study shows the importance of the use of data display for the whole building and the comparison against others' performance.

Mercier et al. presents a study on self-monitoring and control strategies. They provided plug meters to one group (self-monitoring), and advanced power strips and timers to another group (control) (Figure 5). The devices used in this study are hardware that can only be accessed offline. The study was conducted for two months with forty-eight library staff and thirty office workers. The result shows Library:51%/Office:31% energy saving from self-monitoring and Library:14%/Office:35-55% energy savings with the control strategy. The fourth study shows the importance of the use of distributed monitoring hardware and controls.

Table 4. Summary of commercially available energy dashboards that employ the features – self-monitoring, advice, comparison and control (Note: advanced features - d: distributed monitoring)

Products	Intervention Type				Interface Type
	Self-monitoring	Advice	Comparison	Control	
BLUEline PowerCost	✓				Both
Watson	✓				Both
TED	✓	✓			Both
Google Power Meter	✓	✓	✓		Online
Opower	✓	✓	✓		Online
Building Dashboard	✓	✓	✓		Online
Kill-A-Watt	✓d				Offline
Watts up	✓d				Offline
CurrentCost ENVI	✓d				Offline
Techtoniq Energy Station	✓d	✓p			Offline
Microsoft Hohm	✓(d)	✓(p)			Online
Enmetric	✓d		✓	✓	Online
Plugwise	✓d		✓	✓a	Online
LifeWare	✓d	✓		✓	Online
Onzo	✓d	✓p	✓	✓	Both



Figure 5. The plug meter and advanced control that PIER's study used

In addition to the previous research, there are many commercial products that employ the strategies of self-monitoring, advice, comparison and control. Table 4 provides an overview of the products. BLUEline Powercost, Wattson, and TED (The Energy Detectives) in Figure 6 are systems that display real-time, total electricity consumption within the household. They require a transmitter device that reads the household's electricity meter and receivers that collect the consumption data wireless and display it with text, chart and LED colors on the portable devices. TED sends alerts via email or text messages when the user consumes more energy than usual. These devices are mainly for monitoring the whole domestic building but not the distributed items.



Figure 6. BLUEline Powercost, Wattson, and TED (The Energy Detectives)

Google Powermeter, OPower, and Building Dashboard (Figure 7) also display the electricity consumption data received from a transmitter with the user's preferred units such as kWh, CO₂, \$ and time range such as day, week, month, or year (Self-monitoring). Through the dashboard, email or text message, they provide tips on how to save energy (advice), and display others' energy consumption performance to motivate them to conserve energy (comparison). Google discontinued the service from June 2011 due to

lack of consumers' participation. As described earlier, these software products provide various features to monitor the energy consumption at home or work but the data is still about the whole building so it is hard to monitor item by item, get the personalized advice and peers' energy performance to compare with the users.

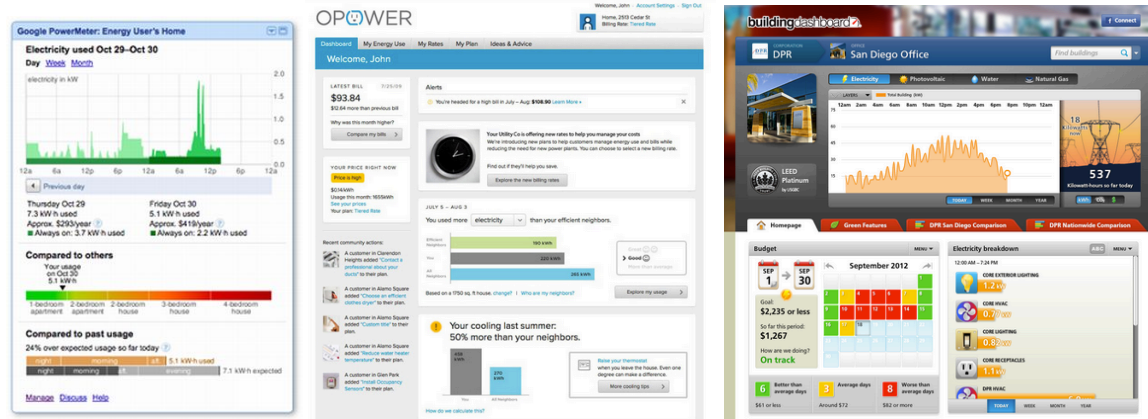


Figure 7. Google Powermeter, OPower, and Lucid's Building Dashboard

Kill-a-Watt, Watts up, ENVY, Energy Station, Microsoft Hohm (Figure 8) provide advanced self-monitoring strategies. Instead of displaying the whole building's energy consumption, they present energy consumption item by item by using distributed plug meters. (Microsoft Hohm predicts user's distributed energy consumption using the survey and an algorithm). By monitoring distributed energy consumption, users can track their energy usage pattern and find opportunity to save energy. Also, the system can provide more personalized advice to the users. CurrentCost EnVI and Techtoniq have a partnership and are in charge of hardware and software respectively.



Figure 8. Kill-a-Watt, Watts up, ENVY, Energy Station, Microsoft Hohm

Enmetric, Plugwise, LifeWare, ONZO (Figure 9) added a control strategy to their system. They designed their plug meters to do two-way (wireless) communication between the server and the meters (e.g., using Zigbee communication) so with the systems users now can remote-control the individual meters. In others words the individual plug devices are not only for metering but also for controlling, and users can remotely monitor and turn on/off their appliances using a web or mobile application.

Thus, companies put effort into developing innovative systems using the described strategies to contribute to energy conservation. However, most of the products are not properly evaluated in terms of their effectiveness for persistent energy savings and energy awareness.



Figure 9. Enmetric, Plugwise, LifeWare, ONZO

2.4. Review of Eco-feedback Presentation Strategies

To understand effective UI interventions, the previous chapters reviewed relevant intervention types and the dashboard studies that employed them. This chapter reviews design strategies that display energy feedback in a dashboard system. A strategy of feedback on energy consumption (eco-feedback) has been widely studied and has resulted in behavior modification and energy conservation. Ehrhardt-Martinez et al. (2010) illustrate in their paper how the eco-feedback strategy has evolved. The typical feedback is about energy consumption for the whole building (or household) on a monthly basis. Researchers have added supportive feedback features to the display, such as historical consumption, comparison to other buildings (or households), (generic) advice on saving energy, frequent feedback delivery (e.g., weekly or daily), and web access. These additions increased energy savings up to 8.4 percent. The recent approach of eco-feedback is to integrate smart meters and an information system that provide users with immediate feedback and appliance-specific energy consumption data. This strategy produced an energy savings improvement of up to 12.0 percent.

Other meta-reviews (Ehrhardt-Martinez et al., 2010; Darby, 2006; Fischer, 2008; Abrahmse et al., 2005; Steg et al., 2009) also reveal a wide range of energy savings produced by different eco-feedback studies, from 3% to 55%. Jain et al. pointed out that this wide range highlights the lack of researchers' understanding of how specific display features should be designed. Fitzpatrick et al. also argue that there are very few guidelines on how to present the feedback information clearly. Froehlich et al. (2009) point out that many eco-feedback studies focus on measuring the energy savings without

evaluating the usability of their system user interface (UI). Karjalainen et al. (2011) highlight the lack of information on effective and preferred kinds of feedback. Roberts et al. (2003) argue that the literature dismisses the manner of feedback representation. In response, this paper summarizes findings on eco-feedback design from existing studies, illustrates the survey findings to highlight what is not clear in other studies, and provides a set of design suggestions for eco-feedback.

According to the review papers (Ehrhardt-Martinez et al., 2010; Darby, 2006; Fischer, 2008; Abrahamse et al., 2005; Steg et al., 2009) on eco-feedback design, the desired strategies for effective eco-feedback are as follows.

2.4.1. Real-time Feedback

Real-time feedback enables users to monitor their energy usage in real time and receive immediate feedback regarding their energy performance (Roberts et al., 2003). Darby's meta-review shows immediate feedback can reduce energy usage by 5% more than feedback without a real-time feature. In Fitzpatrick et al. (2009)'s survey, 49% of people preferred real-time feedback (33%-when they receive their bills, 28%-when something changes) and all the participants in their field study also responded that real-time feedback raised their energy awareness the most. Immediate and frequent feedback has a high potential to save a great amount of energy, but should be given only at the user's demand (Darby, 2006). If the feedback is too frequent, it will reduce the user's engagement with the system (Yun et al., 2013).

2.4.2. Disaggregated (appliance-specific) Feedback

Disaggregated feedback provides people with the consumption information of each of their individual appliances. With the feedback, users can understand which devices use more energy than others and learn what they can do to save energy (Roberts et al. 2003). Fischer states that an appliance-specific breakdown requires very “sophisticated” technology and Ehrhardt-Martinez et al. (2010) rank disaggregated feedback in real-time as the most advanced strategy, and termed it “real-time plus.” Fitzpatrick et al. (2009)

point out that disaggregated feedback can also increase users' engagement with the energy display by realizing when they efficiently or inefficiently use a certain device. Energy displays that employed these strategies report 9-18% energy savings (Ehrhardt-Martinez et al., 2010).

2.4.3. Historical and Social Comparison

Froehlich et al. (2010) state that historical and social comparisons are a fundamental part of feedback display. Historical comparison allows users to compare their current data to prior data. Jain et al. (2012) state that this feature allows users to recall their behavior, infer the reason for high-energy usage, and devise strategies to improve their energy consumption pattern. Darby (2006) argues that historical comparison is one of the most important eco-feedback strategies, along with real-time feedback and cost information. Karjalainen et al. (2011) point out the energy consumption data should be normalized by seasonal factors (e.g., weather) when historical comparison is used. Froehlich et al. (2010) state that historical comparison emphasizes the relative difference and can reduce the importance of understanding measurement units.

Another type of comparison, social comparison, allows users to compare their consumption data with others'. Siero et al. (1996) show that presenting comparison data can help motivate office workers to conserve energy. Ehrhardt-Martinez et al. (2010) argue that social comparison requires complex data sources and calculation, but once it is designed correctly, it is relatively low cost and can lead to energy savings. Karjalainen et al. (2011) and Yun et al. (2013) state that comparison feedback can be relevant and effective only when it compares similar groups of people (e.g., similar income or job groups). Abrahamse et al. (2005) argue that social comparison should not be employed alone but with individual feedback to maximize the effectiveness of the strategy. Foster et al. (2012) point out that privacy issues need to be considered in case individual data is disclosed.

2.4.4. Metrics (Measurement Unit)

KWh, Cost, and CO₂ are commonly used for eco-feedback representation. KWh is a direct electricity consumption unit and the most commonly used unit. According to Wood et al. (2007), kWh is not easy for the average person to use in estimating energy consumption due to the limited understanding of this scientific metric. This unit can be more effective when used together with other supportive tools such as charts or other graphics (Roberts et al., 2003).

Cost is the most easily understandable unit for eco-feedback representation because people are already familiar with this unit. However, monetary electricity savings are typically very low; personal expenditure per day or week could be ineffective or even unhelpful to motivate people to save energy (Wood et al., 2007). Researchers (Fitzpatrick et al., 2009; Wood et al., 2007; Wolsink et al., 1997) suggest using long-term potential savings (e.g. 1 year) or organizational-level savings (e.g. energy savings that can be achieved if 5000 employees execute similar actions).

CO₂ emission is another commonly used metric. This unit shows the environmental impact index based on the user's energy consumption. This unit has been employed in eco-feedback studies (e.g., Jain et al., 2013, Grevet et al., 2010; Vassileva et al., 2012) and many commercial energy displays (see Table 5). Similar to kWh, the CO₂ metric is not easily understood by users (Jain et al., 2013; Fitzpatrick et al., 2009). To improve clarity to this metric, the tree unit (e.g. the number of trees needed to offset CO₂ emission) has also been introduced (e.g. Wood et al., 2007). Lucid Design's Building dashboard attempts to show a series of units, such as pounds of coal, number of hamburgers, or miles driven in a bus, for the building's electricity consumption to increase users' engagement. Yet few studies have evaluated the effectiveness or engagement of the various units and the impact of energy conservation from each unit. (Jain et al., 2013)

2.4.5. Advice

Advice provides people with suggestions for reducing energy consumption. Sustainability in the workplace report (2011) states that a lack of ‘how to’ information can be one of the biggest barriers that prevents energy-efficient behavior. Fischer (2008) introduced Mosler and Gjutscher’s study that shows advice can reduce electricity consumption by 14% .

Yun et al. (2013) suggest that advice can be more effective if the advice is personalized (e.g., You left your light on last night, please turn it off tonight.) and the timing of the advice is appropriate (e.g. display advice right before the user leaves the office). Roberts et al. (2003) and Darby (2008) state that advice can greatly support energy savings if it is used with other eco-feedback data.

Table 5. Chart, metrics, and advice use for commercial eco-feedback systems

	Main Chart (default)			Breakdown Level	Comparison	Metrics				Advice
	Type	Range	Interval			kWh	Cost	CO ₂	Others	
Lucid’s										
Building Dashboard	Bar	Day	Hourly	Building	Building	✓	✓	✓	✓	Generic
Opower	Line	Month	Daily	Building	Building	✓	✓	✓	-	Generic
Plugwise	Bar	Day	Hourly	Appliance	Appliance	✓	✓	✓	-	-
Enmetric	Bar	Day	Hourly	Appliance	Appliance	✓	✓	✓	-	-
Hohm	Line	6 hours	30 secs	Appliance (by algorithm)	Building	✓	✓	✓	-	Personalized (by algorithm)
Powermeter	Bar	2 days	15 mins	Building	Building	✓	✓	-	-	-
CurrentCost	Line	Day	6 secs	Building	-	✓	✓	✓	-	-
BertBrain	Bar	Day	Hourly	Appliance	Appliance	✓	-	-	-	-

The preceding summary gave examples of studies on eco-feedback design. What continues to be lacking is how this information should be represented. A number of design questions still remain, such as what type of chart is most effective to display disaggregated energy data? Or what time interval and time range should be used in the chart? Table 5 shows what the default features in commercial eco-feedback systems. Since Google Powermeter and Microsoft Hohm discontinued service in 2011 and 2012

respectively, their features were analogized based on online reviews and screenshots. The contents in Table 5 are based on the default display settings of the main chart. As shown in the table, each energy display provides different types of charts, time ranges, and time intervals, among other information. Although some of the systems provide options to display other chart types or time ranges, the default design is important because it can increase or decrease the usability and engagement of the whole system.

2.5. Research Hypotheses

The purpose of this research is to investigate if user interface (UI) interventions influence workstation energy consumption. While there have been efforts to develop dashboards to motivate people to behave in an environmentally-conscious way, little has been developed for the workplace domain, evaluated thoroughly with a large sample size and a lengthy study, or that has employed advanced techniques such as on-line plug-control or automated plug-control strategies. This research aims to address some of the limitations in previous studies. To effectively compare the effectiveness of the intervention strategies selected in this chapter, intelligent dashboards for occupants (ID-O) were developed based on the literature review (Chapter 2), pilot studies (Chapter 3), and usability studies (Chapter 4). A long-term, large-scale field study was conducted (Chapter 5) and three outcomes were measured: 1) dashboard energy savings, 2) energy awareness, and 3) persistent energy savings after the dashboard is removed. Three intervention strategies are considered in this dissertation in the following order:

- Feedback;
- Feedback and on-line control;
- Feedback, on-line control and automated control

The first two give rise to the following expectation, namely, that there is an increase in energy conservation, energy awareness and persistent energy savings, even after the intervention has been removed. The third strategy suggests that it will (relatively) provide the greatest increase in energy conservation with a (relative) reduction in energy

awareness and persistent energy savings, after the intervention has been removed. These then are the hypotheses that underlie this dissertation.

This chapter reviews the theories and strategies behind behavior change and also provides an overview of current dashboard systems and strategies for presenting energy feedback strategies. It was found that Geller's model illustrates environmental behavior change process clearly, so this dissertation adapts the model to explain the intervention strategies and plan the rest of the study. The review shows there are relatively few studies that investigate within the domain of the workplace. Commercial systems have recently started employing the advanced strategies, but they have not been properly evaluated yet to see their effectiveness. It was also found that there are few design guidelines on how to present the eco-feedback information. The following chapters address the limitations and examine the hypotheses illustrated in this chapter through a series of field studies and lab-based studies with Intelligent Dashboards for Occupants (ID-O).

3. ID-O DEVELOPMENT AND PILOT STUDY

This chapter demonstrates the Intelligent Dashboard for Occupants (ID-O) developed for evaluating the research hypotheses introduced in the previous chapter. Preliminary field studies were conducted to evaluate the system.

3.1 System Structure

To enable monitoring and controlling each desktop technology's electricity usage, plug meter/control devices are required. For the duration of this research, a product manufactured in Holland, Plugwise™ was used for each connected technology to measure electricity consumption and to allow the users to control these items through digital media (<http://plugwise.com>).



Figure 10. Plugwise circle (left) and the network between the circles and the server (right)

In Figure 10, the Plugwise device (left), is set within a network of such devices to form a circle that wirelessly transmits power consumption to a server. The Plugwise Circle™ allows on/off settings and energy consumption information to be sent to the Plugwise server in real time using a Zigbee protocol, and allows for control commands to be sent back to the Plugwise device.

To support the development of an intelligent dashboard with user-friendly interfaces, the python program at the local server collects real-time Plugwise data and sends it to a web server, hosted by Dreamhost (<http://dreamhost.com/>). The web server contains a MySQL database that maintains four layers of information:

- user information (user_id, password, email, activation, group_id),
- appliance information (app_id, app_name, app_type, app_demand, app_sensitivity, app_power_mode, app_energy_hog, app_on_off, app_threshold_idle, app_threshold_sleep, plugwise_id, plugwise_status, owner_id),
- appliance group information (group_id, owner_id, group_name, activated, group_order), recommendations (appliance_id, recommendations),
- an appliance's hourly data (time_stamp, app_1, app_2, ... app_50) and its daily data (time_stamp, app_1, app_2, ... app_50).

Data coming from individual Plugwise circles are stored in two different Database tables (appliance's hourly data, appliance's daily data) to enable fast data retrieval.

When users remotely control their appliances from the dashboard by pressing the on or off buttons, this changes one of the attribute values in the appliance information database (*app_on_off*) that is assigned to each appliance. The Python program at the local server checks the values every second, and once the value is changed, the server sends the command to the circles to turn the appliances on or off.

To minimize traffic issues, the ID-O indirectly communicates with the Plugwise server through a complementary web server acting as a mediator, reducing web traffic to the Plugwise server. It also allows for better security since there is no need for external access to the Plugwise server. The overall architecture of the system is represented in Figure 11.

The server has several processes built in to guarantee it will function properly. To avoid missing data during a server crash, the system checks the server every fifteen minutes internally and also has an external process to check its functionality. Once the server is down, the system sends notification emails to the research team members. Once the

server is restarted by one of the team members, the system automatically updates the accumulated missing data and restarts to update the current data.

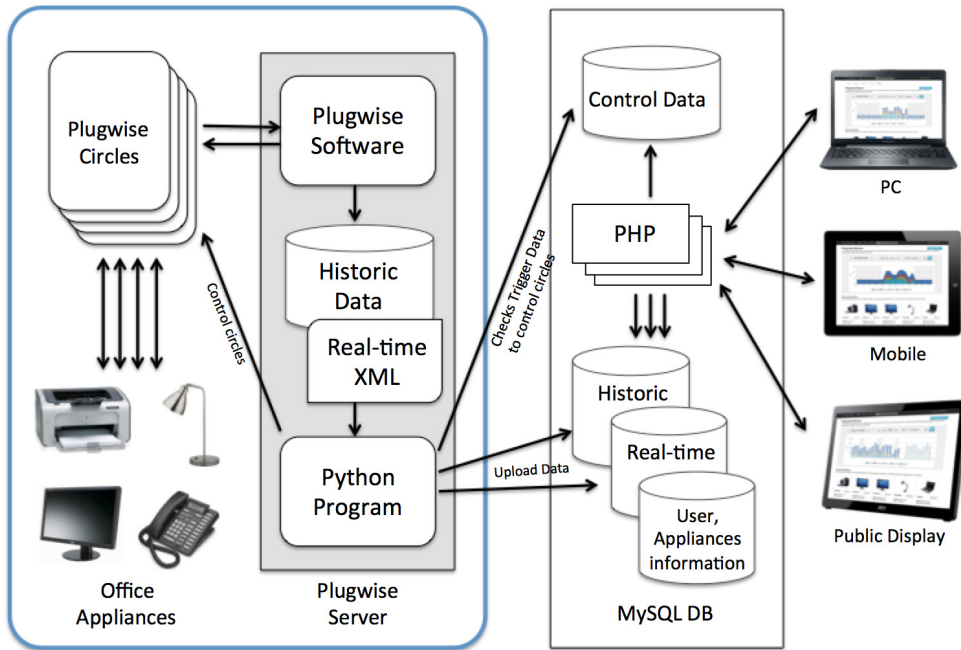


Figure 11. ID-O system structure

Using the data from the web server, the Intelligent Dashboard for Occupants creates bar charts and linear plots for self-monitoring or comparison, provides personal recommendations, and allows users to remotely control their appliances. To develop the web-based dashboard, PHP language is used. The data from Plugwise, user information, appliance information, and all other dynamic information that users can view in the dashboard comes from the MySQL database. PHP scripts retrieve the needed data from the database and display them on the web interface. For the chart representation, Highchart's Javascript-based chart library is used (<http://www.highcharts.com/>). For styling the overall web components (e.g., buttons, popup windows, fonts, colors), Bootstrap CSS library is used (<http://twitter.github.io/bootstrap/>). In the next section, the features implemented in the dashboard will be discussed as they evolved over the course of the dissertation.



Figure 12. 2nd generation dashboard screenshot

3.2. System Features

Based on the literature review and early field research, at least five variables were deemed critical to effective user interfaces for plug load control: self-monitoring, comparisons, advice, and two types of control – on-off and automated. The features developed for the study are further described in the following sections

3.2.1. Self-monitoring

If energy consumption data is displayed 1) item by item 2) in real time, and 3) with historical data, it can help motivate users to save more energy (Fogg, 2002; Fischer 2008; Fitzpatrick et al, 2009). While it used to be technically difficult to build an individual plug monitoring system, companies such as Plugwise and Enmetric have released products to support this feature. The Intelligent Dashboard for occupants (ID-O) collects users' electricity usage data from the Plugwise circles, mines it for the various features, and then visualizes it for the consumer (Figure 12).

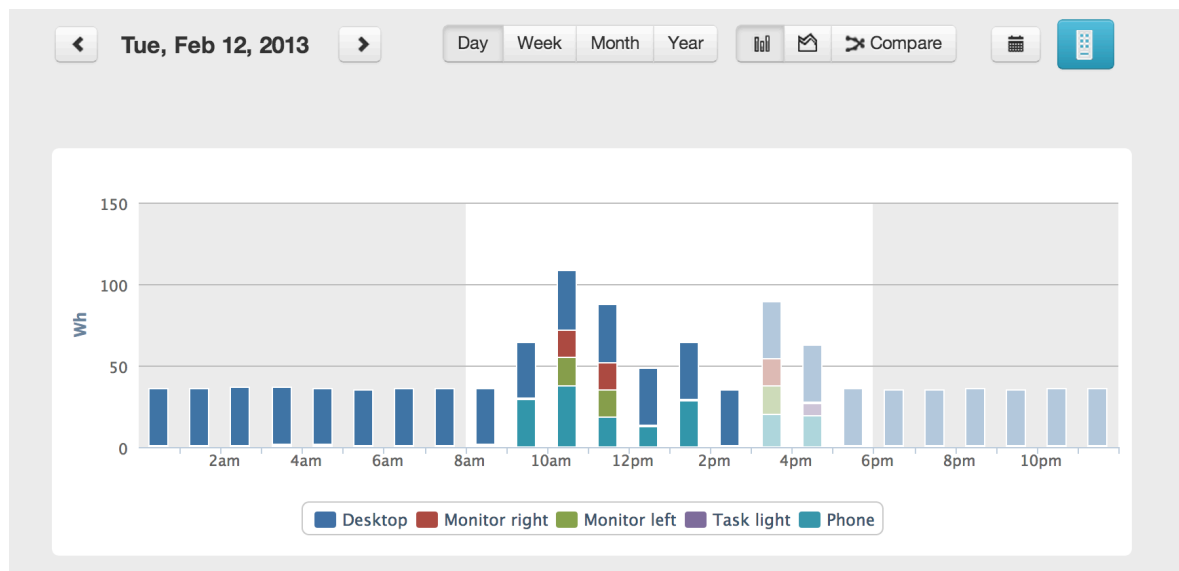


Figure 13. ID-O's chart for self-monitoring

The Intelligent Dashboard for occupants (ID-O) provides views of data usage in different time ranges (day, week, month, year) and chart types (bar, area, 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.

Based on the design usability study (see Chapter 5), area charts for the week were chosen as the default in the self-monitoring section since these give the quickest overview of energy use by device and time of day or week. The Intelligent Dashboard displays the overall week's consumption in hourly intervals, with the energy use of each monitored device differentiated by color. Other chart types (bar chart) and time ranges (day or month) are available to the user by toggling to view the data from other perspectives.

The self-monitoring features are categorized as instructional interventions in Geller's behavior change model (Section 2.2.1). They aid in increasing users' energy awareness by providing information of when and where the energy waste occurs.

3.2.2. Advice

The second feature of the Intelligent Dashboard for occupants (ID-O) is advice (Figure 14). The first generation dashboard's advice section provided four types of information – the operating mode, system sensitivity to control (type), and short-term and long-term recommendations.

- Mode refers to the current power mode of the appliance - active / idle / standby / off.
- Type refers to the equipment sensitivity -sensitive / non-sensitive / special- for safe remote control.
- The short-term recommendation can be enacted immediately to save electricity (e.g., turn off the task light), and
- The long-term recommendation can be acted on over the long term to reduce electricity usage (e.g., replace the task light with a more energy-efficient product).

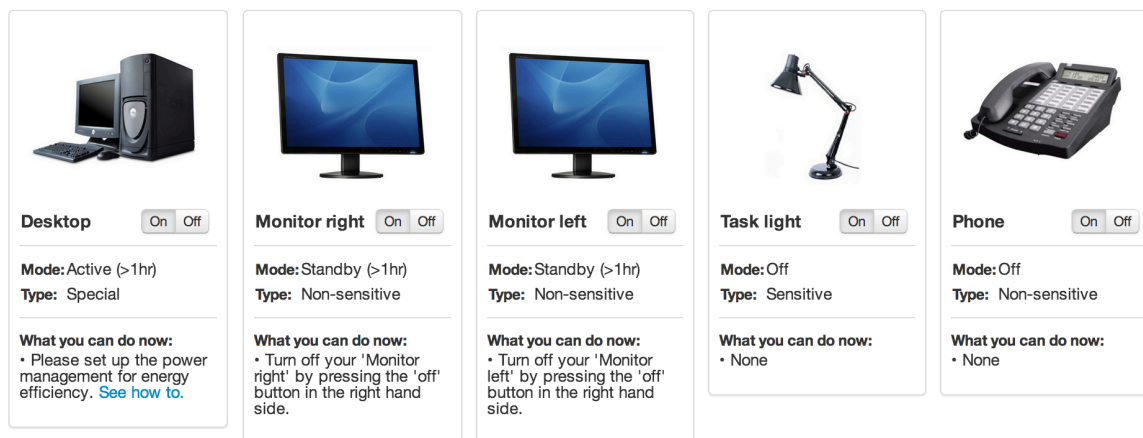


Figure 14. ID-O's advice section

The recommendations used in the first generation dashboard were generated based on a decision tree created by using each device's current power mode (active / idle / sleep / off), sensitivity (sensitive / non-sensitive / special) and the employee's typical work hours (8am – 6pm). For example, if it is 4pm in a weekday and the task light is on, the system thinks the user is using it and doesn't suggest a short-term recommendation. But if it is 9 pm and the appliance is still on and it is a non-sensitive item, then a recommendation is made to turn it off. This can be done remotely using the on-off button on the dashboard, a functionality that could be transferred to smart phones as well. Recommendations extend beyond turning off specific items when not in use, to include setting up power management if it is a computer or a printer that is consuming comparatively high amounts of energy. A long-term recommendation suggests replacing an energy hog device with an energy-efficient one such as an Energy Star™ product to eventually save energy over the long-term.

While the first generation dashboard already identified what the user can do to improve the performance, the next version added the amount of energy that could be saved if a certain behavior is performed in percentages. This was estimated based on the California Energy Commission (PIER) report entitled – Commercial office plug load savings and assessment (2011) - and appeared on the dashboard as a message like this, “adjusting the monitor's brightness can save up to 10% of its energy usage.”

Along with the self-monitoring features, advice is also categorized as instructional intervention in Geller's theory. Users learn their energy usage performance through self-monitoring features, and then how to improve their performance through advice features.

3.2.3. Peer and Self Comparisons

Two types of comparisons were developed to inspire the users to more energy effective behavior: comparisons with their peers and self-comparisons over time.

When the peer compare mode is selected by the individual, the Intelligent Dashboard for Occupants (ID-O) provides a linear energy use chart that displays three consumption trends: the energy consumption of the user, the office average, and the best person in the office (Figure 15). The blue shaded area represents the user's personal energy usage at work, most clearly read on the chart. This data is the hourly total of the user's appliances connected to the Plugwise circles. The red line represents the average value of the employees' energy usage in the office. The green line represents the best person in the office's energy consumption. The best person is defined as the one who consumes the least energy for the day, week or month depending on the period selected. With the comparison chart, users can monitor their energy performances compared with others' as a motivator and reward for more energy efficient behavior.

Based on the results of the survey (see Chapter 5), line charts were preferred over bar charts for peer competition. In a time-series chart, the line chart shows the result of a user's performance compared to the average and the best person's performance, such as "Your energy consumption this month is 32% better than the average and 9% worse than the best person in the group." Some users worked to have their energy profile be the best in the office.

Peer comparison is categorized as a motivational intervention in Geller's behavior change model. Users can be motivated to save energy by comparing one's performance over the average and best practice in a user group.

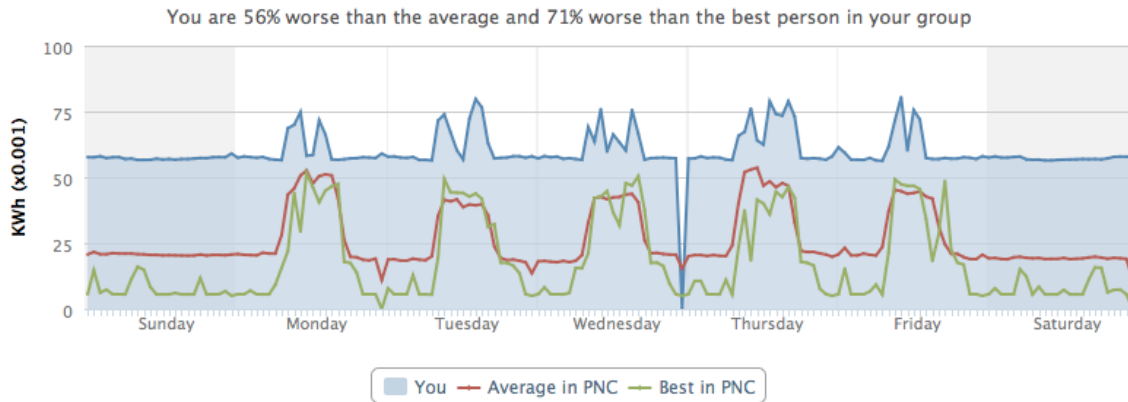


Figure 15. ID-O's chart for comparison

For self-motivation, an individual's behavioral effectiveness is calculated as the ratio between the optimal use of the appliance (power in active mode x number of occupied working hours) and the total energy consumption over the measured period (Lasternas et al., 2014). The dashboard displays behavior effectiveness with a colored bar and the percentage number to indicate poor, average and good behavior (i.e., < 33%: red; 33 - 66%: yellow; >67%: green). This performance index was developed to support user behavior regardless of the quality of technology they have been given, since most office workers do not have the luxury of choosing their own energy efficient computer, screen or light fixture. They do have the power to improve the performance of whatever equipment they have been given, however, through settings and time management. The black vertical line through the colored bar represents the past effectiveness (e.g., last week or last month based on the user selected period of interest), so that users can see whether their behavior effectiveness is better than in the past. Most users strove to get each of their behavioral effectiveness bars to move to green positions.

Self-comparison can play both roles of instructional and motivational interventions. From self-comparison, users can learn how good or bad their performance is and be motivated to perform better by comparing the most recent one to past ones. Based on the usability survey conducted after the field experiment (Chapter 7), this feature was selected as one of the most motivating features.

3.2.4. Cost Savings

Another feature that was added to the dashboard was cost savings, indicating what each individual's actions would mean for the organization as an instructional intervention in Geller's model. As stated in Section 2.4, cost is the most easily understandable unit for eco-feedback representation because people are already familiar with this unit. A survey that the research team conducted with four hundred attendees at the Greenbuild 2013 conference also identified the dollar as the most motivating form of measurement for office workers. For the experiment, the team assigned one of five roles (i.e., office worker, building owner/executive, politician, teenager, and green team member) to each participant and showed metric examples to represent environmental index (e.g., dollar, power plant, kWh, Car, CO₂, Saving %, House, Tree). Then, the team asked respondents to rank the metrics in order of how much they motivated them to save energy. Figure 17 shows the dollar is the most popular metric for all the roles except for the teenager group (The dollar was ranked second for teenagers). The dollar metric was preferred significantly more than other metrics for all the groups except a few cases and the * represents the ones that have no statistical difference from the dollar metric.

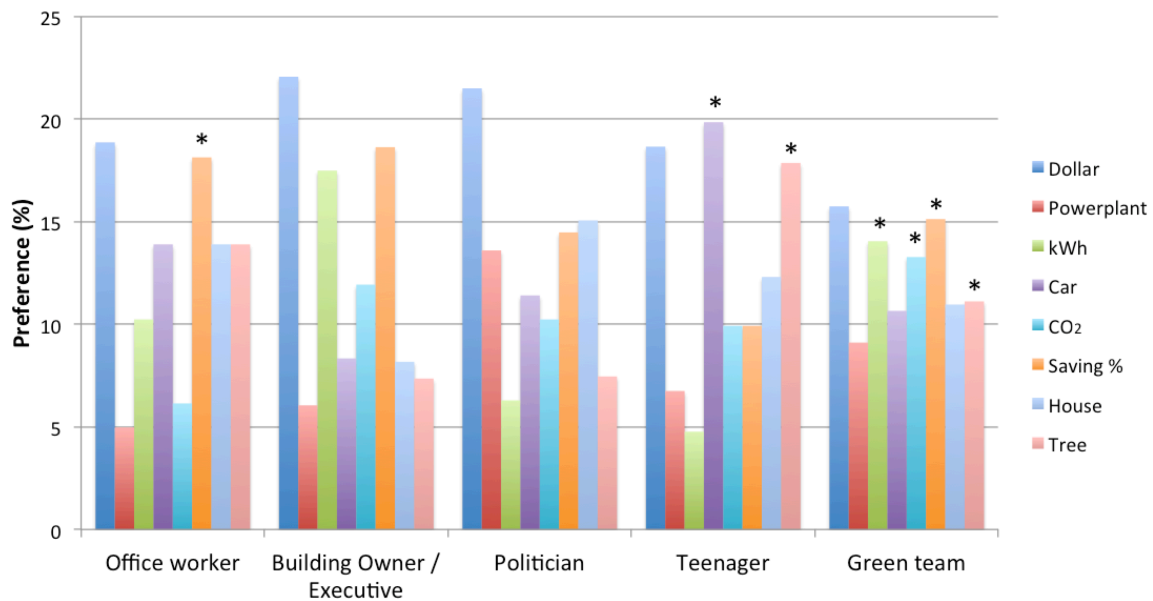
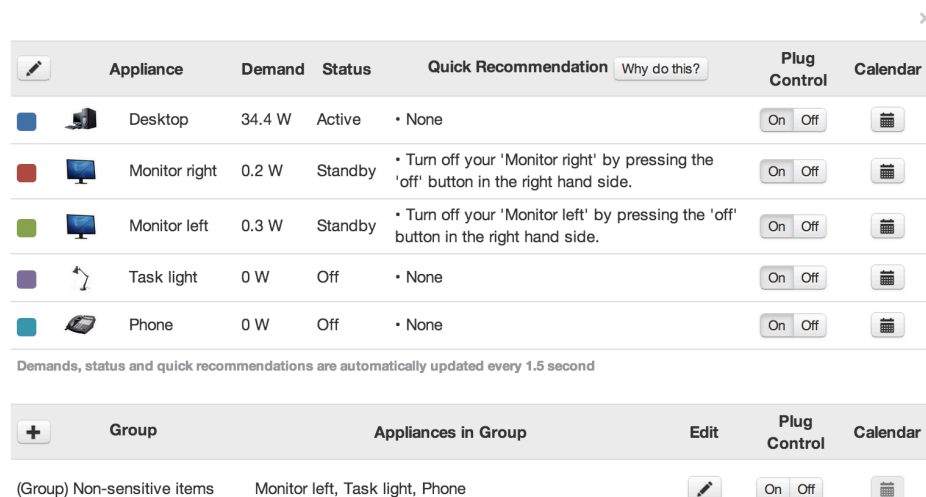


Figure 16. Metric preference survey result conducted at Greenbuild'13

However, Fitzpatrick et al. (2009) and Foster et al. (Wood, 2007) argue that the cost for an individual person may demotivate people to save electricity since the monetary value of electricity savings are typically very low. Therefore, to make the cost information effective, the Intelligent Dashboard was designed to show the organization scale cost/saving information such as, “If all the employees at ABC company behaved as you have last month, the savings would be \$10,491.”

3.2.5. Controls : Two Options

The last strategy feature of the Intelligent Dashboard for Occupants (ID-O) was to provide for on-line on-off and automated control. In order for office workers to safely control their items with the web-based application, the sensitivity of typical office devices is identified. Electrical devices are categorized as sensitive, special, and non-special. For example, desktop computers are categorized as *sensitive* because remotely turning them off by disconnecting the electricity supply can badly affect them. Also the following items are categorized as *special*: 1) monitors to view the dashboard, 2) modems and routers to enable network connectivity, and 3) refrigerators that should be on all the time. All the rest are categorized as remotely-controllable items, *non-sensitive* (e.g., fan, lamp, or secondary monitor).



Appliance	Demand	Status	Quick Recommendation	Why do this?	Plug Control	Calendar
Desktop	34.4 W	Active	• None		On Off	
Monitor right	0.2 W	Standby	• Turn off your 'Monitor right' by pressing the 'off' button in the right hand side.		On Off	
Monitor left	0.3 W	Standby	• Turn off your 'Monitor left' by pressing the 'off' button in the right hand side.		On Off	
Task light	0 W	Off	• None		On Off	
Phone	0 W	Off	• None		On Off	

Demands, status and quick recommendations are automatically updated every 1.5 second

Group	Appliances in Group	Edit	Plug Control	Calendar
(Group) Non-sensitive items	Monitor left, Task light, Phone		On Off	

Figure 17. ID-O's control panel

The dashboard allows users to control the items not only individually but also as a group. For example, at the bottom of Figure 17, a monitor, a task light and a phone are grouped. When the user presses the ‘off’ button for a row, it turns off everything in the group at once. Again, when the control button is pressed, instead of sending the command to the Plugwise server, it changes the Boolean value in the database first, and then the Plugwise server checks the value in real time and sends the control command to the circle to shut it off. This improves security and minimizes data traffic for the main Plugwise server.

At the second generation dashboard, three levels of control were designed: on-off control for an individual item adjacent to the picture and title of each item; group on-off control for multiple items selected by the user; and calendar control for individual or multiple items set up by the user. Since one of the study participants pressed the wrong button during the usability study, the buttons were moved to be next to the device names and images. To show the state of the devices more clearly, the buttons are highlighted with blue when the device is on (see Figure 12) and white when off.

A calendar control feature was developed for the Intelligent Dashboard for Occupants (ID-O) to allow users to set up a schedule to turn on and off the devices. The first version of the calendar was designed as a Google or Outlook calendar (Figure 18, top). In this calendar, users set the time duration by a mouse-drag in the time table and then entered the control information such as schedule name, what to control (e.g., fan, lamp), and control types (e.g., switch on or off) like typical calendar applications. This requires dragging bars across hours, an inefficient interface for items that are just being turned off. A second generation calendar was developed that asks the user when the devices should be turned off and on (instant actions) rather than asking how long a device should be turned on or off (continuous state).

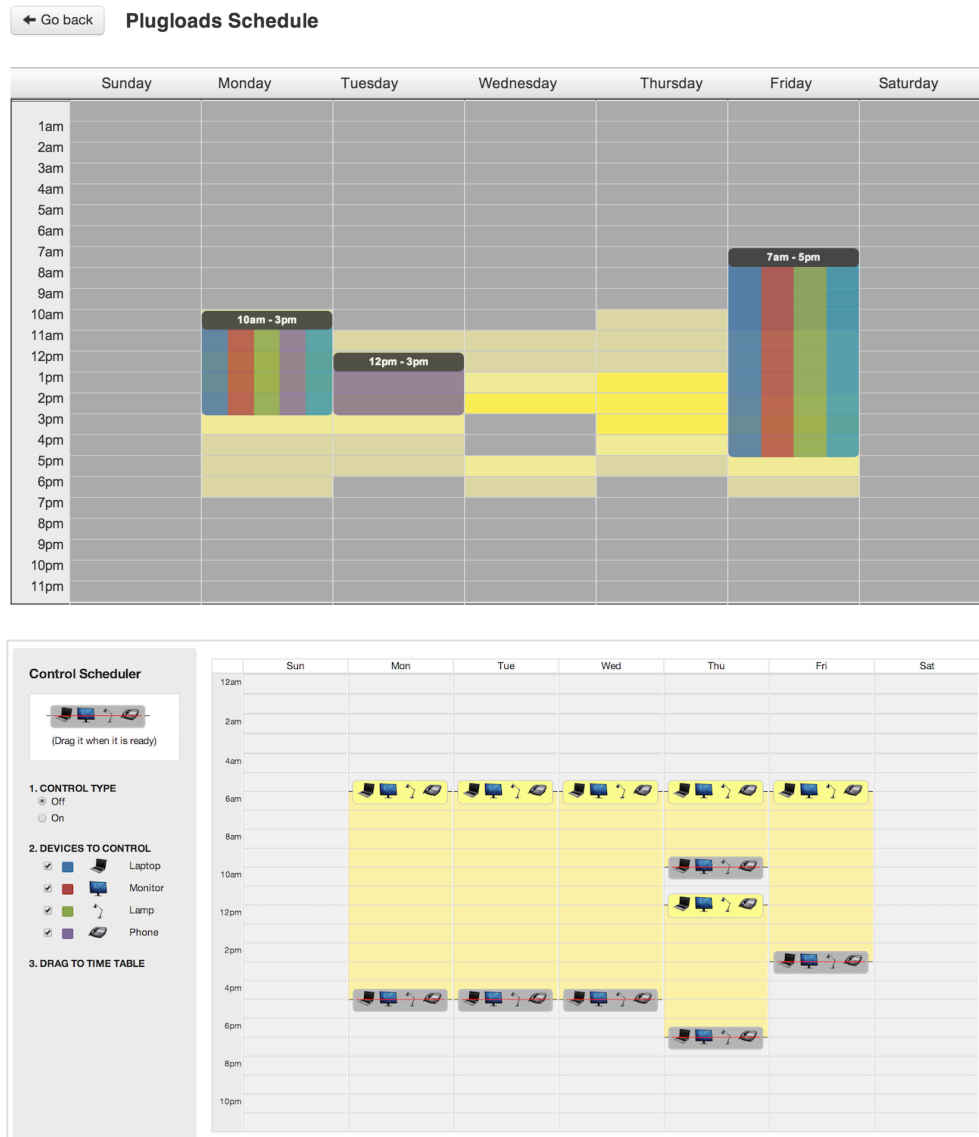


Figure 18. The old (left) and new (right) calendars

The revised calendar (Figure 18, bottom) contains a drag-able scheduler which allows users to select the devices to control and control types (on/off) and then drag the item(s) over to the timetable to set the day and time for those control settings during the typical work week. This calendar was evaluated in the usability study (see Section 5.3.7) and 91% of the participants successfully understood the functions and created a new schedule using it. 83% of them think it is easy or very easy to understand, and 94% of them reported it to be easy or very easy to create schedules.

The Control features are categorized as supportive interventions in Geller’s model. The group control button simplifies the target behavior and calendar feature supports user’s behavior performance. There is some debate about whether automated controls create “lazy” users who are no longer aware of their energy use and energy inefficiencies, with long term energy consequences. This was evaluated in the long term Intelligent Dashboard for Occupants (ID-O) study as fully detailed in Chapter 5.

Many of the features of the Intelligent Dashboard for Occupants (ID-O) were refined through field-testing and user interface studies. Three preliminary field studies were followed by usability testing with twenty-one subjects, culminating in a 9 month field study with a major corporate partner. The usability and long-term field test will be described in more detail in the following chapters, with the early studies described in the following sections.

3.3. Preliminary Study

With the first generation web-based intelligent dashboard, a pilot study was conducted at three sites over a period of eight weeks. At the workstations of six people in a university lab, seven people in a university office suite, and eight people in a government research lab as shown in Figure 19, more than 120 appliances were monitored.



Figure 19. Three sites for the pilot study – a university lab, a government research lab and a university office suite

In addition to usability feedback through user manipulation of the intelligent dashboard, the pilot study revealed that energy consumption decreased by 17% during weekends, 8%

during weeknights and 8% during the weekdays, for an average of 10% desktop energy savings through the introduction of the ID-O across the three sites (Figure 20).

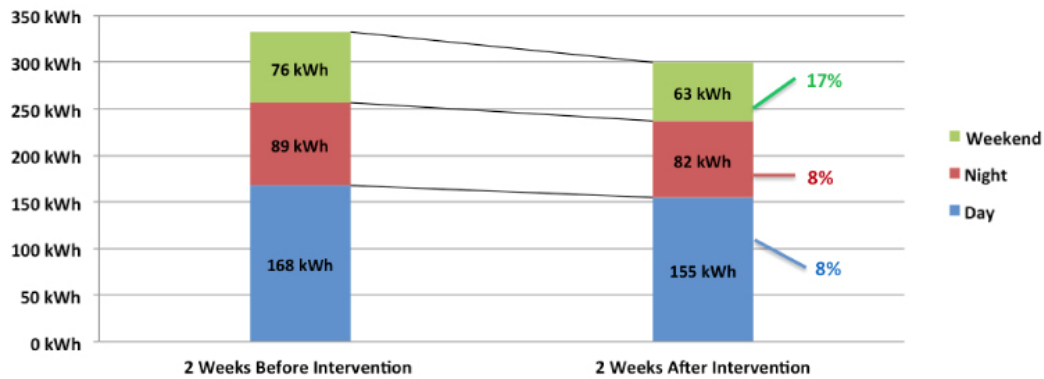


Figure 20. The ID-O at three sites achieved a 10% overall energy consumption reduction.

Two of the sites showed significant energy savings: the university lab employees saved 31.5% and the university office employees saved 30% of their desktop energy. The university office achieved a 54% and 79% savings during the weekend and weekday nights respectively (Figure 21). The government lab had an internal policy mandating that computers be left on all the time for remote updating, eliminating control of one of their most power-consuming devices - desktop computers.

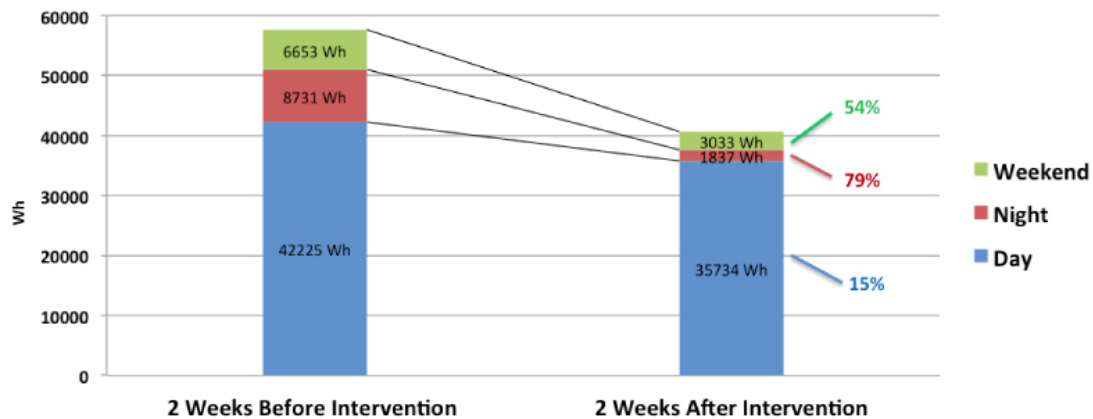


Figure 21. The university office suite achieved a 30% energy consumption reduction. Specifically, there was a 54% savings in weekday nights and 79% during weekends.

To understand what ID-O features contributed to these results and what did not, we distributed questionnaires about the dashboard's usability and engagement to our users.

Most of the respondents believed they received useful and clear information (11/12) and it influenced them to behave in a more environmentally-conscious way (9/12). Self-monitoring was appreciated the most (7/12) because they learned the most about their performance, and control buttons were the least popular because they are not yet used for controlling appliances via a user interface (2/12).

4. ID-O USABILITY STUDY AND REFINEMENT

To evaluate the hypotheses illustrated in the previous chapter, the effectiveness of the dashboard interventions must be measured. To minimize potential usability issues when measuring it, a lab-based usability test was conducted. This chapter discusses the methods, results and findings from the ID-O usability study.

4.1. Visualization Choices

Charts were selected for evaluating data presentation because charts have been a common way to display historical (time-series) electricity data (Fienberg, 1979; Roberts et al., 2004) on energy bills and online applications. There are numerous types of charts, such as bar, line, area, pie, etc., but few studies discuss in any depth which chart should be used for any given specific purpose. The CoC (Commission on Cancer) report (2010), NCES (National Center for Education Statistics), Microsoft Office Help, and many blogs (e.g. Henry, 2012) provide tips on how to select the right chart in general, but these resources are not academic or in-depth in their analyses. In Figure 22, Abela suggests a chart selector guide in his book (2008) and this, to some degree, clarifies how to choose the proper chart for any given data set. Beginning at the center of the flow chart by determining what to show (the chart's focus) - comparison, relationship, distribution, or composition - it then narrows down the options in regards to the number of variables, categories and periods.

Abela's chart selector guide (2008) was followed to determine the type of charts used in this study. *Individual charts* that display users' disaggregated consumption and *comparison charts* that show two or more users' data were investigated. The main purpose of an individual chart is to highlight the opportunities the user has to save energy. From the chart selector guide's four categories (Figure 22), the individual chart's falls in the "Composition" category. The individual chart shows users' energy consumption data with absolute value in real-time and over time (e.g., over a day, a week, a month, or a year) so the diagram suggests either a stacked bar chart or a stacked area chart. The chart can be either one, depending on whether there are a few or many periods, but Abela does

not define what constitutes a few or many. For example, it is not clear if twenty-four periods (twenty-four hours for one-day of data representation), seven periods (seven days for one-week of data representation), or 168 periods (hour-by-hour data representation for one week) are either “many” or “a few.” These numbers are the actual number of periods largely used in commercial energy displays. Despite the ambiguity over ‘a few’ and ‘many,’ Abela’s chart selector system is still useful for narrowing down the chart selection for individual data to a stacked bar chart and a stacked area chart. Thus, for our study we designed stacked bar charts and stacked area charts with disaggregated data for five office appliances.

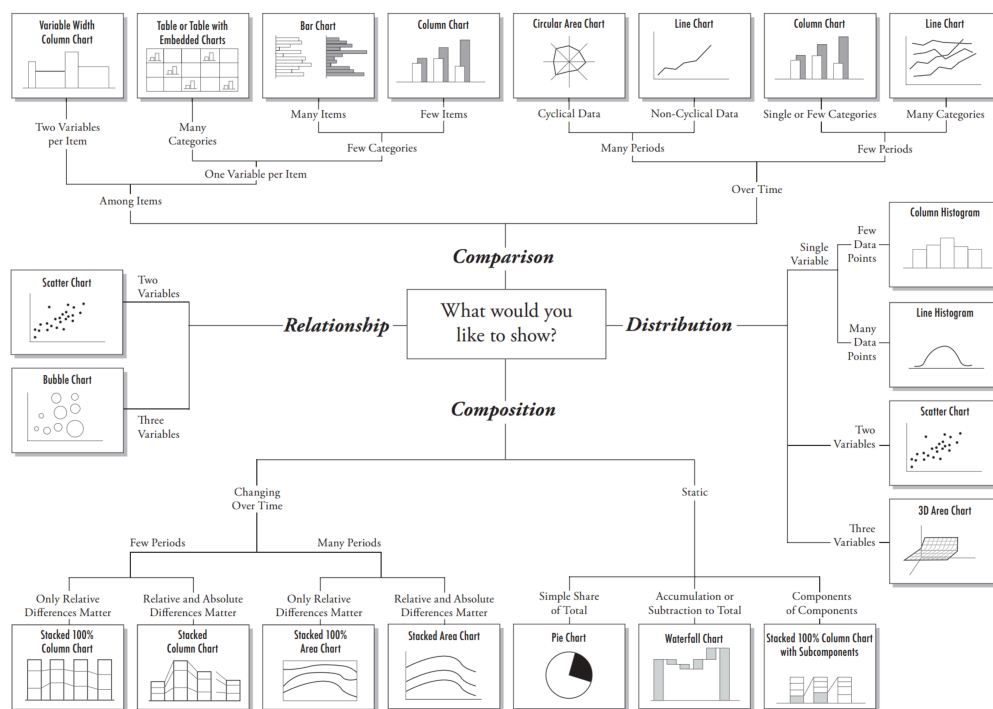


Figure 22. Abela's chart selector guide (Used with permission)

A chart is also useful to display the comparison data. The purpose of the comparison strategy is to show one’s historical energy consumption compared with others’, so that people can be motivated to save more energy. It is most similar to the Comparison category in the Figure 22. The comparison chart contains time series data (which is relevant to “over time” in Figure 22) but not cyclical data, so the chart should be a line or bar graph. Similarly, it is not clear whether seven (days a week), twenty-four (hours a day), or 168 (hours a week) periods are “a few” or “many”, and whether the three

categories (a user's energy consumption, the average consumption in the office, and the best practice in the office) are "a few" or "many". Although other energy displays listed in Table 5 show comparison data with ranking bars or slider charts, they do not present historical data. A historical comparison provides not only the user's relative rank in the group, but also the average and best person's energy profile history, so users know where they rank in the workgroup.

As stated earlier, the methods of eco-feedback presentation have been largely overlooked (Roberts et al., 2003), and their usability has not been deeply studied (Fitzpatrick et al. 2009; Froehlich et al., 2010; Roberts et al., 2003). In this work, we conducted a study to understand what type of eco-feedback presentation is easily understood and preferred. Design features for eco-feedback strategies are listed in Table 6. They were evaluated by surveying thirty-five participants with fifty-four questions (performance and preference tests).

4.2. Methods

To study eco-feedback presentation that fulfills the design strategies explained in the previous section, we divide this study into two sections. The first section details how a chart should be designed for strategies #1 - #3 (e.g., chart type, time range, time intervals) and how the supportive information should be represented for strategies #4 - #5 (e.g., unit selection, advice type, display orientation). To avoid having too much information in the chart, design features for strategies #4 and #5 were evaluated as supportive information to the chart (Roberts et al., 2003). The presentation methods and the evaluation methods are listed in Table 6.

To recruit participants, flyers were posted in university buildings and a digital flyer was posted online at <http://pittsburgh.craigslist.org/>. The flyer briefly describes this study and specifies that participants should be people who spend most of their time doing computer work and preferably work in an office. The flyers also explain that the study takes 45 minutes and the compensation for participation is \$10. The study was conducted in a university laboratory.

Table 6. Presentation methods evaluated by performance and preference test

UI Sections	Eco-feedback strategies		Presentation methods	Evaluation methods
Chart (individual, comparison)	#1	Frequency	• Chart type,	• Performance (response time / correctness)
	#2	Granularity by appliance	• Time range, • Time intervals for individual and comparison data	• Preference (understandability / visual attractiveness)
	#3	Comparison		
Supportive information	#4	Metrics	• Metrics and advice types	• Performance (correctness)
	#5	Advice	• Display orientation	• Preference (rank order)

Two monitors connected to a desktop computer and one laptop were used for the study (Figure 23). The two monitors display two different user interfaces (UI) and the laptop was used for the investigators to record answers, measure response time, and write down comments using the Qualtrics survey tool (<http://www.qualtrics.com/>).

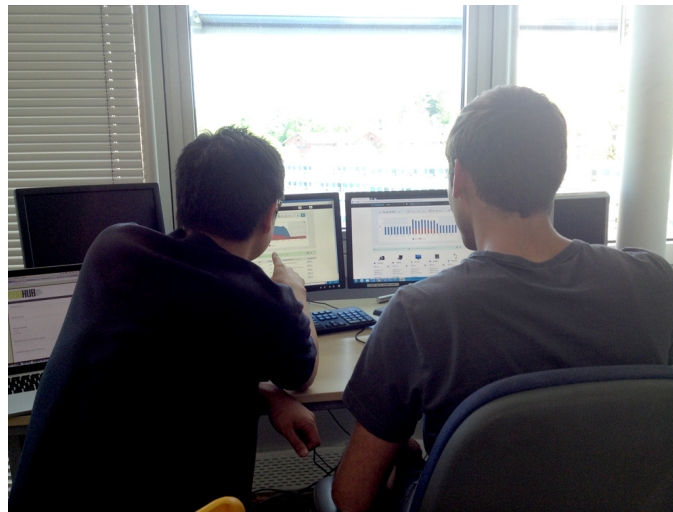


Figure 23. Study settings for the usability study. Participants were asked performance and preference questions on each feature in the Intelligent Dashboard

The interviews were audio-recorded. To make the study as fair as possible, 1) the two UI designs were shown in random order using two 17-inch screens, 2) the two UI designs were created with real but slightly different data, 3) three investigators conducted the interviews using the same questionnaires and script, 4) the studies were done at the same

place with the same study settings, and 5) before the main interview began, the participants had a practice session. In this portion they were shown charts similar to those in the actual interview portion and asked questions based on the charts that were similar to the actual ones. During this session all of the respondents gave accurate answers and the research team was able to minimize any questions that were unclear and thus delayed the participants' response time. The width of the dashboard interface is 1000px and was designed to fit the standard minimum screen resolution (1024 x 768px). Highcharts library (<http://highcharts.com>), one of the most popular chart libraries for web interfaces, was used to develop the charts in the dashboard. Bootstrap CSS library (<http://getbootstrap.com/>), another of the most popular CSS libraries, was used to stylize the overall components in the interface. A Plugwise electricity meter data (<http://www.plugwise.com/>) is used to visualize the energy charts.

To evaluate each feature, performance test and preference test questions were asked (Table 7). For the performance test, two different designs (e.g., bar chart and area chart) of each feature were shown one by one, and the participants were asked questions about reading or analyzing the chart or understanding certain terms and designs. If they answered incorrectly, the investigators corrected them and moved forward. After participants experienced both designs in the performance test section, preference questions were asked about the designs' understandability, visual attractiveness, and overall preference. The selected example questions are in Table 7.

Table 7. Performance and preference question examples.

Sections	Type	Question examples
Chart	Performance	<ul style="list-style-type: none">• What is the monitor's consumption between 4 to 5 pm?• What day does the user consume electricity the most?• What makes the users save more energy by turning them off during night or weekend?• Referring to the average of the group, how good is the user's performance on energy consumption?• Referring to the best person in the group, what can the user do to save more energy?
	Preference	<ul style="list-style-type: none">• Which chart is easier to understand?• Which chart is visually more attractive?• Overall which chart works better for you to monitor your energy performance and save electricity?• Overall which chart works better for you to compare your energy performance and others?
Supportive information	Performance	<ul style="list-style-type: none">• Explain what the contents mean at this section.
	Preference	<ul style="list-style-type: none">• Choose and rank the useful information to you.• Which type of view (of category view and table view) do you prefer and why?• Do you prefer to see your savings information or consumption information?

The survey responses provide valuable information about how users perceived the chart and the supportive information represented in the UI that they saw.

4.3. Study Findings

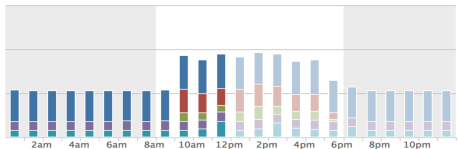
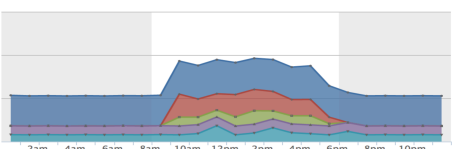
Thirty-five people participated in this study. They consisted of office workers (11/35), university graduate students (14/35) and undergraduate students (10/35). The genders of the participants were evenly distributed: male (17/35) and female (18/35). The ages of the participants were unevenly distributed: 19-29 (18/35), 30-39 (10/35), 40-49 (5/35) and

over 50 (2/35). Participants reported their ability in reading charts as proficient (31/35) and neutral (4/35). Table 8 - 13 and the following sections summarize the participants' performance and preferences as they looked at the charts in the sample interfaces and responded to the survey questions (e.g. Table 7).

4.3.1. Charts for Individual Data (Day)

For the individual user's data, participants were able to read both charts correctly and read the bar chart faster, but preferred the area chart overall, as shown in Table 8. Most participants answered the basic reading questions correctly (bar: 100%, area: 97%), but they spent more time reading the area chart (bar: 13.01 seconds, area: 21.55 seconds). For the applied reading questions, 91% of participants answered correctly for both charts, and again they spent more time reading the area chart (bar: 17.84 seconds, area: 23.96 seconds). Although the area chart took longer for the participants to read, 71% of them think that it is more understandable and visually attractive. Overall, 77% of the participants chose the area chart over the bar chart (20%) to represent the individual's data for a day.

Table 8. Study results on bar and area charts for an individual's disaggregated data (day)

Questions				
	Bar chart		Area chart	
Basic reading	100% (13 sec)		97% (22 sec)	
Applied reading	91% (18 sec)		91% (24 sec)	
Understandability	23%		71%	
Attractiveness	23%		71%	
Overall preference	20%		77%	

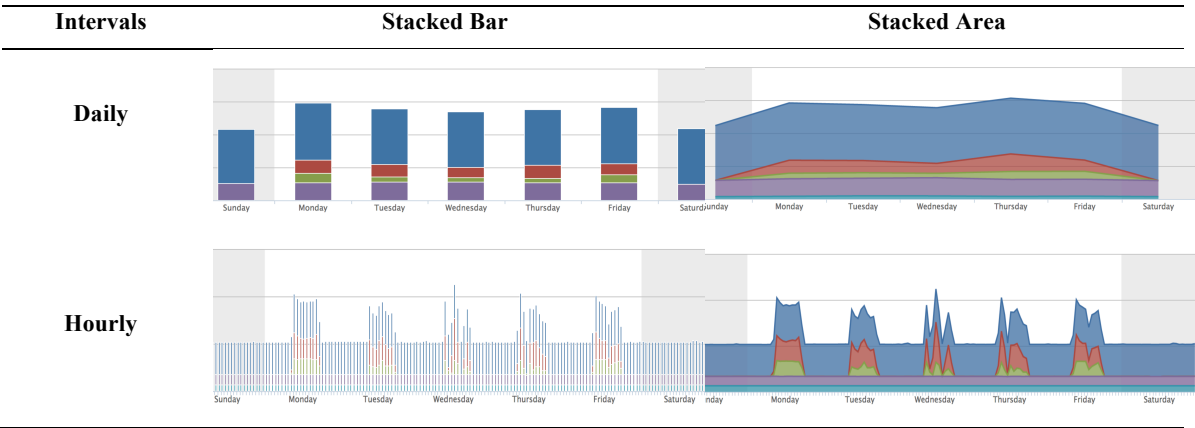
Based on their comments, the area chart is better for reading the overall trends due to the line that connects the data points, whereas the bar chart is better for reading hour-by-hour

data due to the divided bars. This led the participants to answer the first question faster, but many participants still think the area chart is relatively easier to understand and less busy. They explained that the area chart looks like it contains only five components, but the bar chart appears to have many more discrete data points (up to 120 components). The participants felt that it is more important to understand the overall trend than reading the data in detail.

4.3.2. Charts for Individual Data (Week)

Two types of an individual’s disaggregated data intervals are evaluated, daily and hourly. First, participants were shown bar and area charts with daily intervals (Table 9, top) and asked for their preference. Then they saw the same charts but with hourly intervals (Table 9, bottom) and were asked for their preference. The participants preferred the bar chart when looking at daily intervals (bar: 80%, area: 17%, both: 3%) and the area chart for hourly intervals (bar: 9%, area: 91%).

Table 9. Bar (left) and area (right) charts representing an individual's disaggregated data for one week, divided into daily and hourly intervals

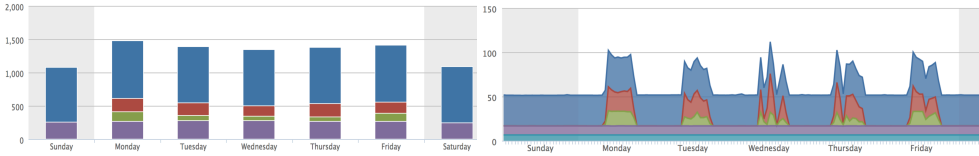


They commented that daily data in a week is not continuous and a bar chart makes more sense instead of an area chart. In contrast, representing the week’s data by dividing it into 168 data points for each hour of the week makes it seem like continuous data with too

many individual points to be displayed by separate bars, so the area chart makes more sense.

Next, the two charts that participants rated as best, the bar chart with daily information and the area chart with hourly data, were compared to determine which should be used in the energy display (Table 10). The participants' responses were analyzed to see which chart is preferred for monitoring weekly electricity consumption. First, a basic reading question was asked: *Which day does the user consume the most electricity?* All the participants answered correctly using the bar chart, but only 60% of them could answer correctly for the area chart. In fact, to answer this question correctly for the area chart, they had to consider “the area” of each day in the chart, but instead they tended to find the peak of the graph to answer this question. When they did not answer correctly, the researchers explained why the answer was incorrect. In regards to applied questions (*What devices can make you save energy by turning them off during the night?*), the participants answered correctly with no difference between bar and area charts (both at 83%). Again, more time was spent reading the area chart for both questions (Basic reading question - bar: 17.01 seconds, area: 23.21 seconds, applied reading question – bar: 23.21 seconds, area: 29.66 seconds).

Table 10. Study results on bar and area charts for an individual's disaggregated data (week)

Questions		
	Bar chart	Area chart
Basic reading	100% (17 sec)	60% (21 sec)
Applied reading	83% (23 sec)	83% (30 sec)
Attractiveness	49%	51%
Overall preference	26%	71%

Participants showed an equal interest in both charts for visual attractiveness (bar: 49%, area 51%) but overall preferred the area chart for presenting the week's data (bar: 26%, area: 71%). The participants who chose the bar chart liked its simplicity and thought the

area chart too complicated. In fact, it sometimes misled them in reading the total daily consumption. The participants who chose the area chart liked that it represents the overall consumption data in detail and informs them how they can save more energy. They pointed out that the missing information in the bar chart (e.g., items still consuming energy at night) is critical for a user's energy conservation, so the area chart is more useful to them.

Then the investigators asked participants which chart they would like to see first as the primary chart (week or day) to effectively monitor their electricity consumption through an energy display. 80% of the respondents prefer to see week then day and 20% preferred day then week (Table 11).

Table 11. Preference for the primary and secondary charts

Day, then Week				Week, then Day			
Bar-Area	Bar-Bar	Area-Bar	Area-Area	Bar-Area	Bar-Bar	Area-Bar	Area-Area
14%	0%	3%	3%	29%	9%	3%	40%
20%				80%			

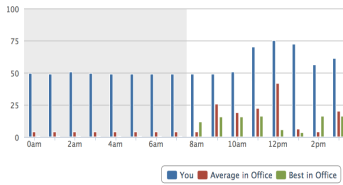
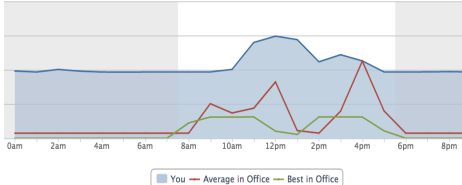
Participants were also asked to make a final decision on their preferred charts for the week and day, considering the overall flow of the interactions and the usability of the energy dashboard. The most preferred pair is the *area chart for the week* and then *the area chart for a day* (40%) and the second preferred pair is the *bar chart for the week* and then the *area chart for a day* (29%). People who preferred *the area chart for the week* and also *for a day* said the *area chart for the week* shows the most information at once, so it does not require any additional steps to view more information. They also care about consistency so both area charts worked best for them. People who preferred the *bar chart for the week*, followed by *the area chart for a day* said they want to start simple with the big picture first (*the bar chart for the week*), and when they want to view more, they can see the area chart for a day. They thought the area chart for the week is too complicated and had too much information at once. Participants were also asked which chart is preferred if there is only one chart option for monitoring electricity usage. 65% of

respondents chose the *area chart for a week*. When formats other than the personal energy displays are needed (e.g., email, public display), this result can inform the chart selection for those formats as well. Summarizing the results of this section of the interview, participants prefer first seeing the *area chart for the week* and then the *area chart for a day*, and think this would be the most effective order for understanding energy consumption.

4.3.3. Charts for Comparison (Day)

The survey also included questions to determine the most effective and comprehensible chart representation of the comparison data. The bar and line charts were evaluated to investigate which chart people prefer using to effectively monitor people's energy performance and encourage them to save energy (Table 12).

Table 12. Study results on charts comparing a day's electricity usage

Questions				
	Bar chart		Line chart	
Basic reading	100% (35 sec)		100% (24 sec)	
Applied reading	86% (37 sec)		86% (22 sec)	
Understandability	14%		80%	
Attractiveness	17%		77%	
Overall preference	17%		80%	

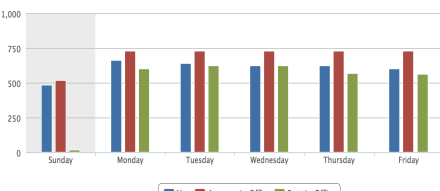
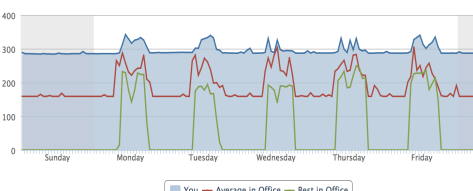
Participants were asked the basic comparison question (*Referring to the group's average, how good is the user's performance on energy consumption?*) and applied comparison question (*Referring to the best person in the group, what can the user do to save more energy?*). All of them answered the first question correctly and 86% of participants correctly answered the questions using both the bar and line charts. They spent less time reading the line chart for both questions (3.93 and 6.45 seconds faster for Q1 and Q2

respectively). Survey respondents preferred the line chart in terms of understandability (bar: 14%, line: 80%), visual attractiveness (bar: 17%, line: 77%), and overall preference (bar: 17%, line: 80%). They commented that the line chart is more intuitive, provides more motivation, and is simpler (because it only has three lines). The bar chart is reported to be easier to read for the hour-by-hour data but contains too many bars and is hard to understand the overall trends.

4.3.4. Charts for Comparison (Week)

The bar chart with the daily intervals and the line chart with the hourly intervals were evaluated for a week's worth of data representation (Table 13). In this session, investigators also asked participants the basic and applied questions. All the participants answered the basic questions correctly. For the applied questions, people answered slightly better when the bar chart was shown (bar: 86%, line: 80%). People spent less time on the line chart for both questions. They think the bar chart is more visually attractive (bar: 63%, line: 37%), but the line chart is more understandable (bar: 37%, line: 57%) and preferred overall (bar: 37%, line: 63%). People commented that the bar chart is simple and attractive and works well for day-by-day comparison. However, it does not show in detail when to save electricity (e.g., turn off the computer when you leave the office), and as this is critical information, people preferred the line chart overall.

Table 13. Study results on charts for comparison for a week's electricity usage

Questions				
	Bar chart		Line chart	
Basic reading	100% (23 sec)		100% (18 sec)	
Applied reading	86% (24 sec)		80% (21 sec)	
Understandability	37%		57%	
Attractiveness	63%		37%	
Overall preference	37%		63%	

Finally, participants were asked to choose their preferred charts for comparison for the daily and weekly data considering the usability and the interactions with the energy display. Their most preferred pair is the line charts for both day and week. They also care about consistency, so the pair of line charts worked the best for them.

4.3.5. Response Time and Chart Selection

Questions requiring basic reading and advanced reading were asked to understand participants' reading performance (Table 14 and 15). Table 14 illustrates the response time taken to read charts for an individual user's data. The basic reading questions require single data-point reading and show the finding that bar charts (day: $M = 13.01$, $SD = 12.26$, week: $M = 13.01$, $SD = 12.26$) are significantly better than area charts (day: $M = 21.55$, $SD = 10.89$, week: $M = 17.01$, $SD = 6.04$) for both a day's ($t(68) = 3.082$, $p < .005$) and a week's ($t(68) = 2.929$, $p = .005$) electricity usage. Regarding the advanced reading questions that demand an overall understanding of the energy data, there was no significant difference between the bar charts (day: $M = 17.84$, $SD = 10.25$, week: $M = 23.21$, $SD = 11.94$) and area charts (day: $M = 23.96$, $SD = 15.28$, week: $M = 29.66$, $SD = 19.36$) for both a day's ($t(68) = 1.967$, $p = \text{n.s.}$) and a week's ($t(68) = 1.679$, $p = \text{n.s.}$) electricity usage.

Although people took more time to answer the basic reading questions with the area chart, they preferred them because they think the area chart looks simpler and better shows the overall trend. To improve single-data reading they suggest making the data points bigger.

When considering the chart that compares the user, average, and best practice, a line chart was favored. People commented that lines make it easier to understand the energy usage trends and compare them. According to Table 15, the response time for the line chart is significantly better than the bar chart for both basic reading questions (day: $t(68) = 3.493$, $p = .001$ / week: $t(68) = 2.093$, $p < .05$) and advanced reading questions (day: $t(68) = 4.120$, $p < .001$ / week: $t(68) = 2.030$, $p < .05$) and supports the user preference found in our study (day: bar (17%) < area (80%) / week: bar (37%) < area (63%)).

Table 14. Response time for charts of individual's data

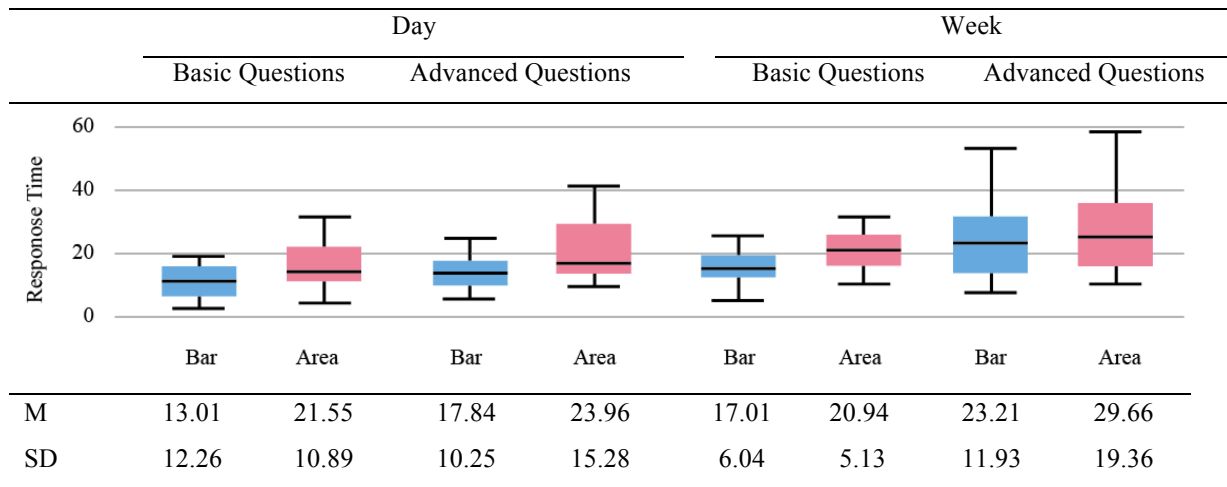
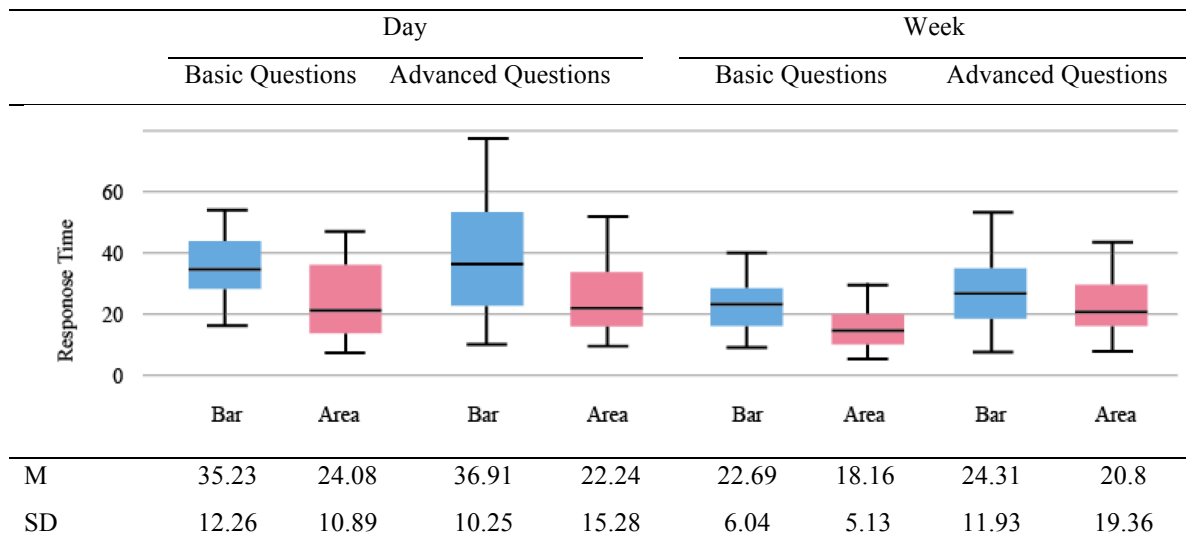


Table 15. Response time for comparison charts



4.3.6. Supportive Information (Energy Metrics and Advice)

Information using various metrics and energy-saving advice were evaluated. The participants' understanding and preference on the following information was tested: demand, status, this week's data (consumption, cost, CO₂ emission, trees), short-term recommendations, and long-term recommendations. Commonly used metrics were selected based on the literature (Fitzpatrick et al., 2009; Wood et al., 2007; Wolsink, 1997; Vassileva et al., 2012) and commercial applications, (Table 5) and recommendations were designed based on PIRE's report (2011) which illustrates good ways to save plug-load energy in office environments. During the interview, participants were given the two UI sections (Figure 24) and asked to guess and explain what each of those terms means. (The intended meanings are in Table 16).

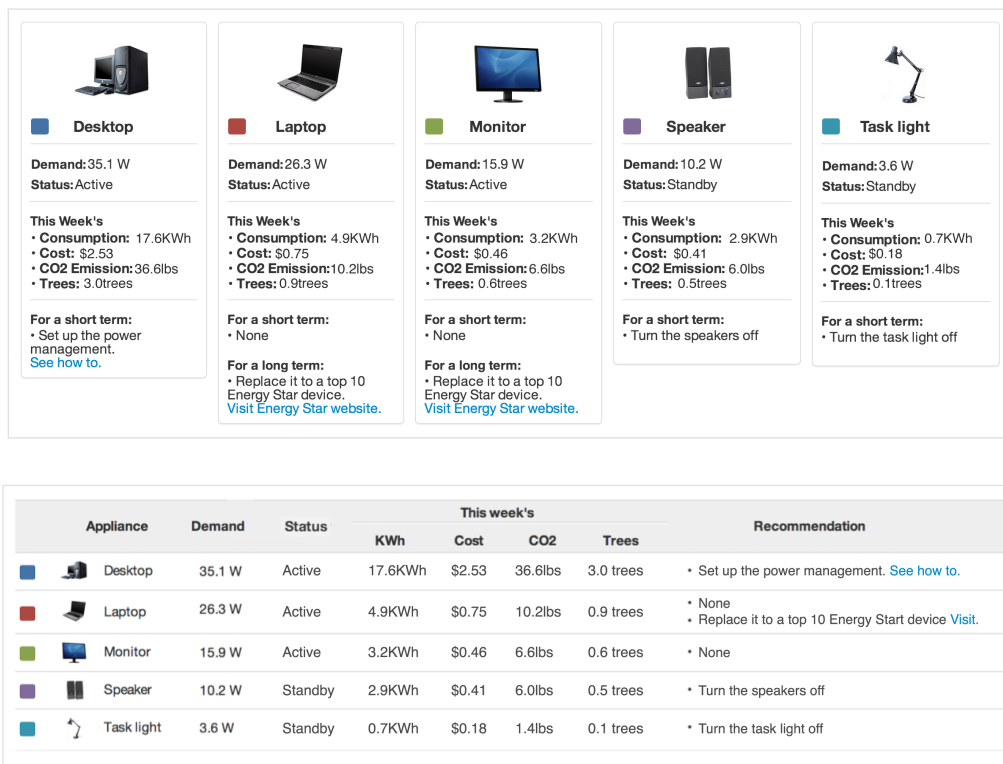


Figure 24. Supportive information, category view (top) and table view (bottom) in the UI

The most ambiguous terms were demand (57%) and trees (46%). The term, demand, is too vague and must be renamed for clarity. Also, people were not familiar with using *trees* to represent energy consumption. Trees can be represented in three different ways: 1) the number of trees needed to absorb the emitted CO₂, 2) the number of trees killed to

generate electricity, and 3) the number of trees saved as a result of the user's energy savings. Investigators asked the participants to choose their preferred representation. They liked option one or two because the section "this week" is about consumption, not savings (1: 49%, 2: 37%, 3: 11%). However, when they were asked for their preference between the consumption and savings information in general, they liked consumption and savings evenly (46%, 43%, 11%-both). People liked savings because it provides an analysis of whether they use electricity efficiently or not in a more understandable manner. However, many people disagree with the savings when the value is negative and think this will be confusing.

Table 16. User preference on information and advice choices

Terms		Intended Meaning	Score
Demand		Electricity the appliance currently consumes	138
Status		Power mode (active / idle / standby / off)	75
	Consumption (kWh)	Total electricity the appliance consumed this week	198
This	Cost (\$)	Cost for the electricity consumption	196
week's	CO ₂ emission (lb)	CO ₂ emitted from electricity consumption	60
	Trees	Trees needed to absorb the emitted CO ₂	70
Short-term rec.		What you can do immediately to save electricity	83
Long-term rec.		What you can do in the long term	78

After the participants understood all the supportive information, they were asked to choose from among the useful information and rank them in terms of usefulness. To calculate the score, weighted values are applied from 9 (rank #1) to 1 (rank #9) and Table 16 shows the total score. This week's consumption and cost, demand, short-term and long-term recommendations were the top five pieces of information selected. They commented that they do not have a good sense of the amount of CO₂, and the meaning of the tree is not directly connected enough to the user's energy usage to be engaging.

The use of kWh and cost (\$) is preferred over environment metrics (CO₂ and trees), and this supports Fitzpatrick (2009) and Fischer's (2009) argument. Although Jain et al. (2013) argue that kWh is a difficult unit to understand due to "its scientific origin and abstract

qualities,” many participants in our study commented that the kWh unit is useful to understand one's accumulated consumption per device when it is used with an energy chart. Jain et al. also argued that the tree metric is more useful than the others because it is a well-known object and easy to visualize. However, when the participants in our study heard the meaning of the tree metric (e.g., the number of trees needed to absorb the CO₂ emitted from one's electricity consumption), they thought that a tree is not the best metric for two reasons. First, because a tree is not directly linked to electricity consumption (electricity consumption generates CO₂ emission and then trees absorb it). Secondly, they find it confusing due to the contradictory logic - when more electricity is consumed, more trees are fed, not destroyed! Another environmental metric, CO₂, was strongly not preferred because people were not familiar with it. In our study, CO₂ and tree were the least-preferred metrics. Regarding advice, people commented these would be more useful if they also provided 1) the expected savings that would result from following the advice, and 2) a “real time” warning notice sent to one's email or mobile phone as soon as the system detects energy waste.

The supportive information section layout is designed two ways, category view (Figure 25, top) and table view (Figure 25, bottom). Participants were asked which one they prefer and 71% of the participants chose the table view. They think it looks more organized. The values are lined up closely so it is easy to compare the values and helps them easily realize which appliances they need to focus on more. The table view also allows for sorting, a useful feature. The rest of the participants preferred the category view because it is more visual due to the large pictures. For overall layout, 94% of people preferred *chart (top) – supportive information (bottom)* over *supportive (top) – chart (bottom)*.

4.4. Limitations

This study evaluates the design of eco-feedback presentation for online energy displays to be used in office environment. However, the results include the following limitations:

(a) Lab based experiment: The study was conducted under laboratory conditions. The tasks were given to the participants and their performance and preference were measured. In the experiment, the survey questions elucidate more in-depth responses that may not be applicable in a real-world setting

(b) Survey participants: This study includes university students who do part-time computer work. However, these students may be more familiar with interpreting charts compared to typical office workers. 89% of the participants reported that they are proficient in reading charts. Therefore, the results may not exemplify a typical office worker's performance and preference.

c) Data visualization type: The experiment only focuses on commonly used web components for energy data display, which are charts (chart types, time range and intervals) and the supportive information (metrics and advice). Many experimental displays are currently being studied to present energy data more effectively and engagingly using metaphors (e.g., polar bears [Froehlich et al., 2009], chickens [Orland et al., 2013], coral [Kim et al., 2010], avatars [Fuijten et al., 2012; Yun et al., 2011], eco-art/visualization [Holmes, 2007], and games [Shiraishi et al., 2009; Gamberini et al., 2012].

d) Study domain: This study targeted office workers. Energy displays for the workplace should not require much of the users' time to understand because their main duty is not saving energy but doing their job (Yun et al., 2013). Based on our pilot study (Yun et al., 2013), users spent less than one minute on average using the energy dashboard. Therefore, all the components are designed to be as concise and as easy as possible for rapid use and comprehension. For example, the display provides very few and critical information only and all information is displayed in one page without the need for scrolling. This simple design and our study findings may not be optimal for residential users due to their different wants and needs compared to those of office workers.

e) Number of items displayed: The energy dashboard in this study presented the user with five plug load devices. Based on our field studies (Yun et al., 2014), a typical workstation in an office environment has four to six connected devices. If the dashboard has fewer than three devices or more than seven, user preference and performance results may be different.

4.5. Summary

This study investigates the eco-feedback presentation methods focusing on charts and their supportive information. Each component was evaluated by measuring the performance of thirty-five participants' (e.g., response time and correctness) and their preferences (e.g., understandability and attractiveness). Although most of the commercial energy-monitoring applications display today's energy usage, it was found that week-level energy usage presentation was more useful and preferred. Additionally, to view an individual's disaggregated data, a stacked area chart was preferred and a line chart was preferred for social comparison data. The response time and accuracy did not always correspond to the participants' final selection for the charts. The environmental metrics (i.e., CO₂ and tree) were preferred the least because they were confusing. kWh was preferred when used with an energy consumption chart. Cost was also preferred, but since an individual's energy usage cost is typically low and not affected, a large monetary impact is recommended, such as the potential cost for one year or the organizational-level cost. The next chapter demonstrates the long-term, large-scale field study designed to prove or disprove the research hypotheses (Section 2.5) with the 2nd generation ID-O refined from the usability test illustrated in this chapter.

5. MEASUREMENT OF ID-O ENERGY IMPACTS

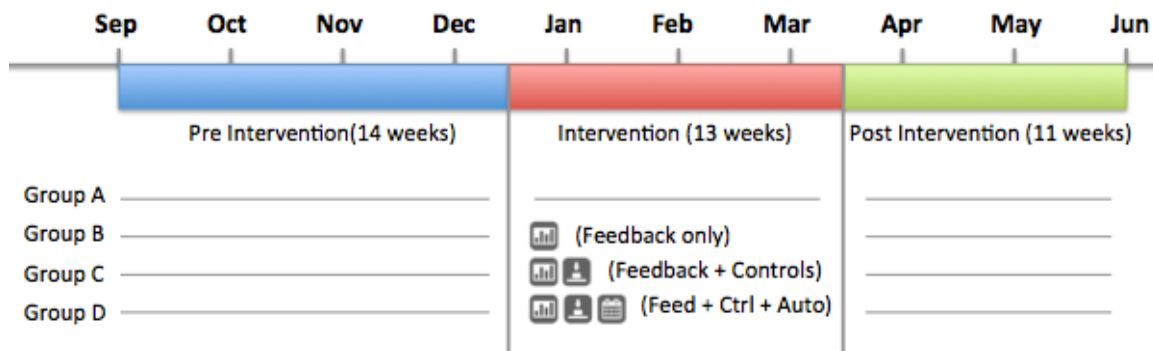
Having discussed previous research in the field and laid out the hypotheses, it is time to turn to an examination of this study's methods, results and findings. This study was a larger-scale study involving over eighty number of individuals and lasting for over nine months.

5.1. Methodology for Large Office Building Dashboard Deployment Study

A major corporate leader in the Pittsburgh area agreed to deploy the Plugwise™ meter-controllers and several variations of the 2nd generation dashboard at 80 workstations over a period of almost a year, encompassing before, during and after monitoring and surveys.

Table 17 shows the time line and structure of the field experiment in three phases – a pre-intervention study, the intelligent dashboard intervention study period, and a post-intervention study.

Table 17. The study timeline with four test groups and in three phases – comprising the pre-intervention (blue) study, intervention study (red), and post-intervention study (green).



Four groups of twenty people were critical to investigate the three-dissertation hypothesis about *feedback*, *manual control* and *automated control*. The participants were recruited from one department (realty services) in a large company and all of them reported that they are full-time workers and spend most of their time doing computer work. Four Plugwise™ interfaces were installed at each of the 80 workstations to monitor user actions and energy use of their laptops, monitor, phone and task light (where existing).

The participants were randomly assigned to the four groups (twenty people per group) and their baseline energy use data was collected for fourteen weeks. After the baseline data collection, three of the four groups were introduced to one of three dashboard systems equipped with different features (Figure 25).

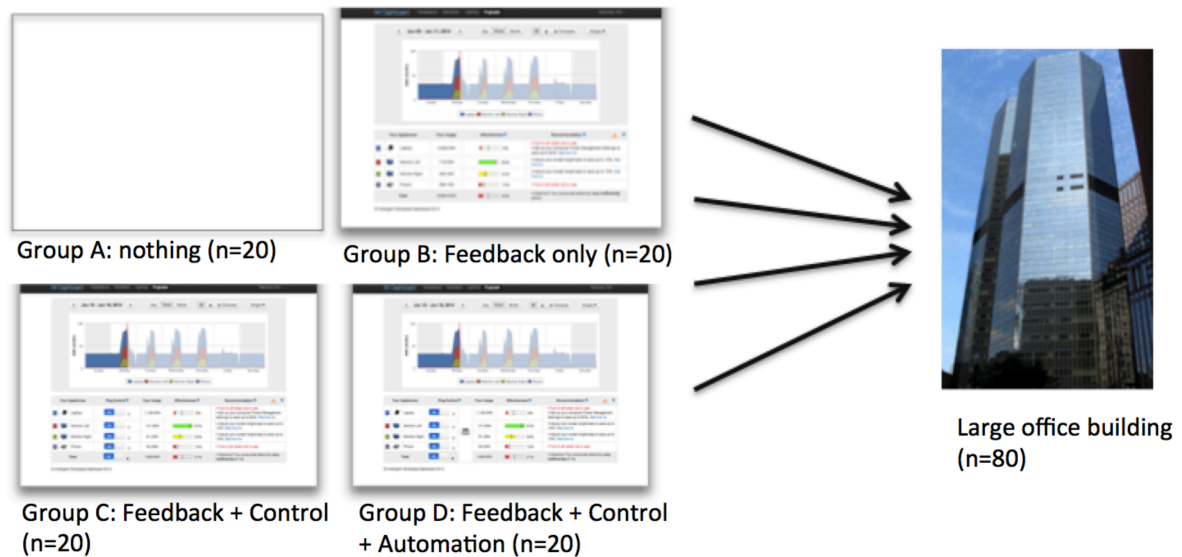


Figure 25. Different energy dashboards provided to four groups in a large office building

The first group (Group A) was not provided with a dashboard interface and served as a “control” group. The second group (Group B) was provided with the five feedback features only (self-monitoring, expert advice, peer comparison, behavioral effectiveness, and organizational cost savings), the third group (Group C) was provided with the five feedback features and on-line controls, and the last group (Group D) was provided with the five feedback features, on-line control, and automated/calendar controls.

To introduce the systems to each group, group-training sessions were held at the company (Figure 26). The team demonstrated the system features, provided user names and passwords, and answered participants’ questions. After these training sessions, energy data was collected for thirteen weeks and each group’s energy savings were measured.



Figure 26. Group training session

Energy savings were calculated based on the difference between during-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, with occupancy estimated based on each participant's daily computer monitor usage. Since our pilot study (Yun et al., 2013) revealed the need for a weekly reminder regarding the use of the dashboard, participants received a reminder email every Monday morning to support engagement. An example of a reminder email is as follows, "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 had 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 savings impact made by the dashboard intervention alone.

5.2. Appliance Selection and Behavior Efficiency

The baseline data has been used to analyze the participants' device efficiency and their behavior efficiency. Figure 27 shows the relationship between the two metrics to represent sustainability. The X-axis is behavior efficiency and the Y-axis represents a user's device efficiency. The upper-right quadrant shows the best case where one's device consumes energy efficiently and this person also uses the device effectively.

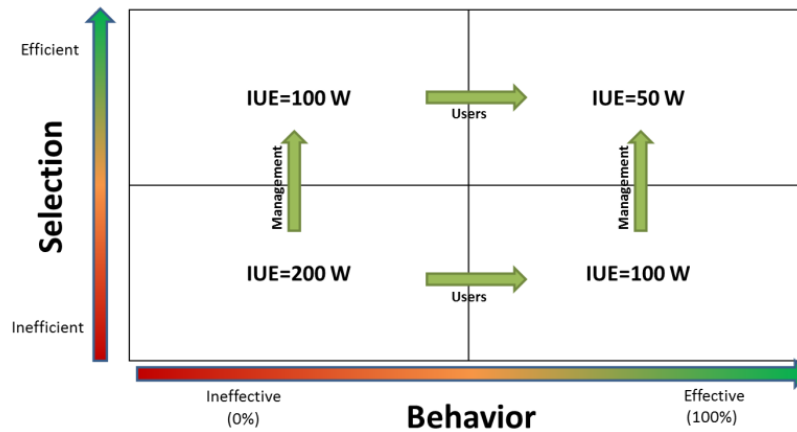


Figure 27. Selection and behavior efficiency as metrics of sustainability (Lasternas, 2014)

The fourteen-week baseline data from the field study is plotted on the selection/behavior chart in Figure 28. The charts illustrate individuals' behavior efficiency (X-axis, see section 3.2.3) and device efficiency (Y-axis), which is a reciprocal of the average consumption in active mode. The groups were differentiated by different colors. The red lines demonstrate each device's typical electricity consumption based on the PIER report (2011). As shown in Figure 28, the baseline data measured from the field shows that typical devices (computer: 100%, monitor: 98%, task light: 71%, phone: 97%) consume energy more efficiently than the usage of typical devices. Monitors were used more efficiently (the shapes in the monitor chart are positioned relatively to the right-hand side) than laptops and phones, and the shape in the chart for lights is evenly distributed and did not show an obvious trend.

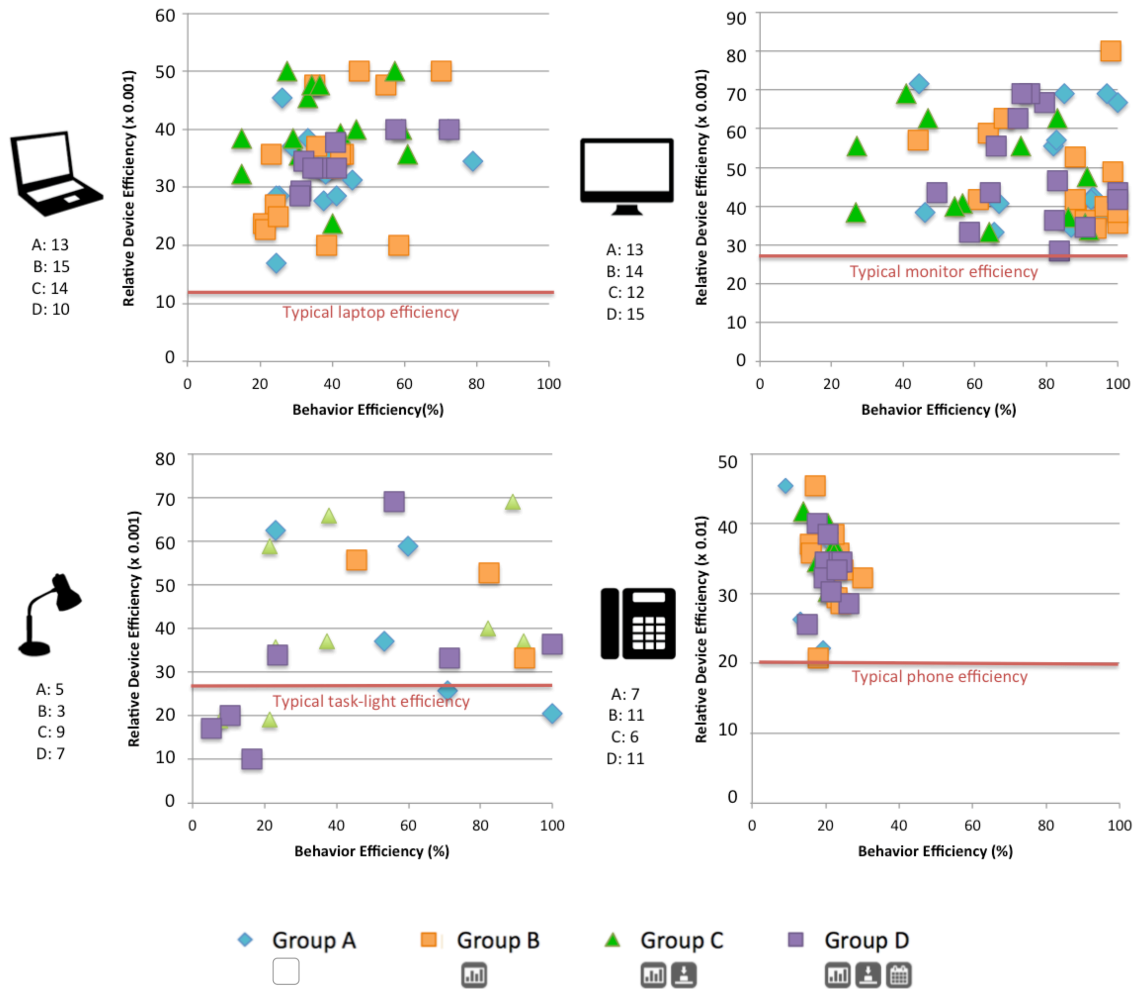


Figure 28. Selection and behavior efficiency of baseline data (pre-intervention)

As described in Section 5.1, dashboards were given to the participants for thirteen weeks. Figure 29 shows the participants' behavior changes before and after the intervention. The black arrow was drawn when the effectiveness difference is greater than 5. It was found that after the dashboard intervention, relatively more positive behavior change was made for computers (A:15%, B:33%, C:27%, D:44%), monitors (A:15%, B:43%, C:38%, D:43%) and lights (A:20%, B:33%, C:67%, D:86%). The sample size for the light users in group A (n=5) and B (n=3) was relatively small. Most of the phone users didn't show obvious behavior change on the phone usage except the calendar users (Group D). The calendar feature aided in turning the phone off when not in use, and Group D participants could manage energy for the phone effectively. One person in Group B also increased his

behavior efficiency to 100%. It turned out that he did this by using a power strip to control his devices at work, and this shows the importance of the control feature.

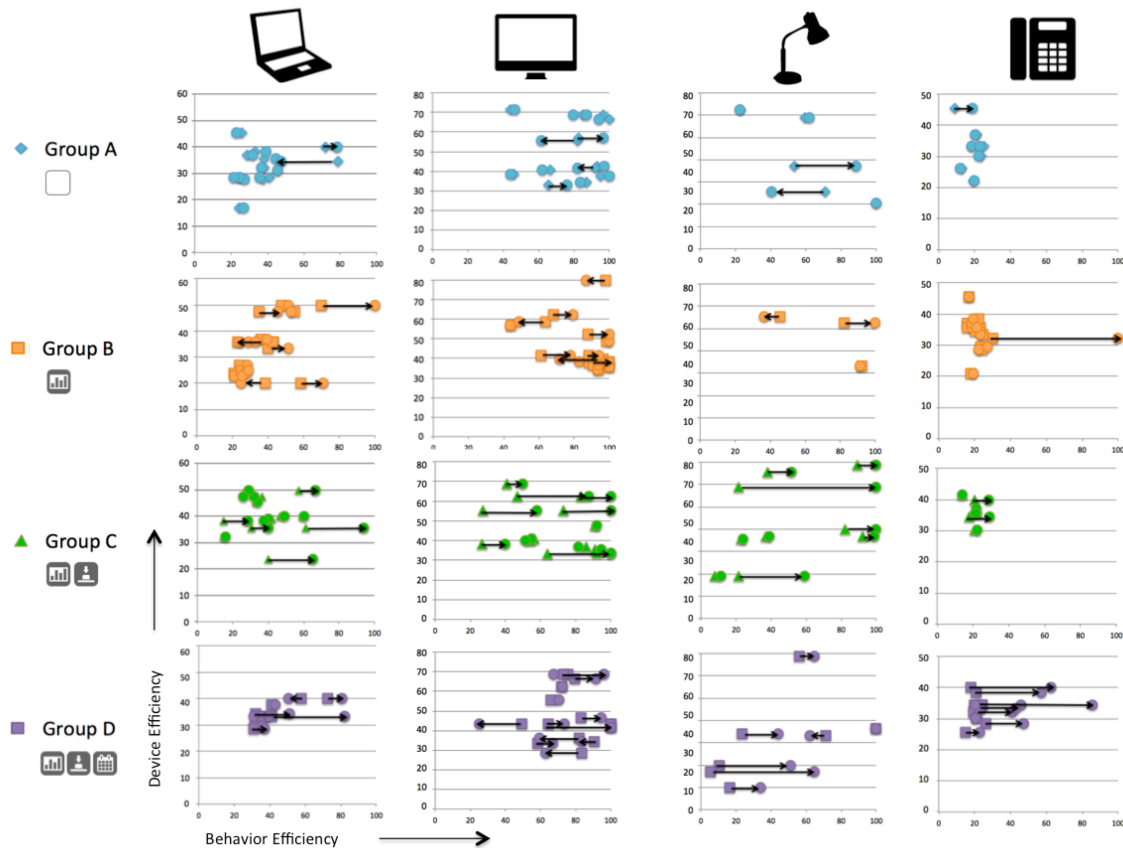


Figure 29. Change of behavior efficiency after dashboard interventions.

5.3. Pre-during-post Intelligent Dashboard Energy Findings

The energy savings enabled by the intelligent dashboard for occupants (ID-O) were significant and persistent. Figure 30 illustrates the weekly average electricity consumption per group before, during and after the introduction of the dashboard. The group with no dashboard (A) showed a 7% energy reduction during the intervention period, possibly caused by peer discussions about desktop energy usage and savings. Group (B) with all five feedback features – self-monitoring, peer comparison, behavioral effectiveness, organizational cost savings, and expert advice – saved 13%. The addition of on-line control of individual devices or groups of devices resulted in a 24% energy

savings for Group C, while Group D, equipped with all features - feedback, on-line controls and automated calendar controls - achieved a 39% savings. Whereas pre and during-intervention measures for the control group (Group A) were not statistically different, the ones for dashboard groups (Group B, C and D) were significantly different [B(pre)-B(during): $t(14)=2.337$, $p<0.04$, C(pre)-C(during): $t(14)=2.526$, $p<0.03$, D(pre)-D(during): $t(14)=2.940$, $p<0.01$].

After the intervention was removed, the energy use slid back up, although not as significantly as expected. Persistence of energy savings, at least over a 14-week period after a dashboard is removed, seems to still be effective. Even the automated calendar users, Group D, had a savings difference that remained effective, contrary to our assumptions that they would become dependent on automation for energy management. Statistically, pre and post-intervention measures for dashboard groups (Group B, C and D) were significantly different whereas the ones for the control group (Group A) were not different. [B(pre)-B(post): $t(14)=1.618$, $p<0.12$, C(pre)-C(post): $t(14)=2.351$, $p<0.04$, D(pre)-D(post): $t(14)=2.459$, $p<0.03$]. No statistically significant differences were found between the groups.

Thus, when feedback alone was provided, more energy savings were made than the no dashboard group, when feedback and control features were provided, even more savings were made, and when those features plus automated control features were given, the greatest energy savings were achieved. This supports our hypotheses. After the dashboards were removed, persistent energy savings with a slight decrease were shown for all the groups. Group D with the calendar feature also showed persistent savings during the third phase, and this was against one of our hypotheses. The dashboards worked as motivational and supportive interventions since the users (Groups B, C and D) showed persistent energy savings after the dashboard interventions were provided and removed.

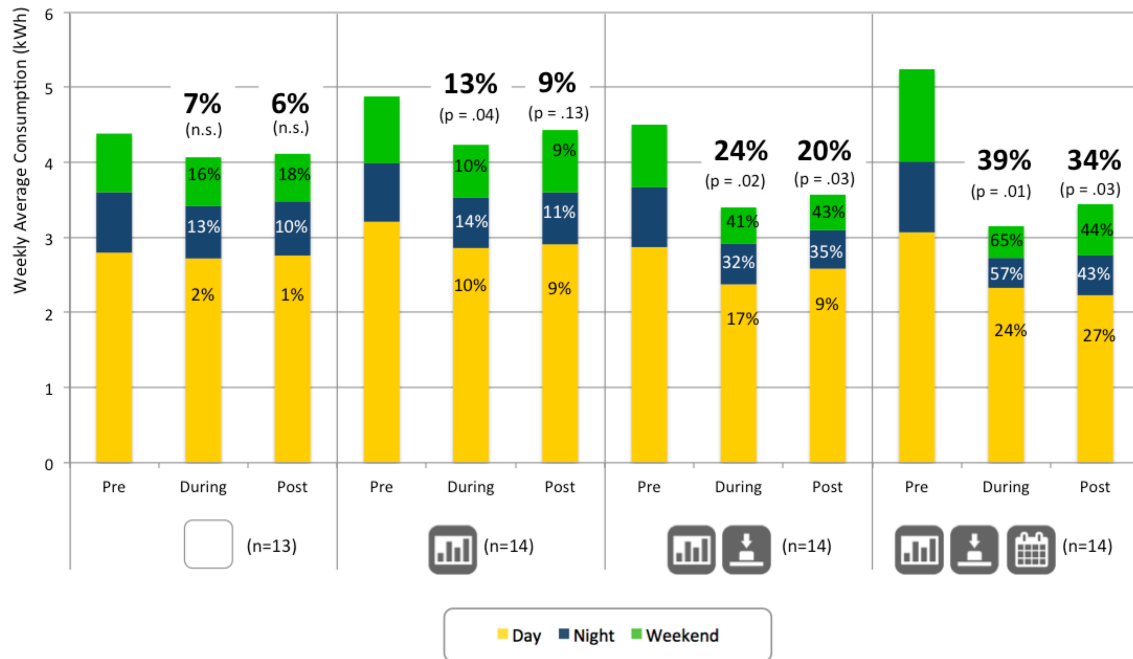


Figure 30. Overall weekly average consumption per group

In analyzing the data, it is important to note that the results from 55 of the eighty participants recruited for the field study were used in the analysis. The following people were excluded from the data analysis: individuals who refused to participate in the study (1 person in Group B); individuals who relocated (11 individuals from different groups A:4, B:2, C:2, D:3); individuals whose occupancy pattern was erratic (3 individuals from B:1, C:2); and individuals who had one or more mal-functioning meters (A:3,B:2,C:2,D:3). Therefore, fifty-five participants were included in the data analysis.

5.4. Energy Savings by Level of Dashboard Support (Groups A, B, C and D)

The following figures show each individual's daily electricity consumption before, during and after the intervention for each of the four groups. Each chart is divided by black lines to distinguish before, during and after the innovation. The percentage at the top of the second phase represents the savings made during the period when the ID-O was deployed and the percentage at the top of the third phase represents the savings made (or lost) after the dashboard was removed. The gray tone areas represent the period when the meter was malfunctioning.

Not surprisingly, the group without a dashboard (A, see Figure 31) has modest variations of +/- 7% except for three individuals who had either measurably improved performance, A2 and A11, or measurably reduced performance, A4. Performance improvements could have been triggered by awareness of peer activities, but do not change the average neutrality of the control group in comparison to the others. Average energy savings for the group during the intervention was 7%, with a long term energy savings of 6%, predominantly due to two individuals (A2 and A11) who corrected significant inefficiencies.

By comparison to Group A with no dashboard, the provision of a feedback-only dashboard for Group B - with self-monitoring, peer comparison, behavioral effectiveness self-comparison, expert advice and organizational cost benefits – did have a measurable impact (see Figure 32). Two people in Group B achieved 51% and 63% savings during the period with a dashboard. While three of the fourteen in this group increased energy use during the intervention period, the average gains in the percent of energy saved for this group was 13%. After the ID-O dashboard was removed, the average gains in the percent of energy saved (persistent savings) continued to be 9%.

The addition of on-line controls for Group C as well as the full complement of feedback interfaces - self monitoring, peer comparison, behavioral effectiveness self-comparison, expert advice and organizational cost benefits – resulted in group energy savings of 24% with a persistent energy savings of 20%. Empowering individuals with both communication and control results in substantially greater persistent savings for the organization.

The provision of automated calendar controls as well as on-line controls and the full complement of feedback interfaces - self monitoring, peer comparison, behavioral effectiveness self-comparison, expert advice and organizational cost benefits – resulted in the greatest group energy savings of 39% with a persistent energy savings of 34%. The addition of a calendar control has measurable benefits for energy efficiency given the work demands on many office workers today. The concern that automation would result

in a loss of energy awareness for the group was not realized, since this group not only achieved the greatest level of savings, they had the greatest persistence in energy savings. Two active calendar users (D1 and D10) who set up a weekly schedule for all their devices achieved 35% and 54% savings during the intervention, but this was reduced to 2% and 28% after the calendar was removed. Once sleep cycles and brightness settings have been corrected, persistence in savings is highly dependent on manually managing on-off schedules for each desktop technology, tasks still most aggressively sustained by this group with a 17% persistent energy savings.

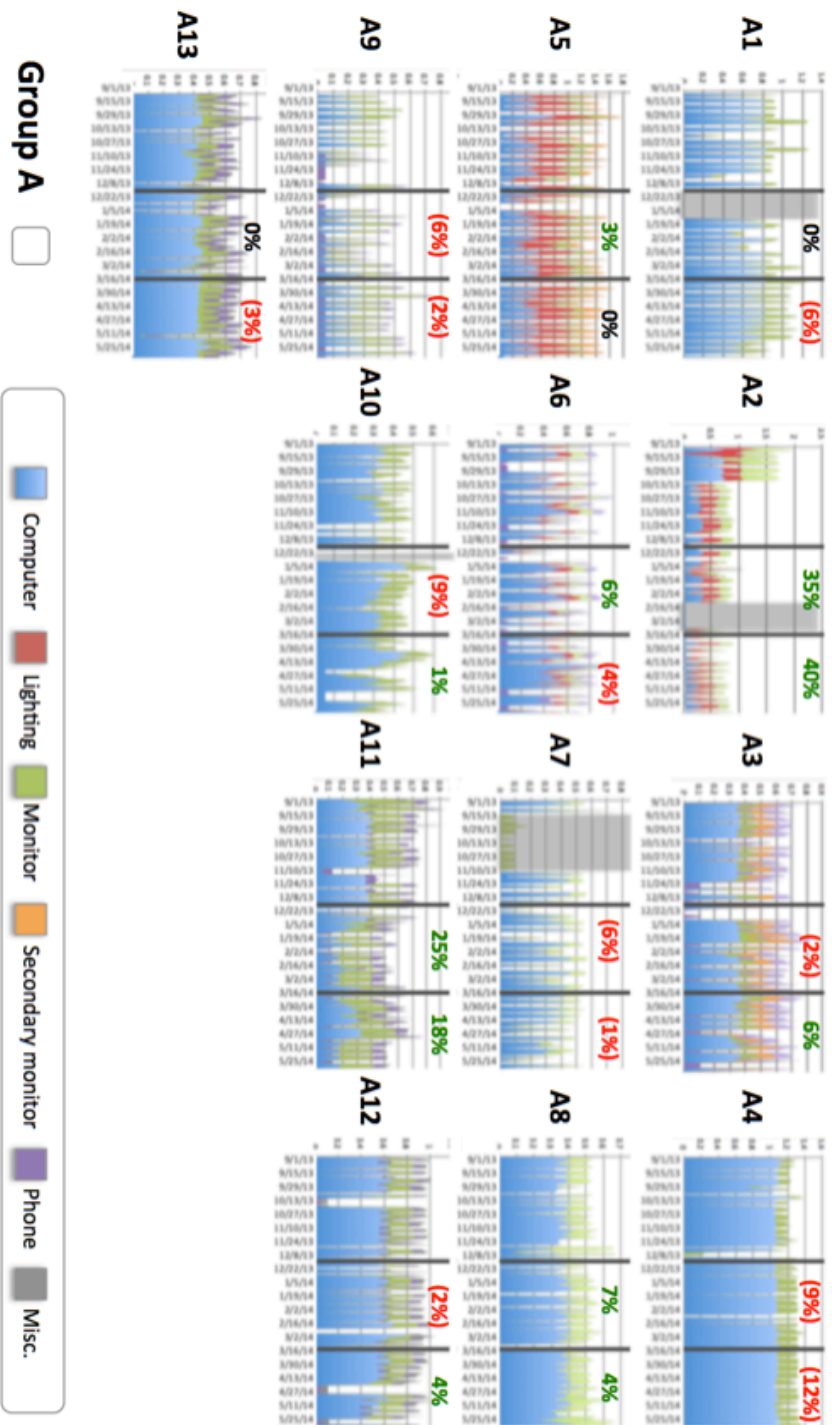


Figure 31. Individuals' electricity consumption in Group A

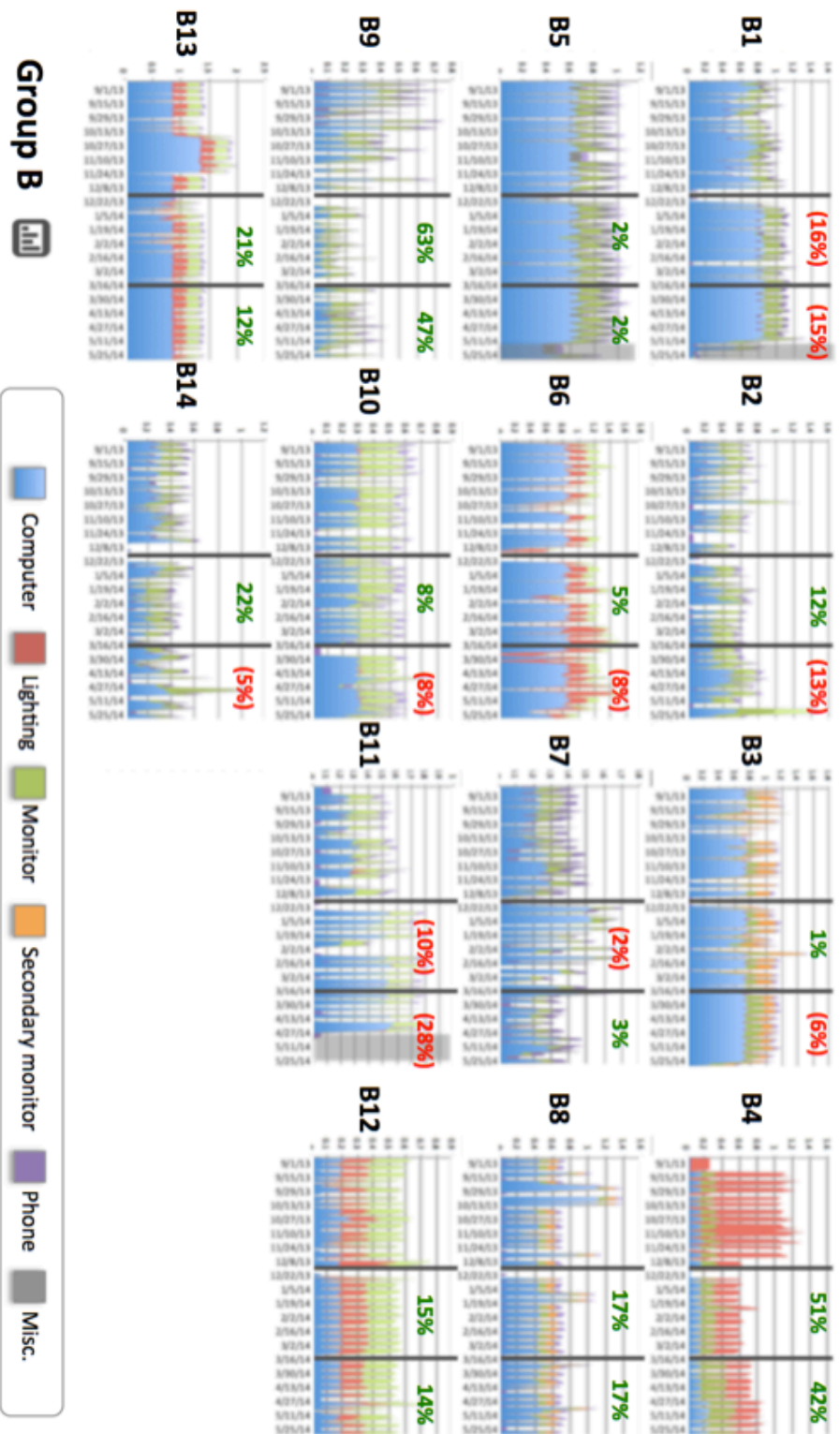


Figure 32. Individuals' electricity consumption in Group B

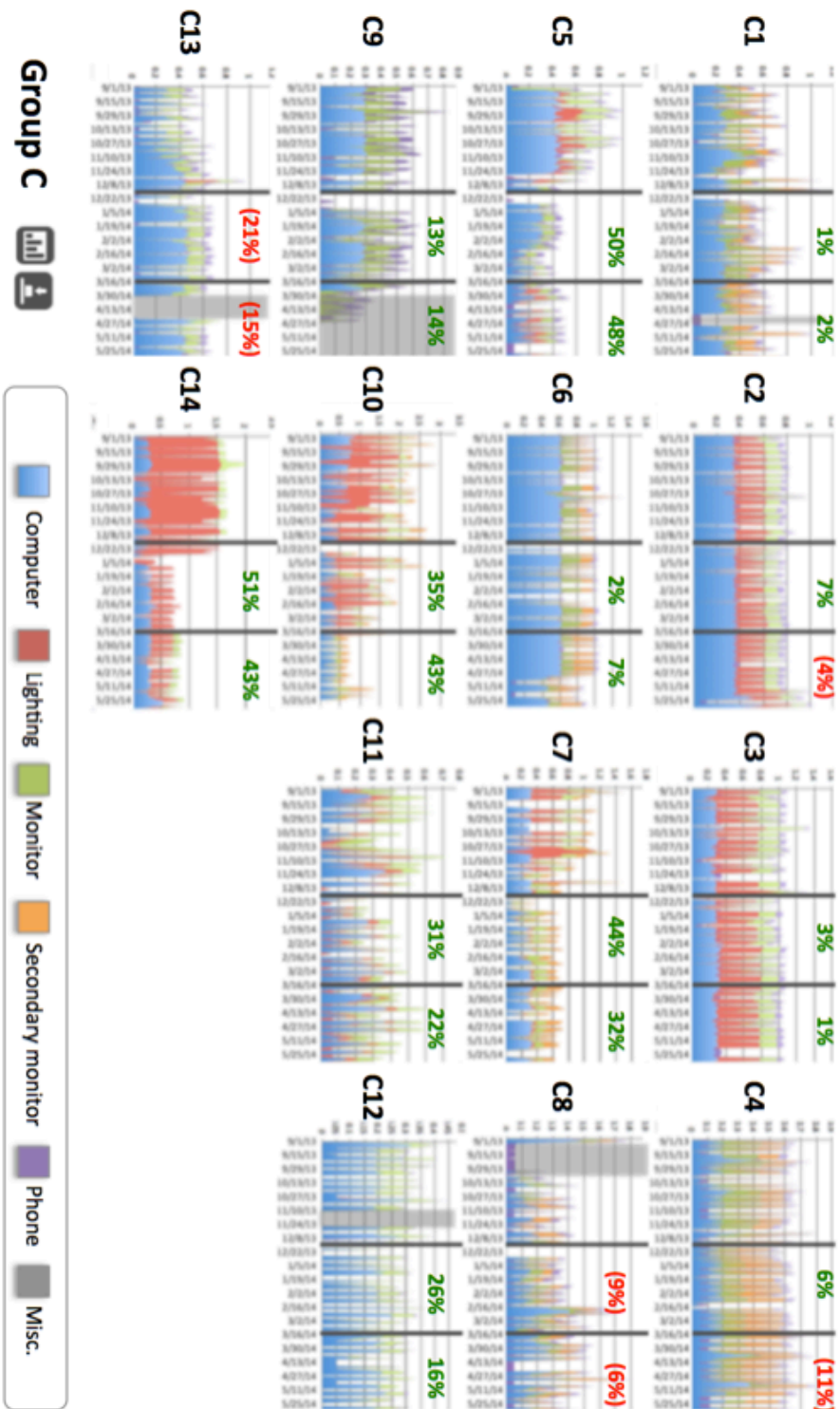


Figure 33. Individuals' electricity consumption in Group C

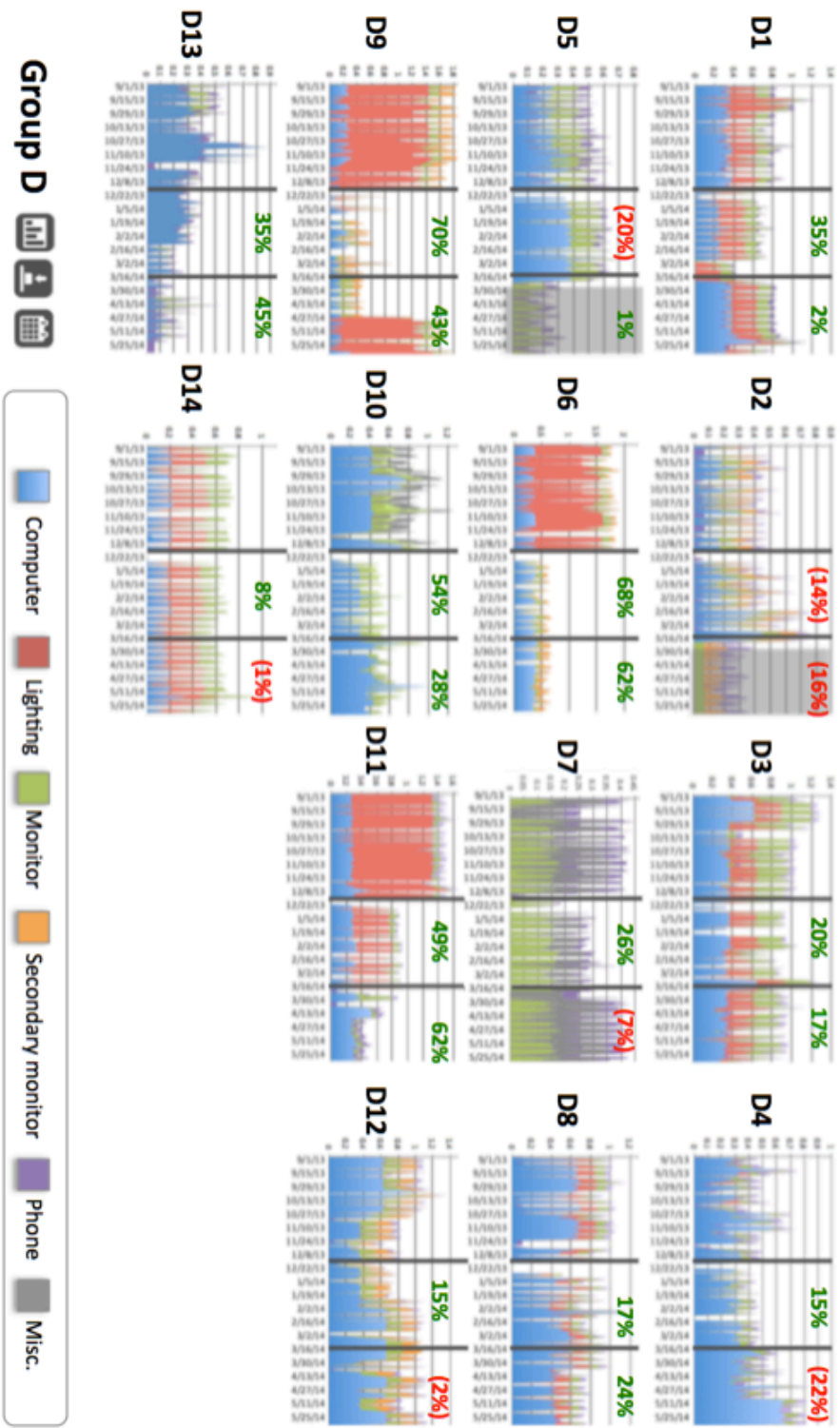


Figure 34. Individuals' electricity consumption in Group D

5.5. Energy Savings per Device

The following figures illustrate the weekly consumption per device. Regarding computer usage during the intervention, it was found that savings from computer usage in our field study was limited due to the company's corporate policy. The company doesn't want the employees to turn off their computers due to maintenance purposes. The online control feature was not useful (10% was shown for Group C, and very similar to Groups A and B) because this feature was not designed for computer control. Only 2 participants in Group D (D1 and D10) used the calendar for their computers, and they showed 45% and 51% savings. The baseline was not even because people use different types of computers (i.e. laptops and desktops). After the intervention is removed, the usage became similar to the baseline point (Groups C and D) or slightly exceeded that of Groups A and B.

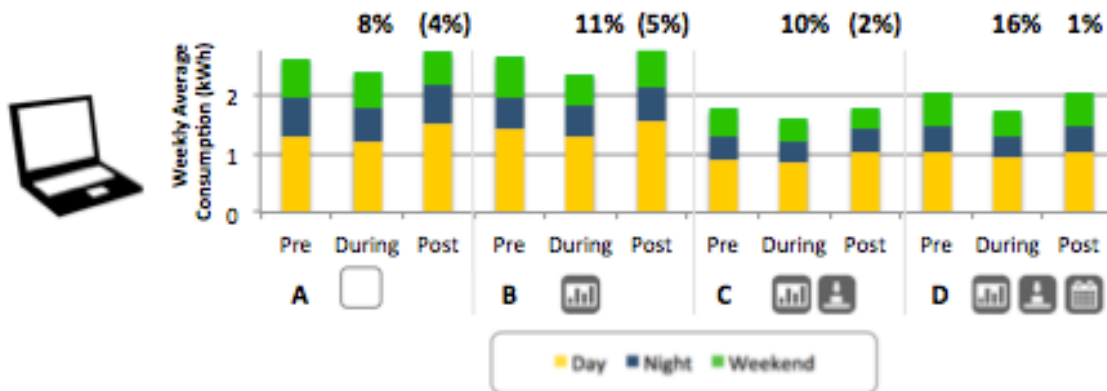


Figure 35. Weekly average consumption for computers

The biggest difference between the monitors and other devices is that the monitors didn't lead to large savings during the weekends and nights. It turned out that most of the monitors that the participants used are already energy-efficient products and the monitors go into sleep mode automatically when they are not used. Figure 36 shows that monitors consume electricity mostly during the week-day period (see yellow).

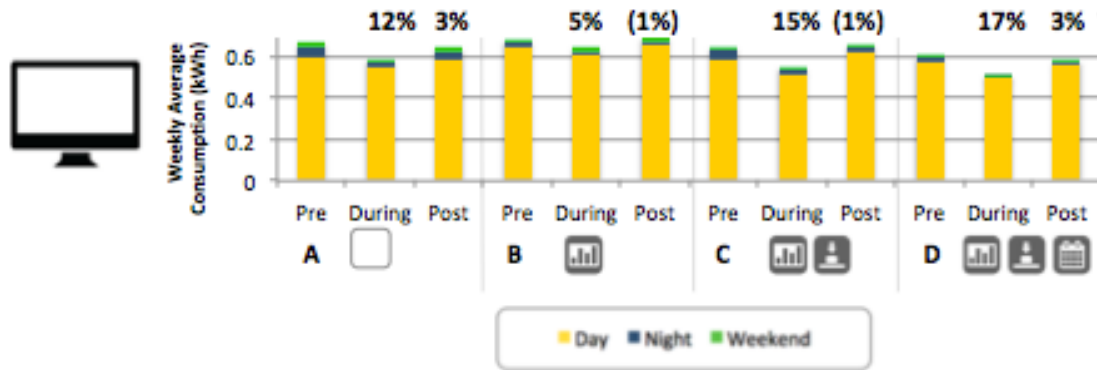


Figure 36. Weekly average consumption for monitors

Large savings were resulted from more effective lighting usage: 31%, 41%, 52% and 75% were made from Groups A to D, respectively. However, as shown in the top chart in Figure 37, the baseline of each group was at a different level. It was found that inefficient light bulb users (A:1, B:1, C:5, D:3) and occasional light users (A:2, B:1, C:3, D:0) were unevenly distributed. Ten participants used light bulbs that consume more than 50 watts (W) which is larger than that of a typical laptop in this company ($\approx 30W$). Six participants used their lights only 2-5 days during the baseline period. The chart at the bottom of Figure 37 shows the per-group consumption after excluding the extreme light bulb users and occasional light users. The baseline became even, and 9%, 15%, 14% and 24% savings were created. The percentage numbers became smaller because big savers were excluded after filtering.

The big difference of the light usage in comparison to other devices is the light usage did not return to the baseline point after the dashboard was removed and still showed some savings (top, Figure 37). After filtering out the big consumers (bottom, Figure 37), the light usage during the third phase rose up to the baseline like other device types. This may be because people who learned about the inefficiency of their bulbs when they used the dashboard remembered it and put effort into using light bulbs effectively, even without the system.

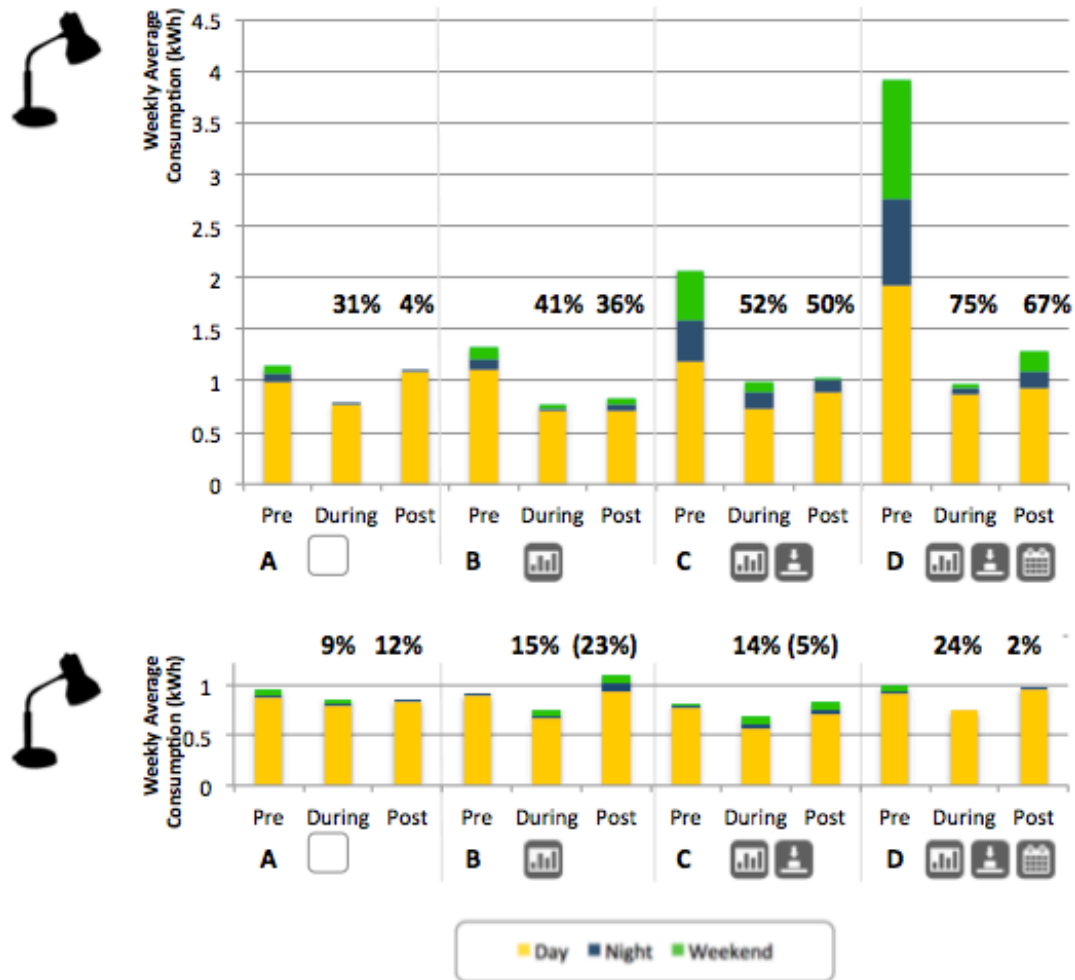


Figure 37. Weekly average consumption for lights before filtering (top) and after filtering (bottom). Filtering was conducted to make the baseline even.

Regarding phone usage, Group A didn't show a difference whereas the dashboard users (Groups B, C, D) achieved 15%, 17%, and 47% energy savings. While the dashboard for Group B does not have control features for phones, people (e.g., B9) used a power strip to turn on and off their phones. The greatest savings from telephone management is by calendar users on nights and weekends – 73%, 67% respectively. After the intervention is removed, it was found that the usage of the phones rose up to the baseline point as well.

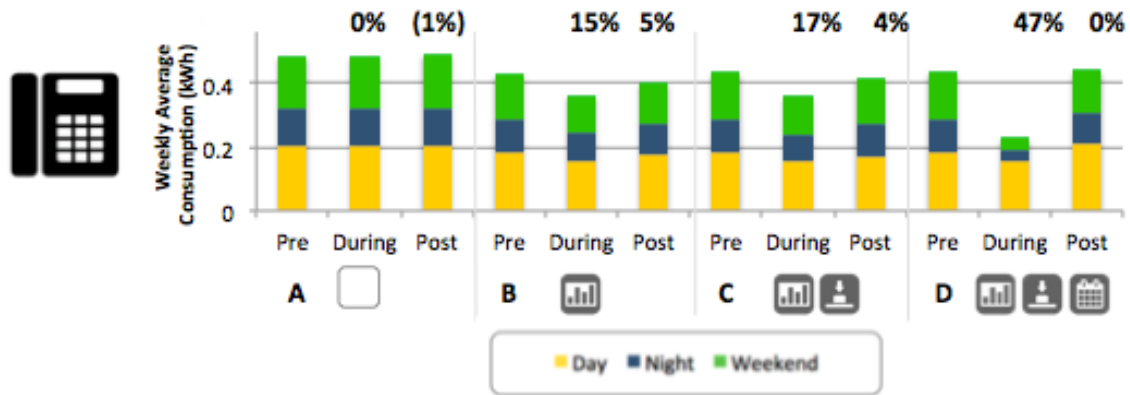


Figure 38. Weekly average consumption for phones

5.6. Energy Savings and Effectiveness

Section 5.3 demonstrates how individuals consume electricity before and after the dashboard was provided. By using the effectiveness index (see section 3.2.3), it can be investigated how the dashboard influenced users who had different effectiveness. For example, it can identify whether the savings after the intervention came only from the users who consumed electricity inefficiently, or whether the savings also came from the efficient energy consumers.

The effectiveness index shows how efficiently a user or a device consumes electricity. It is calculated as the ratio between the optimal use of the appliance (the power in active mode x the number of occupied working hours) and the total energy consumption over the measured period (Lasternas et al., 2014). The chart below (Figure 39) shows the correlation between individuals' effectiveness index before the intervention (X-axis) and the energy savings achieved after the intervention (Y-axis). A Pearson product-moment correlation coefficient was computed to assess the relationship between the two factors per group. There was a negative correlation for Group D, $r = 0.78$, $n = 14$, $p < 0.01$, but no significant correlation was found for the other groups.

It was found that the automation feature showed low effectiveness towards energy saving for the users who originally consumed energy efficiently, but high effectiveness for the

ones who wasted energy. This may be because automation lets people depend on the feature, and the savings are only made to the extent that the system will allow. In contrast, the feedback and manual control features did not show any correlation with the user's consumption effectiveness. People in those groups put effort towards understanding their consumption and reducing energy waste regardless of their pre-efficiency. But this requires the user's time and effort, so not everyone showed an increase in savings.

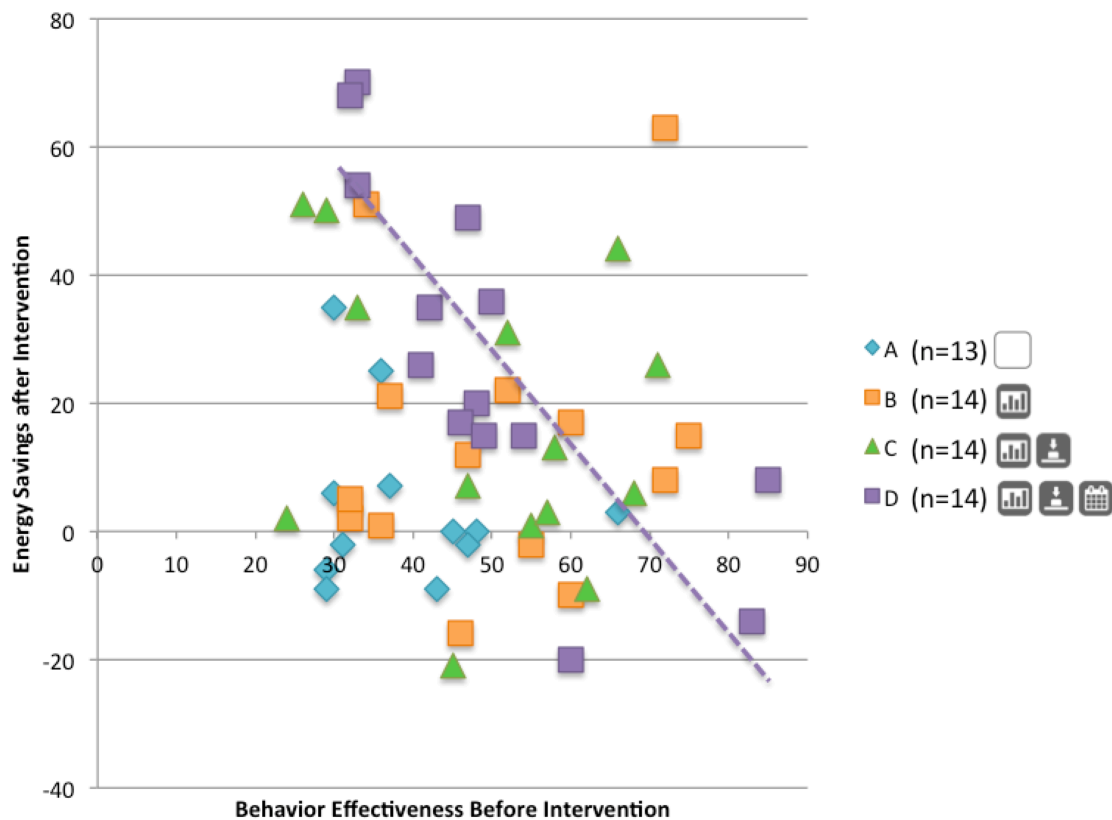


Figure 39. Individuals' behavior effectiveness before the dashboard intervention (x axis) and the energy savings achieved after the intervention (y axis)

Therefore, to maximize the effectiveness of the dashboard features for a company, it is important to research users in advance and decide whether to include the automation feature when the system is deployed. If they use highly energy-efficient products and behave pro-environmentally in general, automation may not be very effective.

The effectiveness index used in this study contains the following limitation. To calculate the effectiveness index, it requires the number of occupied hours over the measured period, and to estimate that duration, the total hours in the monitor's active mode are used. Depending on the monitor's settings, this may differ from the users' actual occupied hours. This method can be improved if occupancy sensors are used.

5.7. Summary

This chapter introduces the second generation dashboard from the findings from the usability study. Then it demonstrates how the ID-O system was deployed to thoroughly investigate the effectiveness towards energy saving. Eighty employees were recruited from a large office building, their baseline data was collected for fourteen weeks, and dashboards equipped with different features were provided to them for thirteen weeks, and then removed for eleven weeks.

During the intervention, the group that was equipped with all the features, including the calendar, achieved the greatest savings. After the intervention was removed, the savings were generally reduced. Computers, monitors, and phones returned to levels close to the baseline, but lights were likely to stay close to the level achieved during the intervention. Automated control features work effectively for the users who tend to waste energy, but not for the users who already consume electricity efficiently.

The next chapter discusses the users' perceived sustainability level as assessed through conducting multiple surveys.

6. MEASUREMENT OF ID-O PERCEPTION IMPACTS

The previous chapter discusses how the users consumed electricity after the differently designed dashboards were given. In order to assess the user perception impact, surveys were conducted as shown in Figure 40. To understand user perception impact at pre-, during- and post intervention, the first, third and fourth surveys were considered. This chapter discusses the methods and results for the survey deployment.

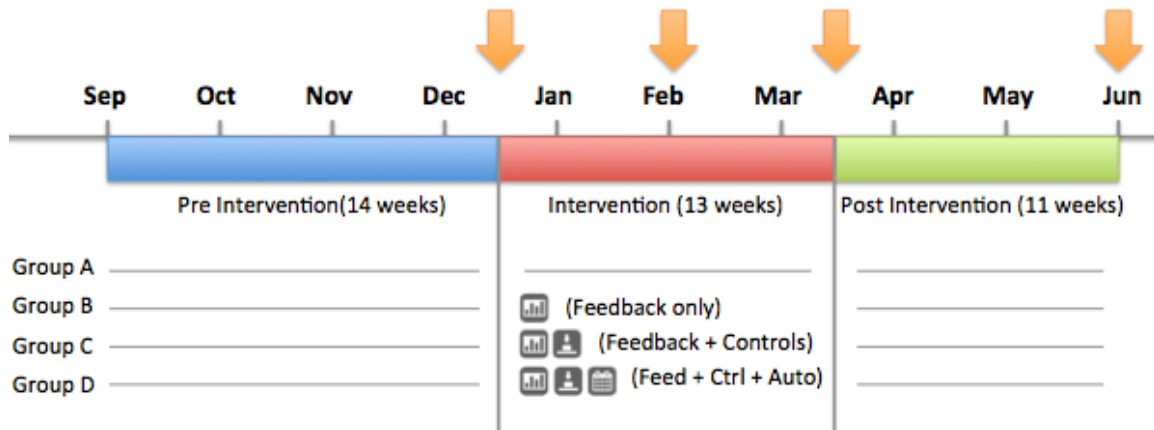


Figure 40. The surveys were conducted four times (orange arrows). The first, third and fourth surveys were considered to understand user perceived sustainability at pre-, during-, and post- intervention.

6.1. Survey Development for Measurement of the Stages

As mentioned in Section 2.1, few studies were found that assess sustainability stages. Mair et al. (2013) developed a survey that asks twenty-nine questions on how often they carry out certain sustainable practices such as commuting by bicycle, recycling and cold-water wash. The response options provided were: never – sometimes – often – regularly – always. Scores were calculated per person and classified according to each TTM stage. When this approach was reviewed, three issues were found. First their survey covered a wide range of sustainable practices (transportation, energy, water use, waste management, etc.) and they were equally weighted. We contend that people may be committed to one aspect of sustainability but not others. Hence, TTM stages may vary by sustainability area practice. For example, one may be a committed recycler at home but

commute by car to work. Second, the TTM model was applied to sustainability, whereas typically it is used for health behavior change. In other words, there may be a requirement for modifications in order for the model to apply to sustainable behavior change. Third, the stages were defined based on the level of practice (e.g., Pre-contemplation: 26-52, Contemplation/preparation: 52-78, Action: 78-104, Maintenance: 104-130), despite the fact that this does not distinguish knowledge, awareness, planning, and behavior. In other words, one may be very informed about sustainability issues and do very little to put into action such knowledge.

This study refined Mair et al.'s approach to address those limitations as follows. First, the sustainability domain was narrowed to plug-load management for desktop technology in the workplace; second, Geller's model was employed because it was developed specifically for sustainability; and third, instead of assigning each person to a specific stage, awareness and behavior scores were mapped in a scatter plot to describe one's stage. The survey questions the team developed are listed in Table 18.

These questions were developed based on the PIER's report (Mercier et al, 2011) which suggests the most effective methods of plug-load management for the office environment. Questions one and two identify the frequency with which users select pro-environmental behavior in terms of the use of office appliances. Question three investigates user understanding of their own energy consumption at work. Questions four and five help understand users' work environment and organizational culture (Bronfenbrenner, 2005).

To quantify behavior change from the survey, a certain score number value has been assigned to each option in Table 18. Those numbers are totaled per group and averaged. To quantify the awareness change, correct answers from question #3 were counted and averaged. The correctness of the answers was evaluated based on the energy usage data collected from the smart meters installed for individual users.

Table 18. Survey question examples

Question examples	Option examples
<p>Q1. How often do you turn off or unplug your:</p> <ul style="list-style-type: none"> - Computer when not in use on nights and weekends? - Computer monitor when not in use on nights and weekends? - Task light (lamp, underbin light) when not in use? - Office phone on nights and weekends? 	<p>a) Never (1)</p> <p>b) Rarely (2)</p> <p>c) Sometimes (3)</p> <p>d) Often (4)</p> <p>e) Always (5)</p> <p>f) Do not know (0)</p>
<p>Q2. Have you:</p> <ul style="list-style-type: none"> - Adjusted power settings (e.g., to power saver mode) for the computer you are using at work? - Adjusted brightness settings for your computer monitor at work? 	<p>a) Yes (5)</p> <p>b) No (1)</p> <p>c) Do not know (0)</p> <p>d) Not applicable</p>
<p>Q3. Put in order the actions you think will have the greatest impact on energy savings:</p> <ul style="list-style-type: none"> - Turn the computer off when not in use (e.g., nights, weekends)? - Turn the computer monitor off when not in use (e.g., nights, weekends)? - Turn the task light (lamp, underbin light) off when not in use (e.g., nights, weekends)? - Turn the phone off or unplug it when not in use (e.g., nights, weekends)? - Adjust computer power settings (e.g., to power saver mode)? - Adjust computer monitor's brightness settings? - Buy energy star office equipment such as: computers, printers, lights, and so forth? 	
<p>Q4. Have you:</p> <ul style="list-style-type: none"> - Discussed energy usage/saving in your work group? 	<p>a) Yes (5)</p> <p>b) No (1)</p> <p>c) Do not know (0)</p> <p>d) Not applicable</p>
<p>Q5. How often does your organization:</p> <ul style="list-style-type: none"> - Provide workers with very energy efficient products (e.g., computers, displays, lights)? - Encourage workers to reduce energy use in the office? 	<p>a) Never (1)</p> <p>b) Rarely (2)</p> <p>c) Sometimes (3)</p> <p>d) Often (4)</p> <p>e) Always (5)</p> <p>f) Do not know (0)</p>

6.2. Survey Deployment and Results

The surveys were conducted four times during the field study (See Chapter 6). Out of the four surveys (the orange arrows in Figure 40), the first, third and fourth surveys were considered to understand user perceived sustainability at pre-, during-, and post-intervention. This chapter refers to those surveys as the pre-intervention survey, the during intervention survey, and the post-intervention survey, respectively.

As noted above, eighty participants were recruited for this study. Sixty-three (Group A:16, B:17, C:14, D:16), fifty-one (Group A:13, B:17, C:10, D:11) and forty-five (Group A:11, B:14, C:10, D:10) participated in the pre, during and post-intervention survey. Out of those, only thirty-seven users (A:10, B:10, C:9, D:8) completed all the surveys, so their answers were considered in analyzing and comparing the users at pre-, during and post-intervention. Age and gender were not collected due to the company policy. To present the comparative data in an easily understandable format, all results have been converted to percentages.

6.2.1. Perceived Behavior Change

Based on the survey responses, perceived behavior change was measured as follows (Figure 41). The y-axis is the average score percentage calculated from each group's response to questions one and two. For example, if a person answered "always" (5) to all Q1 questions and "yes" (5) to all Q2 questions, his or her behavior score is 30 and is converted to 100.

Pre- and during intervention surveys show dashboard user groups' (Groups B, C and D) perceived behavior scores are increased by 48, 46, and 71%. And Group A that had no dashboard also increased by 19%. The pre- and during measures for all the groups were significantly different [A(pre)-A(during): $t(9)=3.412$, $p<0.01$; B(pre)-B(during): $t(9)=6.876$, $p<0.001$; C(pre)-C(during): $t(8)=7.344$, $p<0.001$; D(pre)-D(during):

$t(7)=3.866$, $p<0.01$]. This shows that all groups' perceived behavior was changed after the dashboards were introduced.

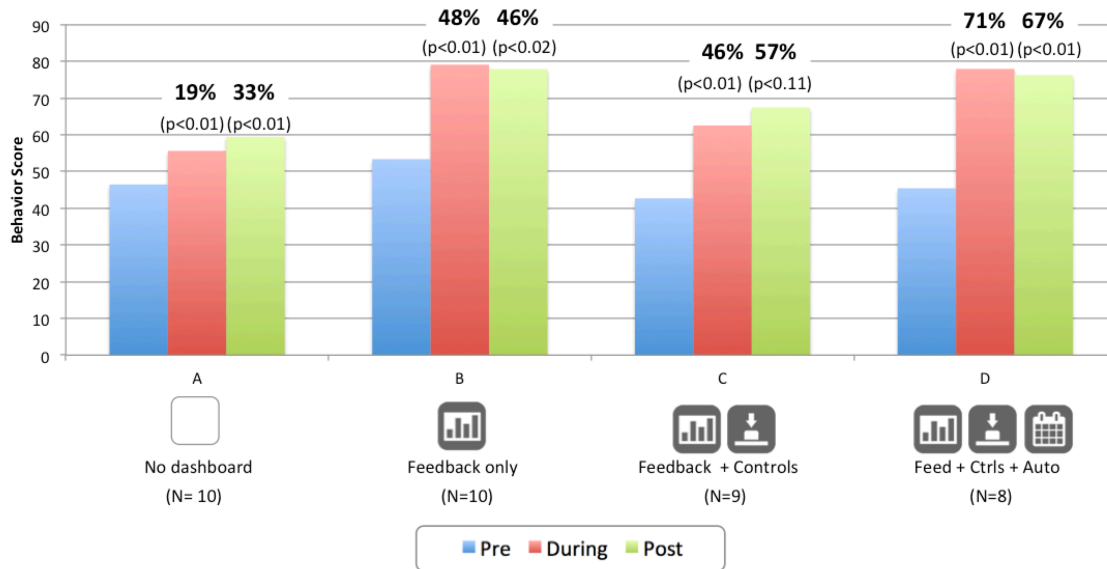


Figure 41. Perceived behavior change measured with survey responses for respondents' behavioral effort based on their answer to questions one and two.

Whereas pre-intervention measures between the groups were not statistically different, the during measures for Groups A and B, Group A and C and Groups A and D were significantly different or trended towards significant difference [A(during)-B(during): $t(9)=2.691$, $p<0.03$, A(during)-C(during): $t(8)=1.766$, $p<0.11$, A(during)-D(during): $t(7)=3.291$, $p<0.015$]. Prior to the dashboards introduction, no perception difference was found between the groups, after the dashboards were introduced, dashboard groups' perception differences were significantly different from the control group (Group A).

Even after the intervention was removed, dashboard users' (Groups B, C, D) perceived behavior scores were higher than the no dashboard group (Group A). Group D, equipped with the calendar, showed a 67% increased score compared to the baseline, 57%, 46%, 33% for Groups C, B and A respectively. The pre and post measures for all the groups except Group C were significantly different [A(pre)-A(post): $t(9)=3.549$, $p<0.01$; B(pre)-B(post):

$t(9)=4.610$, $p<0.002$; $C(\text{pre})-C(\text{post})$: $t(8)=1.766$, $p<0.115$; $D(\text{pre})-D(\text{post})$: $t(7)=4.833$, $p<0.01$].

Thus, all the dashboards in Group B, C, and D played roles of motivational and supportive interventions introduced at Geller's theory. Group D that equipped with automated control features showed the highest perceived behavior score increase for both interventions. Similar to the results in section 5.3, the more features were offered, the greater behavior score increase was measured for during and post-interventions (Group C's average behavior score is slightly lower than Group B's). This is aligned with the hypothesis stated at the Chapter 2.

6.2.2. Awareness Change

Awareness changes for pre-, during and post-intervention were also assessed from the survey. The y-axis in Figure 42 represents the average correctness of each group's response to question three (the impact on energy savings). For example, if a person answered all seven questions correctly in Q3, his or her correctness was represented as 100%.

Groups B and C showed a 21% and 28% increase after the dashboard was provided. The calendar group's (Group D) score showed less of an increase at only 3% than the other dashboard groups. The no dashboard group's awareness showed a 7% decrease. After the intervention was removed, Groups B and C also showed the biggest increase, 25%, Group D showed an 11% increase and Group A showed a 2% decreased awareness score.

The groups that had feedback only (Group B) or feedback with online controls (Group C) showed a greater awareness increase than the calendar group (Group D), and a similar trend was shown after the dashboards were removed. This trend supports our hypotheses about awareness change, but no statistically significant differences were found between the groups and the study phases. Thus, the feedback features (with the online control) worked as instructional interventions in Geller's theory but the addition of an automation feature may weaken the functionality of instructional intervention.

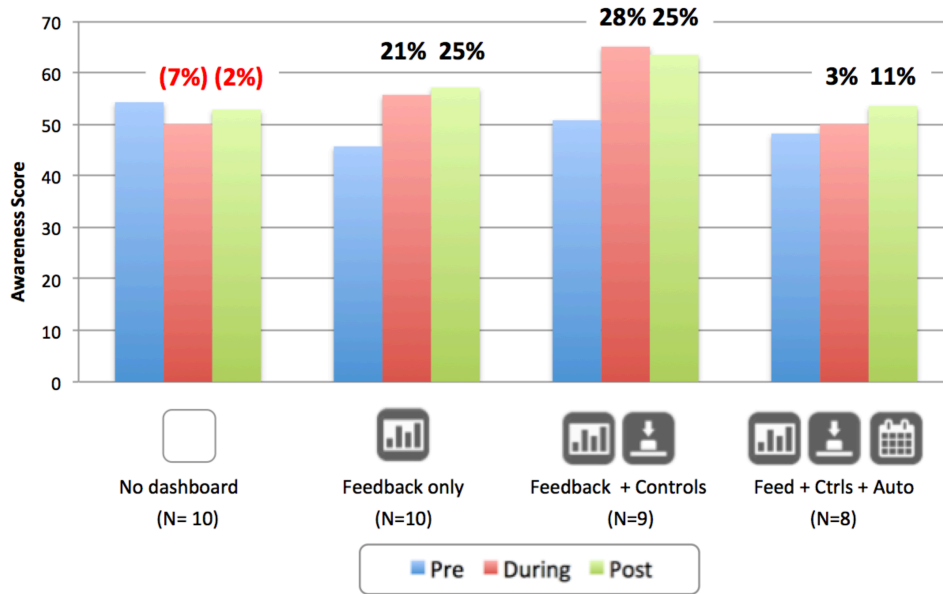


Figure 42. Perceived awareness changes measured with seven questions on the impact of energy savings.

6.2.3. Plot on Sustainability Level Change

Using the behavior and awareness percentage measured from the survey, each group's sustainability level is presented in Figure 43. Before the intervention, all four groups are likely to be located at the center of the charts (blue). After the intervention was provided, Group D moved straight up vertically, and Groups B and C moved up and right. Group A (no dashboard) didn't show an obvious movement direction. Whereas Group D's behavior score was highly increased with a low increase of awareness, Groups B and C's behavior score was less increased than Group D, but with a higher increase of awareness.

Figure 44 shows the sustainability level changes after the interventions were removed. Different from the pre- and during intervention movement (Figure 43), the during and post-intervention surveys didn't show an obvious movement trend (Figure 44). Users showed strong behavior and an awareness score improvement when they received the information and tools to act for better energy management during the intervention. However, after the intervention was removed, people in the groups randomly showed an increase and a decrease in terms of behavior and awareness.

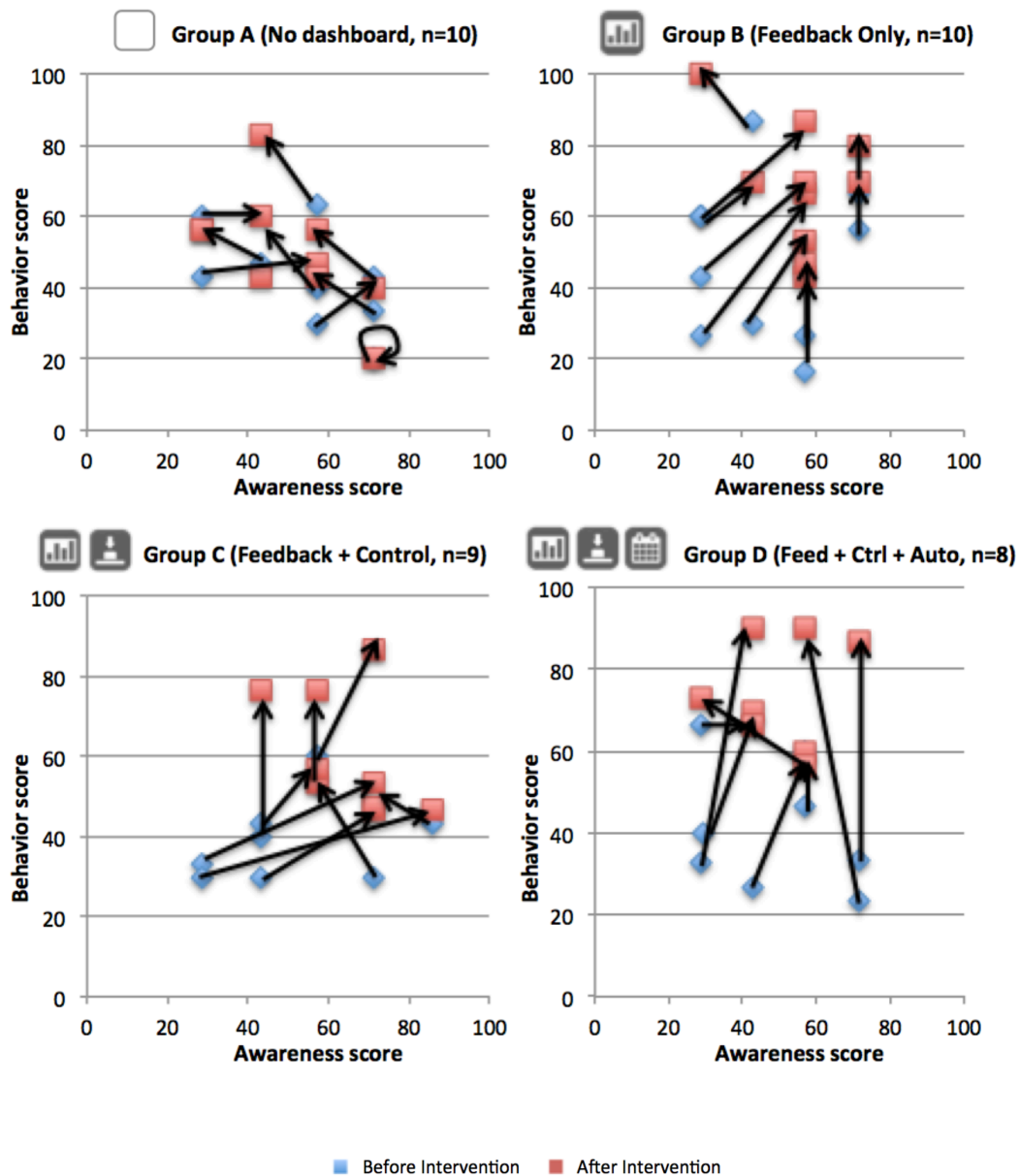


Figure 43. Sustainability level changes measured from pre- and during intervention surveys. The black arrow shows individual user's movement from pre- to during the intervention

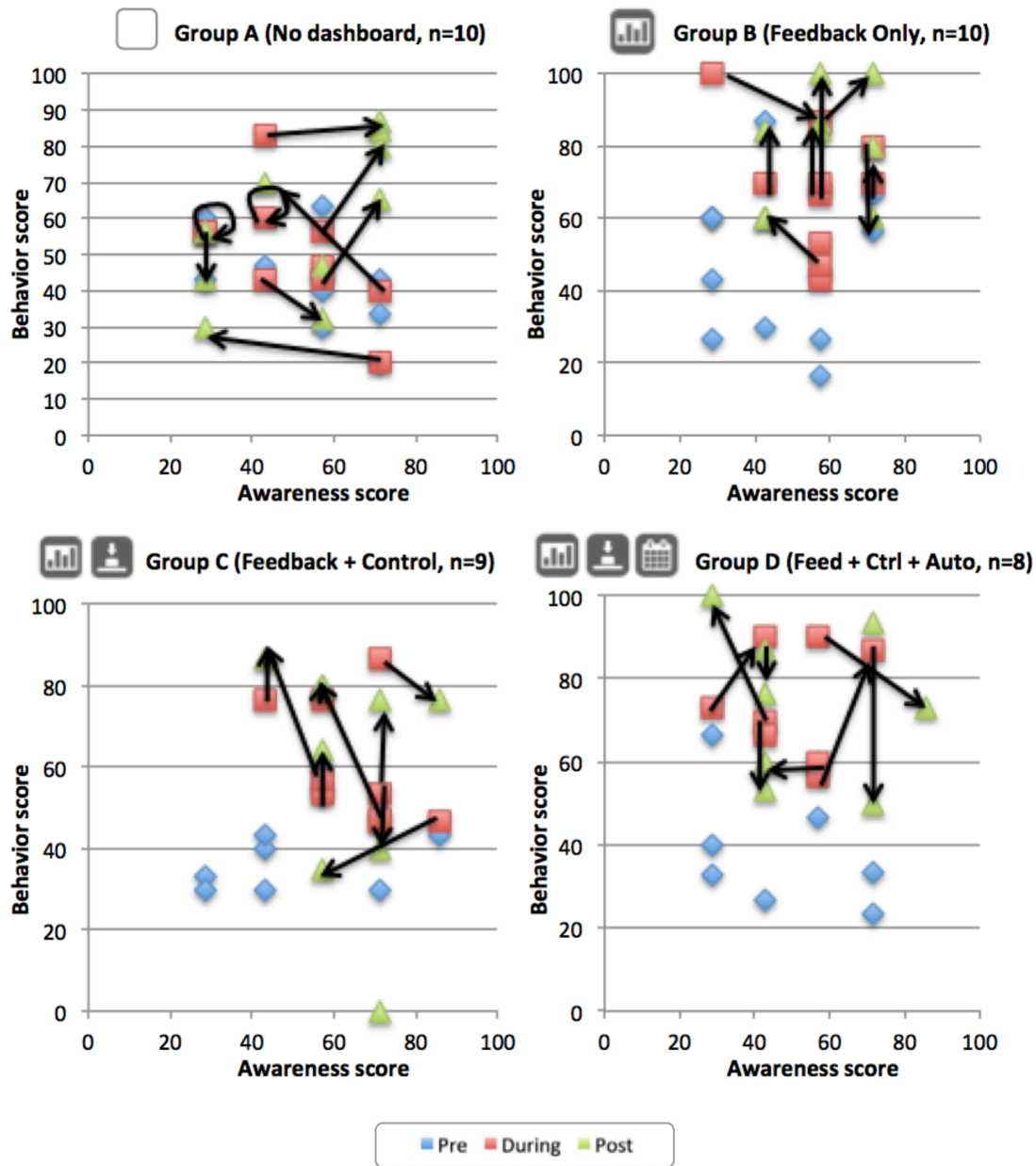


Figure 44. Sustainability level changes measured from pre, during and post intervention surveys. The black arrow shows individual user's movement from during to post-intervention.

6.2.4. Discussion Level Change

In addition to behavior and awareness, questions focused on the discussion frequency and the company's effort related to energy conservation. Figure 45 illustrates the discussion

frequency with the Y-axis representing the average discussion frequency of each group. For example, if a person answered “yes” to question 4, the frequency becomes 100 percent. After the intervention was provided, all groups reported that their discussion frequency was increased (A: 15%, B: 57%, C: 32%, D: 40%). Even after the intervention was removed, the increase of the discussion level was shown as 15%, 76%, 26%, and 54%, compared to the baseline. Overall, before the dashboard was given, all groups’ discussion levels were at 45-55 (See the blue columns in Figure 45). Whereas Group A with no dashboard’s discussion level was increased up to 60, dashboard user groups (Groups B, C, and D) showed an increase of the level to 70 or even above 80 at the during and post-intervention surveys. However the groups didn’t show any statistically significant differences.

Discussion is one of the factors explained in Bronfenbrenner’s Ecological systems theory (2005) and in Geller’s theory (2002) as a supportive intervention. Based on the survey results, dashboard interventions increased users’ discussion frequency and that increase possibly aided in achieving perceived savings.

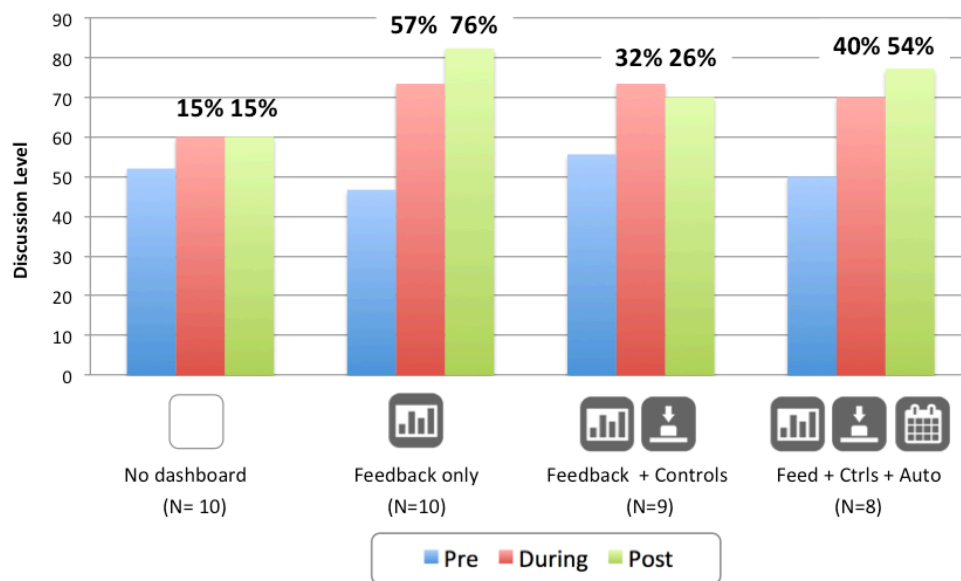


Figure 45. Discussion of energy usage and savings in the workgroups measured pre-, during and post-intervention with one survey question.

6.2.5. Perceived Organization's Effort

To investigate the organization's effort at providing energy efficient products and increasing encouraging energy-saving employee behavior, those two specific inquiries were included as part of question five. The first part of question five asked employees directly whether the company provides energy efficient products for their use. The second part of question five asked participants whether the company encourages them to save energy. Participants generally reported positively. Only 9% of people surveyed responded that their organization "never" or "rarely" provided energy efficient products and just 6% responded that their organization "never" or "rarely" encouraged them to save energy. After the dashboard intervention was given, Group D showed the biggest increase for both questions (Q5-1: 20%, Q5-2: 29%), Groups B (Q5-1: 16%, Q5-2: 14%) and C (Q5-1: 17%, Q5-2: 8%) showed some increase as well. Group A hardly showed any increase (Q5-1: -3%, Q5-2: -2%). Similar trends were shown after the intervention was removed. Group D showed the biggest increase (Q5-1: 22%, Q5-2: 26%), Groups B (Q5-1: 21%, Q5-2: 8%) and C (Q5-1: 16%, Q5-2: 7%) were next, and Group A showed a relatively low increase (Q5-1: 1%, Q5-2: 2%). Participants might have thought that as more technologically advanced systems were given, more effort was made by the organization. In addition, the results show that this company's energy savings encouragement level was a little higher than its energy efficient product support. Some of the participants might have realized from the dashboard that their appliances are energy hogs and it is hard to consume energy efficiently with those products. At the usability testing survey (See Section 7.1), several people also reported that they did their best by following the dashboard recommendations, but it was not easy to consume energy well with inefficient products. This shows that not only making continuous pro-environmental actions (e.g., switching off devices when not in use), but selecting efficient products is also important for sustainability in the workplace. No statistically significant differences of the groups pre, during, or post-intervention or between groups were found.

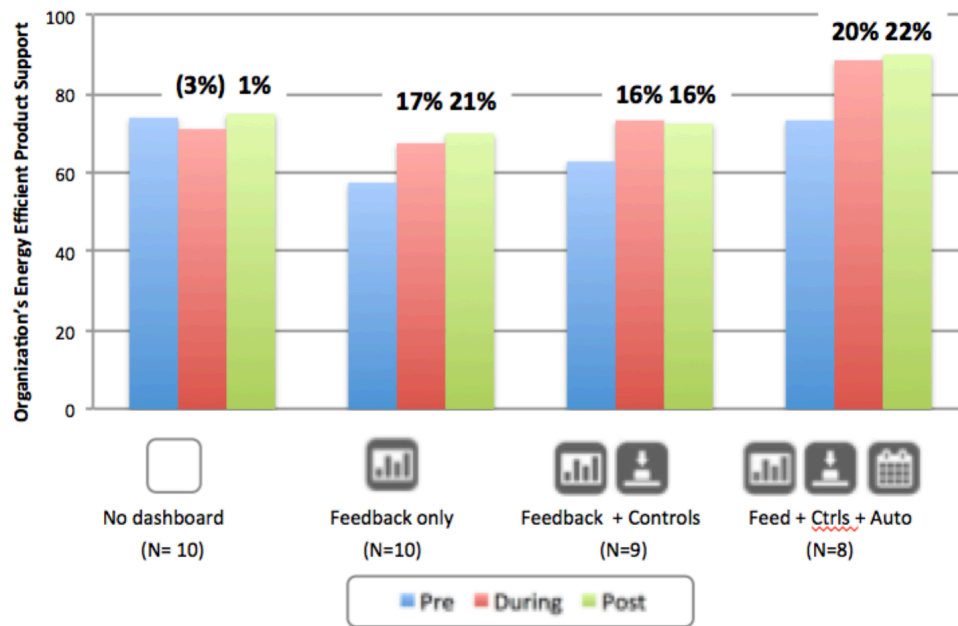


Figure 46. The company's effort in providing energy efficient products from Group A to Group D.

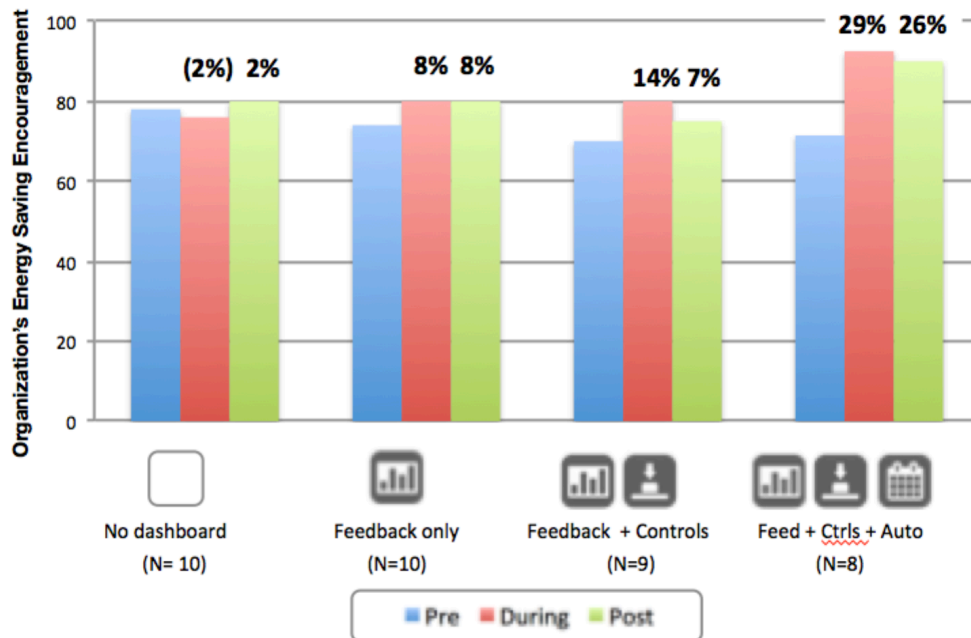


Figure 47. The company's effort in encouraging office workers from Group A to Group D

Organization's encouragement and product support is associated with Macrosystem in Bronfenbrenner's Ecological systems theory (2005). This factor is not explained in Geller's model since the model focuses on the individual level. The increase of user perception in organization's encouragement and product support possibly aided in achieving energy savings.

6.3. Summary

This chapter discusses investigating sustainability stages on plug-load management in the office environment. The survey was developed based on Geller's behavior change model, measured participants' behavior and awareness scores, and displayed their sustainability level on the scatter plots. Geller's model defines each stage based on whether a person behaves pro-environmentally or is pro-environmentally conscious. In reality, however, it is not a simple thing to judge with a binary value, so we used scores to focus on displaying each individual's sustainability level change. After the dashboard system was provided, Group D increased perceived behavior the most, but not their awareness. Groups B and C showed an increase of both behavior and awareness. However, no obvious movement direction was found after the system was removed.

Since the domain of the users are office workers and their behavior is shaped by a larger context that includes at least the workgroup and organization, the survey includes the questions to understand their discussion level and organization's support/effort. It was found that after the dashboard was introduced, users had more discussion about energy savings with others and thought their company is putting more effort in encouraging and supporting them than the no dashboard group users. The next chapter discusses the usability, engagement and perception that the dashboard users experienced.

7. ID-O USABILITY AND ENGAGEMENT

7.1. Usability of the Dashboard System

In the third survey conducted after the dashboard was removed, questions about the system's usability were asked. These questions were asked to the dashboard users only. Thirty out of sixty users responded to the survey (Group B: 12, group C: 10, group D: 8). Five questions about usefulness (7.1.2.), motivation (7.1.3.), barrier (7.1.4.), behavior outside work (7.1.5.), and future requests (7.1.6.) regarding the system were asked.

7.1.1. Most Useful Dashboard Features

The first question asked how useful the dashboard features were to learn about the user's energy consumption at work (Figure 48).

How useful are the following dashboard features to learn about your energy consumption at PNC?

	Very useless	Useless	Neither useful nor useless	Useful	Very useful	× Not applicable
1) Energy chart	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2) Comparison chart	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3) (Behavior) effectiveness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4) PNC cost impact	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5) Recommendation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 48. A question about the usefulness of the dashboard features

The question provided options from “very useless” to “very useful” on the informational features: energy chart, comparison chart, behavior effectiveness, organization-level cost impact, and recommendation. A screenshot of the system and the description of each feature were also provided at the beginning of this survey.

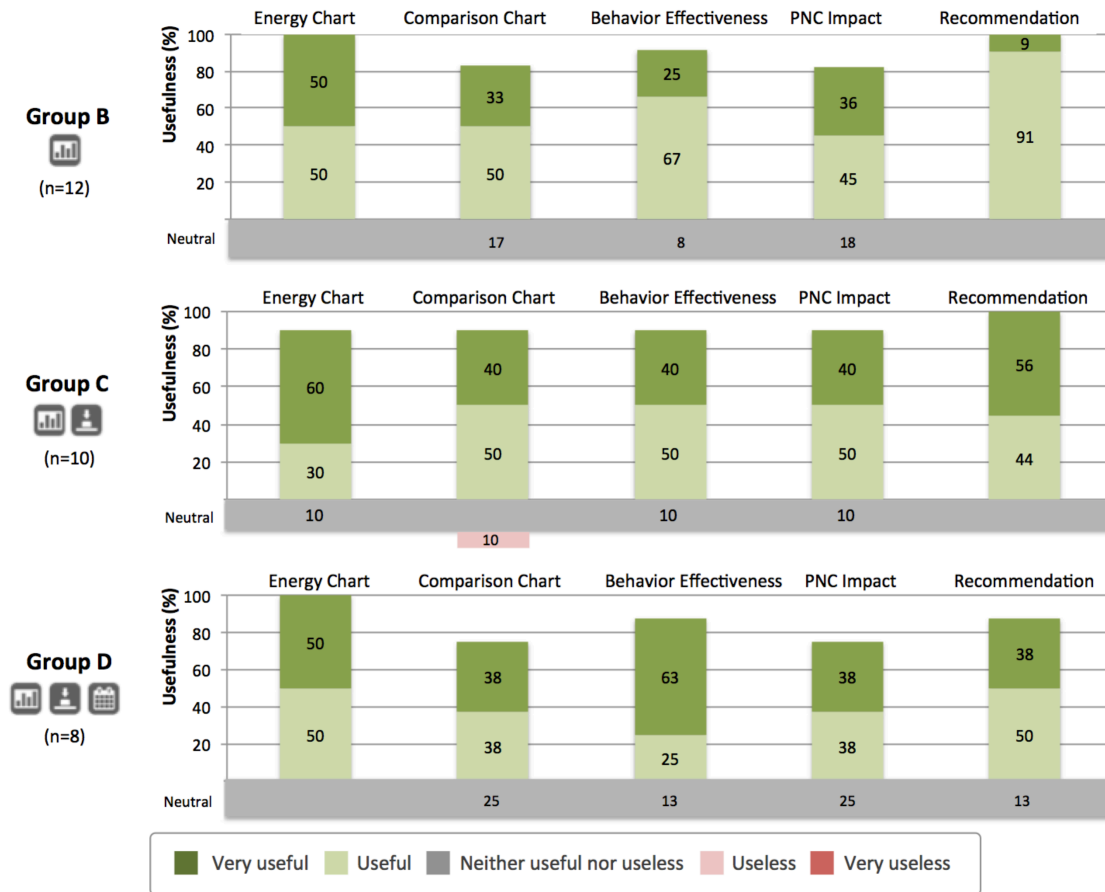


Figure 49. Survey results about the usefulness of the dashboard features. People answered that most features were useful in learning about their energy consumption

The result shows that most respondents answered positively (very useful or useful) on all the features (Figure 49). The question also asked participants to explain the reason for their answer. People wrote that they used the charts as a reflection tool to track their energy usage (e.g., “I used charts in tracking my personal energy use,” “The comparison chart was very useful in showing how I can reduce my energy consumption,” “The energy chart helps remind me to power down when not in the office.”). Some people stated the features are easy to use and the (visualizing) data is useful (e.g., “The Energy Dashboard is easy to use and provides useful information,” “The data is useful,” “Visual images are always the best way to learn about an issue”).

7.1.2. Most Motivational Dashboard Features

The second question asked how much the dashboard features motivated the user to save energy (Figure 50).

How much do the following dashboard features motivate you to save energy (e.g. turn off your devices or adjust power settings for computer and monitors)?

	Very demotivating	Demotivating	Neither motivating nor demotivating	Motivating	Very motivating	✗ Not applicable
1) Energy chart	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2) Comparison chart	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3) (Behavior) effectiveness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4) PNC cost impact	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5) Recommendation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6) Control buttons	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7) Calendar	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 50. A question about the motivational dashboard features

As shown in Figure 51, the question provides the options from “very demotivating” to “very motivating” on the dashboard features: energy chart, comparison chart, behavior effectiveness, organization-level cost impact, recommendation, control buttons and calendar. Group B was only asked questions 1-5, while Group C was asked questions 1-6 and Group D was asked all seven questions. This variation is due to asking only the questions that directly related to each group’s experience with the dashboard.

Similar to the previous results, most people answered positively about the features (very motivating or motivating, Figure 51). People commented that they were motivated by learning how they use energy at work (e.g., *“My light uses more energy than I would have ever guessed.”*) and by voluntarily making a goal (e.g., *“My goal is to much lower my energy usage so all of my Effectiveness bars are in the green,”* *“Being able to visualize your own energy use helps turn it into a game almost - "what can I do to make my results better?"*).

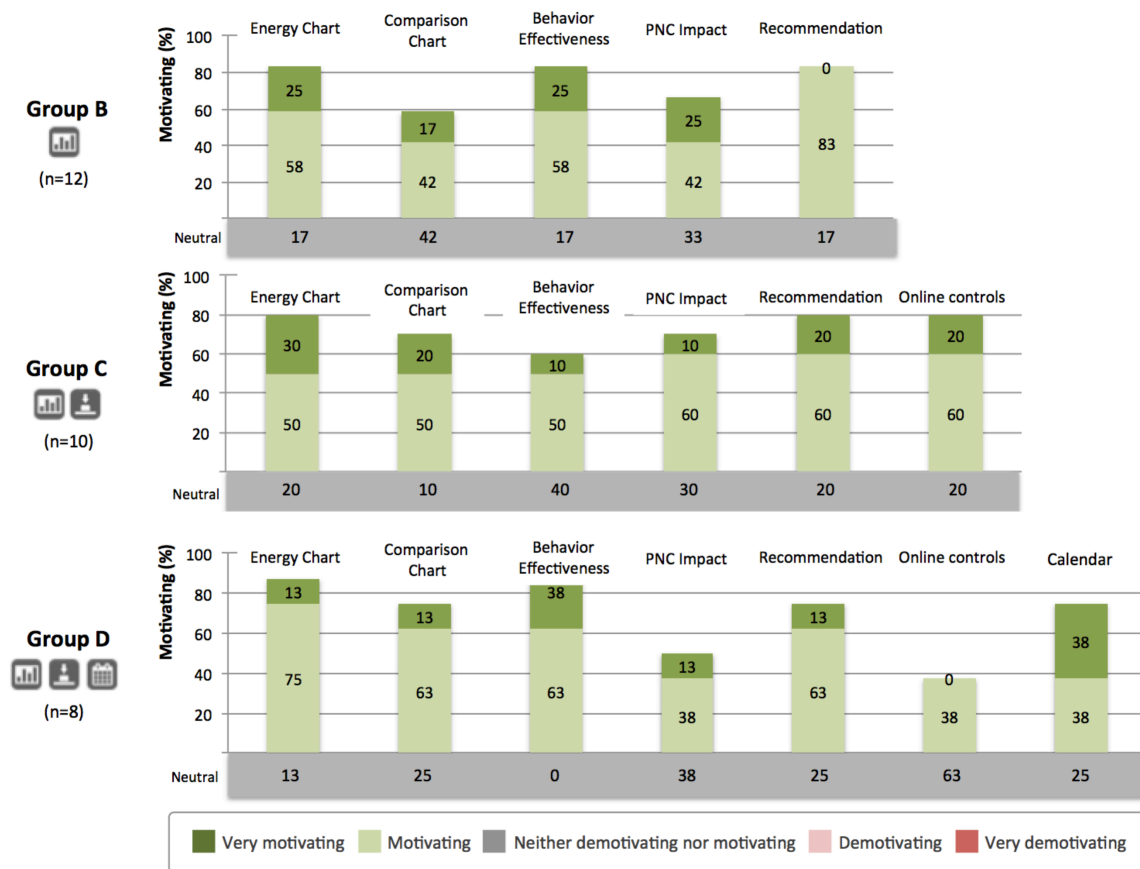


Figure 51. Survey results about the motivational dashboard features. People answered that most features were motivating to save energy.

Figure 52 shows the percentage of respondents who answered positively on how useful or motivating each feature is. Although it doesn't show the obvious differences between the features, the comparison chart and organization-level cost impact were slightly less preferred. It may be because they are the features that require additional clicks to use, and this might influence individuals to use them less. Whereas Group C answered that the control button is one of the most motivational features (Figure 52, bottom), Group D answered that the control button is the least motivational feature. Once the automation was given, people were not likely to prefer to use the manual controls as their main controllers.

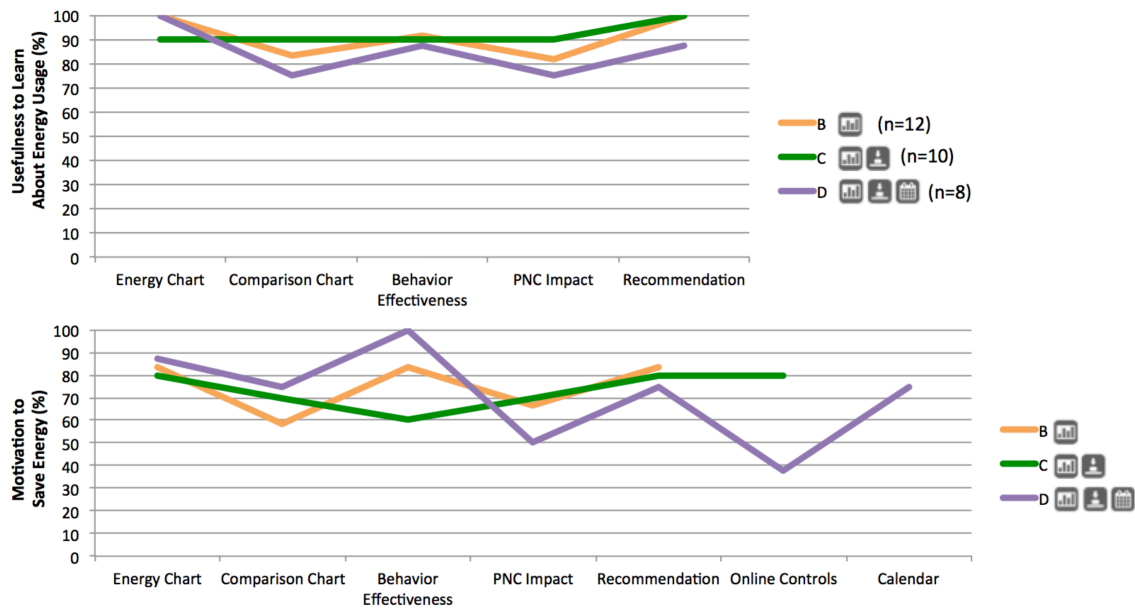


Figure 52. The percentage of positive answers regarding usefulness (top) and motivation (bottom).

7.1.3. Barriers to Prevent People from Using the Dashboard

To understand what prevented participants from using the dashboard, the following question was asked.

Indicate your level of agreement with the following statements.

	Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree
Energy Dashboard is user-friendly	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Energy Dashboard is easy to access	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Energy Dashboard provide useful information	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Energy Dashboard functions properly	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am too busy to use it	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I forgot about using it	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 53. A question about the barriers to use the dashboard

As shown in Figure 53, the question addresses the possible issues that the users could have experienced (not user-friendly, hard to access, not useful, mal-functioning, too busy to use, forgot to use) and asked for their agreement on each. The first four issues were provided as positive statements to avoid confusion from double-negative expressions.

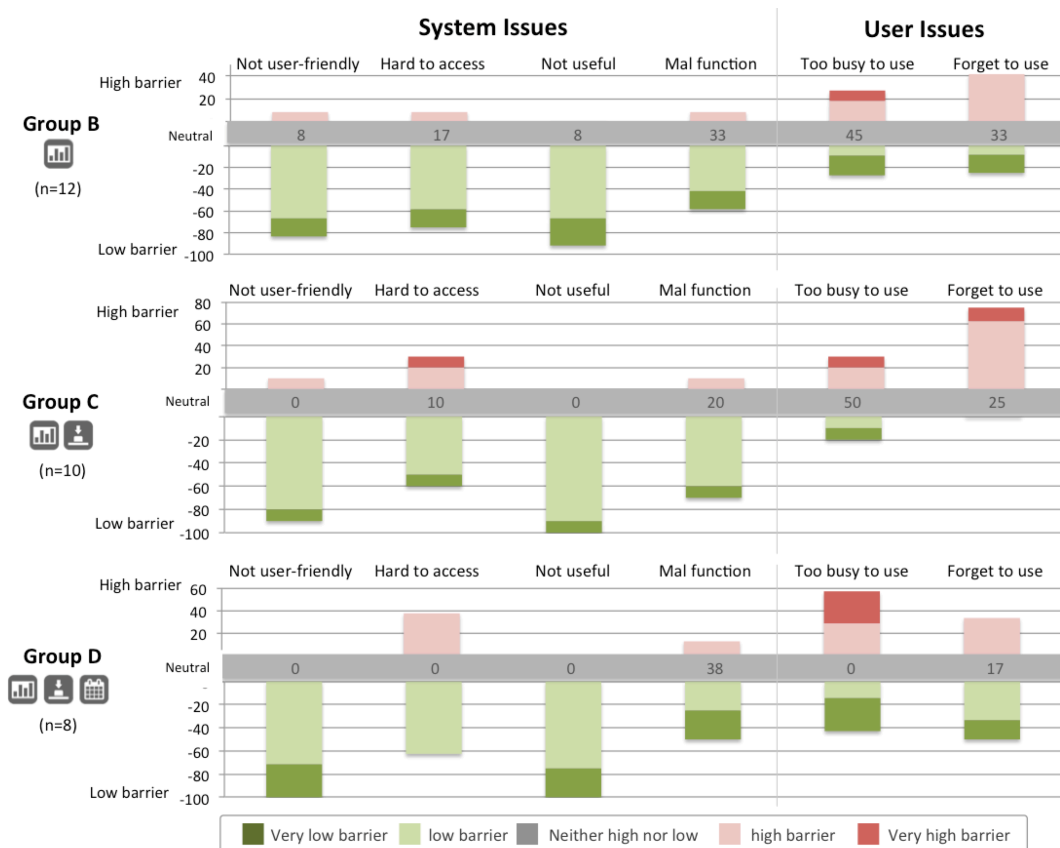


Figure 54. The response to the barriers to use the dashboard. The barriers were mainly not system issues but user issues.

The results (Figure 54) show that the barriers were not mainly system issues (not user-friendly, hard to access, not useful, mal-functioning) but user issues (too busy to use, forgot to use). Some people stated that they do not turn off the computer when they leave work because it takes long to restart the computer every morning (e.g., “*Booting up my computer every day is time-consuming and cuts into early morning productivity*”). Some of them pointed out users’ business and forgetfulness issues can be resolved if they could access the system more easily (e.g., “*Because we had to log in every time, I think I used it less - if it were installed as a program that I could easily access from my start menu, it*

might have become something that I opened automatically every morning,” “Because it was not automatically something that was visible to me, I did not go out of my way to use it due to my busy schedule.”).

7.1.4. User Effort Outside Work

The next question asks whether the users have engaged in saving energy in other environments since the dashboard was introduced to them.

Have you been engaged in saving energy outside your workplace (eg, at home, driving) since the inception of the dashboard project?

☐ Yes

☐ No

Figure 55. A question about the user effort outside work

The result did not show a big difference between the groups. 75% of Group B, 70% of Group C, and 75% of Group D answered, “Yes”. Respondents also told us about the efforts they had taken to save energy after the dashboard inception. Some examples of these include (programmable) thermostat control (e.g., *“turn down thermostat when leaving the house for weekend,” “we fitted a programmable thermostat”*), light control (e.g., *“turn off lights when leaving a room,” “using blinds in the house for energy savings”*), buying energy efficient products (e.g., *“buying energy star, switch to LED where practical”*) and using public transportation (e.g., *“I take the bus to work in place of driving”*).

7.1.5. Feature Request

The last question asked what additional feature they would like to have in a future dashboard.

Have you been engaged in saving energy outside your workplace (eg, at home, driving) since the inception of

- ☐ Mobile dashboard access (online controls via smart phone access)
- ☐ Public kiosk to display and control common appliances usage (e.g., printers, coffee machines)
- ☐ Real-time recommendation/alert via text message (e.g., you left your light on when you left the office. Please turn it off using the control button)
- ☐ Advanced automation using occupancy sensors (e.g., The system turns off the devices x minutes after the worker left the office)
- ☐ Rewards for good performers (monetary, meal coupons, recognition, etc.)
- ☐ Ranking of users towards energy savings
- ☐ Others

Figure 56. A question about the dashboard feature request

This question listed several possible features which we thought could be useful but did not implement because they were out of the scope of the study. The options describe each feature and allow users to multi-select.

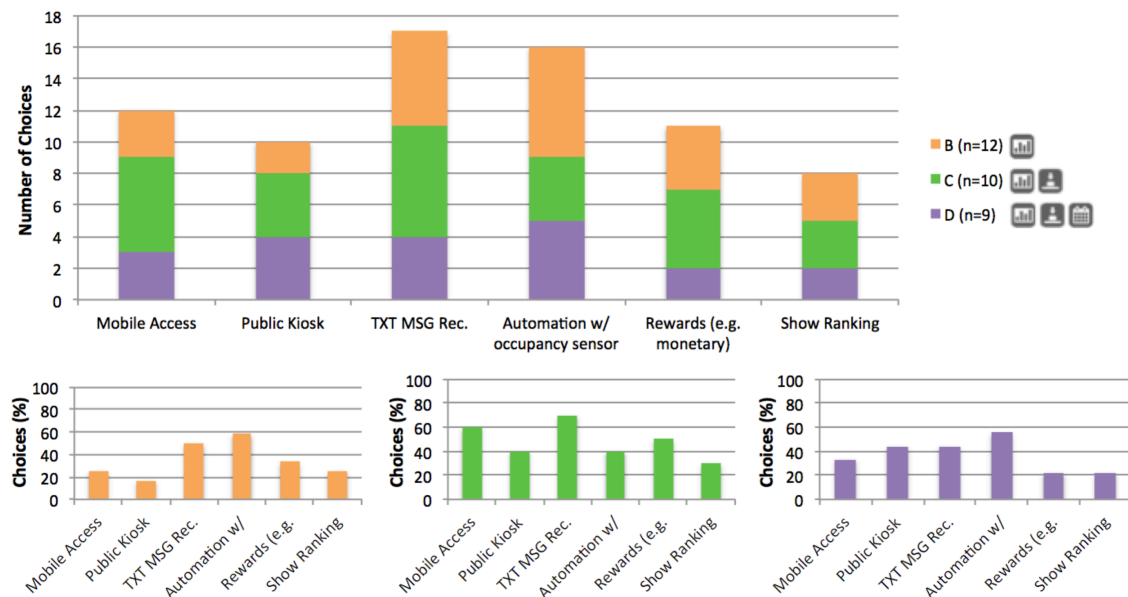


Figure 57. Survey results about potentially useful features. The real-time recommendation via text message, automated control using occupancy sensors, and mobile dashboard access were the top three preferred features

The most popular potential features were the real-time recommendation via text message, automated control using occupancy sensors, and mobile dashboard access. Group C preferred to have the mobile access feature more than the other groups. They might think the mobile access would allow them to use the control buttons more easily. People preferred the 'show rank' feature the least, and this is possibly because this feature causes them to feel pressure.

7.1.6 Other Issues

People commented on other issues during the survey and their comments follow.

1) Corporation policy: Many users were not willing to switch off their computers when not in use due to the corporate policy against this, whereas a few users did not care about it. (e.g., *"After I had my computer shut down over night, I was told by IT that I should leave it on for updates to load properly and not have drag during the day."*)

2) Computer setting: The IT team at the company has a program that monitors and controls individual's computers. Many users in our study tried to adjust the computer power settings to follow the dashboard recommendations, but they found that the settings went back to the default mode in one or two days. It made the recommendations hard to follow and caused the people to feel some frustration. (e.g., *"Every time I changed my computer settings - they seemed to auto reboot to a mode each day that wiped out the previous day's settings," "I can't reset my computer settings every day. I don't have time."*)

3) Recommendation: The recommendations that the dashboard provided were personalized recommendations, but some respondents thought they could be more useful if they were more specific. (e.g., *"The recommendations are helpful, but seem rather generic. The more specific, the better."*) Another user suggested that more (harder) recommendations could be provided when easy things were achieved. (e.g., *"For the first few weeks I would look at it more frequently and made changes accordingly. After that,*

even when receiving email nudges I didn't look that much as there didn't seem like much I could do to change things.”)

4) Calendar: One of the users pointed out it is not easy to redesign the calendar for every vacation or irregular business trip. (i.e., “*The calendar function should be able to be overridden if one is on vacation or out of the office. I had to remove all of my settings when on vacation, and then I never took the time to add back all the settings when I returned.*”) The next version of the calendar can allow people to design multiple schedules or link it to the occupancy sensors to automate controls.

7.2. Engagement: User Interaction with the Dashboard

The user’s interaction with the ID-O system was logged through the time of access and button clicks. The chart below (Figure 58) illustrates individual users’ number of access times and their energy savings.

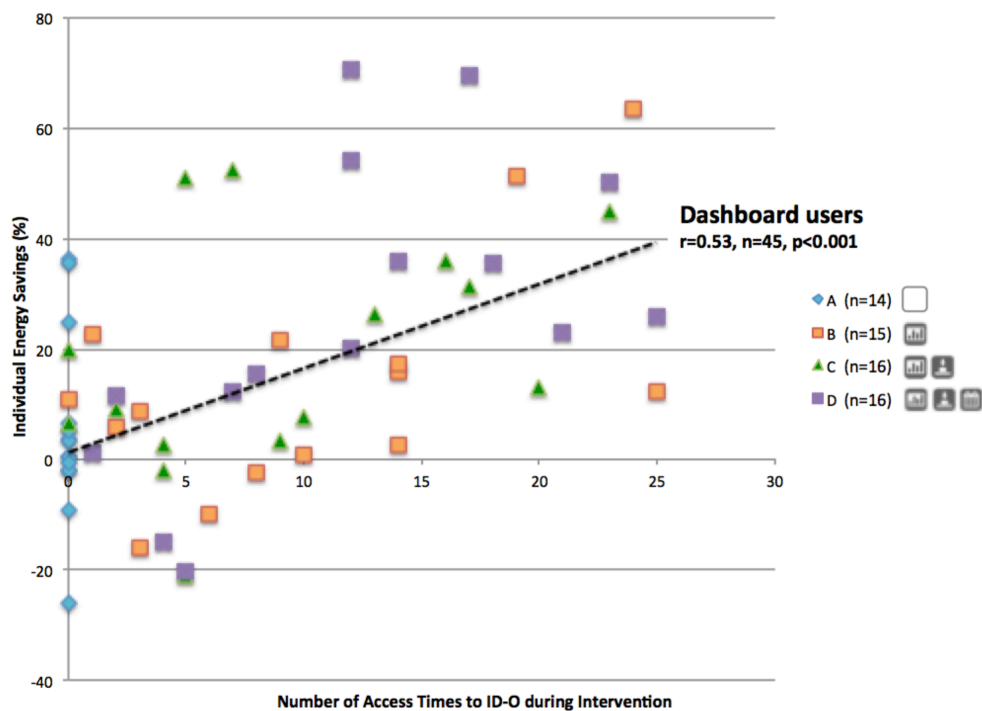


Figure 58. Individual user's number of access times (x axis) and energy savings (y axis)

Based on Pearson product-moment correlation coefficients computed with the dashboard users' (Group B, C and D) number of access times and energy savings (%), a positive correlation was found, $r=0.53$, $n=45$, $p<0.001$. Group B and Group D showed a significant correlation between those variables (B: $r=0.576$, $n=15$, $p<0.025$, D: $r=0.510$, $n=16$, $p<0.05$), but Group C didn't show a statistically strong correlation.

During the intervention, the average number of access times for the individuals in Groups B, C, and D were 10.8, 9, and 12.06. Group C users accessed the ID-O relatively less than others. According to the survey discussed in the previous chapter, Group C users reported the access issues more than other users. For example, they chose the issue, "hard to access," as the biggest barrier from among the system issues (Figure 54) and "mobile access" as one of the preferred features for the next version of the dashboard (Figure 57). It may be because the control buttons were not easy to access through the web-based system. It was expected that Group D would not access the features often because once they set up the calendar, the system would control their devices automatically and they would not care about it any longer. But they turned out to access the ID-O the most. To investigate the user interaction further, user actions on each feature were logged. Table 19 shows the numbers of specific features that were used.

Since it could not directly track whether a user is looking at the chart or not, this was inferred indirectly by counting the number of button clicks. Out of the feedback features in Table 19, people clicked the navigation button and time range buttons the most, but didn't change the chart types much. The comparison chart and cost impact were used less than others and it may be because those features require additional clicks to use (see Section 7.1.3.).

Possibly the purpose of the dashboard use between Group B and Groups C and D may be different. Group B used feedback features more than the other groups. They spent time navigating their energy data to learn about their consumption. People in Groups C and D used control features (control buttons and the calendar), but less actively used feedback features. The control features might influence them to use those features less. The

calendar button was clicked the most, and people might have had to access it to modify it when needed.

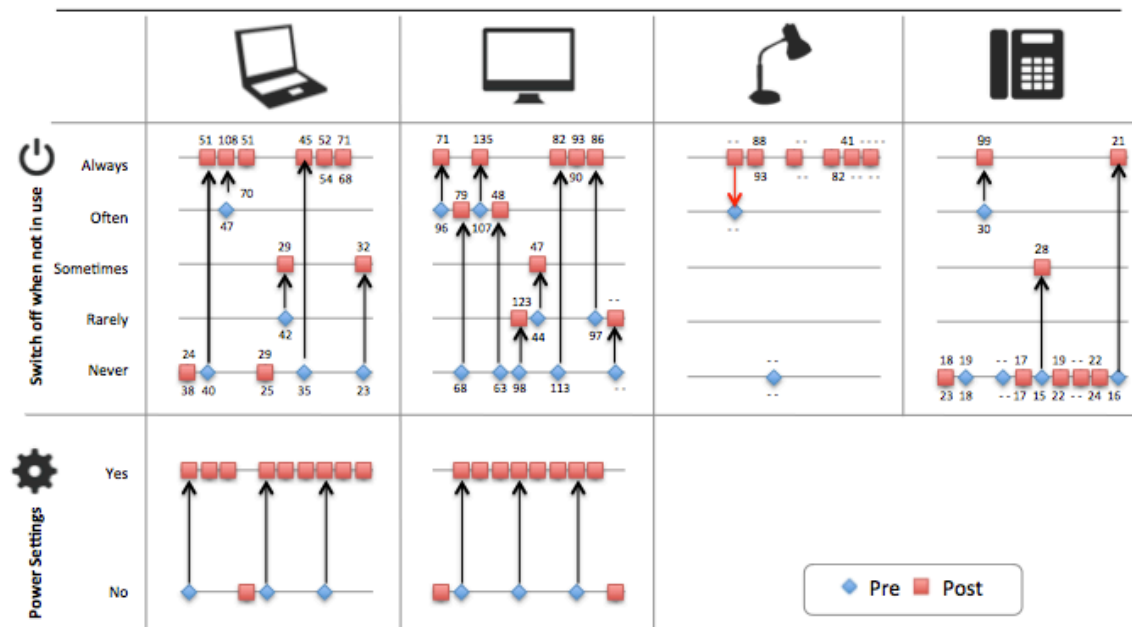
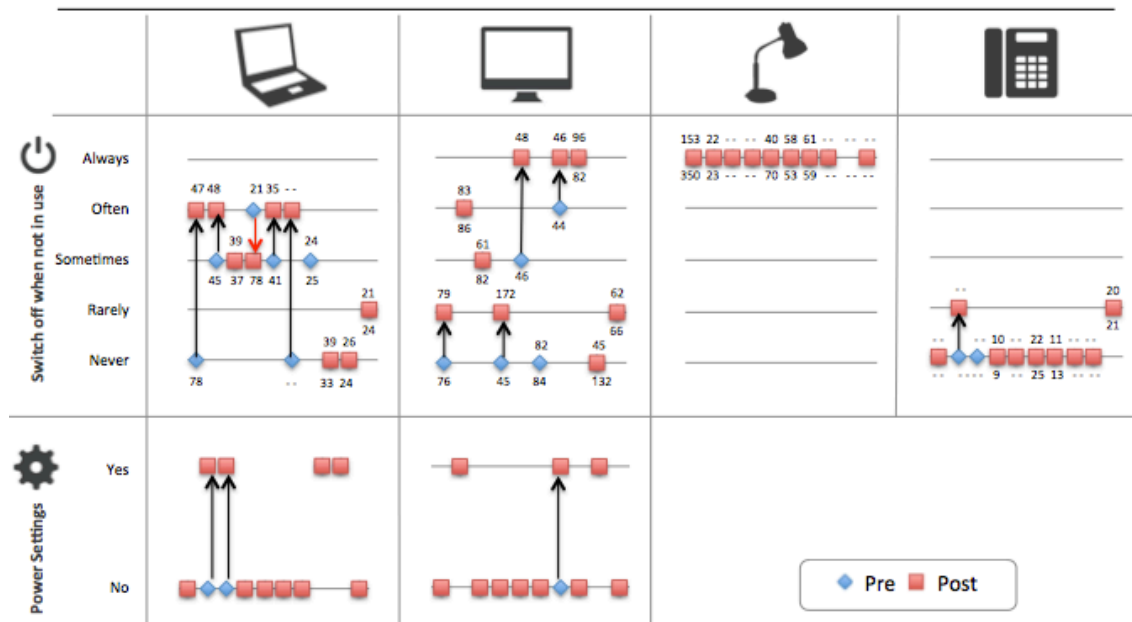
Table 19. Average count numbers of the ID-O features clicked per group

User groups		B (n=15)	C (n=16)	D (n=16)
Number of access times		10.8	9	12.1
Feedback (Informational) Features	Navigation buttons	17.6	12.9	14.6
	Time ranges	10.9	3.8	2.3
	Chart types	1.1	0.6	0.6
	Comparison chart	2.7	1.4	1.3
	Cost impact	2.4	1.2	0.5
	Control buttons	-	5.7	7.7
Control Features	Calendar	-	-	19.6

7.3. Perceived Behavior vs. Real Behavior

This chapter details the match between the perceived behavior and the real behavior. As discussed in Chapter 6, perceived behavior was measured from the survey. The first row in the chart in Figure 59 is about the “switch-off” behavior based on survey question Q1 and the second row is about the “setting-change” behavior based on survey question Q2 (see Section 6.3). The blue diamonds represent individuals’ behavior status before the intervention was given, and the red squares represent behavior status after the intervention was given. The black arrows show the change before and after the intervention, and no arrow means that there was no change of status. If there is neither a diamond nor a square at a spot, it means that that person provided no answer for the specific question. The numbers represent individuals’ effectiveness and “- -” means that

the effectiveness could not be calculated because no meter was installed for the specific device, or the installed meter was mal-functioning.



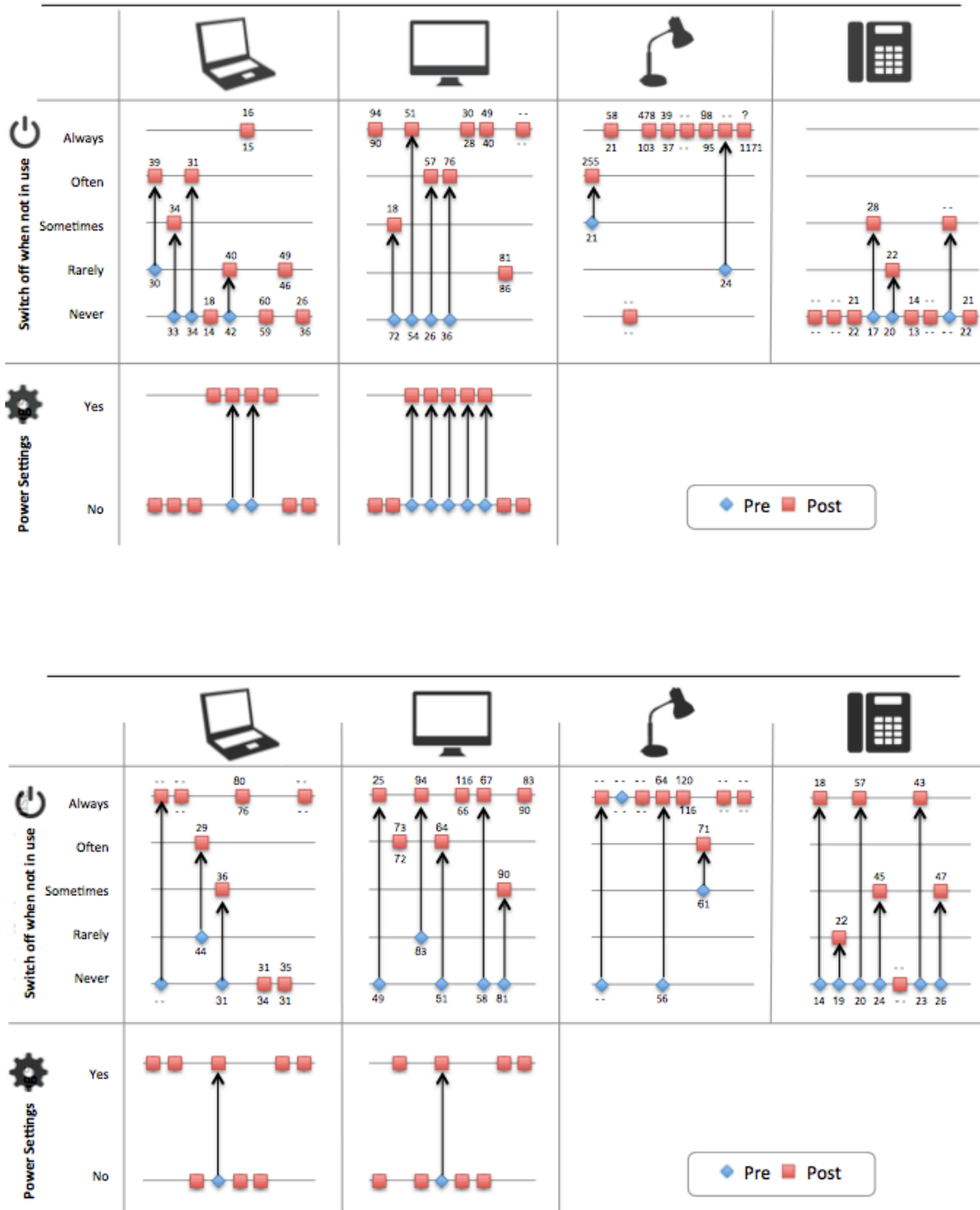


Figure 59. Individuals' perceived behavior change (arrows) and behavior effectiveness (numbers) in Groups A (top) - D (bottom)

The charts in Figure 59 show that only two people reported their behavior became worse, and the rest reported their behavior was improved or wasn't changed. However the effectiveness index based on the real behavior change showed a “decrease” in many more than two cases. This reveals that not all of the participants' perception matched with reality. To investigate if there is any statistical correlation between the perceived behavior and the effectiveness, the difference of the two variables between pre- and post-intervention was calculated per device and illustrated in Figure 60. The different shapes represent the different groups that individuals belong to (Groups A to D).

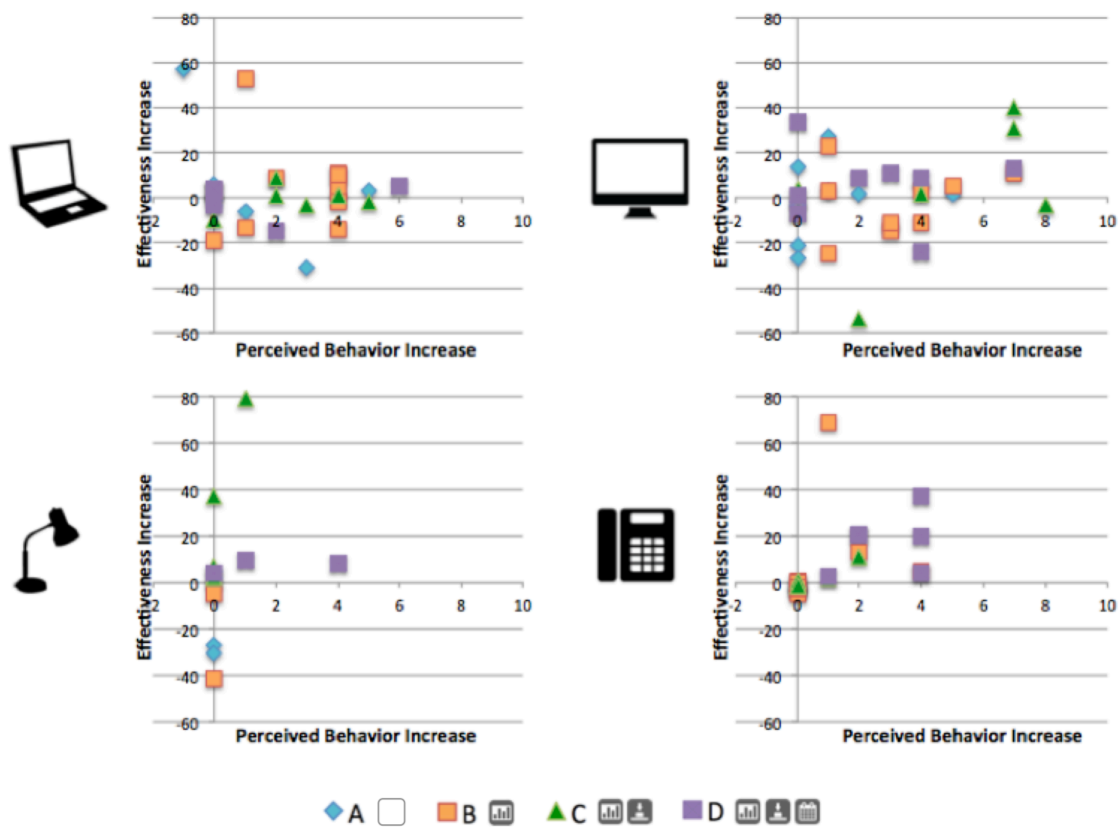













Figure 60. Individual's perceived behavior increase and effectiveness improvement per device: computers, monitors lights, and phones.

Based on Pearson product-moment correlation coefficients computed with the variables, no significant correlation was found for any group's device due to the small sample size. Without differentiating the groups, significant correlation was found only for the phones,

$r=0.435$, $n=23$, $p=0.038$, but not for other devices. Participants may answer the survey with a different perception of the frequency level (i.e. never-rarely-sometimes-often-always), and their answer may have caused some mismatch between the perception and the reality. The phone showed a strong correlation because most participants answered that they “never” switched off the phone before the intervention, and this made their perception close to reality.

To see whether the perception and the reality matched for an increase and decrease without considering the extent of the increase, a match was counted when both variables increased, decreased or rarely changed (the index change was made within 5). As shown in Table 20, Groups A, B, C and D’s percentage of matching were 72%, 72%, 70 %and 76% respectively. The match rates between the groups had only a 6% difference, and all were equal to or greater than 70%. The phone showed the greatest match rate at 96%, and computers, lights and monitors showed 73%, 67%, and 60%, respectively. In this approach, an overall 73% match was made between the perceived behavior and behavior effectiveness.

Table 20. The count and percentage of matching between perceived behavior and effectiveness. This considers the match of increase and decrease. O and X represent matched and not matched respectively.

									Percent of Match
Matching	O	X	O	X	O	X	O	X	
A	8	2	6	4	3	2	4	0	72%
B 	7	3	5	4	1	1	8	0	72%
C  	6	3	5	3	3	2	5	0	70%
D    	3	1	5	3	3	0	5	1	76%
Percent of Match	73%		60%		67%		96%		73%

7.4. Summary

This chapter discusses the usability of the ID-O system based on the survey, engagement of the dashboard based on the log analysis, and the perception match against the behavior change in reality. According to the survey about system usability, users report all the features in the ID-O were useful and motivated them to save energy. The barriers that prevent them from using the systems most were the user issues (e.g., too busy to use) rather than the system issues (e.g., not user-friendly). For the next version of the dashboard, they preferred to have real-time text message advice and occupancy sensing automated control. The more they accessed the system, the more savings were likely to be made (e.g., Groups B and D). The perceived behavior change reported in the survey was 73% when matched to the real behavior change. The next chapter discusses the limitations and future work of the research and concludes the dissertation.

8. CONCLUSION

This dissertation work has found that UI interventions can promote user behavior and awareness towards energy savings in the workplace. To begin with, it reviewed behavior change theories, intervention strategies, dashboard studies, and UI design strategies. It was found that Geller's theory illustrates the environmental behavior change process clearly, so this dissertation adapts the model to explain the intervention strategies and plan the rest of the research. Four intervention strategies were chosen to experiment UI interventions - self-monitoring, advice, comparison and control. Commercial systems have recently started employing advanced strategies, but they have not been thoroughly quantified to see their effectiveness. It was also found that there are relatively few studies that investigate within the domain of the workplace and few design guidelines on how to present eco-feedback information. This dissertation addressed these limitations through the development of an Intelligent Dashboard for Occupants (ID-O) that provides diverse feedback (self-monitoring, advice, comparison) and control (remote and automated control) features. With an ID-O, through a variety of interventions, one can explore 1) energy conservation, 2) energy awareness, and 3) persistent energy savings. Three intervention strategies were considered in this dissertation in the following order:

- Feedback;
- Feedback and on-line control;
- Feedback, on-line control and automated control

The first two give rise to the following expectation, namely, that there is an increase in energy conservation, energy awareness and persistent energy savings, even after the intervention has been removed. The third strategy suggests that it will (relatively) provide the greatest increase in energy conservation with a (relative) reduction in energy awareness and persistent energy savings, after the intervention has been removed. These then are the hypotheses that underlie this dissertation.

The feedback (self-monitoring, advice, and comparison) and control (online control, calendar) features implemented for the ID-O system are as follows. Self-monitoring features provide ways (e.g., charts) to monitor and learn about one's energy usage in different metrics (e.g., kWh, cost). Advice provides suggestions about how to save energy, comparison shows one's energy consumption in regards to either others or one's past usage to motivate users, and a control feature provides simple ways to control and manage one's energy usage. These features were iteratively redesigned based on the lab and field studies.

For a long-term and large-scale field study to evaluate the intervention strategies, eighty office workers were recruited. The subjects were divided into four groups, A through D, and their energy usage data was collected through the three phases – baseline (fourteen weeks), intervention (thirteen weeks), and intervention removal (eleven weeks) phases. At the second phase, differently designed dashboards were provided – the first group, A, was not provided with a dashboard interface and served as a “control” group. The second group, B, was provided with the feedback features only (self-monitoring, advice, and comparison), the third group, C, was provided with the feedback features and on-line controls, and the fourth group, D, was provided with the feedback features, on-line control, and automated/calendar controls. During the interventions, the more features that were provided, the more savings that were achieved. After the interventions were removed, all the dashboard groups persistently saved energy with only a slight decrease. Surveys were conducted at the end of the pre, during and post interventions. Between the during- and post-interventions, the biggest awareness increase was found for the group with only feedback and the group with feedback and on-line control. A relatively low increase was measured for the group with feedback, on-line and automated control. The following results were demonstrated:

- Provision of feedback (self-monitoring, advice, and comparison) through energy dashboards increases 1) energy conservation, 2) energy awareness, and 3) persistent energy savings, even after the intervention has been removed.

- Introduction of feedback and on-line controls have greater 1) energy conservation, 2) energy awareness and 3) persistent energy savings, even after the intervention is removed.
- Added intervention by automated calendar control demonstrated the highest energy savings, after the interventions had been removed. As expected, there is reduced energy awareness, but not reduced persistent energy savings.

In the survey, dashboard users also reported that their discussion frequency is increased, and they perceived their company puts increased effort in making their company follow more sustainable practices. Dashboard users thought that the ID-O features were useful and motivating, but they were not able to use them more often because they were busy or forgot to use them. Real-time text-message advice, automated control with occupancy sensors, and a mobile platform were the most preferred features for the next generation ID-O. It was found that individual users' dashboard usage is strongly associated with their energy consumption change (Figure 61). A bigger impact is expected if the dashboard can support the reported feature request (Section 7.1.5) and the user issues that they were experiencing (Section 7.1.3).

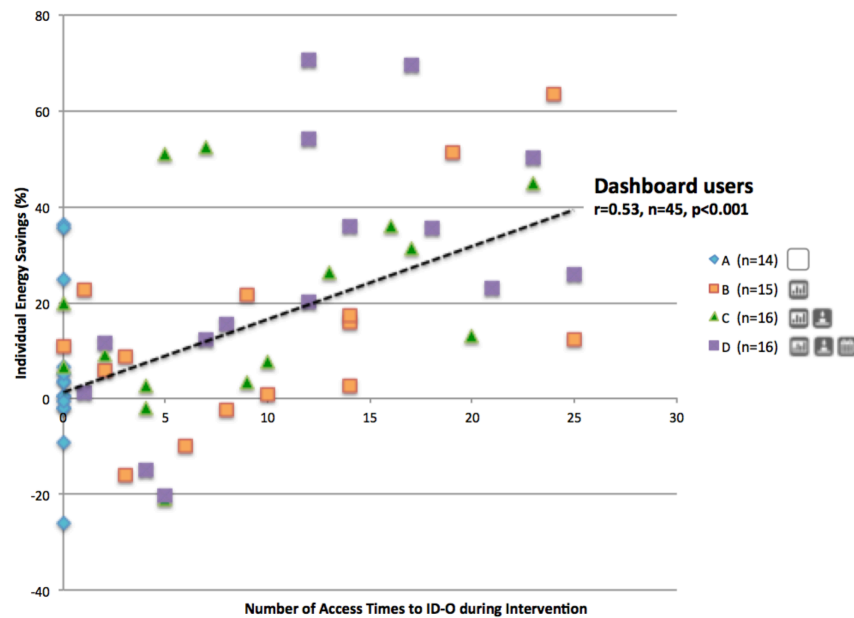


Figure 61. Measured user interaction with ID-O

8.1. Contributions

This dissertation contains the following contributions beyond its main contribution on energy conservation, awareness and persistent savings. First, it adds to the field study literature on HCI interface choices, focusing specifically on energy and behavioral impacts. It expands Geller's model to apply at an organizational level— has developed and tested interface choices to increase user engagement with multiple measures of organizational impact such as organization's discussion frequency, energy efficient product support and energy saving encouragement. It contributes to critically needed studies on energy data representation for behavior and awareness change in sustainable ways.

Second, this dissertation extends the breadth of existing field HCI intervention studies in office environments to include greater participant numbers over longer durations, and to include further HCI interface choices and behavioral impact metrics. Existing HCI studies focus mainly on domestic users rather than workplace users (Lehrer et al., 2011; Foster et al. 2012) and deal with small occupant sample size of 11 on average and short duration, 2.5 weeks on average (Froehlich et al., 2010). This dissertation tackles the limitations of the existing HCI studies.

Third, this dissertation provides quantified energy savings through behavioral change from technology-specific plug load management in offices. By measuring the electricity outcomes by using high-tech smart meters, the research hypotheses can be evaluated.

8.2. Limitations

Despite a robust and structured research plan, there are several limitations that would benefit from future investigation. First, automated control intervention could have been tested alone. Automation without on-line control is akin to removing thermostats from the smart home and letting the “system” decide the users' preferences. Experimenting with automated-control intervention alone is not necessary given computational power today.

Second, the sample size could have been greater. Eighty office workers were recruited, but twenty-five were excluded because of relocation, their refusal to participate, , irregular work schedule, and meter malfunction. Limited responses to the survey further reduced the sample. This limits the statistical power to demonstrate some of the findings from the field study.

Third, the control group could have been more isolated. The control group with no dashboard in the field study may not have been completely controlled because the participants were recruited from the same department and were located in close proximity to participants in other groups. The field study results show that two participants (namely, A2 and A11) in the control group (Group A) may have been affected by the dashboard users. Group A achieved an energy savings of 7% (see Section 5.3) and their energy-related discussion frequency increased by 15% (see Section 6.2.4) after dashboard intervention, even though, as the control group, they did not receive a dashboard or have any direct feedback. The numbers on savings and discussion frequency for the control group are relatively low compared to the other groups; however, these numbers indicate that through casual conversations the other (dashboard) users might have influenced the control group.

Last, mobile interfaces could have been added. To effectively control the intervention, one type of platform – web based – was used. A mix of other platforms (e.g. mobile, desktop widget, kiosk) used may increase the dashboard impact on sustainability in the workplace. This study investigates the potential energy-saving impact from the introduction of different UI strategies. To focus on the effectiveness of a “web-based” UI strategy, the author did not include a mobile system in this study. However, mobile UI is expected to increase the energy-saving potential significantly. The ID-O 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.

8.3. Potential for Future Research

To overcome these limitations and improve the current approach, the following research has been planned and is underway. According to the usability survey introduced in Section 7.1, participants reported that the dashboard features were useful and motivated them to save energy at work. However, there are still opportunities for improvement. For example, features (i.e., comparison chart, cost impact) that require an additional click were less preferred, so the design needs to be revised. Real-time text advice and occupancy-sensing automated control were the most preferred features and are under consideration for inclusion in the next version of ID-O. Different platforms such as mobile (phone, tablet) and public display (wall mount, kiosk) are also strongly considered and some of them are already underway by the research team. This can answer questions on combinations of platforms that lead to improved impacts on user experience towards energy conservation in the workplace.

Moreover, due to the limited sample size, some of the findings were not able to show statistical significance. A bigger sample size needs to be considered for the next field study to strongly argue the findings with statistical power. The participants were recruited from the same department of an office building, but other types of office workers need to be included to ensure the findings can be applied to office workers in general. If different results are shown from a different type of worker, this would open up another interesting topic to explore – namely, what makes the difference between impacts for two distinct user types and how differently should the dashboard be designed for each?

Lastly, this research focuses on individual plug-load management; however, the consumption by common appliances (e.g. printers, coffee makers) is huge and needs to be considered. In addition to plug-load, HVAC, temperature and lighting also accounts for energy consumption in office buildings, so they should be considered to improve sustainability in the workplace. The ID-O was originally designed to apply to all these domain areas and be initiated from the plug-load management area. Currently, the ID-O has expanded to include the lighting domain: The team is investigating effective ways to monitor and control light fixtures of the buildings by using outdoor weather information.

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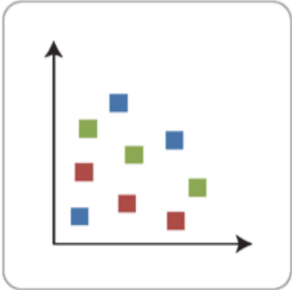
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APPENDIX

1. Usability Study Flyer (Offline)





Energy Dashboard Usability Study

We are conducting a research study to test the usability of energy dashboard user interface.

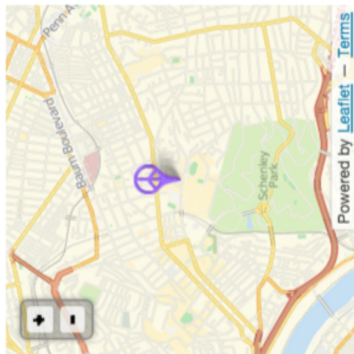
We are looking for participants (18-65 years old) who are familiar with web browsing and and preferably work in the office.

Participants will be paid **\$10** (The study will take 45 minutes).
Please contact: Ray Yun (ryun@cmu.edu)

Energy Dashboard ryun@cmu.edu	Energy Dashboard ryun@cmu.edu	Energy Dashboard ryun@cmu.edu	Energy Dashboard ryun@cmu.edu	Energy Dashboard ryun@cmu.edu	Energy Dashboard ryun@cmu.edu	Energy Dashboard ryun@cmu.edu	Energy Dashboard ryun@cmu.edu	Energy Dashboard ryun@cmu.edu	Energy Dashboard ryun@cmu.edu
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Reply [rzdsl-3707959206@comm.craigslist.org](#) [flag](#) [\[?\]](#) : [miscategorized](#) [prohibited](#) [spam](#) [best of](#) Posted: 2013-03-27, 8:50PM EDT

Participate! Usability Study on Energy Dashboard (45min) - Earn \$10 (Carnegie Mellon University)



We are conducting a research study to test the usability of our Energy Dashboard. The purpose of the study is to refine and further develop the energy dashboard interface to ensure that potential users understand that information being displayed and are able to be fully engaged in all the features of the energy dashboard.

This is a simple test.

Participants will be asked a series of questions for each feature of the energy dashboard - chart, text, image, buttons.

You will be shown a series of differently-designed user interface components for each feature and choose which design works better to you.

Requirement:

We are looking for office workers or students (18-65 years old) who are familiar with Internet browsing.

Participants will be paid \$10 for this study.

This study takes 45 min and we are located at Carnegie Mellon University.

If you are interested, please contact:

ryun@andrew.cmu.edu

5000 Forbes Avenue ([Google Map](#)) ([Yahoo Map](#))

- Location: Carnegie Mellon University
- it's NOT ok to contact this poster with services or other commercial interests
- it's OK to distribute this charitable volunteerism opportunity for inclusion in 3rd party web sites that have been approved by craigslist

[email to a friend](#)

Posting ID: 3707959206 Posted: 2013-03-27, 8:50PM EDT Edited: 2013-03-27, 8:52PM EDT

3. Usability Study Questionnaires

Section 1

- 1-1. Participant Code
- 1-2. Participant's Age
- 1-3. Participant's gender (a: Male, b: Female)
- 1-4. Participant's job
- 1-5. Job field
- 1-6. Proficiency in chart reading (a: Proficient, b: Neutral, c: Not proficient)

Section 2

- 2-1. (Bar) what is the laptop's consumption from 4pm-5pm? (Answer: 18.84)
- 2-2. (Bar) what devices can make you save energy by turning them off during night? Tell us all the devices. (Answer: desktop, speaker, and task light).
- 2-3. (Area) what is the speaker's consumption from 9am-10am? (Answer: 10.24)
- 2-4. (Area) what devices can make you save energy by turning them off during night? Tell us all the devices. (Answer: desktop, laptop, and task light)
- 2-5. (Both) which chart is easier to understand?
- 2-6. (Both) which chart is more visually attractive?
- 2-7. (Both) overall, which chart works better to you?
- 2-8. (Both) Tell us why you chose the chart or give us any comments.

Section 3

- 3-1. Both charts show someone's electricity usage of a week with daily intervals. Which chart works better to you?
- 3-2. Tell us why you chose the chart or give us any comments

Section 4

- 4-1. Both charts show someone's electricity usage of a week with hourly intervals. Which chart works better to you?
- 4-2. Tell us why you chose one at the previous question.

Section 5.

- 5-1. (Bar) what day does the user consume electricity the most? (Answer: Thursday)
- 5-2. (Area) what day does the user consume electricity the most? (Answer: Can't tell easily or Monday)- People might answer "Wednesday". Explain if their answer is wrong.
- 5-3. (Area) what devices can make you save energy by turning them off during night? (Answer: desktop, speaker, and task light)
- 5-4. (Bar) what devices can make you save energy by turning them off during night? (Answer: cannot tell from the chart)
- 5-5. (Both) you experienced pros and cons for each chart. Considering of which pro is more important to you, tell us which chart works better to you.
- 5-6. (Both) which chart is more visually attractive?
- 5-7. Tell us why you chose one at the previous question.

Section 6.

- 6-1. Which duration would you like to see first? Day or Week?
- 6-2. Which chart would you like to see for day view and week view respectively?
- 6-3. If you can see only one chart in the energy dashboard (e.g., in email, public display, etc.) which one would you like to see?
- 6-4. Note comments - why?

Section 7.

- 7-1. Can you please explain the contents one by one at the Recommendation section? (Check what they don't answer properly)
- 7-2. For "Trees" information. It can be one of the three meanings. Which one makes sense the most to you?
 - a. Number of trees that absorbed the emitted CO₂
 - b. Number of trees killed to generate the electricity
 - c. Number of trees that are saved from energy saving
 - d. Doesn't matter to me
- 7-3. "This week's" information can be "This week's saving" information. For example, it can be: "This week, you saved 500W saved, \$0.8, 0.7lb of CO₂ emission... compared to the last week (baseline)" Which information do you prefer?
- 7-4. What information is useful to you?
- 7-5. What information is not useful to you at all?
- 7-6. Please rank-order the information you selected at the previous question.
- 7-7. What layout do you like better?
- 7-8. Which orientation do you prefer? Rows or Columns?

Section 8.

- 8-1. (Bar) How good is the user's performance compared to average? (The user is worse than average,)
- 8-2. (Bar) based on the chart, what would the user do to save more energy referring to the best person? (Answer: turn off devices during night) – Even if they can't answer, don't explain the correct answer
- 8-3. (Line) How good is the user's performance compared to average? (Answer: The user is better than average)
- 8-4. (Line) based on the chart, what would the user do to save more energy referring to the best person? (Correct answer: turn off devices during night)
 - Even if they can't answer, don't explain the correct answer
- 8-5. (Both) which chart is easier to understand?
- 8-6. (Both) which chart is more visually attractive?
- 8-7. (Both) overall, which chart works better to you? Tell us why you chose one at the previous question

Section 9.

- 9-1. (Bar) how good is the user's performance compared to average? (A: The user consumed less than (almost equal to) average)

- 9-2. (Bar) Based on the chart, what can the user do to save more energy referring to the best person? (A: turn off devices during weekend) Even if they can't answer, don't explain the correct answer
- 9-3. (Line) How good is the user's performance compared to average? (Answer: The user consumed more than average)
- 9-4. (Line) based on the chart, what would the user do to save more energy referring to the best person? (B: turn off devices during weekend and night) Even if they can't answer, don't explain the correct answer
- 9-5. Which chart is easier to understand to compare your performance and others?
- 9-6. Which chart is more visually attractive?
- 9-7. Overall, which chart works better to you? Tell us why you chose one at the previous question

Section 10.

- 10-1. Which comparison chart would you like to see for day view and week view? Ask them if they care about consistency.
- 10-2. This comparison chart compares performance based on "energy consumption", but it can be based on "energy saving". Which one do you prefer for comparison chart?
Note comments - why

Section 11.

- 11-1. Turn off the task light (Advice-Column)
- 11-2. Turn off the task light (Advice-Row)
- 11-3. Is the location of the buttons good to you? Tell us if you have other idea.
- 11-4. Does the one-line feedback useful to you?
- 11-5. What is the best location of the one-line feedback?
- 11-6. Guess and explain the current schedule on the calendar.
- 11-7. Make a schedule to turn off the laptop and the speaker at 3am every Wednesday?
- 11-8. Is it easy to understand the schedule?
- 11-9. Is it easy to make schedule it?

Section 12.

- 12-1. I think that I would like to use this system frequently.
a. Strongly disagree b. Disagree c. Neutral d. Agree e. Strongly agree
- 12-2. I found the system unnecessarily complex.
a. Strongly disagree b. Disagree c. Neutral d. Agree e. Strongly agree
- 12-3. I thought the system was easy to use.
a. Strongly disagree b. Disagree c. Neutral d. Agree e. Strongly agree
- 12-4. I think that I would need the support of a technical person to be able to use this system.
a. Strongly disagree b. Disagree c. Neutral d. Agree e. Strongly agree
- 12-5. I found the various functions in this system were well integrated.
a. Strongly disagree b. Disagree c. Neutral d. Agree e. Strongly agree
- 12-6. I thought there was too much inconsistency in this system.
a. Strongly disagree b. Disagree c. Neutral d. Agree e. Strongly agree
- 12-7. I would imagine that most people would learn to use this system very quickly.
a. Strongly disagree b. Disagree c. Neutral d. Agree e. Strongly agree
- 12-8. I found the system very cumbersome to use.

- a. Strongly disagree b. Disagree c. Neutral d. Agree e. Strongly agree
- 12-9. I felt very confident using the system.
- a. Strongly disagree b. Disagree c. Neutral d. Agree e. Strongly agree
- 12-10. I needed to learn a lot of things before I could get going with this system.
- a. Strongly disagree b. Disagree c. Neutral d. Agree e. Strongly agree

4. Perception Survey

1) How often do you turn off or unplug your:

- Computer when not in use on nights and weekends
a. Never b. Rarely c. Sometimes d. Often e. Always f. Not applicable
- Computer monitor when not in use on nights and weekends
a. Never b. Rarely c. Sometimes d. Often e. Always f. Not applicable
- Task light (lamp, underbin light) when not in use
a. Never b. Rarely c. Sometimes d. Often e. Always f. Not applicable
- Office phone on nights and weekends
a. Never b. Rarely c. Sometimes d. Often e. Always f. Not applicable

2) Have you:

- Adjusted power settings (e.g., to power saver mode) for the computer you are using at PNC?
a. Yes b. No c. Do not know d. Not applicable
- Adjusted brightness settings for your computer monitor at PNC?
a. Yes b. No c. Do not know d. Not applicable
- Discussed energy usage/savings in your work group?
a. Yes b. No c. Do not know d. Not applicable

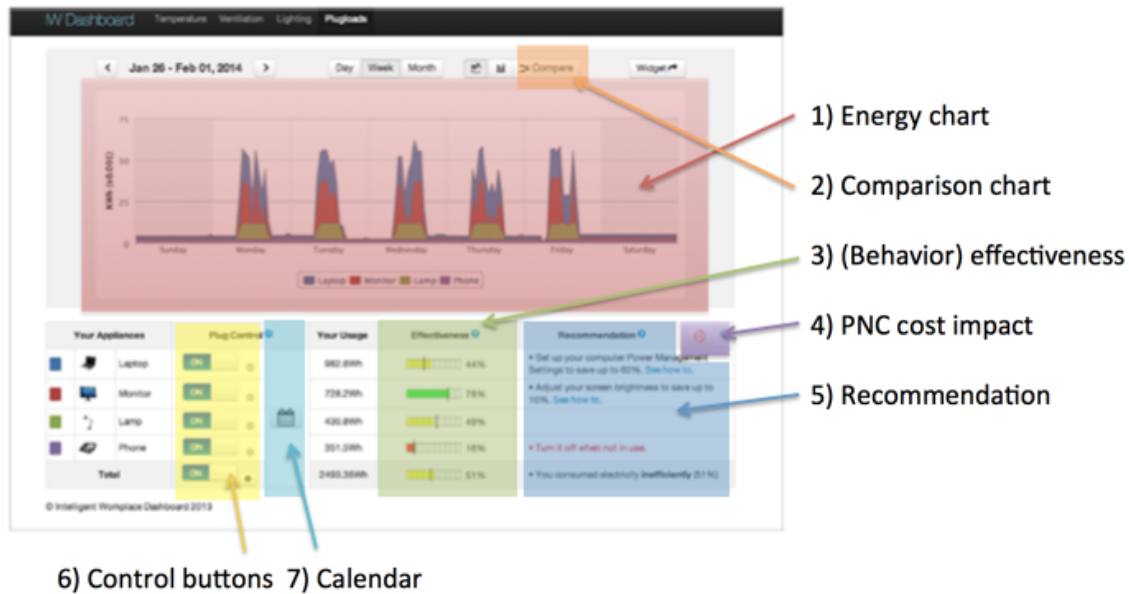
3) How often does your organization :

- Provide workers with energy efficient products (e.g., computers, displays, lights)?
a. Never b. Rarely c. Sometimes d. Often e. Always f. Do not know
- Encourage workers to reduce energy use in the office?
a. Never b. Rarely c. Sometimes d. Often e. Always f. Do not know

4) Put in order the actions you think will have the greatest impact on energy savings: (Drag to 1st: highest - 7th: lowest)

- Turn the computer off when not in use (e.g., nights, weekends)?
- Turn the computer monitor off when not in use (e.g., nights, weekends)?
- Turn the task light (lamp, underbin light) off when not in use (e.g., nights, weekends)?
- Turn the phone off or unplug it when not in use (e.g., nights, weekends)?
- Adjust computer power settings (e.g., to power saver mode)?
- Adjust computer monitor's brightness settings?
- Buy energy star office equipment such as: computers, printers, lights, and so forth?

Please refer to the graphic below to answer questions 5 and 6.



5-1) How useful are the following dashboard features to learn about your energy consumption at PNC?

- Energy chart
 - a. Very useless b. Useless c. Neither useful nor useless Useful d. Very useful
 - e. Not applicable
- Comparison chart
 - a. Very useless b. Useless c. Neither useful nor useless Useful d. Very useful
 - e. Not applicable
- (Behavior) effectiveness
 - a. Very useless b. Useless c. Neither useful nor useless Useful d. Very useful
 - e. Not applicable
- PNC cost impact
 - a. Very useless b. Useless c. Neither useful nor useless Useful d. Very useful
 - e. Not applicable
- Recommendation
 - a. Very useless b. Useless c. Neither useful nor useless Useful d. Very useful
 - e. Not applicable

5-2) Please explain why you answered as above.

6-1) How much do the following dashboard features motivate you to save energy (e.g. turn off your devices or adjust power settings for computer and monitors)?

- Energy chart

- a. Very demotivating b. Demotivating c. Neither motivating nor demotivating
 - d. Motivating e. Very motivating f. Not applicable
- Comparison chart
 - a. Very demotivating b. Demotivating c. Neither motivating nor demotivating
 - d. Motivating e. Very motivating f. Not applicable
- (Behavior) effectiveness
 - a. Very demotivating b. Demotivating c. Neither motivating nor demotivating
 - d. Motivating e. Very motivating f. Not applicable
- PNC cost impact
 - a. Very demotivating b. Demotivating c. Neither motivating nor demotivating
 - d. Motivating e. Very motivating f. Not applicable
- Recommendation
 - a. Very demotivating b. Demotivating c. Neither motivating nor demotivating
 - d. Motivating e. Very motivating f. Not applicable
- Control buttons
 - a. Very demotivating b. Demotivating c. Neither motivating nor demotivating
 - d. Motivating e. Very motivating f. Not applicable
- Calendar
 - a. Very demotivating b. Demotivating c. Neither motivating nor demotivating
 - d. Motivating e. Very motivating f. Not applicable

6-2) Please explain why you were motivated or demotivated to reduce your energy use.

7-1) Indicate your level of agreement with the following statements.

- Energy Dashboard is user-friendly
 - a. Strongly disagree b. Disagree c. Neither disagree nor agree d. Agree e. Strongly agree
- Energy Dashboard is easy to access
 - a. Strongly disagree b. Disagree c. Neither disagree nor agree d. Agree e. Strongly agree
- Energy Dashboard provide useful information
 - a. Strongly disagree b. Disagree c. Neither disagree nor agree d. Agree e. Strongly agree
- Energy Dashboard functions properly
 - a. Strongly disagree b. Disagree c. Neither disagree nor agree d. Agree e. Strongly agree
- I am too busy to use it
 - a. Strongly disagree b. Disagree c. Neither disagree nor agree d. Agree e. Strongly agree
- I forgot about using it
 - a. Strongly disagree b. Disagree c. Neither disagree nor agree d. Agree e. Strongly agree

7-2) Please explain why you answered as above or specify if there is anything else.

8-1) Have you been engaged in saving energy outside your workplace (eg, at home, driving) since the inception of the dashboard project?

a. Yes b. No

8-2) If yes please share with us your actual effort(s).

9) What additional features would you like to see at the dashboard system?

- ☐ Mobile dashboard access (online controls via smart phone access)
- ☐ Public kiosk to display and control common appliances usage (e.g., printers, coffee machines)
- ☐ Real--time recommendation/alert via text message (e.g., you left your light on when you left the office. Please turn it off using the control button)
- ☐ Advanced automation using occupancy sensors (e.g., The system turns off the devices x minutes after the worker left the office)
- ☐ Rewards for good performers (monetary, meal coupons, recognition, etc.)
- ☐ Ranking of users towards energy savings
- ☐ Others