Using dynamic messaging to increase energy conserving behavior

Final report

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Executive Summary

Rensselaer Polytechnic Institute's Lighting Research Center (LRC) investigated the effectiveness of using dynamic message displays in private offices to encourage turning lights off manually with the aim of increasing energy savings. The changing messages were presented on small display screens near light switches in offices at the State University of New York (SUNY) System Administration building in Albany, NY. The messages were designed to encourage occupants to shut off the lights manually when they left their offices.

At the start of the study, 40 offices without automatic lighting controls were included in the study and monitored for occupancy and light usage over the course of three months. The offices were separated into two equal groups based on inclusion criteria described within the report: an experimental group with dynamic messaging devices (which displayed a variety of prompts and feedback messages) and a control group with static message devices (which displayed one message all the time). During the first month, April 2016, the offices were monitored, but there was no intervention (the before-intervention period), during the second month, May 2016, the dynamic or static device was installed in each office (the intervention period), and during the third month, June 2016, the messaging devices were removed but the monitoring continued (the after-intervention period) for one month.

The authors designed the experiment to investigate three hypotheses regarding changes in wasted light, which is defined as the amount of time that the lights are on in an unoccupied office.

1. Hypothesis #1. Wasted light would be reduced during the intervention period relative to the before-intervention period because the occupants would respond to the prompts displayed on the messaging devices.
2. Hypothesis #2. Wasted light during the intervention period would be reduced more in the dynamic message offices than in the static message offices because the occupants would be more responsive to the dynamic messages. Testing this hypothesis was the primary motivation for the experiment.
3. Hypothesis #3. Wasted light would increase during the after-intervention period relative to the intervention period because occupants would relapse to previous behaviors when prompts were no longer present.

Four of the static offices were removed from the study prior to data analysis. Two were removed because the occupants moved to other offices during the experiment. One was removed because of a problem with light usage monitoring. Another one was removed because the user was an outlier (wasted light was three times the mean of the other offices due to the lights being left on for a weekend, which was not representative of this or other offices). After these removals, data from 16 static offices and 20 dynamic offices were analyzed.

Five different analyses of the results were conducted.

Analysis #1: Wasted light. The amount of time, in units of hours, that lights were on in an office while it was unoccupied.

Analysis #2: Wasted light per occupied hour. The ratio of the wasted light to the hours of occupancy, in units of wasted light hours per hours of occupancy. This analysis normalized the results by accounting for work attendance.

Analysis #3: Other indicators of behavior. This analysis included the number of times that the occupants used the light switch per day and the average duration of each occurrence of wasted light.

Analysis #4: Survey results. Analysis of both Likert scale results and comments provided by the occupants.

Analysis #5: Alternative energy conservation strategies. Comparison of energy savings due to the messaging devices with other commercially-available lighting controls strategies such as an astronomical timer, an automated motion sensor, or a combination of an automated motion sensor and manual switches.

Only Analyses #1 and #2 were applied to the three hypotheses because the hypotheses anticipated the effects of the devices on wasted light. The other three analyses provided a more nuanced understanding of the effects of the devices.

The results show that Hypothesis #1 was supported by the data. For all 36 analyzed offices collectively, the average wasted light per occupied hour (Analysis #2) was reduced from 0.297 hour/hour in the before-intervention period to 0.253 hour/hour during the intervention period, a 14.6% reduction, and this result was statistically significant ($p < 0.027$). **However, the second and third hypotheses were not supported by the data.** Contrary to Hypothesis #2, there was a greater decrease in wasted light per occupied hour during the intervention period among the static message offices (from 0.244 hour/hour to 0.186 hour/hour, a 23.8% reduction) than in the dynamic message offices (from 0.339 hour/hour to 0.307 hour/hour, a 9.2% reduction), and only the decrease among the static message offices was statistically significant. Contrary to Hypothesis #3, there was a further decrease in wasted light per occupied hour during the after-intervention period relative to the intervention period in both the static and dynamic message offices, though the difference was not statistically significant.

While these results are based on Analysis #2 (wasted light per occupied hour), applying Analysis #1 (absolute hours of wasted light) to the hypotheses instead, Hypothesis #1 was not supported because the decrease in wasted light was not statistically significant. Hypothesis #2 was not supported, but in this case neither the static or dynamic message offices had a statistically significant change from the before-intervention to the intervention period. Hypothesis #3 was not supported, but in this case the continued decrease in wasted light among dynamic message offices, from 30.96 hours during the intervention to 23.81 hours after the intervention, was statistically significant ($p=0.010$).

Surveys administered after the intervention period (Analysis #4) point to two potential reasons why the dynamic message devices were less effective in reducing wasted light than had been anticipated:

- Nine occupants of dynamic message offices indicated that they left their lights on to signal that they were "at work" for the day, while only 4 occupants of static message offices did.
- Six occupants of dynamic message offices thought that it was better, for economic or energy reasons, not to switch fluorescent lights off for short periods of time, while only 3 occupants of static message offices thought this.
- When comparing the before-intervention and after-intervention survey results of the dynamic message offices, there was a statistically significant trend toward disagreement with the statements "It is important to turn off the lights every time I leave my office" and "I would rather switch off the lights myself than have a sensor turn them off automatically." There was not a statistically significant trend among the static message offices. One possible explanation for this is that the dynamic message devices may have annoyed occupants.

The results showed that there was an average of 30 hours of wasted light per office per month during the before-intervention period (Analysis #1), with both the static and dynamic message offices considered together. Installing the message devices reduced this by 12% to an average of 27 hours per office per month. The authors used the measured occupancy and light usage data to calculate the effect on wasted light if different control strategies had been installed instead of the message devices (Analysis #5). For example, if the lights had been on an astronomical timer with no manual override, then there would have been 98 hours of wasted light per office, a 227% increase. If an automatic motion sensor had been installed and occupants never turned the lights off manually (such as with an auto on, auto off occupancy sensor), then there would have been 43 hours of wasted light per office per month, a 43% increase compared with manual switches. However, if the occupants continued to operate the manual switches as they did during this study, and there was also a vacancy sensor installed (e.g. as backup for the times when the occupants didn't use the switch), then the wasted light would have been 15 hours per office per month, a 50% reduction compared with manual switches alone and a 65% reduction compared with automatic switches alone.

Although Hypothesis #2 was not supported by the data, the results of this experiment still show the importance and potential of using behavioral techniques in saving energy. For example:

- The presence of a messaging device reduced wasted light per occupied hour by 14.6%.
- Calculations showed that in an office building that has automated controls installed (unlike the offices in this experiment) encouraging occupants to still turn off lights manually would reduce wasted light by 65% compared with relying solely on the automatic controls to turn the lights off.
- In the survey comments, many occupants indicated that there were cultural reasons that discouraged them from turning off the lights when leaving their

office (such as using the lights as an attendance indicator and not being confident that turning off the lights is economically beneficial), so behavioral techniques would likely be effective in modifying this culture.

Background

Behavior research

People have honed techniques to influence others for centuries. Aristotle wrote *Rhetoric* on the topic in the fourth century B.C., and the techniques of persuasion were practiced over the subsequent centuries, including by Niccolò di Bernardo dei Machiavelli, who wrote *The Prince* in the sixteenth century. In the twentieth century, B.F. Skinner applied scientific methods to understanding influencing behavior (Skinner, 1938), primarily with animals. There was a surge in scientific research on this topic in the mid-1960s (Corlan, 2004). From the mid-1970s through the mid-1980s, there was increased interest in how to use the new scientific understanding of persuasion to decrease behaviors harmful to the environment (Dwyer, Leeming, Cobern, Porter, & Jackson, 1993). Prominent researchers included Richard Winett and E. Scott Geller at Virginia Polytechnic Institute (for example Geller, 1981; R. A. Winett, Kagel, Battalio, & Winkler, 1978; R. A. Winett, Leckliter, Chinn, Stahl, & Love, 1985; R. a. Winett & Neale, 1979; Winkler & Winett, 1982) and others (Cialdini, 2003).

The design of the present investigation draws heavily on principles and procedures from the field of applied behavior analysis (ABA), the applied arm of the larger field of behavioral psychology. ABA employs the use of basic behavioral principles to modify various aspects of human behaviors as part of a learning or treatment process. Behavior analysts focus on the observable relationship between behavior and the environment. By functionally assessing the relationship between targeted behaviors and the environment, the methods of ABA can be used to systematically change the behaviors. Applied Behavioral Analysis techniques call for examining the antecedent (A) to a behavior, the behavior (B) itself, and the consequences (C) of the behavior, which is abbreviated as A-B-C analysis. Psychologists studying how to modify behavior classified their techniques as antecedents (or prompts) or consequences (or feedbacks). In the 1970s, Richard Winett examined techniques for modifying environmentally destructive behavior including (Winett & Neale, 1979):

<u>Antecedent examples</u>

- provide information about the environmental problem and behavior
- give frequent reminders
- modify people's expectations and perceptions
- make personal or public commitments

<u>Consequence examples</u>

- changes to rate schedule
- rebates or tax credits
- information feedback
- interpersonal approval

Applying behavioral science to reducing lighting energy use

In general, Winett found that antecedent techniques such as information and appeals seem to be ineffective while consequences are quite effective (Winett & Neale, 1979). The feedback that was found to be most effective was monetary, such as rebates. (In fact, environmental behavioral scientists went on to study price elasticity, the basis for modern carbon taxes.) However, some effective antecedent techniques were found for reducing lighting energy use (Winett & Neale, 1979):

> Virtually all feedback and rebate techniques have also incorporated prompting (an antecedent event), here more loosely defined as 'messages' to promote conservation behaviors. The environmental-prompting literature [42] indicates that prompts are inexpensive, relatively simple to deliver, but transient in effect, and only effective with a limited (15%) segment of persons. However, this same literature demonstrates that prompts may be made more effective if their information is specific ("Turn out the light", not "Conserve energy"), and if prompts are perceptible at the time and point of potential action. When the location and timing of prompts is optimized, then such prompts also have a built-in feedback-reinforcement capability [43], that it, the response follows the prompt and successfully completes the requested behavior. After 1973 - 74, we all saw many signs in different buildings urging us to conserve energy. The brief review of prompts suggests that such signs were probably ineffective, but more specific signs may promote conservation behaviors. In one pilot effort [44], university- produced signs urging persons to conserve energy were placed in rooms in which lights were frequently left on, even though the rooms were unoccupied. The sign was placed above a light switch, and then a small sticker that also urged the saving of energy was placed on the light switch. These conventional prompts had no effect; the lights were always left on (100% of observation days) when the rooms were unoccupied. In the next phase of the study, larger signs with specific information (when and who should turn out the lights) were placed near the exit points of the room. Now the lights were left on for only 40% of the observation days.

Figure 1: An example of a commercially available switch plate sticker.[1]

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[1] http://www.awarenessideas.com/AI-edlite201-09-1-Color-Please-Turn-Off-The-Lig-p/ai-edlite201-09.htm. Accessed Oct. 25, 2016.

Lighting accounts for about 15% of electricity use in commercial spaces and about 10% in residential spaces.[2] One study showed that in commercial private offices only 31% of lighting energy was used when the office was occupied (Maniccia, Rutledge, & al., 1998). A common way to reduce the waste of the other 69% of the lighting energy is through vacancy sensors. However, switch plate sticker reminders have been shown to reduce lighting use by 15% (Rea, Dillon, & Levy, 1987) to 40% (Winett & Neale, 1979), with fast payback due to low initial cost.

Applying behavioral science to dynamic message devices

The early behavior modification research included using static prompts at the switch plate. The authors of this study hypothesized that a greater amount of energy could be saved by replacing the switch plate sticker with a device that makes the prompt message dynamic in both content and timing and makes the feedback/ consequence message responsive to switching events and variable in whether or not it is displayed. The dynamic message device designed to implement these techniques incorporated the following behavioral science techniques.

Dynamic antecedent prompts

The switch plate stickers in the experiments describe above were static antecedents; the stickers remained unaltered, so all they could do was remind people that they should turn out the lights. More recently, technology allows the cost-effective display of changing messages, such as with LCD screens or electronic ink. Winett discusses in the above passage that to be effective, the message should be specific, including when and who should turn out the lights. Electronic control over the switch plate message provides the opportunity to be ultra-specific, addressing the office occupant by name and saying exactly when the lights should be turned out. Also, humorous or whimsical prompts were included to keep occupants engaged with the dynamic message switch plate.

Dynamic feedback consequence messages

As discussed above, Winett found that feedback techniques were more effective in modifying behavior than antecedent techniques. According to Geller (Geller, 1995):

> …Skinner (1987) maintained that human behavior is selected (or determined) by its consequences, and we should not expect many individuals to change their behavior as a result of activators alone, especially when the information is about a distant future. Most of the behavioral science research for environmental protection has supported Skinner's position, with activators alone being effective only when the target behavior is relatively convenient and the activator is polite, response specific, and occurring in close physical and temporal proximity to opportunities for the target behavior to occur.

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[2] https://www.eia.gov/tools/faqs/faq.cfm?id=99&t=3. Accessed Dec. 5, 2016.

By monitoring the use of the light switch, the device provided a message after switching occurred in order to provide positive feedback to the occupants.

Variable reinforcement schedules

One issue that has plagued behavioral influence on environmentally related behaviors is a gradual decrease in the desired behavior. This is called response extinction, and it occurs when the response is no longer reinforced by the stimulus. Because extinction is anticipated, researchers and agencies trying to influence behavior either try to achieve a short-term behavior, such as purchasing energy efficient equipment that will remain in use for a long time, or plan to continue the stimulus, such as ongoing price rebates. It is likely that traditional switch plate stickers would have some effect on behavior when first posted, but would subsequently be unnoticed by occupants.

B.F. Skinner discovered a method of overcoming response extinction in rats, called variable reinforcement schedules. Dr. C. George Boeree explains variable schedule reinforcement (Boeree, 2006):

> Skinner likes to tell about how he "accidentally -- i.e. operantly -- came across his various discoveries. For example, he talks about running low on food pellets in the middle of a study. Now, these were the days before "Purina rat chow" and the like, so Skinner had to make his own rat pellets, a slow and tedious task. So he decided to reduce the number of reinforcements he gave his rats for whatever behavior he was trying to condition, and, lo and behold, the rats kept up their operant behaviors, and at a stable rate, no less. This is how Skinner discovered schedules of reinforcement!
>
> Continuous reinforcement is the original scenario: Every time that the rat does the behavior (such as pedal-pushing), he gets a rat goodie.
>
> The fixed ratio schedule was the first one Skinner discovered: If the rat presses the pedal three times, say, he gets a goodie. Or five times. Or twenty times. Or "x" times. There is a fixed ratio between behaviors and reinforcers: 3 to 1, 5 to 1, 20 to 1, etc. This is a little like "piece rate" in the clothing manufacturing industry: You get paid so much for so many shirts.
>
> The fixed interval schedule uses a timing device of some sort. If the rat presses the bar at least once during a particular stretch of time (say 20 seconds), then he gets a goodie. If he fails to do so, he doesn't get a goodie. But even if he hits that bar a hundred times during that 20 seconds, he still only gets one goodie! One strange thing that happens is that the rats tend to "pace" themselves: They slow down the rate of their behavior right after the reinforcer, and speed up when the time for it gets close.
>
> Skinner also looked at variable schedules. Variable ratio means you change the "x" each time -- first it takes 3 presses to get a goodie, then 10, then 1, then 7 and so on. Variable interval means you keep changing the time period -- first 20 seconds, then 5, then 35, then 10 and so on.
>
> In both cases, it keeps the rats on their rat toes. With the variable interval schedule, they no longer "pace" themselves, because they can no longer establish a "rhythm" between behavior and reward. Most importantly, these schedules are very resistant to extinction. It makes sense, if you think about it. If you haven't gotten a reinforcer for a while, well, it could just be that you are at a particularly "bad" ratio or interval! Just one more bar press, maybe this'll be the one!
>
> This, according to Skinner, is the mechanism of gambling. You may not win very often, but you never know whether and when you'll win again. It could be the very next time,

> and if you don’t roll the dice, or play that hand, or bet on that number this once, you’ll miss on the score of the century!

While Skinner did his experiments on animals, the effectiveness of variable reinforcement schedules has since been documented with humans (Mathews, Shimoff, Catania, & Sagvolden, 1977; Saari & Latham, 1982).

Variable feedback is a technique that had not previously been applied to persuasion for energy conservation. The authors identified one study that made use of the technique for water conservation, but detailed results were not made available (Arroyo, Bonanni, & Selker, 2005).

To incorporate variable feedback, the dynamic message device provided feedback messages not after every time the lights were switched off, but only a certain fraction of the time. This was intended to keep the occupants engaged with the switch plate message display and in order to sustain an increased use of the light switch for reducing energy.

Potential benefits of dynamic message devices

The authors anticipated that dynamic message devices would have potential benefits over automated controls, including:

- Automated controls are designed to waste some energy during delay periods, typically 10 to 20 minutes long, in order to avoid annoying building occupants. If dynamic message devices were effective, there would not be a time delay when the lights are shut off.
- Some occupants override automated controls out of frustration when they are not properly commissioned. Humans are able to determine their own occupancy and whether or not daylighting is sufficient for the task at hand better than any automated sensors, so occupant satisfaction may be greater.
- Photosensors, which dim or turn off lights when sufficient daylighting is available, are less common in commercial buildings than vacancy sensors, and are more difficult to commission properly. The dynamic message device could be used to remind people to turn off lights when they are not needed due to daylighting.
- The dynamic message device could provide other energy saving lighting tips, such as to turn off overhead lights and use desk task lights instead.
- Anticipated lower product and installation costs than vacancy- or photo-sensors could lead to a faster payback period.
- Dynamic messaging could be applied to other conservation areas besides lighting such as water usage, heating, cooling, and transportation.

An additional literature review pertaining to using dynamic message displays to encourage energy savings is shown in Appendix: Literature summary.

Experimental design and implementation

Experimental design

As shown in Table 1, the experiment initially consisted of two groups of private, single occupant offices: 20 experimental offices with dynamic message devices and 20 control offices with static message devices.

At the start of the experiment, one data logger was installed in each office. In the before-intervention period (one month long), no other modifications were made to any offices. During the intervention period (one month long), a dynamic message device was installed in each office of the experimental group, and a static message device was installed in each office of the control group. At the start of the after-intervention period, all message devices were removed. The data loggers recorded occupancy and light usage data for an additional one month. At the end of the after-intervention period, the data loggers were removed.

This plan allowed the LRC to test the effects of:

1) static messages and dynamic messages against base cases of no intervention (during-intervention vs. before-intervention)
2) static messages and dynamic messages against each other (control group vs. experimental group)
3) and the persistence of each intervention after they are removed (after-intervention vs. during-intervention).

Table 1: Experimental design

	Before	**Intervention**	**After**
Experimental group	No message device	Dynamic message device	No message device
Control group	No message device	Static message device	No message device

Hypotheses

Based on the background research, the hypotheses of the experiment were that there would be:

1. a reduction in wasted light (the amount of time that the lights are on in an unoccupied office) during the intervention period relative to the before-

intervention period because the occupants would respond to the prompts displayed on the messaging devices.
2. a greater decrease in wasted light during the intervention period in the dynamic message offices than in the static message offices because the occupants would be more responsive to the dynamic messages.
3. an increase in wasted light during the after-intervention period relative to the intervention period because occupants would relapse to previous behaviors when prompts are no longer present.

Location of experiment

The experiment was conducted at the State University of New York (SUNY) System Administration Building, also known as SUNY Plaza, at 353 Broadway, Albany, NY 12207.

Office recruiting and assignment

Potential offices in the SUNY building were identified in partnership with building maintenance staff. The authors together with SUNY maintenance staff approached potential occupants and asked if they would participate in the study. Requirements for inclusion were:

- Private office.
- Manual light switch inside the office.
- No automated lighting controls.
- Occupant was willing to participate. (i.e. the study was opt-in.)

Ideally, the offices would have been situated on two separate floors in order to easily balance the experiment between experimental offices (with dynamic message devices installed) and control offices (with static message devices installed). Unfortunately, not enough qualifying offices were available on any one floor, so offices throughout the building were included. The offices were balanced one-to one, so for every experimental office, there was a corresponding control office. The LRC took three factors into consideration when balancing the offices:

- Existence of an exterior window.
- Orientation of exterior window, if present.
- Avoidance of mixing control and experimental offices within the same department when possible, in order to minimize the chance of an occupant seeing the opposite type of device.

During the course of the experiment, three static message offices were removed. Occupants of two of these offices were relocated to other offices midway through the study. In a third office, the light usage readings were compromised; a light pipe was not used with the data logger because there was not an exterior window (discussed below), but there was a window to a hallway which affected the light measurements. By the end of the measurement period, there were 20 dynamic message offices and 17 static message offices. As discussed below, a fourth static message office was removed from the analysis because it was an outlier.

Occupant orientation

A letter was provided to participants at the start of the experiment, shown in Appendix: Orientation letter.

IRB exemption

The authors received an exemption from the Rensselaer Institutional Review Board (IRB) on March 4, 2016.

Experiment schedule

Each of the three experimental periods lasted four weeks.

1. The before-intervention period went from April 4 to May 1, 2016. At the start of this period, the data loggers were installed and the baseline surveys was distributed. The first week of data from the loggers were downloaded on May 11 to confirm that the loggers were working correctly. Twenty business days were included in this period.
2. The intervention period ran from May 2 to May 30, 2016. At the start of this period, the message devices were installed and data from the loggers were downloaded (and the loggers were left in place). During the intervention period, the batteries were changed in the dynamic message devices weekly. Correct operation of all dynamic and static message devices was confirmed weekly. Twenty business days were included in this period.
3. The post-intervention period ran from May 31 to June 26, 2016. Data loggers were removed on June 27, and the data were downloaded. Surveys were administered during this period on June 6, 13, 22, and 27. The authors returned multiple times in order to encourage as many participants as possible complete a survey. Nineteen business days were included in this period due to the Memorial Day holiday.

Surveys

The authors requested that occupants fill out surveys during the before-intervention and again during the after-intervention periods. Please see Appendix: Survey questions for the questions that were posed to occupants. For the after-intervention survey, the authors transcribed occupants' verbal comments.

Analyses

Five analyses were conducted: Analysis #1: wasted light, Analysis #2: wasted light per occupied office, Analysis #3: other measures of behavior, Analysis #4: survey responses, and Analysis #5: comparison with alternative energy conservation measures. Only

Analyses #1 and #2 were applied to the three hypotheses because the hypotheses anticipated the effects of the devices on wasted light. The other three analyses provided a more nuanced understanding of the effects of the devices.

Analysis #1: Wasted light

The first dependent variable that was analyzed for this study was wasted light, defined as the hours that the lights are on while the office is unoccupied.

$$\text{Wasted light} = \text{Time}_{\text{lights on while unoccupied}}$$

Analysis #2: Wasted light per occupied hour

The second dependent variable that was analyzed for this study was wasted light per occupied hour. Wasted light is defined as the time that the lights are on but the office is unoccupied. Wasted light is analyzed as:

$$\text{Wasted light} = \text{Time}_{\text{lights on while unoccupied}}/\text{Time}_{\text{occupied}}$$

Using the ratio of wasted light to the time the office is occupied eliminates changes in work attendance as a variable. For example, if an occupant was away from the office during one of the experimental periods due to a conference or vacation, the absolute amount of wasted light would presumably be lower, but not due to a change in behavior by the occupant. Also, the after-intervention period included one fewer business day than the other two periods because of the Memorial Day holiday.

A discussion of calculating wasted light can be found in *Value Metrics for Better Lighting* by Mark S. Rea, pp. 48-49.

Analysis #3: Other measures of behavior

In addition to wasted light, the authors calculated two other measures of behavior: the number of times that light switches were used per occupied day and the average wasted light period. Many occupants indicated through surveys that they turned off the lights more frequently due to the message devices and that they turned off the lights when they planned to be out of their office for shorter periods compared to their initial behavior.

Light switch usage is defined as the average number of times an occupant turned off the lights per occupied day. An occupied day for an office is defined as any day during which total occupancy exceeded one hour.

Another measure of behavior was the average duration of wasted light. This is the average duration of time that an office was unoccupied with the lights left on, as illustrated in Figure 2. The average duration of wasted light has the units of hours. It is an absolute value, and is not calculated per occupied day or per occupied hour.

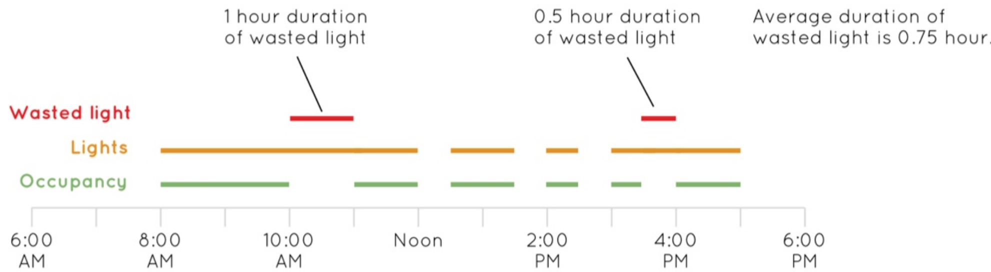

Figure 2: Illustration of the definition of the duration of wasted light. In this fabricated example, there is one 1-hour and one 0.5-hour duration of wasted light, so the average duration of wasted light is 0.75 hour.

Analysis #4: Survey responses

The authors analyzed the subjects' responses to a brief survey asked before and after the intervention period.

Analysis #5: Alternative energy conservation strategies

This experiment explored the effectiveness of encouraging the use of manual light switches in reducing wasted light. Although not explicitly part of the experimental design, one of goal of the research was to investigate a method that could be an alternative or supplement to using automated lighting controls, another method for reducing wasted light. To provide a comparison, the authors measured or calculated the anticipated wasted light for four lighting control methods: with and without manual light switches and with and without automated motion sensors, as shown in Table 2.

Table 2: Method of determining wasted light per occupant per month using four lighting control strategies. Motion sensors are assumed to have a 20-minute time delay.

	No motion sensor	With motion sensor
No manual switch	Method: calculated. Scenario: lights on an astronomical timer. Algorithm: • Lights on 8 AM to 6 PM. • 20 business days per month. • Subtract occupied hours.	Method: calculated. Scenario: lights controlled by an occupancy sensor (auto on, auto off). Data used for calculation: Average of static and dynamic averages during pre-intervention period. Algorithm: • If unoccupied period <20 minutes, wasted light=unoccupied period. • If unoccupied period>= 20 minutes, wasted light=20 minutes.
With manual switch	Method: measured. Scenario: manual switch only. Data used: • No message device value is average of static and dynamic averages during pre-intervention period. • With message device value is average of static and dynamic averages during intervention period.	Method: calculated. Scenario: lights controlled by a vacancy sensor (manual on, auto off) and also occupants sometimes manually turn lights off when exiting. Data used for calculation: Average of static and dynamic averages during pre-intervention period. Algorithm: • If wasted light period < 20 minutes, wasted light=wasted light period. • If wasted light period>=20 minutes, wasted light=20 minutes.

The case with no motion sensor and no manual switch is representative of an office where the lighting is on an astronomical timer without a manual override. The case with a motion sensor but no manual switch is found in offices with lights controlled by an occupancy (auto on, auto off) or vacancy sensor (manual on, auto off) that occupants choose not to manually control upon exiting. The case with a manual switch and no motion sensor is representative of the office environment where this experiment was conducted. The case with both a motion sensor and a manual switch represents an office environment that has a vacancy sensor and occupants choose to manually turn off the lights at least sometimes, but when they do not the vacancy sensor turns the lights off automatically after a time delay.

Only the case with a manual switch but no motion sensor was measured as part of this experiment. The case with a timer was calculated based on a fixed number of hours of use per day minus the occupied hours. The other two cases representing an occupancy sensor and a vacancy sensor, were calculated based on the measured occupancy and light usage data during the before-intervention period, using the algorithms shown in the table.

Experimental apparatus

In order to investigate the hypotheses described above, the authors designed and fabricated dynamic message devices. In order for the device to respond to occupants turning off their lights, a remote light sensor was also fabricated, which sent a signal wirelessly to the dynamic message device. As an experimental control, static message devices were fabricated to have a similar appearance as the dynamic message device, but only one message was displayed constantly. Please see Appendix: Device components to see the individual components that were used to fabricate the two types of message devices and the remote light sensor. Data loggers that recorded occupancy and light usage were installed in each office.

Dynamic message device and remote light sensor

Each dynamic message device displayed one of 20 prompt messages and turned on the LCD backlight when a person approached it, and sometimes displayed a feedback message after the lights were turned off. One dynamic message device was installed above the light switch (next to the door) in each experimental office at approximately about eye level (about 5 feet above the ground), as shown in Figure 3. The device was held to the wall with a temporary Velcro strip with adhesive backing (which was removed when the device was removed).

Figure 3: A dynamic message device mounted above a light switch. The occupant's first name is blurred in the photo for anonymity. The circle to the left of the display is the range finder. The black case is 5.75 inches by 3.25 inches.

Remote light sensor

Each dynamic message device was paired with a remote light sensor that was mounted at a ceiling troffer within each office in order to monitor if the light was on or off, as shown in Figure 4. The device was placed into a clear plastic bag, and the bag was clipped onto the luminaire's basket diffuser or frame, depending on the luminaire type. The remote sensor communicated wirelessly (via Bluetooth) with the dynamic message device.

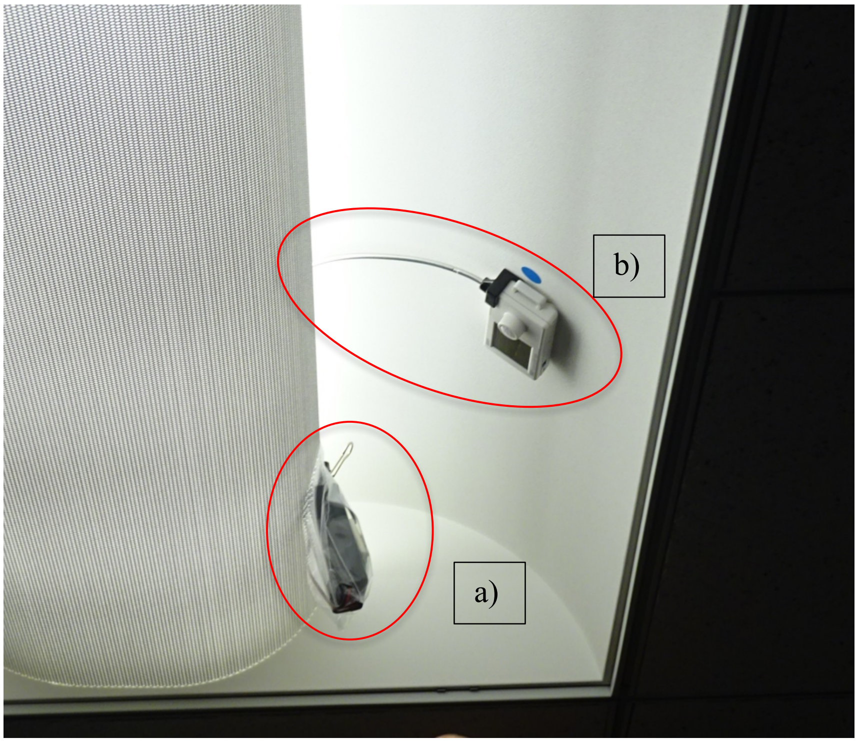

Figure 4: a) Remote light sensor clipped to luminaire basket at bottom of photograph. b) Data logger attached to luminaire reflector with magnets on the right side of the photograph. A fiber optic light guide runs from the data logger to the fluorescent lamps to prevent ambient light from being recorded. A sticker was placed at the location of the data logger during the experiment so it could be reinstalled at the same location after downloading data.

Displayed messages

The messages displayed on the dynamic message device are shown in Appendix: Messages displayed on dynamic message device. The messages were approved by the project sponsor prior to deployment.

The first name of each office occupant was programmed into the device, and many of the messages addressed the occupant by his or her name.

There were 20 prompt messages that were displayed every time the occupant approached the device while the lights were on. Of these:

- 11 reminded occupants to turn off the lights when leaving the office
- 3 encouraged occupants to turn off the light when sufficient daylight was present

- 1 was a fact about lighting energy
- 4 were jokes

There were six feedback messages, which were sometimes displayed after occupants turned the lights off.

The prompt or feedback message displayed was selected from that set of messages randomly by the microcontroller.

Algorithm

The microcontroller in the dynamic message devices was usually in a low power mode in order to conserve the batteries. Once every 120 milliseconds, the microcontroller would "wake up" and check if the Bluetooth receiver was reporting that the office lights were on. If they were, then a reading from the rangefinder was taken to check the distance to the nearest large object, presumed to be the occupant. If the distance decreased in three successive readings, then it was assumed the occupant was approaching. When that occurred, a random number was generated to determine which prompt message to display. (Each message had an equal chance of being displayed.) The LCD backlight was turned on and the selected prompt message was displayed for 10 seconds. While the prompt message was displayed, the microcontroller monitored if the office lights were turned off. If 10 seconds passed and the lights were not turned off, the message was removed from the screen and the LCD backlight was turned off. If the lights were turned off, then either a randomly selected feedback message was displayed (66% of the time) or no message was displayed and the backlight was turned off immediately (33% of the time), thereby providing the "variable feedback" described in the Variable reinforcement schedules section, above.

The program that was used to implement this algorithm is shown in Appendix: Microcontroller program.

Static message device

The exterior of the static message device looked similar to the dynamic message device and was mounted over light switches in the same location as the dynamic message devices, as shown in Figure 5. The differences were that it did not include a range finder, the LCD screen displayed two lines of black characters on a gray background, the display did not have a backlight, and constantly displayed the same message: "Please turn off the lights when leaving."

Figure 5: Static message unit mounted to wall.

Light and occupancy data logger

One Onset HOBO UX90-005 Room Occupancy and Light Logger was installed in each office. In offices with exterior windows, it was mounted to a troffer diffuser (e.g. perforated basket) or frame and an Onset UX90 light pipe was installed to be sure only light from the troffer was measured (to avoid daylighting interfering with the measurement), as shown in Figure 4. In offices without exterior windows, the data logger was hung on a temporary wall hook that was held in place with adhesive and removed at the end of the experiment. The data loggers were positioned so the integrated passive infrared (PIR) motion sensor was aimed at the occupant's desk. The data loggers were set to record light and occupancy information every 5 minutes. If any electric light was detected within that period, the light was recorded as being on for that period. If any occupancy was detected within that period, it was recorded as being occupied for that period. More information about the data logger is available at http://www.onsetcomp.com/products/data-loggers/ux90-005.

Operation of equipment

The messaging devices and data loggers worked as planned during the experiment.

The static message devices worked continuously. The dynamic message devices worked almost the entire time with possibly a few brief interruptions. When the authors replaced the batteries in the devices each Monday morning during the intervention period, they found that a few devices over the course of the month that were not “paired” with the remote light sensor in the office, so they would not display any message. However, in these cases the office occupant said that the device had been working at the end of the previous week, so there was little or no occupied time when the device was not functioning. The authors re-paired the dynamic message devices with the remote devices and they continued to work after that.

All of the data loggers worked correctly throughout the experiment. In one office with a static message device, the authors did not sufficiently protect the sensor from ambient light, so the sensor registered light from a hallway through an interior window in addition to the troffers within that office. That office was removed from the analysis.

Results

Table 3 shows the cumulative hours of occupancy and light usage measured by the data loggers. The bottom left quadrant within each small table (such as the one highlighted in red) shows "lights on, unoccupied" which is wasted light. The small table on the bottom right, highlighted in green, shows the results for all of the offices over the entire three-month measurement period.

Table 3: Light usage and occupancy measurements in hours and percentage of total time. Each small table shows the total number of hours for the conditions that lights are on and off and the offices are occupied and unoccupied. The total of the four cells represents all of the time within that period. The small tables in right column, outlined in blue, show the total for all three periods of time. The tables in the bottom row, outlined in orange, show the totals for both groups of offices. The table at the bottom right, highlighted in green, shows the total for all offices throughout the whole measurement period.

Cumulative light usage and occupancy (hours, percent of total)

		Before		During		After		Total	
		Lights On	Lights Off	Lights On	Lights Off	Lights On	Lights Off	Lights On	Lights Off
Static	Occupied	1,636 14.3%	175 1.5%	1,706 14.4%	248 2.1%	1,299 11.8%	242 2.2%	4,641 13.5%	665 1.9%
Static	Unoccupied	467 4.1%	9,149 80.1%	369 3.1%	9,507 80.4%	289 2.6%	9,186 83.4%	1,124 3.3%	27,842 81.2%
Dynamic	Occupied	1,748 13.0%	282 2.1%	1,795 12.9%	296 2.1%	1,448 11.2%	364 2.8%	4,991 12.4%	942 2.3%
Dynamic	Unoccupied	658 4.9%	10,754 80.0%	619 4.4%	11,209 80.5%	476 3.7%	10,674 82.3%	1,753 4.3%	32,636 80.9%
Total	Occupied	3,384 13.6%	457 1.8%	3,501 13.6%	544 2.1%	2,748 11.5%	606 2.5%	9,633 12.9%	1,607 2.2%
Total	Unoccupied	1,124 4.5%	19,903 80.0%	988 3.8%	20,715 80.5%	765 3.2%	19,859 82.8%	2,877 3.9%	60,478 81.1%

Four of the analyses were conducted on the light usage and occupancy data: Analysis #1: wasted light, Analysis #2: wasted light per occupied office, Analysis #3: other measures of behavior, and Analysis #5: comparison with alternative energy conservation measures.

Static message office S1 is an outlier and was removed from analysis. This office had a high amount of wasted light during the before-intervention period (wasted light was three times the mean of the other offices, as illustrated in Figure 12) due to the lights being left on over a weekend. This was not representative of the occupant's light switch usage during other weekends, nor was it representative of other occupants in the study. Also, the authors did not determine if the lights were left on by the occupant or cleaning staff.

As an aside, the average fraction of time that occupants were in their offices with the lights off (i.e. occupants working in their office without overhead electric lighting) increased from 1.8% of the time in the before-intervention period to 2.1% of the time during the intervention period to 2.5% in the after-intervention period, as shown in Table 3. This is likely to be due to the available daylight increasing from April to May to June.

Analysis #1: Wasted light

The first analysis that was conducted was on the hours of wasted light. While Table 3 shows the cumulative values for the offices, analysis was conducted on the results for individual offices, shown in Figure 6 and Figure 7.

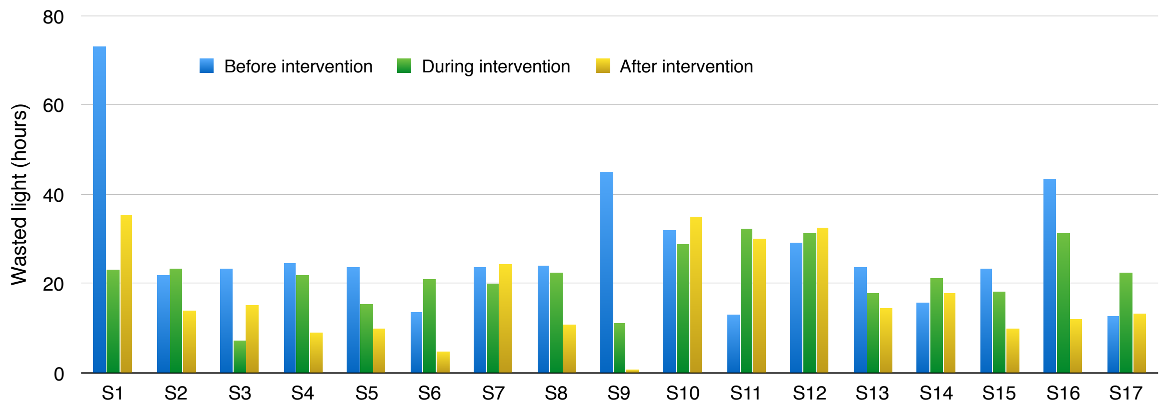

Figure 6: Wasted light for static message offices. Subject S1 was removed from the summary statistics as discussed above.

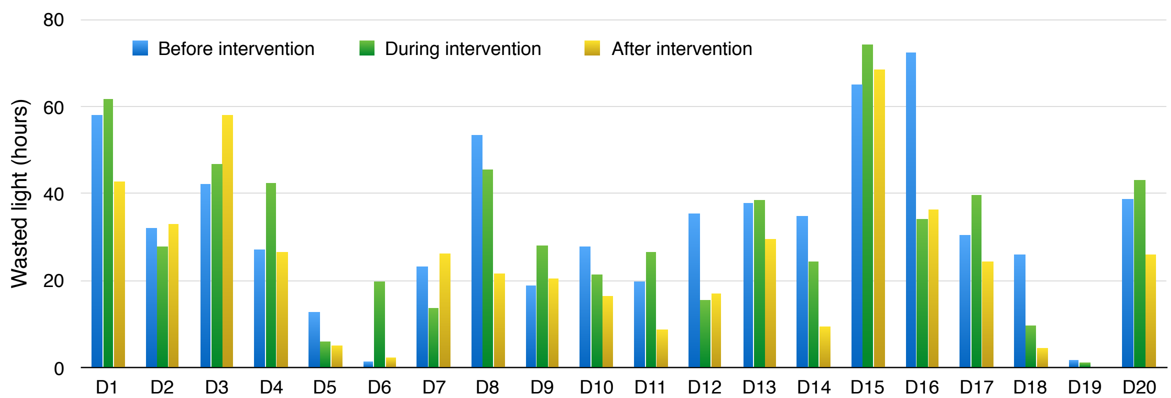

Figure 7: Wasted light for dynamic message offices.

The mean wasted light is shown in Figure 8.

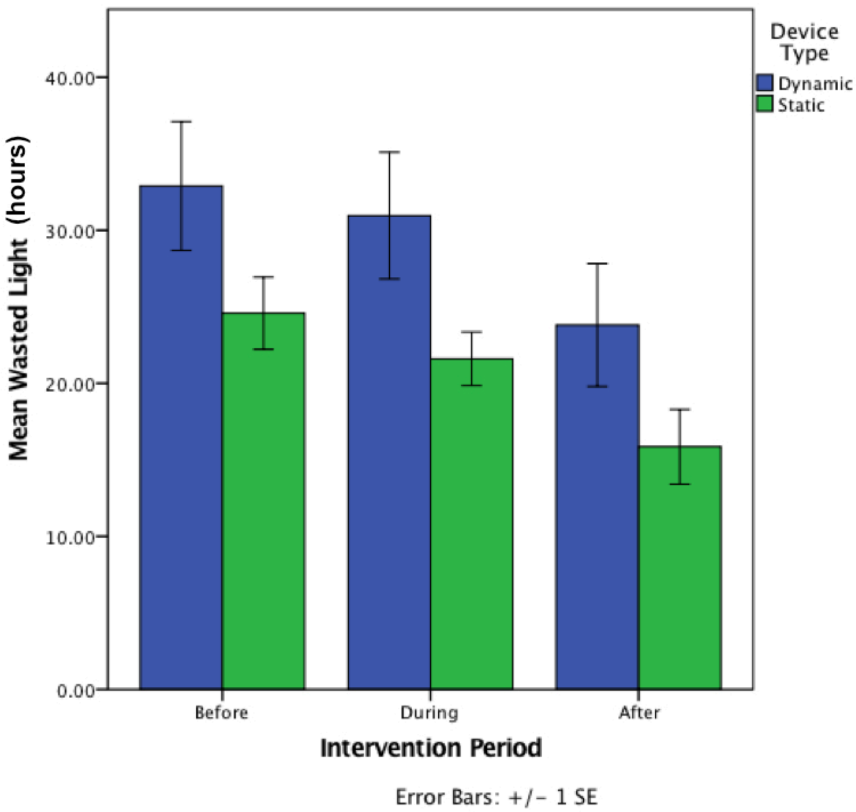

Figure 8: Mean wasted light by message device type and period of time. This shows the average wasted light per office within each group. The hours are the total for each month-long intervention period.

The wasted light data for the individual offices were submitted to mixed-model linear regressions using IBM SPSS 24.0 statistical software. While the experimental plan called for an ANOVA analysis, this method was chosen instead as having superior power to repeated-measures ANOVA, because it is more sensitive for smaller sample sizes, and it is not affected by the difference in the number of static and dynamic message offices.

The test period (*before, during, after*) and type of message device (*static, dynamic*) were entered as fixed factors in the regression, while the device type was entered as a random factor. The effects of the factors of interest were considered significant if the associated p-value was < 0.05. Note that the random effect of the device type will normally be significant, as individual units or participants always vary from one another.

The type of message device came close to having a statistically significant main effect on wasted light ($F(1, 34) = 3.69$, $p = 0.063$), although the differences trended in favor of the static devices.

The test period had a very significant main effect, however ($F(2, 68) = 10.37$, $p < 0.0001$). At baseline, the mean wasted light +|- SEM for the static devices was 24.58 +|- 9.44 hours, falling to 21.60 +|- 7.01 hours during the test, down to 15.86 +|-9.76 hours after the test. The difference between 'before' and 'after' conditions was statistically significant in planned pairwise comparisons (*df* = 68, *p* = 0.005), but the difference between 'before' and 'during' conditions was not, nor was the difference between 'during' and 'after.'

The dynamic devices also showed a downward trend as well. However, their mean wasted light +|- SEM began higher, at 32.90 +|- 18.83 hours, falling to 30.96 +|- 18.52 hours during the test, down to 23.81 +|- 17.95 hours after the test. The difference between the 'before' and 'after' conditions was significant in planned pairwise comparisons (*df* = 68, *p* = 0.001), as was the difference between 'during' and 'after' (*df* = 68, *p* = 0.010), but the difference between 'before' and 'during' conditions was not.

In addition to analyzing the static and dynamic offices separately, the authors also analyzed all 36 offices together, as illustrated in Figure 9. The regression that combined both static and dynamic devices together revealed a very significant effect of time of test ($F(2, 70) = 10.88$, $p < 0.0001$). In this case, the difference between 'before' and 'after' was statistically significant (*df* = 70, $p < 0.0001$), as was the difference between 'during' and 'after' (*df* = 72, *p* = 0.002). However, the difference between 'before' and 'during' did not reach significance (*df* = 70, *p* = 0.229).

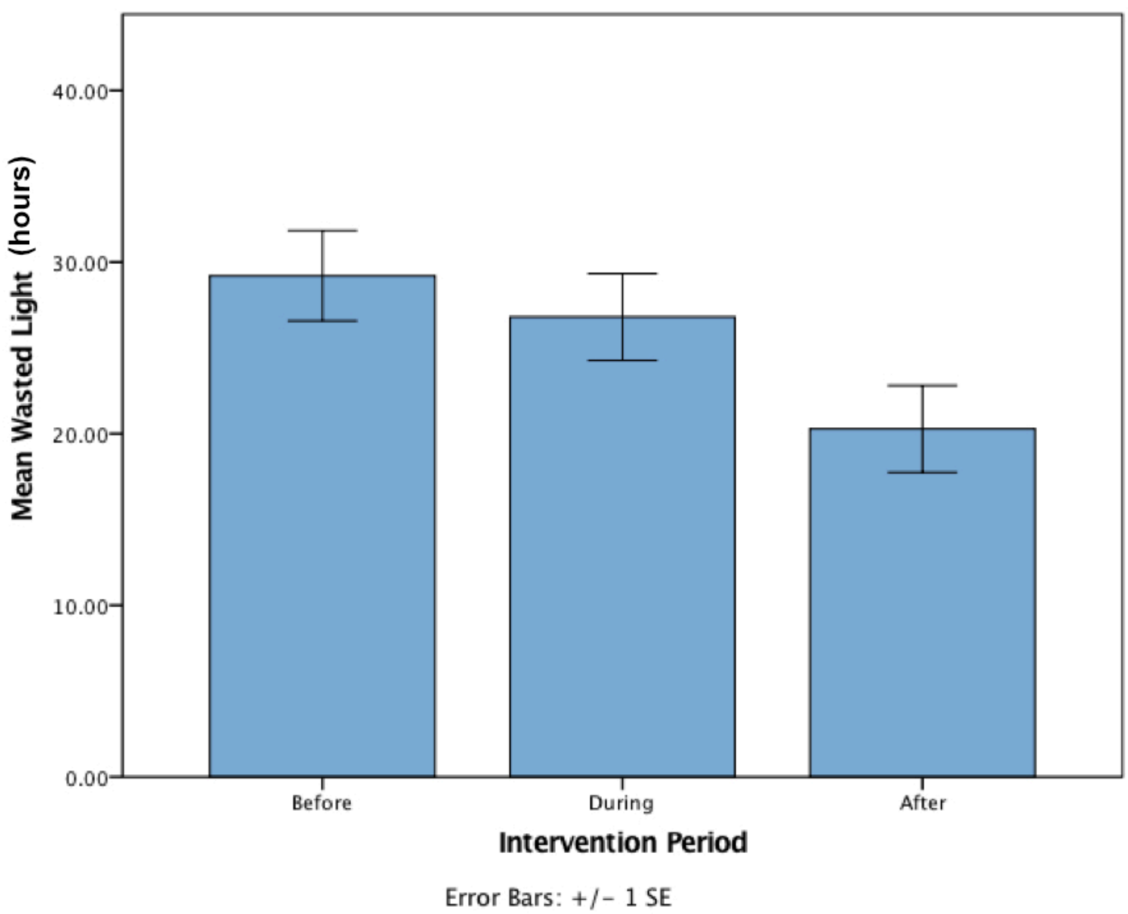

Figure 9: Mean wasted light by time period for all analyzed offices. This shows the average wasted light per office for all analyzed offices.

Analysis #2: Wasted light per occupied hour

Figure 6 and Figure 7 show the wasted light for each office. However, some of the variation in wasted light is due to variation in occupancy of the offices. As shown in Figure 10 and Figure 11, there was a wide variation in occupancy, ranging from 32.3 hours in office D14 during the after-intervention period to 163.1 hours in office S17 during the intervention period.

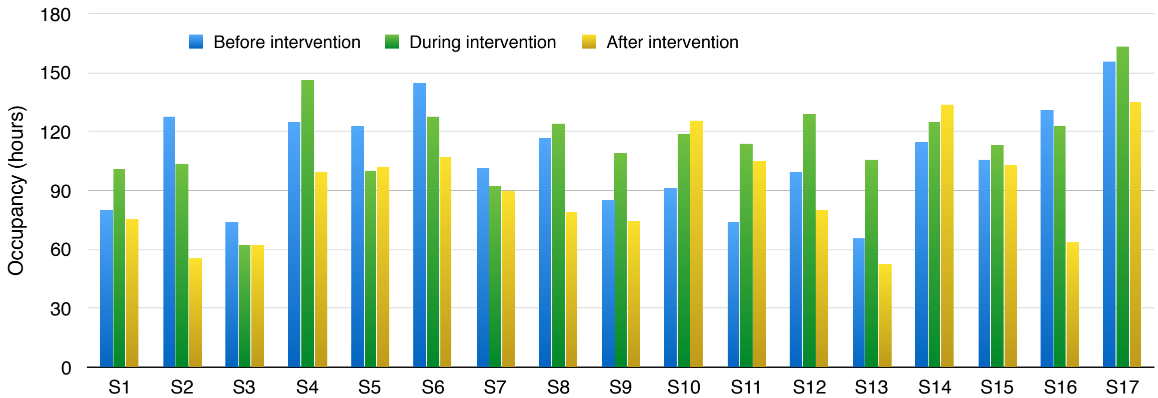

Figure 10: Occupancy of static message offices.

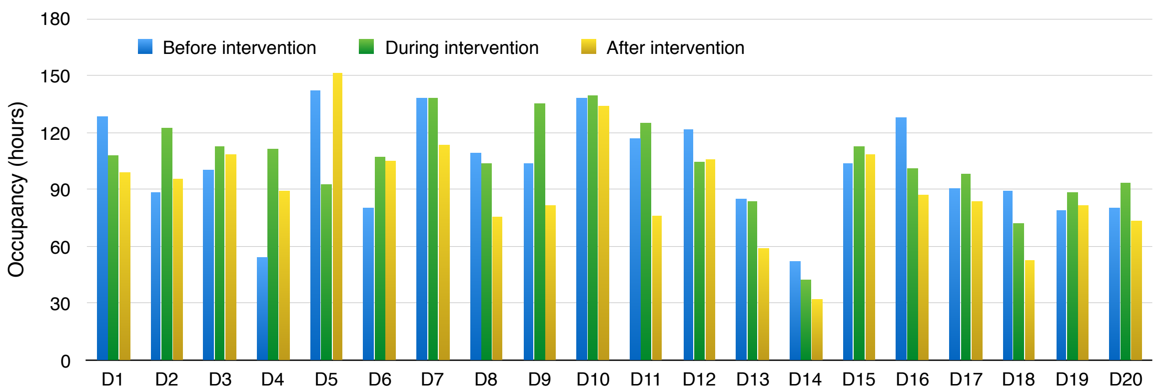

Figure 11: Occupancy of dynamic message offices.

For this reason, the ratio of wasted light to occupied hours, shown in Figure 12 and Figure 13, was analyzed. In other words, the wasted light data shown in Figure 6 was divided by the hours of occupancy shown in Figure 10 to obtain the values shown in Figure 12. Similarly, the wasted light data shown in Figure 7 was divided by the hours of occupancy shown in Figure 11 to obtain the values shown in Figure 13.

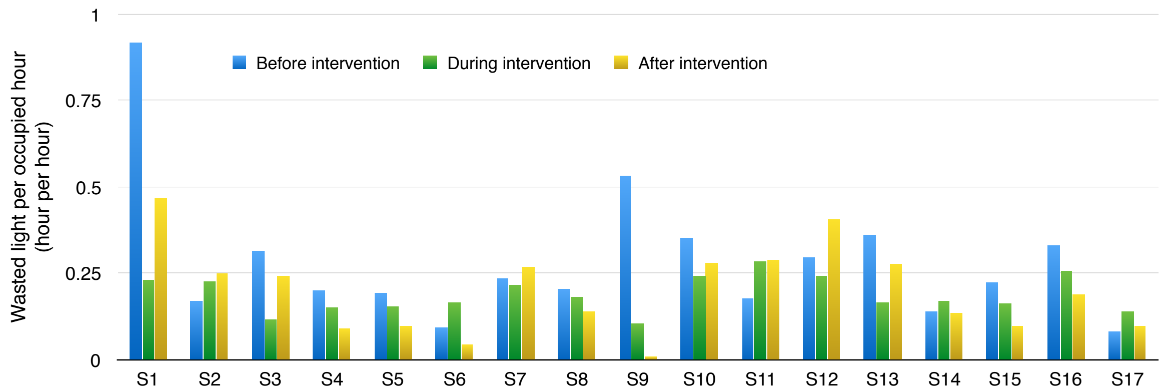

Figure 12: Wasted light per occupied hour for static message offices. Subject S1 was removed from the summary statistics as discussed above.

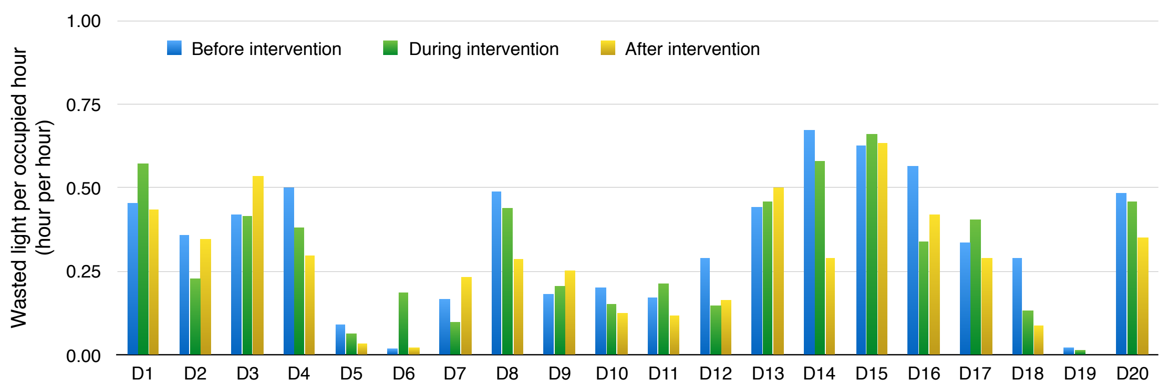

Figure 13: Wasted light per occupied hour for dynamic message offices.

The mean values of wasted light per occupied hour are shown in Figure 14.

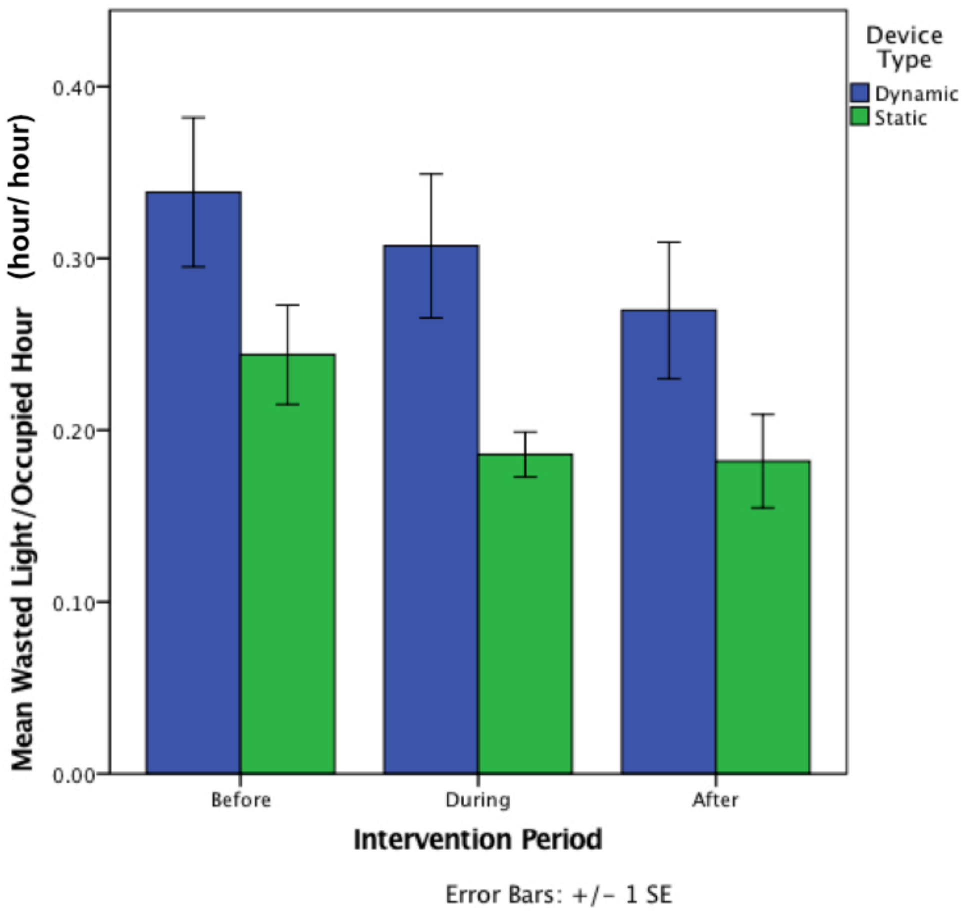

Figure 14: Mean wasted light per occupied hour by office type and time period.

The individual office data for wasted light per occupied hour were also submitted to mixed-model linear regressions using IBM SPSS 24.0 statistical software, using the same parameters as in Analysis #1.

The results of a regression on wasted light per occupied hour showed that the type of message device did have a statistically significant main effect on this measure ($F(1, 34) = 4.78$, $p = 0.036$).

For the static device offices, at baseline, the mean wasted light per occupied hour +|- SEM was 0.244 +| 0.116 hour/ hour, falling to 0.186 +| 0.052 hour/ hour during the test (a 23.8% reduction), down to 0.182 +| 0.109 hour/ hour after the test (an additional 2.1% reduction). In planned pairwise comparisons, two differences were statistically significant: the difference between 'before' and 'during' conditions ($df = 68$, $p = 0.048$) and the difference between 'before' and 'after' ($df = 68$, $p = 0.036$) but not between 'during' and 'after.'

The dynamic devices showed a downward trend as well. Their mean wasted light per occupied hour +|- SEM began higher, at 0.339 +| 0.194 hour/ hour, falling to 0.307 +| 0.187 hour/ hour during the test (a 9.2% reduction), down to 0.270 +| 0.178 hour/ hour after the test (an additional 12.2% reduction). The difference between the 'before' and 'after' conditions was statistically significant ($df = 68$, $p = 0.010$).

Combining both static and dynamic devices in a regression on wasted light per occupied hour also revealed a significant effect of time of test ($F(2, 70) = 6.10$, $p = 0.004$). Here, the difference between 'before' and 'during' was statistically significant ($df = 70$, $p < 0.027$). The difference between 'before and 'after' also reached significance ($df = 70$, $p = 0.001$). But in this case, the difference between 'during' and 'after' did not reach significance.

Analysis #3: Other measures of behavior

The change in the rate of light switch usage was analyzed. Among the dynamic message offices, the occupants' average light switch usage increased from 1.74 times per occupied day in the before-intervention period to 2.52 times per day during the intervention period. This is an increase of 45% and is statistically significant (p=0.027, one tailed paired Student's t-test). Light switch usage among this group then dropped to 1.90 times per day (a 24% decrease in light switch usage) from the intervention period to the post-intervention period (p=0.011), further showing that the presence of the device had an impact on behavior, as the occupants reverted close to their original behavior. The static message device also resulted in an increase in switching during the intervention period, but the increase was not statistically significant, showing that the dynamic device had a greater impact on this behavior than the static device.

Both groups of offices had a decrease in the average duration of wasted light, the average duration of time that an office was unoccupied with the lights left on**Error! Reference source not found.**. Among the dynamic message offices, the average duration decreased by 20% from 0.259 hours to 0.208 hours, and the among the static offices the average duration decreased by 22% from 0.232 hours to 0.182 hours. Both results are statistically significant (p=0.017 and p=0.005, respectively).

Although the occupants of dynamic message offices did use the light switch more frequently and there was a decreased average duration of wasted light, this did not result in less wasted light. This may be because these occupants went in and out of their offices more frequently and for short periods of times, unrelated to the dynamic message device.

Analysis #4: Surveys

Occupants were asked to complete a brief survey during both the before-intervention and after-intervention periods. The surveys included statements with occupants providing their responses on a Likert scale and an opportunity for comments. Please see Appendix: Surveys for the questions that were posed in the before- and after-intervention surveys.

Figure 15 shows the results of both the before- and after-intervention surveys. Both the static and dynamic message office occupants are represented in this figure. Thirty-eight of the initial 40 occupants in the study completed at least one of the two surveys. For the question about daylight, occupants of the 32 offices with exterior windows provided answers. In the after-intervention survey, question #4 regarding the feedback message was posed only to occupants of dynamic offices because the static message device did not have this feature.

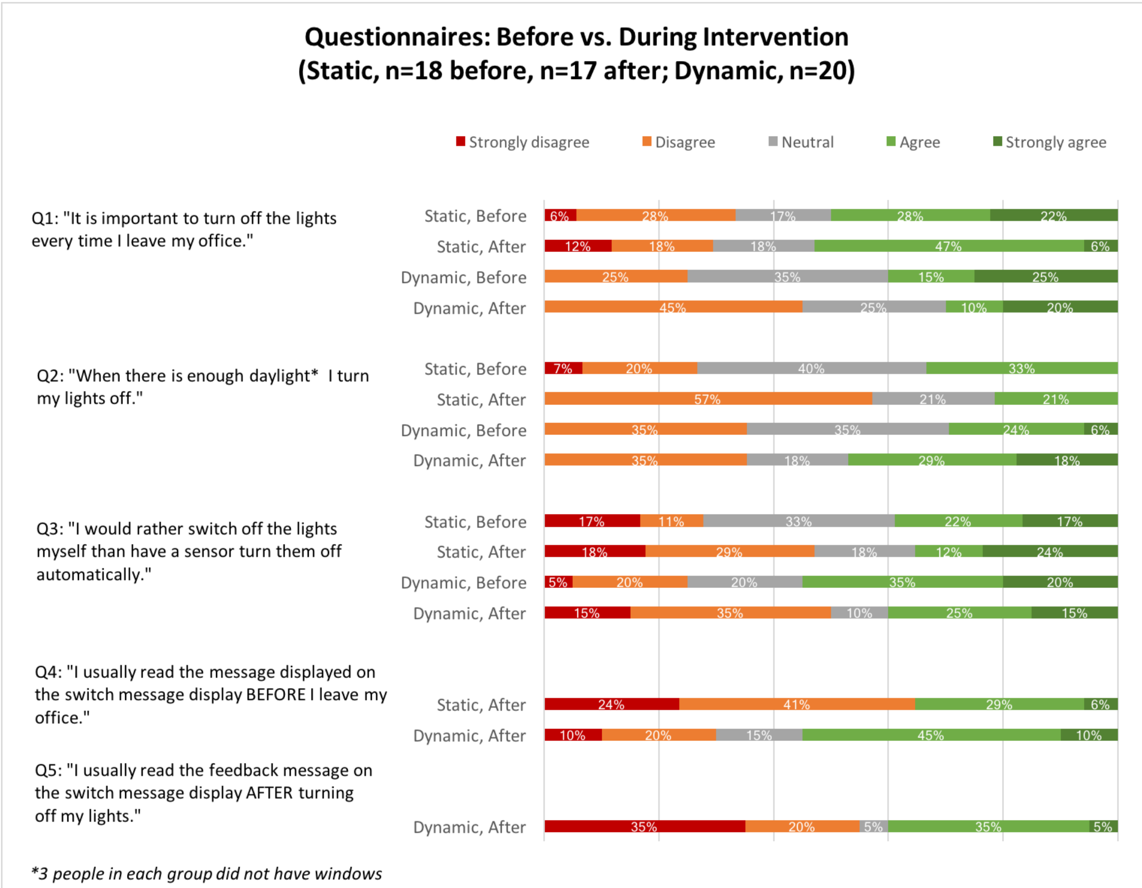

Figure 15: Survey results for all offices. n=38. For Question 2, regarding daylight, the results are shown only for occupants who had exterior windows.

The results of question #1 show that more people disagree about the importance of turning off lights if they had a dynamic message device. There were higher rates of agreement for the static device.

The results of question #3 show that both static and dynamic office occupants prefer automated controls rather than being required to turn the lights off manually.

The results of question #4 show that the dynamic messages caught occupants' attention more than the static messages, as expected.

The results of question # 5 indicated that over half of occupants with dynamic message devices didn't see the feedback message. This is likely because occupants turned off the lights as they walked out of the office.

When comparing the before-intervention and after-intervention survey results, there was a statistically significant[3] trend toward disagreement with questions #1 and #3 among the dynamic message offices (p=0.005 and p=0.037, respectively). There was not a statistically significant trend among the static message offices. One explanation for this is that the dynamic message devices may have annoyed occupants or in some other way made them prefer not to use light switches. As discussed below, annoyance toward the device was indicated by only one occupant in the comment section of the surveys. Another occupant with a dynamic message device turned the device upside down, which is possibly another indication of annoyance.

In addition to rating their agreement to the statements above on a Likert scale, the survey also provided occupants with an opportunity to provide comments. These comments were helpful in understanding the decisions about turning off the lights.

Forty-five percent of the dynamic message office occupants and 41% of the static message office occupants indicated in the comments that they felt that the message devices changed their behavior. An additional 5% of dynamic message office occupants and 18% of static message office occupants felt their behavior changed, but because their light usage was being monitored for the study, not due to the message devices.

Many occupants in both the dynamic and static groups indicated that they would turn off their lights if they were leaving for longer than a certain threshold time. For example, they would turn off their lights if they planned to be gone for over an hour. As shown in Figure 16, they provided several reasons for why they did not turn off the lights for periods less than their own threshold. Some occupants gave multiple reasons.

The most common reason given was that in the culture of the SUNY System Administration office environment, leaving the lights on was an attendance indicator, showing that the occupant was at the office for the day (even if away at the moment). For the occupants that gave this reason, this was important for two reasons. First, it was important for colleagues to know that they were nearby because it affected their work efficiency. They wanted their colleagues to return to speak to them directly rather than, for example, sending an email. Examples of comments include:

- "I get a lot of traffic"
- "It's a pop-in culture."

Second, they said it was important to leave the lights on as an attendance indicator because their manager and/ or coworkers would question if they were absent from work without permission. Examples include:

- "[if I turn my lights off] it creates unnecessary gossip."

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[3] Microsoft Excel 2010 was used to perform 2-tailed paired t-tests comparing before vs. after intervention, for both dynamic and static data sets.

- “It’s not good to be seen as absent due to office culture.”
- “[I will] get an email or question in hall later [about why I was away from work].”
- “My boss asked me to leave my lights on.”

Many occupants that said they used their lighting as an attendance indicator also expressed willingness to turn off the lights when they left for relatively long periods of time (e.g. lunch or long meetings). Perhaps this discrepancy could be explained by managers and coworkers knowing about the meetings and not expecting to find staff in their offices during these periods or during lunch.

Another type of reason given for not turning the lights off for periods of time shorter than their own stated threshold was that the occupants thought it reduced energy use or expenditures on lighting to leave the lights on. Comments included:

- “If you show me dollars and cents savings from turning off lights when I go to the copier, then I'll do it. I was told that starting a fluorescent light uses more energy than you save by turning it off, and there is wear and tear on the switch.”
- “I was taught it took more energy to turn lights off.”
- “I’m not sure if it would save any energy.”
- “I think it takes more energy to switch them off. I bought lights for home that were fluorescent and instructions said don't turn off and on too much because it wears down equipment and uses more energy to go on and off.”
- “I’ve read a ton of things, but haven't seen a definite answer if it's more cost effective or best practice to turn off lights for even 10 seconds. I want a definitive answer.”
- “I don't know how long lights have to be off to save energy due to the turn-on energy use.”
- “My parents told me it takes more energy to turn lights back on.”
- “I’m concerned about extra energy to turn lights back on.”
- “I think that it's more wasteful of electricity if I turn off lights more, or it's not good for the light.”
- “I’m not against turning off lights, but I felt that it doesn't make a difference. If I got a document saying it would make a difference, then I would be more inclined to turn off lights.”

A third common reason for not turning the lights off for periods of time shorter than their own threshold was that the occupants’ minds were on other matters when leaving, and the message device was not sufficient to draw attention to the issue. Comments included:

- “I’m thinking about something else.”

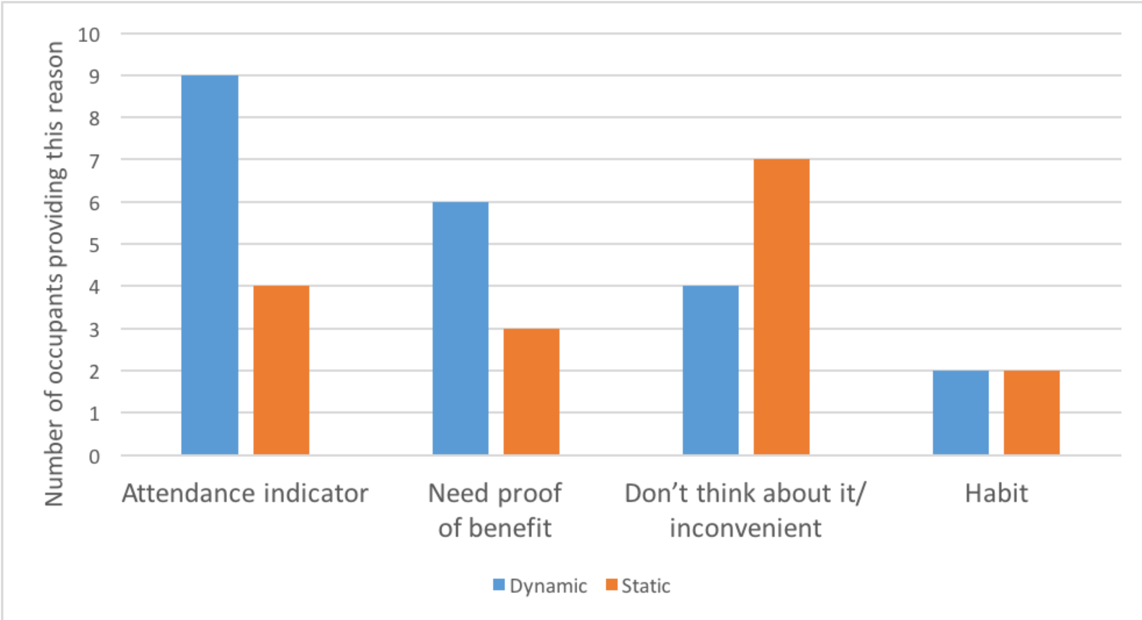

Figure 16: Reasons given by occupants for not turning off lights for "short" periods of absence. Many occupants indicated that they did not turn off the lights if they planned to be away from their office for a period of time shorter than their own particular threshold length of time (e.g. one hour), and these are the reasons given for this choice.

Most of the occupants with dynamic message devices expressed a positive attitude about the device and messages it displayed. There was one exception, with the occupant providing the comments: "I want to give it the finger… I don't want to be shamed into [turning off the lights]… The device just annoyed me. I deliberately did not look at it because it annoyed me."

Most occupants with dynamic message devices expressed a preference for the least-serious messages. Comments included:

- "I liked the jokes."
- "I liked the funny messages."
- "The messages made me giggle sometimes."
- "Some messages were too negative, such as 'Save the children.'"
- "I liked the little sayings that were funny."
- "Having more jokes would have made me look at it more."
- "It was nice to break up the day."

Two occupants were displeased with the funny messages, providing comments such as:

- "Some messages were too goofy."
- "The messages were for entertainment only, and not to be taken seriously."

One occupant expressed displeasure with the occupant's first name being programmed into the messages, saying it was "weird." No other occupants expressed an opinion, positive or negative, about this aspect of the messages.

Among the occupants with static message devices, comments about the message included:

- "After a few days I stopped noticing it."
- "I can't tell you what the message said."
- "If it changed message, I would have read it."
- "I saw [a dynamic message device in another office] and I would have preferred that."

Analysis #5: Alternative energy conservation strategies

Table 4 shows the measured experimental results (manual controls only) and calculated results for three alternative conservation strategies. This comparison shows that controlling lights with only an astronomical timer results in the greatest amount of wasted light: 98 hours per month. Installing an automated occupancy sensor (auto on, auto off, with a 20-minute delay period) can reduce the wasted light to 43 hours per month. The measured data from this experiment show that occupants wasted an average of 30 hours of light per month before messaging devices were installed, and 26 hours per month after. This shows that manual switching can result in less wasted light than automatic controls, even without using messaging devices. However, if vacancy sensors (manual on, auto off, 20-minute delay period) are installed to cap the maximum period of wasted light but occupants still choose to turn off the lights manually as often as they did during the experiment, then the wasted light would be reduced to 15 hours per month, which has the greatest energy savings of the four scenarios. This shows that even if vacancy sensors are installed, encouraging occupants to still turn lights off manually, such as with messaging, offers significant energy savings potential compared with relying only on sensors.

Table 4: Results of calculated or measured wasted light per occupant per month using four lighting control strategies. Motion sensors are assumed to have a 20-minute time delay.

	No motion sensor	With motion sensor
No manual switch	**98 hours**	**43 hours**
With manual switch	**30 hours** without message devices **26 hours** with message devices	**15 hours**

Discussion

Comparison of hypotheses with results

Only the first of the three hypotheses was supported by the results.

Hypothesis #1

The first hypothesis was that there would be a reduction in wasted light (the amount of time that the lights are on in an unoccupied office) during the intervention period relative to the before-intervention period because the occupants would respond to the prompts displayed on the messaging devices.

This hypothesis was supported by the data for wasted light per occupied hour for all 36 analyzed offices together. The average wasted light per occupied hour was reduced from 0.297 hour/hour in the before-intervention period to 0.253 hour/hour during the intervention period, a 14.6% reduction. As noted above, the difference between 'before' and 'during' was statistically significant ($df = 70$, $p < 0.027$).

Hypothesis #2

The second hypothesis was that there would be a greater decrease in wasted light during the intervention period in the dynamic message offices than in the static message offices because the occupants would be more responsive to the dynamic messages.

Contrary to the hypothesis, there was not a greater decrease in wasted light per occupied hour during the intervention period in the dynamic message offices than in the static message offices. Based on Analysis #2, the mean wasted light per occupied hour for the dynamic offices fell from 0.339 hour/hour in the before-intervention period to 0.307 hour/hour during the intervention period, a 9.2% reduction, which was not statistically significant. The wasted light per occupied hour in static offices, in contrast, fell by a statistically significant 23.8% from 0.244 hour/hour to 0.186 hour/hour.

Analysis #1 showed similar results. The mean wasted light for the dynamic offices fell from 32.90 hours in the before-intervention period to 30.96 during the intervention period, a 5.9% reduction, which was not statistically significant. The wasted light in static offices fell by 12.1% from 24.58 hours in the before-intervention period to 21.60 hours during the intervention, but in contrast with Analysis #2, this decrease was not statistically significant.

The surveys reinforced the difference between the static and dynamic message offices. When asked about the statements "It is important to turn off the lights every time I leave my office," and "I would rather switch off the lights myself than have a sensor turn them off automatically," both before and after the intervention periods, there were statistically significant changes in response toward disagreement ($p=0.005$ and $p=0.037$, respectively) among the dynamic message occupants. There were no statistically significant changes in responses among the static message offices. This may indicate that the dynamic message devices annoyed the occupants, although this was indicated in the comments of only one survey.

Based on these results, if messaging were to be used, it would be more cost effective to use static messages, which do not require any electronics.

One other measure of behavior did support hypothesis #2. Occupants of dynamic message offices increased their light switch usage a statistically significant 45%, while the change among static message offices was not statistically significant, as discussed in the section Analysis #3: Other measures of behavior, above.

Hypothesis #3

The third hypothesis was that there would be an increase in wasted light during the after-intervention period relative to the intervention period because occupants would relapse to previous behaviors when prompts were no longer present.

Contrary to the hypothesis, there was not an increase in wasted light per occupied hour during the after-intervention period relative to the intervention period. Among both groups, wasted light was further reduced after the message devices were removed from offices, though the changes were not statistically significant. There are two potential reasons why this occurred. First, the act of the authors carrying out the surveys during the after-intervention period could have had an influence on occupants' behavior. Second, the after-intervention period was in June, so more daylight was available in the offices, resulting in less use of electric lighting (as shown in Table 3) and therefore less wasted light.

Methods to further reduce wasted light using behavioral approaches

Based on the reasons given by occupants for not switching off their lights shown in Figure 16, two actions could be taken that possibly would increase use of light switches.

First, many occupants said they used their lighting to indicate attendance. Attendance can alternatively be indicated using non-electrical means such as door slider messages[4] or magnetic in/out staff boards[5].

Second, many occupants also expressed a belief that it was better for energy savings or maintenance costs to leave their fluorescent lights on, but these occupants also expressed an openness to learning more about this issue. Therefore, providing documentation[6] about

---

[4] Such as this product: http://www.mydoorsign.com/Exit-Entrance-Signs/In-Out-Slider-Sign/SKU-SE-1088.aspx

[5] Such as this product: https://www.uline.com/Product/Detail/H-5831/Boards-Easels/In/Out-Staff-Board-15-Person?pricode=WY518&gadtype=pla&id=H-5831&gclid=CNKdzdzz6c8CFQlZhgodEl0FDQ&gclsrc=aw.ds

[6] An example of this type of documentation can be found at https://www.scientificamerican.com/article/turn-fluorescent-lights-off-when-you-leave-room/

the benefits of turning off the lights every time the office will be unoccupied may reduce energy use.

Conclusion

The main hypothesis of the experiment, that a dynamic message device would have a greater impact on wasted light than a static message device, was not supported by the data. However, the results did show the importance and potential of using behavioral techniques in saving energy. First, the presence of any messaging device (i.e. considering all 36 analyzed offices together) reduced wasted light per occupied hour by an average of 14.6% (p=0.027). Second, calculations showed that encouraging office occupants to still turn off lights manually in offices with automatic lighting controls would reduce wasted light by 65% compared with relying solely on the automatic controls to turn the lights off. Finally, many occupants indicated that there were cultural reasons that discouraged them from turning off the lights when leaving their office (such as using the lights as an attendance indicator and not being confident that turning off the lights is economically beneficial), so behavioral techniques would likely be able to have an important role in modifying this culture.

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Literature cited

Arroyo, E., Bonanni, L., & Selker, T. (2005). Waterbot : Exploring Feedback and Persuasive Techniques at the Sink. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 631–639). Portland OR: Association for Computing Machinery. Retrieved from http://dl.acm.org/citation.cfm?id=1054972&picked=prox&CFID=236928816&CFTOKEN=16364158

Boeree, C. G. (2006). B. F. Skinner. Retrieved July 31, 2013, from http://webspace.ship.edu/cgboer/skinner.html

Cialdini, R. B. (2003). Crafting Normative Messages to Protect the Environment Crafting Normative the Environment Messages to Protect. *Current Directions in Psychological Science*, *12*(4), 105–109. Retrieved from http://www.jstor.org/stable/20182853

Corlan, A. D. (2004). Medline trend: automated yearly statistics of PubMed results for any query. Retrieved July 31, 2013, from http://dan.corlan.net/medline-trend.html

Dwyer, W. O., Leeming, F. C., Cobern, M. K., Porter, B. E., & Jackson, J. M. (1993). Critical Review of Behavioral Interventions to Preserve the Environment: Research Since 1980. *Environment and Behavior*, *25*(3), 275–321.

Geller, E. S. (1981). Evaluating Energy Conservation Programs: Is Verbal Report Enough? *Journal of Consumer Research*, *8*(December), 331–335.

Geller, E. S. (1995). Actively Caring for the Environment: An Integration of Behaviorism and Humanism. *Environment and Behaviorr*, *27*(2), 184–195.

Maniccia, D., Rutledge, B., & al., et. (1998). Occupant use of manual lighting controls in private offices (p. 489). New York: Illuminating Engineering Society of North America.

Mathews, B. A., Shimoff, E., Catania, A. C., & Sagvolden, T. (1977). Uninstructed Human Responding: Sensitivity to Ratio and Interval Contingencies. *Journal of the Experimental Analysis of Behavior*, *3*(3), 453–467.

Rea, M. S., Dillon, R. F., & Levy, A. W. (1987). The effectiveness of light switch reminders in reducing light usage. *Lighting Research & Technology*, *19*(3), 81.

Saari, L. M., & Latham, G. P. (1982). Employee Reactions to Continuous and Variable Ratio Reinforcement Schedules Involving a Monetary Incentive. *Journal of Applied Psychology*, *67*(4), 506–508.

Skinner, B. F. (1938). *The Behavior of Organisms* (p. 473). Cambridge MA: Copley Publishing Group.

Winett, R. A., Kagel, J. H., Battalio, R. C., & Winkler, R. C. (1978). Effects of Monetary Rebates, Feedback, and Information on Residential Electricity Conservation. *Journal of Applied Psychology*, *63*(1), 73–80. doi:10.1037//0021-9010.63.1.73

Winett, R. A., Leckliter, I. N., Chinn, D. E., Stahl, B., & Love, S. Q. (1985). Effects of Television Modeling on Residential Energy Conservation. *Journal of Applied Behavior Analysis*, *18*(1), 33–44.

Winett, R. A., & Neale, M. S. (1979). Psychological framework for energy conservation in buildings: Strategies, outcomes, directions. *Energy and Buildings*, *2*(2), 101–116. doi:10.1016/0378-7788(79)90026-4

Winkler, R. C., & Winett, R. A. (1982). Behavioral Interventions in Resource Conservation A Systems Approach Based on Behavioral Economics. *American Psychologist*, *37*(April), 421–435.

Appendix: Literature summary

Below is a list of research papers and conference presentations on the topic of using dynamic message displays to encourage energy savings.

Arnot, L., Smith, B., & Seelig, M. (2013). PG&E Residential Smart Thermostat Trial. In Behavior Energy and Climate Conference. Sacramento, CA. Retrieved from http://beccconference.org/becc-presentations-2013/

Pacific Gas and Electric (PG&E) conducted a field trial involving the installation of "smart" thermostats. The trial included 1,388 households. In the non-control houses, PG&E installed Honeywell thermostats that interfaced with an Opower web portal and smart phone control app that had push messaging capability. The messaging was available only through the web and smart phone, not at the thermostat. PG&E found a statistically significant 2.4% reduction in electricity use. The reduction in natural gas use was not statistically significant.

Arroyo, E., Bonanni, L., & Selker, T. (2005). Waterbot: Exploring Feedback and Persuasive Techniques at the Sink. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 631–639). Portland OR: Association for Computing Machinery. Retrieved from http://dl.acm.org/citation.cfm?id=1054972&picked=prox&CFID=236928816&CFTOKEN=16364158

The authors describe a series of experiments that explored methods of water conservation at sinks. From the abstract: "This paper presents an exploration of user interfaces, persuasive interfaces and feedback techniques in the domain of the sink. Waterbot is a system to inform and motivate behavior at the sink for the purpose of increasing safety and functionality and ultimately motivating behavior change." The passage from this paper that is most relevant to the LRC's dynamic message project is: "While constant reinforcers should be presented at the beginning stages of behavioral modification, once a behavior is established, they can become less effective and potentially annoying. In 'variable interval reinforcement' the reinforcers occur at intervals that cannot be readily predicted by users in order to be less annoying and more effective. Variable schedules of reinforcement are effective at producing behavior change that remains consistent. Because water is often used in intimate contexts, it is especially important to vary feedback modalities so that interaction does not become annoying or invasive." Quantitative results of the variable feedback are not provided.

Darby, S. (2006). The Effectiveness Of Feedback On Energy Consumption: A Review For Defra Of The Literature On Metering, Billing And Direct Displays. Oxford. Retrieved from http://www.eci.ox.ac.uk/research/energy/downloads/smart-metering-report.pdf

The author conducted a literature view on the topic of providing feedback about energy use and energy prices. The paper includes section titled "Direct displays on monitors separate from the meter," which is the most applicable to the LRC's dynamic message project. Findings within that section include: “Direct displays are a supplement to the meter. Almost all show electricity consumption, though there is one recorded trial of a display that showed the previous day’s gas consumption in relation to a weather-adjusted target, producing savings of 10% against controls…. Over half of those interviewed during the trial said that they would like to have such a display permanently.”

Frantz C. et al (2010). How Do Context & Form of Real-Time Feedback on Resource Use Affect Consumer Response? Behavior, Energy, and Climate Change Conference, November 14, 2010. Retrieved from http://www.stanford.edu/group/peec/cgi-bin/docs/events/2010/becc/presentations/2C_CindyFrantz.pdf

The authors reported on three experiments on providing feedback to reduce energy use: presenting contextualizing photographs of nature, using animated empathic gauges, and providing feedback on energy use via glowing orbs. Of these, the orbs lead to resource use reduction. Dormitory areas at Oberlin College “with orbs reduced electricity while those [without] orbs increased electricity, $F (2, 20) = 5.38$, $p < .05$” According to an Oberlin press release (http://www.oberlin.edu/news-info/08apr/energyorbs.html) “[W]hen a dorm is consuming half its normal electricity use, the orb glows green. It shifts to yellow when consumption reaches a typical rate, and then bright red when electricity use doubles.”

Geller, E. S. (1995). Actively Caring for the Environment: An Integration of Behaviorism and Humanism. Environment and Behavior, 27(2), 184–195.

Behavior analysts follow an activator-behavior-consequence (ABC) approach also called a "three-term contingency." The process of intervention follows "DO RITE":

D- define the target behavior to change

O- observe the target behavior to obtain a baseline

R- record the results until there is a stable baseline

I- intervene to change the behavior

T- test the impact of the intervention

E- evaluate whether it was cost effective

Environmentally-related behavior changes can require a one-time action (e.g. buying energy efficient equipment) or ongoing action (e.g. collecting recyclables).

“Activators” are environmental manipulations. Forms include verbal or written messages, awareness/ education sessions, modeling or demonstration, goal-setting and commitment techniques (e.g. pledging to emit a particular behavior by signing a promise card), and engineering and design techniques.

It is intuitive to believe that attitude change is necessary for behavior change. However, Skinner maintained that human behavior is determined by its consequences, and is not strongly influenced by activators. Research on behavior for environmental protection has backed up Skinner. Activators alone are effective only when the target behavior is relatively convenient and the activator is polite, response specific, and occurs in close proximity to opportunities for the target behavior to occur.

Consequences for environmental protection can be events (e.g. monetary rebates, verbal commendations, energy efficient honor roll), opportunities for behaviors (e.g. preferred parking space), removal of negative consequences, penalties, rewards, and feedback displays.

The author proposes a classification system to find the most effective intervention based on how motivated the person is. The author proposes an actively-caring model. The model holds that empowerment varies directly with perceptions of personal control, self-efficacy, and optimism. Perceptions of empowerment can be increased by breaking down overwhelming tasks, setting short-term goals and tracking them, offering frequent rewards, subjects setting their own goals, and teaching the DO RITE process.

Luyben, P. D. (1980). Effects of Informational Prompts On Energy Conservation In College Classrooms. *Journal of Applied Behavior Analysis*, *13*(4 (Winter 1980)), 611–617.

The author studied the effect of written reminders to turn off lights in college classrooms. Fifty-five classrooms were observed for 14 weeks. These were randomly split into two groups. The observation period of the first group, comprising 28 classrooms, was divided into three periods. For the first 5 weeks, baseline conditions were observed. After the fifth week, a letter was sent to the professors that taught in those classrooms asking that they turn out the lights when exiting. In the 11^{th} week, an 11cm x 14 cm poster was hung by the light switch. “The poster urged classroom users to turn out lights after *specified* class periods.” (Italics in the original.) This is an example of specific directions being given with signage. When just the letter was sent (before the poster was hung), the fraction of time that the lights were appropriately turned off rose from a mean of 67% during the baseline to 80%. When the poster was put up, the mean time that the lights were turned off rose further to 84%.

Mathews, B. A., Shimoff, E., Catania, A. C., & Sagvolden, T. (1977). Uninstructed Human Responding: Sensitivity to Ratio and Interval Contingencies. Journal of the Experimental Analysis of Behavior, 3(3), 453–467.

Earlier work by B.F. Skinner on variable schedule feedback had been conducted with rats and pigeons as subjects. This study found the same effects in humans. From the paper: "When procedures are equated for humans and for pigeons, by eliminating the special effects of instructions on human behavior and by requiring a consummatory response, humans behave much like pigeons." This study showed that Skinner’s work on variable feedback is applicable to humans.

Rea, M. S., Dillon, R. F., & Levy, A. W. (1987). The effectiveness of light switch reminders in reducing light usage. Lighting Research & Technology, 19(3), 81.

This study investigated energy savings from applying switch plate stickers in offices to remind occupants to turn off lights. The abstract of this paper summarizes the findings: “A carefully controlled field study has shown that reminder stickers attached to light switch plates reduce lighting energy consumption in private offices. The magnitude of the energy savings is large enough for the switch stickers to be cost effective in 10 weeks or less. A questionnaire administered at the end of the study showed that people were generally receptive to the switch stickers as reminders for saving energy.”

The energy reduction results were presented as follows: “Light usage was reduced significantly in private offices after reminder stickers were attached to light switch plates…, but perhaps surprisingly, the labels did not have to be introduced into all offices to achieve such reductions. Offices with and without switch stickers reduced light usage by approximately 15% in relation to initial test periods without switch stickers. Since offices with and without labels were intermixed, occupants encountered labels throughout the building and very likely discussed them with their colleagues. It is not known whether saturating all offices with labels would have had a greater (or lesser) effect on light usage. Further, there are no data to ascertain whether this reduction in light usage would have remained indefinitely. Although it is possible that another, unknown variable contributed to the reduction in light usage in this study, it seems most likely that reminder stickers in private offices can lead to reduction in light usage.”

In this study, the message used on the switch plate stickers said “Turn me off.”

Saari, L. M., & Latham, G. P. (1982). Employee Reactions to Continuous and Variable Ratio Reinforcement Schedules Involving a Monetary Incentive. Journal of Applied Psychology, 67(4), 506–508.

The authors studied the effectiveness of variable reinforcement schedules on humans. From the paper’s abstract: “Employee performance and reactions to a monetary incentive administered on continuous and variable ratio four (VR-4) schedules of reinforcement were examined…. The results of the questionnaire indicated that the VR-4 schedule was perceived as including job enrichment variables such as recognition, task variety, task accomplishment, and feedback whereas this was less likely to be the case when the incentive was paid on a continuous schedule.” This paper indicates the effectiveness of varying how frequently feedback is given, and this technique will be implemented in the LRC’s dynamic messaging project.

Winett, R. A. (1977-78). Prompting Turning-Out Lights in Unoccupied Rooms. *Journal of Environmental Systems*, *7*(3), 237–241.

The author studied the effect of written reminders to turn off lights in college classrooms. In this experiment, three classrooms were monitored daily for six weeks. Two of the rooms were unmodified and considered the baseline. The third room was unmodified during the first two weeks for comparison purposes, and then various prompts were used to encourage turning out the lights when not in use in weeks three through six. During weeks three and four, general messages were provided near the light switch of the classroom, such as "Please turn lights and electrical equipment off when not in use" and "Turn this light off when not in use." These measures were found to be ineffective. During the fifth week, a more specific message was provided on a 2' x 3' sign that was directed at particular categories of people that used the room: "Students and Faculty, Conserve Energy, Turn Out Lights After 5:00 PM or When No Class." This was found to be effective and the percent of days when the experimenters found the lights in this classroom were left on was reduced from 80% or 100% during base case conditions to 40% when this measure was implemented. This experiment shows the importance of using targeted messages with specific directions, which will be used in the LRC's dynamic message project.

Winett, R. A., & Neale, M. S. (1979). Psychological framework for energy conservation in buildings: Strategies, outcomes, directions. Energy and Buildings, 2(2), 101–116. doi:10.1016/0378-7788(79)90026-4

The authors reviewed literature about demonstrating the application of psychologically based procedures to conserve energy in buildings. The following passage was on the topic of conserving energy with lighting: "Virtually all feedback and rebate techniques have also incorporated prompting (an antecedent event), here more loosely defined as 'messages' to promote conservation behaviors. The environmental-prompting literature [42] indicates that prompts are inexpensive, relatively simple to deliver, but transient in effect, and only effective with a limited (15%) segment of persons. However, this same literature demonstrates that prompts may be made more effective if their information is specific ("Turn out the light", not "Conserve energy"), and if prompts are perceptible at the time and point of potential action. When the location and timing of prompts is optimized, then such prompts also have a built-in feedback-reinforcement capability [43], that is, the response follows the prompt and successfully completes the requested behavior. After 1973 - 74, we all saw many signs in different buildings urging us to conserve energy. The brief review of prompts suggests that such signs were probably ineffective, but more specific signs may promote conservation behaviors. In one pilot effort [44], university-produced signs urging persons to conserve energy were placed in rooms in which lights were frequently left on, even though the rooms were unoccupied. The sign was placed above a light switch, and then a small sticker that also urged the saving of energy was placed on the light switch. These conventional prompts had no effect; the lights were always left on (100% of observation days) when the rooms were unoccupied. In the next phase of the study, larger signs with specific information (when and who should turn out the lights) were placed near the exit points of the room. Now the lights were left on for only 40% of the observation days." The discussion at the end of this passage refers to the Winett 1977-78 study discussed above.

Appendix: Messages displayed on dynamic message device

The name of each occupant was programmed into the dynamic message device in his or her office. Where "name" appears below, the occupants first name appeared. The message identifiers "P1, P2, …, F1, F2…" and the delay-time indicators did not appear on the display.

Prompts: Occupancy-related

P1

Name,

Please turn off your

lights every time

you leave.

P2

Name,

Please do your part.

Turn off the lights

before you leave.

P3

Name,

Please, don't waste

energy--turn off

your lights!

P4

Please turn off

the lights.

P5

Name,

Thanks for turning

off your lights when

leaving your office!

P6

Name,

Turning off lights

before you leave

prevents pollution.

P7

Name,

Do it for our kids!

Please

turn off the lights.

P8

Name,

We can help prevent

climate change by

turning off lights.

P9

Name,

It just takes a sec

to turn off

your lights!

P10

(Boss' name)

asks you to

turn off the lights

before you leave!

P11

Name,

Turn off your lights

even if you'll be

gone just a minute.

Prompts: Daylighting-related

P12

Name,

Got daylight? Please

turn off the lights.

P13

Name,

Please, only use

your lights when

you need them. ☺

P14

Name,

Please use your

task light instead

of overhead lights.

Prompts: Facts

P15

Lighting uses 26% of

electricity in our

building. Please

turn off the lights!

Prompts: Jokes

P16

How many consultants

does it take to

change a light bulb?

[3 second delay]

I'll have an

estimate for you

in a week.

P17

How many

professors

does it take to

change a light bulb?

[3 second delay]

None. That's what

grad students

are for.

P18

How many

economists

does it take to

change a light bulb?

[3 second delay]

None. Just assume

it's changed.

P19

How many

actors

does it take to

change a light bulb?

[3 second delay]

Only one. They

don't like sharing

the spotlight.

P20

How many

bacteria

does it take to

change a light bulb?

[3 second delay]

one.

[1 second delay]

No, 2.

[1 second delay]

No, 4.

[1 second delay]

No, 8.

[1 second delay]

No, 16.

[1 second delay]

No, 32.

[1 second delay]

No, 64.

[1 second delay]

No, 128.

Feedback Messages

F1

Name,

Thank you

for turning off

your lights!

F2

Name,

Thanks for

doing your part!

F3

Name,

GREAT JOB

with the lights!

F4

Name,

THANKS!

F5

Name,

Thanks for

preventing

pollution.

F6

Name,

Thanks for

saving energy.

Appendix: Microcontroller program

The following program was loaded onto the Arduino-compatible microcontroller of each dynamic message device. The program was modified for each office; in the line "String occupantName="Name"; //First name of office occupant," the first name of the office occupant was programmed in place of "Name."

```
//****NOTES****

// This Arduino code is for the wall unit of the LRC's NYSERDA Behavior Project

// Last update date is in the file name.

// Created by Jeremy Snyder

// Don't stand in front of wall unit when connecting power to allow range finder callibration. From MaxSonar LV-EZ0 instructions: "Each time the LV-MaxSonar-EZ is powered up, it will calibrate during its first read cycle. The sensor uses this stored information to range a close object. It is important that objects not be close to the sensor during this calibration cycle. The best sensitivity is obtained when the detection area is clear for fourteen inches, but good results are common when clear for at least seven inches. If an object is too close during the calibration cycle, the sensor may ignore objects at that distance."

// MaxSonar LV-EZ0 Range data can be acquired once every 49mS.

// Hardware includes:

//  LCD screen

//  range finder

//  Bluetooth receiver from photosensor


//****INCLUDE LIBRARIES*****

#include <LiquidCrystal.h>;

#include <elapsedMillis.h>  //http://playground.arduino.cc/Code/ElapsedMillis#intro

#include <LowPower.h>
//http://www.rocketscream.com/blog/2011/07/04/lightweight-low-power-arduino-library/


//****GLOBAL CONSTANTS AND PARAMETERS*****

String occupantName="Name"; //First name of office occupant
```

```
String bossName="Chancellor Zimpher"; //name of occupant's boss

int distanceToTurnOn = 58; // Inches. 44" for JDS office with desk in usual place.
When occupant is within this distance to wall, LCD backlight turns on.

unsigned int displayTime= 10; //time to leave message on screen in seconds

int LCDBackLightPin=13; //output pin to mosfet that controls the LCD's backlight

int photoSensorPin=9; // input pin from blue tooth receiver that indicates
photosensor. High= lights on.

int rangeFinderScaleFactor = 147; //uS per inch. For pulse width representation of
range

int rangeFinderPWPin= 6;// input pin from range finder for Pulse readings. Connects
to pin 2 on range finder.

int rangeFinderAnalogPin=A7;//input pin from range finder for analog readings.
Connects to pin 3 on range finder.

int rangeFinderControlPin=1; //output pin to range finder. High=on, low=off  "This
pin is internally pulled high. The LV-MaxSonar-EZ will continually measure range and
output if RX data is left unconnected or held high. If held low the sensor will stop
ranging. Bring high for 20uS or more to command a range reading."




LiquidCrystal lcd(12,11,5,4,3,2);



//****GLOBAL VARIABLES*****

boolean currentStateOfLights=LOW; //HIGH means lights are off, LOW means lights
are on.

int currentRange= 61;//inches

int rangeLast=61;

int rangeLast2nd=61;

int rangeLast3rd=61;

int rangeLast4th=61;
```

```
//****SETUP FUNCTION****   // put your setup code here, to run once:

void setup() {

Serial.begin(9600); //set baud rate. See http://www.maxbotix.com/articles/085-
pt3.htm#coding

pinMode(rangeFinderAnalogPin, INPUT); //range finder analog

pinMode(rangeFinderPWPin, INPUT); //range finder analog

pinMode(photoSensorPin, INPUT);

pinMode(LCDBackLightPin, OUTPUT);

pinMode(rangeFinderControlPin, OUTPUT);

digitalWrite(rangeFinderControlPin, LOW);

lcd.begin(20,4); //initialize LCD


//Set pins not being used to output at LOW

pinMode(0, OUTPUT);

digitalWrite(0, LOW);

pinMode(7, OUTPUT);

digitalWrite(7, LOW);

pinMode(8, OUTPUT);

digitalWrite(8, LOW);

pinMode(10, OUTPUT);

digitalWrite(10, LOW);

pinMode(A0, OUTPUT);

digitalWrite(A0, LOW);

pinMode(A1, OUTPUT);

digitalWrite(A1, LOW);

pinMode(A2, OUTPUT);

digitalWrite(A2, LOW);
```

```
pinMode(A3, OUTPUT);
digitalWrite(A3, LOW);
pinMode(A4, OUTPUT);
digitalWrite(A4, LOW);
pinMode(A5, OUTPUT);
digitalWrite(A5, LOW);
pinMode(A6, OUTPUT);
digitalWrite(A6, LOW);
pinMode(rangeFinderAnalogPin, OUTPUT);
digitalWrite(rangeFinderAnalogPin, LOW);

byte smiley[8] = {  //This code creates the smiley face emoji
  B00000,
  B10001,
  B00000,
  B00000,
  B10001,
  B01110,
  B00000,
  };
  lcd.createChar(0, smiley);

}

//****LOOP FUNCTION****    // put your main code here, to run repeatedly:
void loop() {
```

```
  LowPower.powerDown(SLEEP_120MS, ADC_OFF, BOD_OFF);


  currentStateOfLights=digitalRead(photoSensorPin);

    if(currentStateOfLights==LOW){ //if the lights are on

      digitalWrite(rangeFinderControlPin, HIGH); //turns range finder on

        currentRange=readRangeFinderPWM();

        if (occupantApproaching(currentRange)){

         printPromptToScreen();

        }

    }

    if(currentStateOfLights==LOW){

      digitalWrite(rangeFinderControlPin, LOW); //turns range finder off

    }


}




//****Is the Occupant Approaching?*****


bool occupantApproaching(int currentRange){

  bool approaching=false;

  if (currentRange < rangeLast && rangeLast < rangeLast2nd &&
rangeLast2nd<rangeLast3rd && rangeLast<distanceToTurnOn &&
rangeLast2nd<distanceToTurnOn){

    approaching=true;

   }

  else{

    approaching=false;
```

```
  }
  rangeLast4th=rangeLast3rd;
  rangeLast3rd=rangeLast2nd;
  rangeLast2nd=rangeLast;
  rangeLast=currentRange;
  return(approaching);
}


//****READ RANGE FINDER PWM****
int readRangeFinderPWM(){
  float currentRange=0;
  float pulseWidth=0;
    pulseWidth = pulseIn(rangeFinderPWPin, HIGH);
  currentRange=pulseWidth/rangeFinderScaleFactor;
  return round(currentRange);
}



//****PRINT PROMPT ON SCREEN****
void printPromptToScreen(){
    elapsedMillis timeElapsed; //elapsed time since entering this function
    int messageNumber=0;
    digitalWrite(LCDBackLightPin, HIGH);   // sets the LCD backlight on
    lcd.setCursor(0,0);
    messageNumber=random(100);
```

```
// Instructions- Occupancy

//P1
if (messageNumber>0 && messageNumber <=5){
  lcd.print(occupantName);
  lcd.print(",");
  lcd.setCursor(0,1);
  lcd.print("Please turn off your");
  lcd.setCursor(0,2);
  lcd.print("lights every time");
  lcd.setCursor(0,3);
  lcd.print("you leave.");
}

//P2
if (messageNumber>5 && messageNumber <=10){
  lcd.print(occupantName);
  lcd.print(",");
  lcd.setCursor(0,1);
  lcd.print("Please do your part.");
  lcd.setCursor(0,2);
  lcd.print("Turn off the lights");
  lcd.setCursor(0,3);
  lcd.print("before you leave.");
}
```

```
  //P3
   if (messageNumber>10 && messageNumber <=15){
     lcd.print(occupantName);
     lcd.print(",");
     lcd.setCursor(0,1);
     lcd.print("Please, don't waste");
     lcd.setCursor(0,2);
     lcd.print("energy-- turn off");
     lcd.setCursor(0,3);
     lcd.print("your lights!");
  }

//P4
   if (messageNumber>15 && messageNumber <=20){


     lcd.setCursor(0,1);
     lcd.print("Please turn off");
     lcd.setCursor(0,2);
     lcd.print("the lights.");
  }

//P5
   if (messageNumber>20 && messageNumber <=25){
     lcd.print(occupantName);
     lcd.print(",");
     lcd.setCursor(0,1);
     lcd.print("Thanks for turning");
```

```
    lcd.setCursor(0,2);

    lcd.print("off your lights when");

    lcd.setCursor(0,3);

    lcd.print("leaving your office!");

  }


//P6

   if (messageNumber>25 && messageNumber <=30){

   lcd.print(occupantName);

    lcd.print(",");

    lcd.setCursor(0,1);

    lcd.print("Turning off lights");

    lcd.setCursor(0,2);

    lcd.print("before you leave");

    lcd.setCursor(0,3);

    lcd.print("prevents pollution.");

  }


//P7

   if (messageNumber>30 && messageNumber <=35){

   lcd.print(occupantName);

    lcd.print(",");

    lcd.setCursor(0,1);

    lcd.print("Do it for our kids!");

    lcd.setCursor(0,2);

    lcd.print("     Please");

    lcd.setCursor(0,3);
```

```
    lcd.print("Turn off the lights.");
  }

//P8
  if (messageNumber>35 && messageNumber <=40){
    lcd.print(occupantName);
    lcd.print(",");
    lcd.setCursor(0,1);
    lcd.print("We can help prevent");
    lcd.setCursor(0,2);
    lcd.print("climate change by");
    lcd.setCursor(0,3);
    lcd.print("turning off lights.");
  }

//P9
  if (messageNumber>40 && messageNumber <=45){
    lcd.print(occupantName);
    lcd.print(",");
    lcd.setCursor(0,1);
    lcd.print("It just takes a sec");
    lcd.setCursor(0,2);
    lcd.print("to turn off");
    lcd.setCursor(0,3);
    lcd.print("your lights!");


  }
```

```
//P10
  if (messageNumber>45 && messageNumber <=50){
    lcd.print(bossName);
    lcd.setCursor(0,1);
    lcd.print("asks you to");
    lcd.setCursor(0,2);
    lcd.print("turn off the lights");
    lcd.setCursor(0,3);
    lcd.print("before you leave!");
  }


//P11
  if (messageNumber>95 && messageNumber <=99){
    lcd.print(occupantName);
    lcd.print(",");
    lcd.setCursor(0,1);
    lcd.print("Turn off your lights");
    lcd.setCursor(0,2);
    lcd.print("Even if you'll be");
    lcd.setCursor(0,3);
    lcd.print("gone just a minute.");
  }
```

```
 // Instructions- Daylighting
//P12
  if (messageNumber>50 && messageNumber <=55){
    lcd.print(occupantName);
    lcd.print(",");
    lcd.setCursor(0,1);
    lcd.print("Got daylight? Please");
    lcd.setCursor(0,2);
    lcd.print("turn off the lights.");
 }

//P13
  if (messageNumber>55 && messageNumber <=60){
    lcd.print(occupantName);
    lcd.print(",");
    lcd.setCursor(0,1);
    lcd.print("Please only use");
    lcd.setCursor(0,2);
    lcd.print("your lights when");
    lcd.setCursor(0,3);
    lcd.print("you need them. ");
    lcd.write(byte(0));
 }

//P14
  if (messageNumber>60 && messageNumber <=65){
    lcd.print(occupantName);
```

```
    lcd.print(",");

    lcd.setCursor(0,1);

    lcd.print("Please use your");

    lcd.setCursor(0,2);

    lcd.print("task light instead");

    lcd.setCursor(0,3);

    lcd.print("of overhead lights.");

  }


  //Facts


//P15

   if (messageNumber>65 && messageNumber <=70){

    lcd.print("Lighting uses 26% of");

    lcd.setCursor(0,1);

    lcd.print("electricity in our");

    lcd.setCursor(0,2);

    lcd.print("building. Please");

    lcd.setCursor(0,3);

    lcd.print("turn off the lights!");

  }


  //P16

  // Jokes

  if (messageNumber>70 && messageNumber <=75){

    lcd.print("      How many");

    lcd.setCursor(0,1);
```

```
      lcd.print("     consultants");
      lcd.setCursor(0,2);
      lcd.print("does it take to");
      lcd.setCursor(0,3);
      lcd.print("change a light bulb?");
      delay(3000);
      lcd.clear();
      lcd.setCursor(0,0);
      lcd.print("I'll have an");
      lcd.setCursor(0,1);
      lcd.print("estimate for you");
      lcd.setCursor(0,2);
      lcd.print("in a week.");
    }

//P17
    if (messageNumber>75 && messageNumber <=80){
      lcd.print("      How many");
      lcd.setCursor(0,1);
      lcd.print("     professors");
      lcd.setCursor(0,2);
      lcd.print("does it take to");
      lcd.setCursor(0,3);
      lcd.print("change a light bulb?");
      delay(3000);
      lcd.clear();
      lcd.setCursor(0,0);
```

```
    lcd.print("None. ");
    lcd.setCursor(0,1);
    lcd.print("That's what");
    lcd.setCursor(0,2);
    lcd.print("grad students");
    lcd.setCursor(0,3);
    lcd.print("are for.");
  }
//P18
  if (messageNumber>80 && messageNumber <=85){
    lcd.print("     How many");
    lcd.setCursor(0,1);
    lcd.print("    economists");
    lcd.setCursor(0,2);
    lcd.print("does it take to");
    lcd.setCursor(0,3);
    lcd.print("change a light bulb?");
    delay(3000);
    lcd.clear();
    lcd.setCursor(0,0);
    lcd.print("None. Just assume");
    lcd.setCursor(0,1);
    lcd.print("it's changed.");
  }

//P19
  if (messageNumber>85 && messageNumber <=90){
```

```
    lcd.print("      How many");
    lcd.setCursor(0,1);
    lcd.print("       actors");
    lcd.setCursor(0,2);
    lcd.print("does it take to");
    lcd.setCursor(0,3);
    lcd.print("change a light bulb?");
    delay(3000);
    lcd.clear();
    lcd.setCursor(0,0);
    lcd.print("Only one. They");
    lcd.setCursor(0,1);
    lcd.print("don't like sharing");
    lcd.setCursor(0,2);
    lcd.print("the spotlight.");
  }

//P20
  if (messageNumber>90 && messageNumber <=95){
    lcd.print("      How many");
    lcd.setCursor(0,1);
    lcd.print("     bacteria");
    lcd.setCursor(0,2);
    lcd.print("does it take to");
    lcd.setCursor(0,3);
    lcd.print("change a light bulb?");
    delay(3000);
```

```
lcd.clear();
lcd.setCursor(0,1);
lcd.print("   One");
delay(1000);
lcd.clear();
lcd.setCursor(0,1);
lcd.print("   No, 2.");
delay(1000);
lcd.clear();
lcd.setCursor(0,1);
lcd.print("   No, 4.");
delay(1000);
lcd.clear();
lcd.setCursor(0,1);
lcd.print("   No, 8.");
delay(1000);
lcd.clear();
lcd.setCursor(0,1);
lcd.print("   No, 16.");
delay(1000);
lcd.clear();
lcd.setCursor(0,1);
lcd.print("   No, 32.");
delay(1000);
lcd.clear();
lcd.setCursor(0,1);
lcd.print("   No, 64.");
```

```
      delay(1000);
      lcd.clear();
      lcd.setCursor(0,1);
      lcd.print("   No, 128.");
    }

     while (timeElapsed <displayTime*1000) {
       currentStateOfLights=digitalRead(photoSensorPin);
       if(currentStateOfLights==HIGH){
        printFeedbackToScreen();
      }
  }

    digitalWrite(LCDBackLightPin, LOW);   // sets the LCD backlight off
    lcd.clear();
}

//****PRINT FEEDBACK ON SCREEN****
void printFeedbackToScreen(){
    int messageNumber=0;
    lcd.clear();
    digitalWrite(LCDBackLightPin, HIGH);   // sets the LCD backlight on
    lcd.setCursor(0,0);
    messageNumber=random(150);



    //F1
```

```
 if (messageNumber>0 && messageNumber <=16){
  lcd.print(occupantName);
  lcd.print(",");
  lcd.setCursor(0,1);
  lcd.print("Thank you");
  lcd.setCursor(0,2);
  lcd.print("for turning off");
  lcd.setCursor(0,3);
  lcd.print("your lights!");
}

//F2
  if (messageNumber>16 && messageNumber <=32){
  lcd.print(occupantName);
  lcd.print(",");
  lcd.setCursor(0,1);
  lcd.print("Thanks for");
  lcd.setCursor(0,2);
  lcd.print("doing your part!");
  }

//F3
  if (messageNumber>32 && messageNumber <=48){
  lcd.print(occupantName);
  lcd.print(",");
  lcd.setCursor(0,1);
  lcd.print("GREAT JOB");
```

```
  lcd.setCursor(0,2);
  lcd.print("with the lights!");
  }


//F4
 if (messageNumber>48 && messageNumber <=64){
  lcd.print(occupantName);
  lcd.print(",");
  lcd.setCursor(0,2);
  lcd.print("      THANKS!");
  }


//F5
  if (messageNumber>64 && messageNumber <=80){
  lcd.print(occupantName);
  lcd.print(",");
  lcd.setCursor(0,1);
  lcd.print("Thanks for");
  lcd.setCursor(0,2);
  lcd.print("preventing");
  lcd.setCursor(0,3);
  lcd.print("pollution.");
  }
```

```
      //F6
        if (messageNumber>80 && messageNumber <=99){
        lcd.print(occupantName);
        lcd.print(",");
        lcd.setCursor(0,1);
        lcd.print("Thanks for");
        lcd.setCursor(0,2);
        lcd.print("saving energy.");
        }


        //This is to not give feedback sometimes.
       if (messageNumber>99 && messageNumber <=150){
        digitalWrite(LCDBackLightPin, LOW);   // sets the LCD backlight off


        }


    delay(displayTime*1000);


}
```

Appendix: Power analysis used to determine number of offices to include in experiment

Before the experiment was conducted, the LRC performed statistical analysis on data from previous experiments to determine the anticipated number of samples needed in order to obtain statistically significant results in the LRC's dynamic message project. The results showed that the studies can be divided into two types of messages at the switch location: those that provided specific messages to occupants and those that provided general reminders.

The Rea et al 1987 study provided a general message at the switch plate ("Turn me off"), and observed a 15% effect with high variance within the data. The Winett 1977-78 study provided a general message during weeks three and four of the study ("Please turn lights and electrical equipment off when not in use" and "Turn this light off when not in use.") and observed no effect.

However, the Winett 1977-78 study in the fifth week changed to a specific message ("Students and Faculty, Conserve Energy, Turn Out Lights After 5:00 PM or When No Class."), and a 56% reduction was observed in the nights when lights were left on. In the Luyben 1980 study, a message was provided at the switch in classrooms in the 11th week of the study that "urged classroom users to turn out lights after specified class periods" (in addition to sending a letter to professors who taught in those rooms), and percentage of time when the lights were turned off rose from 67% during the baseline period to 84% when the message was provided (in addition to the letter), a 25% increase.

Because the dynamic message project will use specific messages on the displays, we believe it is most appropriate to use data from experiments where specific, rather than general, messages were provided at the switch location.

The equation used to calculate the number of samples used is provided in Experimental Psychology, Methods of Research: Fifth Edition by F.J. McGuigan in equation 6-6:

$$\text{Number of samples} = 2 * t^2 * s^2 / (X_1 - X_2)^2$$

where t=1.7 for a one-tail result, as in this case (i.e. the experimental effect is expected to make the outcome better, not either better or worse)

s= the standard deviation of the results

X_1= the mean of the results during the baseline condition

X_2= the mean of the results during the experimental condition

The first experiment used for this analysis was described in the article

Winett, R. A. (1977-78). The analysis considers only the fifth week, when targeted messages with specific directions were used. Results from this experiment are shown in Table 5.

Table 5: Percent days lights remained on in unoccupied rooms. Reproduced from Winett, R. A. (1977-78).

Room	Per cent days lights on					
	Weeks					
	1	2	3	4	5	6
1	60(B)	75(B)	80(B)	60(B)	80(B)	100(B)
2	100(B)	80(B)	75(B)	75(B)	75(B)	80(B)
3	100(B)	80(B)	100(S)	100(S+St)	40(P)	40(3P)

Note: B = Baseline or control conditions; S = University sign; St = University sticker; P = One Large, special sign; 3P = Three large, special signs.

Using the data from week 5:

Standard deviation, s= 54.8 (This is based on Room 3, week 5, and assumes that on 3 days the lights were off and on 2 days the lights were on in order to arrive at 40% average on-days for the week.)

Mean during baseline conditions, X_1=90%. (This is based on room three, with an average of 100% for week 1 and 80% for week 2.)

Mean during experimental conditions, X_2= 40% (During week 5.)

Sample size needed=7

The second experiment used for this analysis was described in the article

Luyben, P. D. (1980). Results from this experiment are shown in Figure 17

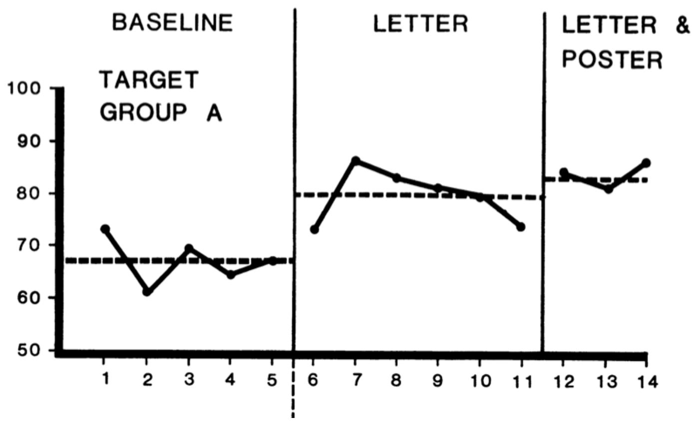


Figure 17: Percentage of target observations in which lights were turned off for group of classrooms that had the letter and poster intervention in weeks 12- 14. Reproduced from Luyben, P. D. (1980).

Standard deviation, s= 3.5

Mean during baseline conditions, X_1= 67 (Weeks 1 through 5)

Mean during experimental conditions, X_2= 84 (Weeks 12 through 14, when a specific message was provided at the switch location.)

Sample size needed=1

Based on the above results, the authors anticipated that 1 to 7 samples would be needed to produce statistically significant results if a change in wasted light occurred. The initial proposal from the LRC to NYSERDA called for 10 static and 10 dynamic message offices, but this was later revised to 20 of each.

Appendix: Orientation letter

The orientation letter below was given to each occupant at the start of the experiment.

The Lighting Research Center (LRC) at Rensselaer Polytechnic Institute is exploring new ways to improve energy efficiency.

In this study, you are being asked to participate in a demonstration and an evaluation of a messaging display located near a light switch ("switch messaging display"). The study will determine the lighting use patterns and building occupant acceptance of a switch messaging display.

Researchers from LRC will install battery-powered monitoring equipment in a light fixture in your office to measure usage patterns, before and after installation of the switch messaging display. Before the switch messaging display is installed, researchers will briefly visit to retrieve data, approximately once a week for four weeks. After the display is installed, researchers will again briefly visit approximately once a week for four weeks.

A short questionnaire will be administered prior to the installation of the switch messaging display. After installation of the display, a second questionnaire will be administered to ascertain your opinions of the display operation and acceptance.

Participation in this study is strictly voluntary. At any time and for any reason, you may withdraw from participation by notifying the researcher.

Note that the data collected in this research will be held strictly confidential, and will in no way be associated with any individual participant.

Thank you for your participation in this research!

If you have any questions please contact:
Jennifer Brons
Lighting Research Center
Rensselaer Polytechnic Institute
21 Union St, Troy, New York 12180
Telephone: 518-687-7100, Fax: 518-687-7120
bronsj@rpi.edu

Appendix: Survey questions

Baseline survey

(Before installation of messaging device)

SUNY System Administration is participating in a research collaboration with Lighting Research Center (LRC) at Rensselaer Polytechnic Institute in Troy, New York. To assist in this research, they request your anonymous feedback about switching the lights on and off in your office. Your participation is voluntary and uncompensated. The answers you provide will be aggregated with responses from your colleagues in other offices in your building. At the conclusion of the study a summary of the results will be presented to you and your colleagues. You may withdraw from participation at any time.

It is important to turn off the lights every time I leave my office.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

When there is enough daylight I turn my lights off.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

I would rather switch off the lights myself than have a sensor turn them off automatically.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Comments?

Thank you! - Lighting Research Center, Rensselaer Polytechnic Institute - www.lrc.rpi.edu

Follow up survey

(After removal of message device)

SUNY System Administration is participating in a research collaboration with Lighting Research Center (LRC) at Rensselaer Polytechnic Institute in Troy, New York. To assist in this research, they request your anonymous feedback about switching the lights on and off in your office. Your participation is voluntary and uncompensated. The answers you provide will be aggregated with responses from your colleagues in other offices in your building. At the conclusion of the study a summary of the results will be presented to you and your colleagues. You may withdraw from participation at any time.

It is important to turn off the lights every time I leave my office.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

When there is enough daylight, I turn my lights off.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

I would rather switch off the lights myself than have a sensor turn them off automatically.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

I usually read the message displayed on the switch message display before I leave my office.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

I usually read the feedback message on the switch message display after turning off my lights.

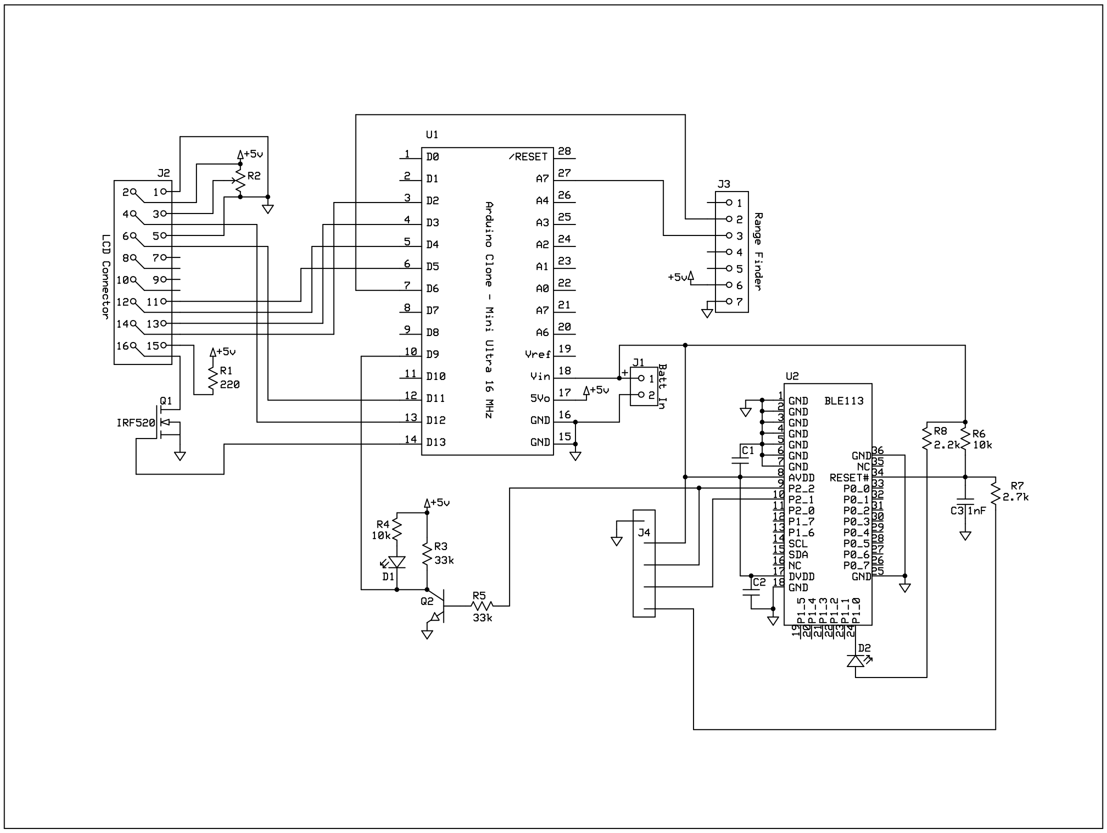
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Comments about the switch message display?

Thank you! - Lighting Research Center, Rensselaer Polytechnic Institute - www.lrc.rpi.edu

Appendix: Dynamic message device electronic schematic

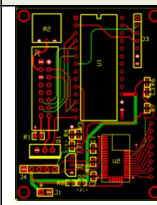
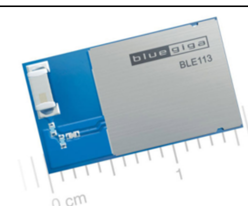
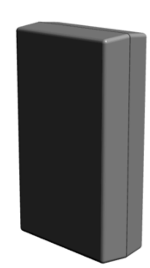
The components shown are the LCD display, the Arduino-compatible microcontroller, range finder, and Bluetooth wireless receiver.



Appendix: Device components

Dynamic message device components

Each dynamic message device was fabricated from the following components:

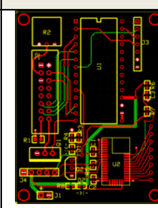
Component	Model	Description	Source	Cost per device	Image
Printed circuit board (PCB)	Custom designed and printed PCB	Custom designed and printed PCB.	https://www.expresspcb.com	$16	
LCD module	LCD 20x4	Displays white characters on a blue background, with a back light. Displays four lines of text, with 20 characters per line.	https://www.adafruit.com/products/198	$18	
Range finder	Maxbotix LV-MaxSonar-EZ0	Ultrasonic range finder that detects the distance of a person from the device.	https://www.sparkfun.com/products/8502	$30	
Microcontroller	Rocket Scream Mini Ultra 16 MHz	Arduino compatible microcontroller with low power demand.	http://www.rocketscream.com/blog/product/mini-ultra-16-mhz-arduino-compatible/	$14	
Bluetooth receiver	Bluegiga BLE113 Bluetooth Smart Module	Receives wireless signal from remote unit to determine when lights are on.	http://www.silabs.com/products/wireless/bluetooth/bluetooth-smart-modules/pages/ble113-bluetooth-smart-module.aspx	$13	
Case	Electronics Enclosure, 5-3/4" x 3-1/4" x 1-1/2", Black	Black plastic housing. Holes were cut into the case for the LCD display and the range finder.	http://www.mcmaster.com/#7593k28	$7	

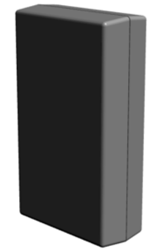
Battery holder	BC22AAL-ND Battery Holder	Holds 2 AA batteries each. Two holders are used in each message device.	http://www.digikey.com/product-search/en?keywords=bc22aal	$2 for two holders	
Batteries	Energizer industrial AA batteries	4 batteries were installed in each device. Replaced weekly.	http://www.digikey.com/product-detail/en/energizer-battery-company/EN91/N107-ND/704822	$3 for 4 batteries	
TOTAL material cost per unit				$87	

The electronic components were connected as shown in Appendix: Dynamic message device electronic schematic. Inside the device, a short wire was hot-glued next to the internal antenna as a signal booster, which improved the reliability of communication between the remote light sensor and the dynamic message device.

Static message device components

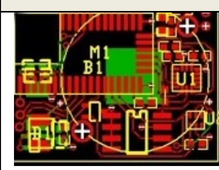
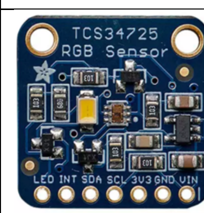
Each static message device was fabricated from the following components:

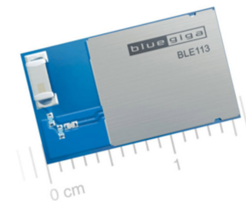
Component	Model	Description	Source	Cost per device	Image
Printed circuit board (PCB)	Custom designed and printed PCB	Custom designed and printed PCB.	https://www.expresspcb.com	$6	
LCD module	Newhaven Display NHD-C0220BiZ-FSW-FBW-3V3M	LCD display with 2 lines of 20 characters each. No backlight.	http://www.newhavendisplay.com/specs/NHD-C0220BiZ-FSW-FBW-3V3M.pdf	$11	
Micro-controller	Texas Instruments MSP430 USB Stick F2012 Board	Microcontroller.	http://www.ti.com/tool/ez430-t2012	$5	

Case	Electronics Enclosure, 5-3/4" x 3-1/4" x 1-1/2", Black	Black plastic housing. A hole was cut into the case for the LCD display.	http://www.mcmaster.com/#7593k28	$7	
Battery holder	BC12AAL-ND battery holder	Holds 2 AA batteries.	http://www.digikey.com/product-search/en?keywords=bc12aal	$1	
Batteries	Energizer industrial AA batteries	2 batteries were installed in each device. Batteries lasted for entire intervention period.	http://www.digikey.com/product-detail/en/energizer-battery-company/EN91/N107-ND/704822	$1 for 2	
TOTAL material cost per unit				$31	

Remote light sensing device components

Each remote sensing device was fabricated from the following components:

Component	Model	Description	Source	Cost per device	Image
Printed circuit board (PCB)	Custom designed and printed PCB	Custom designed and printed PCB.	https://www.expresspcb.com	$4	
Photosensor	Maxim Integrated MAX44006	RGB sensor.	https://datasheets.maximintegrated.com/en/ds/MAX44006-MAX44008.pdf	$5	

Bluetooth receiver	Bluegiga BLE113 Bluetooth Smart Module	Transmitted wireless signal from remote unit to dynamic message device to communicate when lights are on.	http://www.silabs.com/products/wireless/bluetooth/bluetooth-smart-modules/pages/ble113-bluetooth-smart-module.aspx	$13	
Battery holder	MPD SBH321AS	Holds 2 AA batteries.	http://www.digikey.com/product-detail/en/mpd-memory-protection-devices/SBH321AS/SBH321AS-ND/275301	$2	
Batteries	Energizer industrial AA batteries	2 batteries installed in each device.	http://www.digikey.com/product-detail/en/energizer-battery-company/EN91/N107-ND/704822	$1 for 2	
TOTAL material cost per unit				$25	