

The Role of Comparative Electricity Use Feedback at the Building Level in University Research Buildings

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Abstract

University research buildings are significant energy consumers in the United States. There is therefore a need to reduce energy use on the nation's campuses, not only cutting their carbon footprints but also saving money. Universities' efforts to reduce energy use include updating older facilities, implementing renewable energy systems, and encouraging energy saving behavior. This study evaluated the differential effects of two forms of feedback on electricity consumption in two groups of research buildings on a college campus to determine whether providing feedback to energy users has an impact on energy conservation behavior. A control group of buildings received no feedback regarding their electricity use. In the first study group of buildings, occupants received information about their electricity consumption with some electricity saving tips, distributed via email. The same procedure was followed with building occupants in the second study group, who received additional information showing their electricity consumption performance in comparison to other buildings within the study group. The baseline reading was conducted a week before the experiment began in August, 2012. Over the course of the five week study, the daily adjusted average reductions in electricity usage compared to the control group were less than 1 percent for both study groups, with study group 1 achieving an average reduction of 0.2 percent and study group 2 an average reduction of 0.8 percent. Although the reduction observed for study group 2 was 4 times greater than that for

study group 1, the saving was not continuous over the study period. Accordingly, the result was deemed to be not statistically significant and the effectiveness of comparative energy use feedback in university research buildings was not supported. However, even small savings in the energy used in university research buildings can be very important in terms of the total amount of energy saved because research buildings use significantly more energy than other buildings on campus such as academic buildings and residence blocks. This study concludes with a consideration of potentially fruitful directions for future research into developing new ways to reduce the energy consumption on university campuses.

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1. Introduction

Global climate change is a subject for much debate for the current generation. Greenhouse gas emissions are one of the main contributors to climate change, and electricity-related emissions account for more than 80 percent of the carbon dioxide, a major greenhouse gas, released into the atmosphere each year (EIA 2008). In the United States, buildings are one of the largest users of electricity and, consequently, emitters of greenhouse gases. According to the United States Environmental Protection Agency, buildings in the United States consume 39 percent of all the energy used and 68 percent of the electricity (EPA 2011). Electricity consumption is projected to continue to increase by 1.5 percent per year throughout the period from 2005 to 2030 (EIA 2006). Prompt action is therefore essential if we are to address the resulting increases in atmospheric carbon concentrations.

As part of this effort to reduce atmospheric carbon emissions, universities and colleges need to contribute by decreasing their energy usage and, hence, their carbon dioxide emissions. Education institutions in the United States spend almost \$14 billion annually on electricity (EPA 2007) and electricity consumption is responsible for the most significant environmental impact associated with campus operations (Simpson 2003). The amount of energy used on the nation's campuses continues to increase; at Harvard University, for example, electricity consumption increased by over 18 percent over a six year period (Sharp 2002). A typical 50,000-square foot higher education building in the northeastern United States spends more than \$200,000 on electricity each year (Hildebrand 2010). In a typical college or university, the largest consumers of electricity are lighting, ventilation and cooling, while space heating accounts for the vast majority of natural gas consumption (Figure 1).

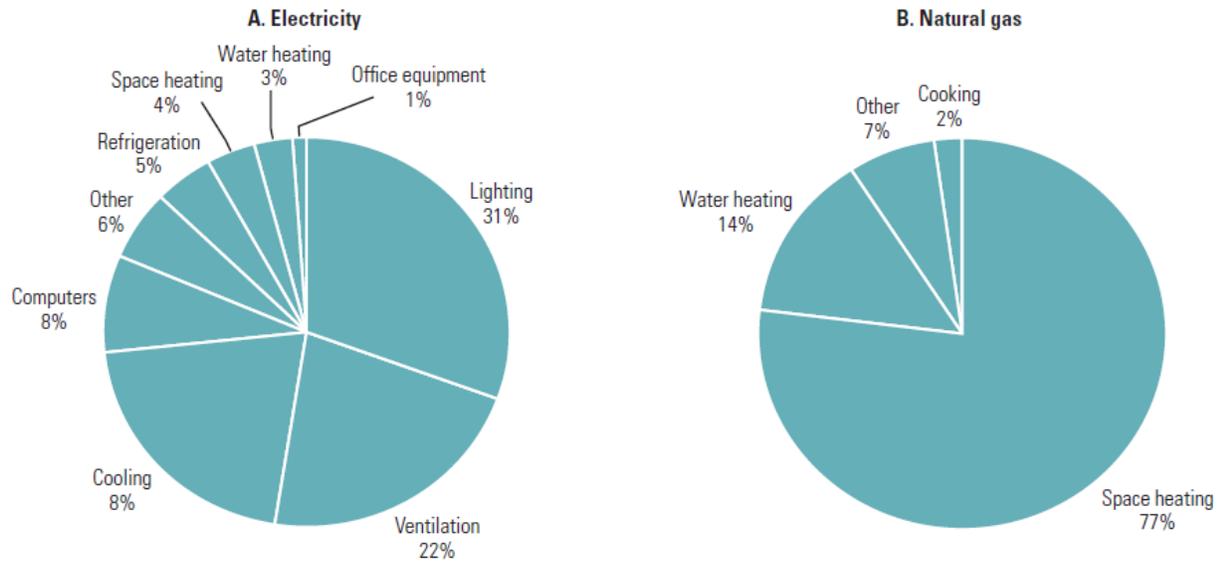


Figure 1: Electricity Consumption in U.S. Educational Facilities by End Use

Sourced from the E Source 2003; data from the U.S. Energy Information Administration

In general, research buildings are the most electricity intensive buildings on campuses, consuming many times more electricity per square foot than typical office buildings (EPA 2012). This is because all of the air that is cooled, filtered, heated, dehumidified and distributed in a lab building as a safety measure, which increases consumption. Academic and office buildings on campuses recirculate air, and exhaust a small amount of conditioned air, causing the system to operate 50 to 80 fewer hours per week than a lab building (Bardaglio 2011). According to the 2009 Virginia Tech (VT) climate action commitment and sustainability plan, the largest electricity consumers on Virginia Tech’s main campus in Blacksburg, Virginia, were research buildings. Figure 2 shows electricity consumption (kWh/ft²) according to VT building type in 2008. Considering environmental concerns and the high costs incurred for electricity use on campus, it is critical to understand why university electricity consumption continues to rise and identify ways to reduce electricity consumption on university campuses. This is particularly critical for research buildings, as they are the largest consumers of energy per square foot of any building type on campus.

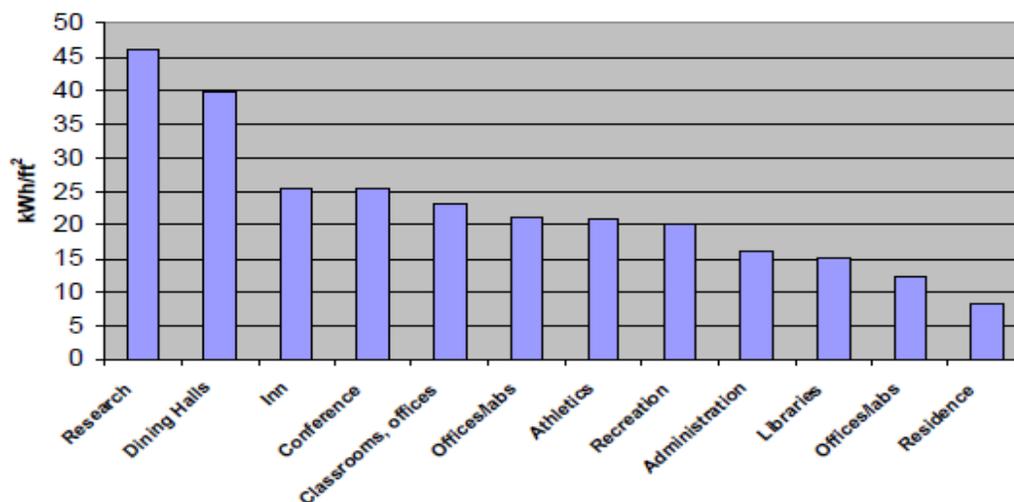


Figure 2: 2008 Virginia Tech Building Type and kWh/ft²

Sourced from 2009 Virginia Tech climate action commitment and sustainability plan

One reason for the high rate of electricity consumption on university and college campuses is that faculty, staff, and students are not directly responsible for paying the utility bills for the electricity they consume. This means that they receive no feedback on their electricity usage and therefore do not know how much they actually use. Kempton and Layne (1994) liken consuming electricity to shopping in a grocery store where no individual item has a price tag and the customer simply receives a monthly bill showing a cumulative price for “food consumption.” Likewise, since electricity users on campuses do not directly pay for their own electricity use they tend to use it without thinking about their consumption, which can lead to unnecessary waste. There is therefore a need for new strategies that raise awareness of electricity consumption for electricity users on campuses, particularly those working in the energy intensive research buildings.

Colleges and universities are beginning to recognize the importance of their roles as environmental leaders, and many are making efforts to contain utility costs and reduce their

greenhouse gas emissions. For example, the “*American College and University President's Climate Commitment*” (ACUPCC) was introduced in 2006, and 600 US colleges and university presidents have already signed on to support this pledge (Marans and Edelstein 2010). An increasing number of students are also turning their attention to persuading their universities to become more environmentally responsible in their campus operations. At the university level, efforts to conserve electricity have generally focused on activities such as updating older facilities, applying renewable electricity systems, and encouraging electricity-saving behavior.

Considering the tight facility budgets of many colleges and universities, it is important to identify low- or no-cost ways to reduce electricity expenditure. Electricity saving behavior is far and away the most cost effective way to reduce electricity. According to the U.S. Energy Information Administration, in a typical college or university lighting represents 31 percent of the electricity usage and computer and office equipment account for 8 percent and 1 percent, respectively. Universities can lower their utility bills by \$100 for every 1,000kWh saved by simply turning equipment off when not in use (E source 2003). For example, in research buildings, vent hoods are electricity intensive and should be switched off unless they are being operated for experimental or material storage purposes. Many lab freezers, which can use as much electricity as an average house, run at temperatures down to -80 degrees Celsius, while they may not need to be this cold. Webber et al. (2006) found that turn-off rates were lower in university buildings than in similar buildings such as high schools and health care centers in a study measuring after-hours power consumption. Electricity saving behavior can be effective anywhere, and there are large savings associated with behavioral changes in electricity consumption in campus buildings in general and research buildings in particular.

2. Background

A number of social and environmental psychological studies (Becker et al. 1981; Bittle et al. 1979; Black et al. 1985; Grønhøj and Thøgersen 2011; Kantola et al. 1984; Newman and Day 1975; Schleich et al. 2012; Seligman et al. 1979; Sexton et al. 1987; Ueno et al. 2006) have focused on issues related to household energy use, but many of the strategies adopted by these studies are also applicable to research into energy consumption by occupants of educational buildings. One interesting line of research is based on using surveys to identify the underlying determinants of energy use such as attitudes toward electricity conservation (Becker et al. 1981; Black et al. 1985; Kantola et al. 1984; Karjalainen 2011; Seligman et al. 1979). Another common approach is to measure the actual electricity consumption after providing electricity use feedback in residential buildings (Bittle et al. 1979; Grønhøj and Thøgersen 2011; Newman and Day 1975; Schleich et al. 2012; Sexton et al. 1987). The numerous studies on behavioral changes in electricity consumption due to various methods have resulted in a good understanding of effective ways to promote energy saving behaviors in residential building occupants, but it is not clear whether these methods transfer to educational settings. Therefore, it is necessary to specifically examine electricity consumption behaviors in educational buildings.

Although substantially fewer studies regarding behavioral changes in electricity consumption have been conducted in organizational settings compared to the residential sector, several studies of buildings used for educational purposes have reported promising results (Carrico and Riemer 2011; Marans and Edelstein 2010; Marcell et al. 2004; Scherbaum et al. 2008; Siero et al. 1996; Staats et al. 2000). As with residential buildings, studies of educational

buildings generally follow one of two approaches: studies predicting electricity consumption without actual data and studies based on actual electricity consumption. The first of these utilizes surveys and simulation, while the second often uses feedback on electricity use.

One interesting study based on electricity consumption without actual data conducted in universities investigated whether people changed their behaviors related to electricity consumption if they were educated on electricity conservation behavior or exposed to social marketing methods designed to encourage a desired behavior change (Marcell et al. 2004). Another study conducted a survey to identify people's electricity spending habits and their degree of willingness to save electricity (Marans and Edelstein 2010). A more recent study predicted electricity spending patterns based on simulations (Azar and Menassa 2011). Even though all three of these studies' main topic was behavioral changes in electricity consumption, their purposes and methodologies varied considerably, as described below.

At Tufts University in Medford, Massachusetts, Marcell et al. (2004) compared the impact on students' environmental behavior by surveying residential students who were exposed to an educational program on climate change alone and students who were exposed to both the educational program and a social marketing campaign encouraging them to turn personal computers off when not in use. They concluded that the addition of the social marketing campaign was more effective than the educational program alone since there was a greater impact on student environmental knowledge, attitudes, and behaviors.

In the study by Marans and Edelstein (2010), University of Michigan faculty, staff, and students were surveyed to identify their behaviors and attitudes in order to improve the design of programs aimed at reducing electricity use. One interesting finding was that almost all of the

faculty, staff, and students were willing to change their electricity consumption behavior to reduce building electricity costs and carbon emissions. However, there is some room for doubt about the consequences of this study because their results were not supported by data on students' actual electricity usage. It is possible that the actual electricity usage by the two groups might have remained the same; people are likely to say that they are saving electricity, but whether they actually do so is a separate matter. It is therefore necessary to identify whether there is any difference in actual energy consumed to verify the survey results. Accordingly, an empirical study focusing specifically on behavioral changes in electricity use is needed to confirm these findings.

A number of empirical and simulation models are widely used in the building sector to estimate electricity consumption, but estimates from these simulation tools have been found to deviate by more than 30 percent from actual electricity consumption (Carroon 2011; Soebarto and Williamson 2001). Azar and Menassa (2011) found that these deviations in previous studies were caused by a series of assumptions, namely that all occupants have similar schedules, they consume electricity at the same rates, and they never change their electricity consumption behavior over time. They therefore proposed a new approach for electricity consumption estimation in commercial buildings based on the use of agent-based modeling, which they argued was more capable of simulating occupant behavior. Azar and Menassa concluded that once behavioral changes have been detected, this affects the total electricity use in commercial buildings and suggested that further research should focus on occupant behavior and the resulting impact on total electricity consumption levels in commercial buildings based on actual electricity consumption data.

In studies of electricity consumption based on measurements of actual data that have been conducted in universities, several researchers have identified ways in which providing feedback on electricity use, in conjunction with different interventions, affects people's electricity use behavior (Carrico and Riemer 2011; Peschiera et al. 2010; Petersen et al. 2007). Feedback, a tool which can change invisible electricity consumption to visible electricity use via numbers or graphs that represent actual electricity usage, is a useful technique that is believed to promote significant electricity savings. The effectiveness of feedback in producing desirable behavioral changes in electricity consumption is well-known as a result of experimental studies that have been conducted on occupants of residential buildings (Hayes and Cone 1977; Henryson et al. 2000; Seligman and Darley 1977; Seligman et al. 1978). Many of these studies showed that sharing electricity usage information for a building among the building's occupants can lead to reductions in the total building electricity use. This approach is particularly useful when there are no financial incentives for electricity users to conserve (Carrico and Riemer 2011; Faruqui et al. 2010; Staats et al. 2000). Only a few feedback studies that involve actual electricity usage data have been conducted in universities and large institutions (Carrico and Riemer 2011; Jain et al. 2012; Peschiera and Taylor 2012; Peschiera et al. 2010; Petersen et al. 2007). Therefore, a study that focuses specifically on the effect of electricity use feedback on electricity conservation behaviors in colleges and universities would be both timely and appropriate.

Previous studies involving educational buildings have focused on campus office buildings or dormitories; there are no reports of studies examining electricity consumption in the research buildings on campus even though these account for a significant percentage of the total university energy usage. The major difference between office buildings and research buildings is

that the laboratories housed in campus research buildings contain a great deal of energy intensive equipment. Although some of this research building electricity consumption is unavoidable because equipment must run 24/7 to support ongoing experiments, there are also more opportunities to conserve electricity in research buildings compared to office buildings or dormitories. For example, research buildings contain many pieces of equipment that can safely be turned off when not in use. It is thus vital to extend electricity feedback studies to include an examination of the impact on electricity consumption of those working in the research buildings on campuses.

There are various types of feedback that have been shown to be effective in different settings, so it is important to tailor the electricity use feedback specifically for those working in research environments. Relevant features of feedback that may determine its effectiveness include the following: duration, content, break-down, frequency, medium and way of presentation, comparisons, and combination with other instruments (Fischer 2008). This is an important issue; in a few feedback studies, no savings were found (Duscha and Dunnhoff 2008; Lene 1993; Sexton et al. 1987). Thus, when designing a feedback study, researchers must take into account which kind of feedback works best for the particular target group because the purposes and results of feedback studies depend considerably on the precise nature of the interventions. Stern noted, “determinants of individual behavior with organization are likely to be different from those of political or household behaviors” (Stern 2000 p.410). Accordingly, there are several barriers that researchers must overcome when designing an electricity use feedback study for those working in university research buildings. First and foremost, electricity users in university research buildings do not have the same direct financial interest in

conserving electricity as they do in their own homes. Moreover, since they often share equipment and appliances with others, opportunities for conservation may be greatly diminished and they could well feel that this is someone else's responsibility.

Despite these barriers, occupants of non-residential buildings such as research buildings may actually be more open to modifying their behavior than those who live in residential buildings. This is because electricity use is more easily observed by one's peers in research buildings, which include laboratories, offices and lecture rooms, compared to in the home environment. Thus, occupants may be more vulnerable to peer pressure with regard to electricity conservation. Siero et al. (1996) showed that employees in the comparative feedback condition saved more electricity than employees who were only provided with information about their own performance by using a Multi Moment Recording (MMR) technique, which can measure electricity-saving behavior. Shalley et al. (1987) demonstrated that task performance is improved by making people believe that their performance will be compared with the performance of others. Additional evidence supporting this contention was reported by Mitchell et al. (1985), who found that presenting information about the performance of others on a wall chart leads to improved task performance. It would therefore be useful to study these comparative feedback impacts on electricity saving behavior for those working in university research buildings.

Petersen et al. (2007) and Peschiera et al. (2010) both tested feedback techniques associated with peer influence in university dormitories. Petersen et al. (2007) enabled residential students to compare the electricity use of their own building with those of other student dorms, while Peschiera et al. (2010) allowed residential students to view their personal

electricity use and compare it with that of their peers and that of an average resident, as well as their historic electricity use. Overall, the results of these two studies demonstrated that across buildings and individuals in peer networks, this type of feedback led to significant reductions in electricity use.

Similarly to dormitory residents, building occupants in research buildings do not pay for their electricity directly, so even if they receive electricity consumption information, they may not pay any attention to it. Therefore, normative comparison should be reflected in the feedback design for research building occupants to encourage them to save electricity. Furthermore, while the test subjects in previous studies have been limited to residential students, those working in research buildings represent a far more diverse population, including not just graduate and undergraduate students but also faculty and staff. In this sense, normative comparison at the building level, such as giving the occupants information on the comparative electricity reduction achieved by other research buildings, could be implemented in a feedback study to provide a wide group of subjects with electricity consumption data.

Carrico and Riemer (2011) selected twenty-four university office buildings and provided their occupants with feedback regarding their electricity usage in an effort to determine the effectiveness of two separate interventions, namely peer education and feedback, as well as the effect of combining the two. Their results showed that feedback and peer education produced 7 percent and 4 percent reductions in electricity use, respectively. Unfortunately, the initial result for the peer education intervention was distorted by an implementation failure in two of the six buildings assigned to receive information, but when the two buildings were excluded from the analysis, this study demonstrated that information that comes from a peer is perceived to be

more reliable than information that comes from a third party. Just as in campus office buildings, research buildings generally include only one or two academic departments. Given the results reported by Carrico and Riemer (2011), future studies should send building occupants feedback on electricity consumption from a person known to them who is responsible for administration in each of the departments.

An additional limitation of the Carrico and Riemer (2011) study relates to the baseline setting, which was measured four months before the research started. If they had used data from a similar period to the experimental period for their baseline, the results might have been more comparable because they would then not have had to consider differences in the weather and the academic load between the earlier period and the treatment period. Therefore, there is a need to study electricity use feedback in university research buildings with a credible baseline.

To sum up, when reviewing previous studies in relation to behavioral changes in electricity consumption, it was found that survey or simulation studies suffer from serious limitations because they may not accord with actual electricity consumption data. In contrast, in studies based on actual electricity consumption data, the use of comparative electricity feedback has been shown to be an effective method of promoting electricity saving behavior, and this is particularly important when there are no financial incentives for electricity users to conserve energy. Currently, there are no known applications of a normative comparison of electricity use feedback at the building level in university research buildings that are based on actual consumption data with a plausible baseline. The current study was therefore designed to address this lack.

3. Methodology

3.1. Study Design and Hypotheses

3.1.1. Research Question

Electricity users at large institutions such as universities, companies, and public agencies do not receive direct electricity use feedback, so they do not know how much electricity they actually use. Although they are able to reduce electricity consumption, they are not incentivized to do so. Since many universities and colleges have tight facility budgets, finding low-or no-cost ways to reduce electricity use and, hence, expenditures can have a significant impact on the institution's bottom line (Hildebrand 2010). Thus, it was anticipated that providing feedback to building occupants would be an effective way to encourage electricity users in university research buildings, which are the most electricity intensive buildings on campuses, to modify their behavior and thus reduce electricity consumption. In large institutions, emphasizing comparison and even competition with others increases motivation to achieve a goal (Siero et al. 1996). Therefore, the present study aimed to identify the role of comparative electricity use feedback at the building level in the research buildings on a university campus.

3.1.2. Experiment Design

For this experiment, fourteen of the eighteen research buildings on the Blacksburg campus of Virginia Tech were selected and assigned to three groups, consisting of one control and two study groups. The control group had four buildings, and the two study groups each had five buildings. When making the group assignments, combining the comparative buildings for study group 2 were necessarily a priority because the building occupants in study group 2 were to

share building electricity consumption data with each other. Thus, the five buildings shared a common departmental affiliation and were located in close proximity to one another. The remaining nine buildings were randomly assigned to the other two groups.

The target building occupants under the present study consisted of faculty, staff, and graduate students. At the start of the experiment, agreements were made with one or two persons from each of the departments occupying each building to distribute electricity use feedback. The others working in the buildings were then sent emails containing the electricity use feedback for their building by these individuals. As explained in the previous chapter, when information is provided by someone within an individual's social group, it tends to be more effective than information that is disseminated by unknown third party (Burn 1991; Hopper and Nielsen 1991). Therefore, by adopting this approach it was expected that building occupants would be more likely to pay attention to the feedback.

Regarding the frequency of feedback, weekly feedback on electricity usage was used in this study as real-time feedback, which has a clear track record of success, was not feasible because few of the buildings had real-time electricity metering installed. The electricity meters at each of the fourteen buildings on the campus were read by a research assistant once a week for a month. This was not expected to be a major limitation, as even though more frequent feedback appears to be more effective, relatively infrequent feedback, such as weekly and monthly feedback, has been associated with considerable behavior changes (Abrahamse et al. 2007; Van Houwelingen and Van Raaij 1989). Weekly electricity use feedback was therefore used for this experiment, which was conducted over a period of 5 weeks in August 2012.

The baseline reading was measured for a week immediately prior to the experimental period, the last week of July 2012. Since the baseline was close to the study period, there were no significant weather differences between the baseline and the study period. Furthermore, it was easier to compare the experimental data to the baseline because reading meters was conducted weekly, making it possible to examine trends in electricity consumption over the study period.

The content of the feedback included tips for electricity conservation in addition to the information on weekly electricity usage. The control group did not receive any electricity use feedback or energy saving tips. The building occupants in the two study groups had different types of feedback. Table 1 represents the feedback utilized in the experiment.

Table 1: Feedback Utilized in the Experiment

	Feedback
Buildings in Experiment	Control group: Torgerson, Randolph, Robeson, and Wallace Study group 1: ICTAS1, Food Science, Norris, Holden, and Derring Hall Study group 2: Patton, Durham, Whittemore, Cowgill, and Bishop-Favrao,
Target Occupants	Faculty, staff, and graduate students
Media	Email from the person responsible for administration in each of the departments located in each building
Frequency	Weekly electricity use feedback
Duration	5 weeks
Baseline	Electricity consumption from a week before the experiment
Content of Feedback	Control group: No feedback Study group 1: Electricity use feedback Study group 2: Electricity use feedback in conjunction with comparative electricity reduction of other buildings

3.1.3. Hypotheses

Two hypotheses guided the present study (Table 2):

Table 2. Hypotheses Guiding the Experiment

Hypothesis 1	Buildings in which occupants are provided with electricity use feedback will consume less electricity than buildings whose occupants receive no feedback.
Hypothesis 2	Buildings in which occupants are provided with electricity use feedback in conjunction with information on the comparative electricity reduction achieved by other buildings will consume less electricity than buildings provided whose occupants receive no feedback or only single building electricity use feedback is provided.

3.2. Study Procedure and Data Analysis

3.2.1. Feedback Development

To conduct the experiment, specific tasks were defined for each objective. First, the design of the feedback approach to be utilized was completed before the experiment started. Administrators in each of the departments were contacted to request their assistance in sending emails containing feedback on their building’s electricity consumption and other information tailored to their assigned study group on a weekly basis. The content of the feedback was then developed in a way expected to attract building occupants’ attention. Two different types of feedback were developed (Figures 3 and 4).

From: Ellie Ma <elliema@vt.edu>
To: "Selby, Fred" <selby@vt.edu>
Cc:
Date: Sun, 12 Aug 2012 11:00:13 -0400
Subject: Do you know the energy use of Derring Hall for August 2 to August 8, 2012?

Dear Derring Hall Occupants,

We are contacting you to make you aware of your building's energy use information and to provide you with some tips for energy conservation. **By following the provided tips below, you can help Virginia Tech save energy!**

< August 2, 2012 - August 8, 2012: Derring Hall >

- Energy Consumption over Time Period Indicated: 36,864 kWh
- No. of Billing Days: 7
- Daily Watt-hour/ft²: 25.3

< Energy Saving Tips > (Source: U.S. Department of Energy)

- Use natural lighting when possible.
- Unplug equipment that drains energy even when not in use.
- When working late, use task lighting to directly illuminate work areas.
- Close or tilt window blinds to block direct sunlight to reduce cooling needs during warm months.
- Use efficient ENERGY STAR products.
- Photocopy only what you need.
- Keep fume hood sashes closed when not in use.

Please forward this to your department's faculty, staff, and graduate students.

Thank you for your efforts in helping us to make Virginia Tech more sustainable!

Sincerely,

Fred Selby

James (Fred) Selby, CEM

Energy and Sustainability Manager

Facilities Services

Office [540-231-6348](tel:540-231-6348) Fax [540-231-9344](tel:540-231-9344)

Figure 3. Feedback Type 1

From: Ellie Ma <elliema@vt.edu>
To: "Selby, Fred" <selby@vt.edu>
Cc:
Date: Sun, 12 Aug 2012 11:00:55 -0400
Subject: Do you know the energy use of Cowgill Hall for August 2 to August 8, 2012?

Dear Cowgill Hall Occupants,

We are contacting you to make you aware of your building's energy use information, to provide you with some comparative building energy use information, and to provide you with some tips for energy conservation. **By following the provided tips below, you can help Virginia Tech save energy!**

< August 2, 2012 - August 8, 2012: Cowgill Hall >

- Energy Consumption over Time Period Indicated: 16,704 kWh
- No. of Billing Days: 7
- Daily Watt-hour/ft²: 34.9

< Comparative Building Energy Use Information >

Cowgill Hall's building occupants consumed the following percentage less or more energy (daily Watt-hour/ft²) compared to the following other buildings on campus:

- Your building consumed **17%** less energy per square foot than Patton Hall
- Your building consumed **45%** less energy per square foot than Durham Hall
- Your building consumed **37%** less energy per square foot than Whittemore Hall
- Your building consumed **75%** more energy per square foot than Bishop-Favrao Hall

< Energy Saving Tips > (Source: U.S. Department of Energy)

- Use natural lighting when possible.
- Unplug equipment that drains energy even when not in use.
- When working late, use task lighting to directly illuminate work areas.
- Close or tilt window blinds to block direct sunlight to reduce cooling needs during warm months.
- Use efficient ENERGY STAR products.
- Photocopy only what you need.
- Keep fume hood sashes closed when not in use.

Please forward this to your department's faculty, staff, undergraduate students, and graduate students.

Thank you for your efforts in helping us to make Virginia Tech more sustainable!

Sincerely,

Fred Selby

James (Fred) Selby, CEM

Energy and Sustainability Manager

Facilities Services

Office [540-231-6348](tel:540-231-6348)

Fax [540-231-9344](tel:540-231-9344)

Figure 4. Feedback Type 2

Feedback was sent every week during the experiment. All building occupants were given the feedback via administrators from their own department. Electricity usage data was collected in collaboration with the Office of Electricity and Sustainability at Virginia Tech.

3.2.2. Data Analysis

To test the study hypotheses about the effect of providing building electricity use feedback in conjunction with information on the comparative electricity reduction achieved by other buildings, it was necessary to identify the following comparative values (Figure 5): the daily average electricity reduction of the control group (R'_c) and each of the two study groups (R'_{s1} & R'_{s2}) relative to the baseline. The raw data, in this case the experimental electricity consumption (E_e) and the baseline's electricity consumption (E_b), are expressed in units of the daily average Watt hours (Wh) per square foot. The daily average reduction rates for the control group (R_c), study group 1 (R_{s1}), and study group 2 (R_{s2}) can be determined using Formula 1. In order to calculate the comparative values (R'_c , R'_{s1} , and R'_{s2}), the daily average electricity

reduction of the control group (R_c) must be subtracted from the daily average electricity reduction of each of the two study groups (R_{s1} & R_{s2}) to take into account variables in the electricity usage which may result from other gaps over a week before the experiment (Formula 2).

Formula 1. $R = \left(\frac{E_e}{E_b} - 1 \right) * 100, \quad (R_c, R_{s1}, \text{ and } R_{s2})$

$R_c' = R_c - R_c$

Then, comparing R' values using **Formula 2.** $R_{s1}' = R_{s1} - R_c$

$R_{s2}' = R_{s2} - R_c$

Figure 5. Formulas Utilized in the Data Analysis

The next task was to construct graphs showing the daily average electricity reduction achieved by each of the two study groups according to each baseline. Comparing these graphs was expected to identify any effect of comparative electricity use feedback. A statistical analysis was then performed to examine the two hypotheses. Table 3 summarizes the experimental approach.

Table 3: Summary of the Experimental Approach

Objectives	Tasks
Design feedback approach	<ol style="list-style-type: none"> 1. Contact each department to ask them to send emails (Feedback) 2. Develop the content of feedback
Conduct the experiment to collect the electricity usage data	<ol style="list-style-type: none"> 1. Collect Data from the Office of Electricity and Sustainability <ol style="list-style-type: none"> a) Data 1: Electricity usage of the fourteen buildings for a week before the experiment b) Data 2: Electricity usage of the fourteen buildings during the study period 2. Send email of electricity use every week
Draw conclusions	<ol style="list-style-type: none"> 1. Identify comparative values <ul style="list-style-type: none"> • The daily average electricity reduction of the control group and the two study groups relative to the baselines • Subtract the daily average electricity reduction of the control group from each of the two study groups 2. Make and compare graphs which show the daily average electricity reduction of the two study groups 3. Conduct statistical analysis of experimental data

4. Results

4.1. Implementation Check

The reading of the electricity usage meters was conducted periodically according to the schedule. Compared to the corresponding data from the previous two years, there were no unreasonable readings found. Summer classes held in the buildings were similar in terms of the number of classes held. To gain further insight into the quality of the implementation, it is necessary to describe the assumptions made and possible limitations. First, no survey was conducted of the individuals providing the electricity use feedback to determine whether they did so as promised, in a timely fashion. There was also no survey of the building occupants to check whether they actually read the emails containing the feedback on their building's electricity use during the experiment. Therefore, results were based on the assumptions that all feedback providers would send building occupants electricity consumption information, as arranged, and that most of the building occupants would be informed of their building's electricity consumption information and that comparative electricity use information related to other buildings would be received by study group 2.

In addition, it was necessary to exclude several buildings from subsequent analysis. Robeson Hall is not a free-standing building but instead is connected to two other buildings and Cowgill and Norris Halls are designed for centralized control of electricity. In the case of these buildings, even if the building occupants changed their electricity consumption behavior as a result of receiving electricity use feedback, this might not actually affect the overall electricity consumption of these buildings. For these reasons, three buildings were excluded among the

fourteen buildings that were initially selected, one from each group, leaving three in the control group and four each in groups 1 and 2.

4.2. Comparison of Electricity Reduction Achieved by the Two Study Groups

Using the electricity consumption for the week before the experimental period as a baseline, Figure 6 shows the average reductions in electricity consumption achieved by the two study groups compared to the control group. There was a clear difference in the level of effectiveness of feedback between the two study groups. Study group 1 had an average of 0.2 percent electricity usage reduction, and study group 2 had an average of 0.8 percent electricity usage reduction. Comparing study group 1 to study group 2, study group 2's reduction was 4 times higher than the study group 1. Even though the reduction percentages were relatively small, this resulted in a considerable saving of electricity consumption in terms of kWh over the month in both study group 1 and study group 2: study group 1 saved 1,175 kWh in August compared to what would otherwise have been expected, and study group 2 saved 3,839 kWh.

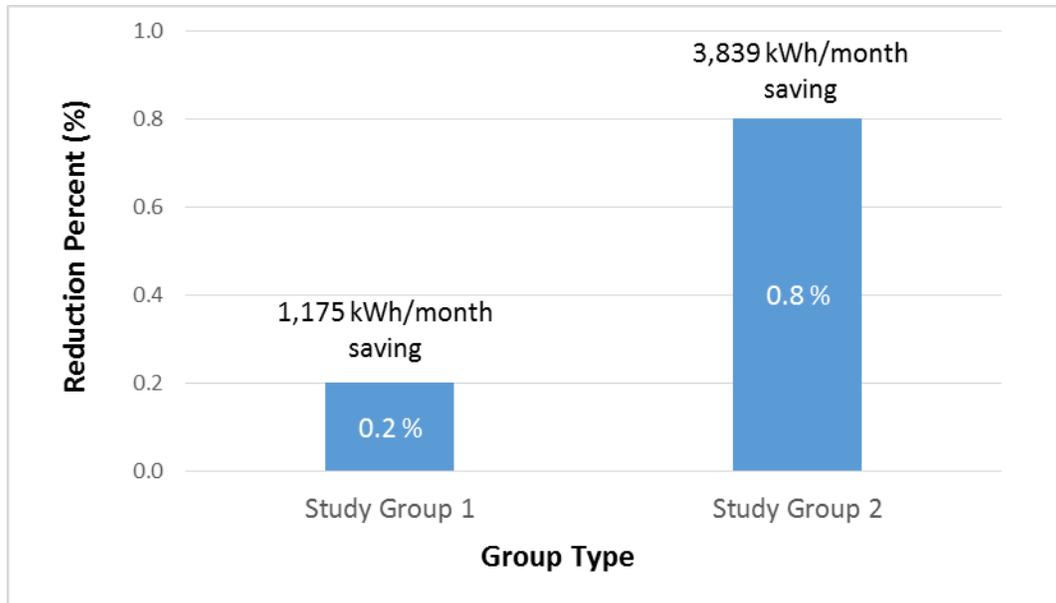


Figure 6. The Daily Adjusted Average Reductions of the Two Study Groups Relative to the Control Group (R_{s1}' & R_{s2}')

(Based on the electricity consumption from a week before the experiment)

4.3. Statistical Analysis

Before the statistical analysis could be conducted, the distribution of the data for normality had to be examined in order to identify the most appropriate statistical test to suit the data collected. Figure 7 shows the normal quantile plot of the data; when the data points are close to a straight line, as is the case here, it is assumed that the original data is normally distributed.

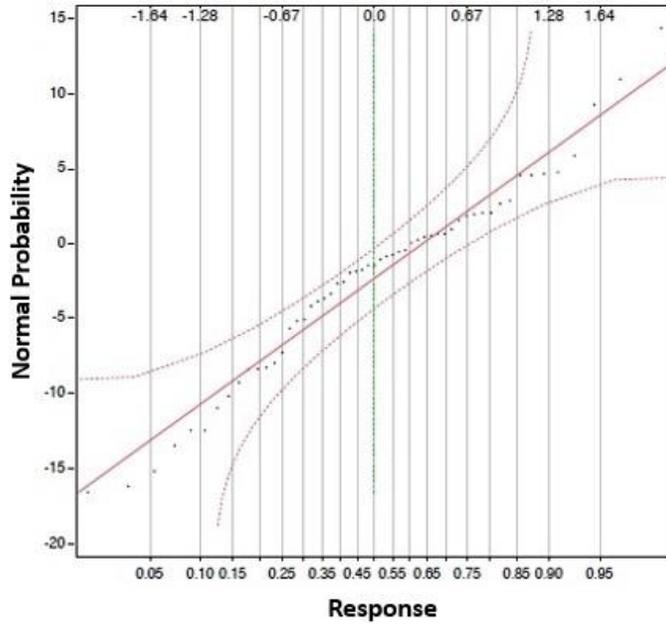


Figure 7. Normal Quantile Plot

Unfortunately, the average reductions in consumption of electricity between the three groups, namely the control group and both study groups, were not found to be statistically significant after conducting the LS Means Tukey Honestly Significant Difference (HSD) test. This test that is sized for all differences among the least squares means using JMP statistical software. Table 4 shows the P values between each pair of groups.

Table 4: P- values Between Groups

Groups Compared:	95% confidence interval		P
	Upper bound	Lower bound	
R- control mean= -2.0 to R- study group 1 mean= -2.2	10.8	-10.4	0.9984
R- control mean= -2.0 to R- study group 2 mean= -2.8	11.4	-9.7	0.9741
R- study group 1 mean= -2.2 to R- study group 2 mean= -2.8	10.4	-9.2	0.9827

5. Discussion

Even though study group 1 had an average reduction of 0.2 percent in their electricity usage, the results were not statistically significant. Therefore, Hypothesis 1, which is that buildings whose occupants are provided with feedback on their electricity usage will consume less electricity than buildings whose occupants do not receive such feedback, was not supported. This is because the reductions in consumption of electricity for study group 1 were not consistently higher than those achieved by the control group during the experiment (Figure 8). For the first two weeks, as expected, a marked reduction in electricity usage was observed for study group 1 due to the introduction of electricity use feedback for the building occupants. However, this behavior was not maintained and study group 1 actually used more electricity on average than the control group for the third and fourth weeks of the experiment. In the final week of the experiment, the average reduction in consumption of electricity for study group 1 was once higher than the control group, which may have been because the only occupants remaining in the building were the staff, faculty, and graduate students, as summer classes had just ended. It is also possible that it took as long as 4 weeks for people to start paying attention to the emails. Therefore, a slight reduction in electricity consumption resulting from the provision of non-comparative electricity use feedback was observed, but Hypothesis 1 was not supported.

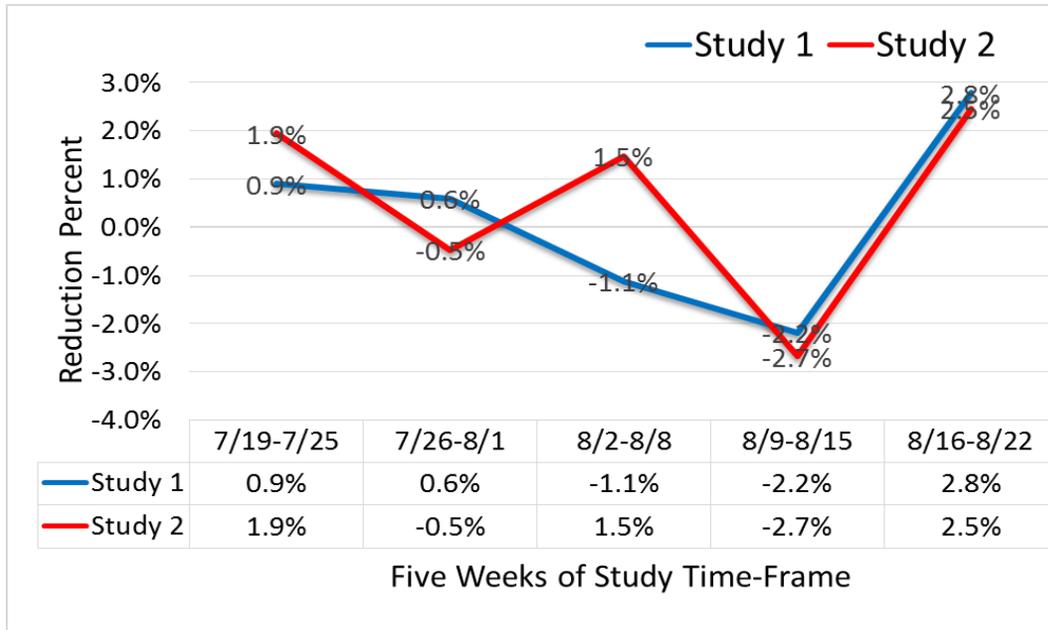


Figure 8. The Trend of the Adjusted Average Reductions of the Two Study Groups Relative to the Control Group

Even though comparative electricity use feedback was found to be 4 times more effective than non-comparative electricity use feedback in this study, once again the result was not statistically significant. Accordingly, Hypothesis 2, which stated that buildings in which occupants are provided with electricity use feedback in conjunction with information on the comparative electricity reduction achieved by other buildings would consume less electricity than buildings whose occupants either received no feedback or those whose occupants received only single building electricity use feedback, was not supported.

At the beginning of the experiment, the effect of comparative electricity feedback appeared to be strongest immediately following implementation of feedback because study group 2 had achieved an average 1.9 percent electricity usage reduction in the first week (Figure 8).

However, once again the electricity reduction achieved by study group 2 decreased as the treatment period progressed and, the reductions in electricity consumption achieved by study group 2 were again not always higher those recorded for the control group and the result was also not statistically significant. In the third week of the experiment, the reduction in consumption of electricity achieved by the occupants of the buildings in study group 2 was 1.5 percent. It is interesting that the period for which study group 2 achieved a greater reduction than the control group lasted for one week more than study group 1 during the experiment. This might be because the information that the occupants of the study group 2 buildings were receiving about the outcomes achieved by other members of the group encouraged a sense of competition and hence the desire to achieve a better performance. Interestingly, both study groups achieved their greatest saving in the final week of the study. As mentioned above, this may have been because only people remaining in each building by the end of August were the normal occupants, namely the staff, faculty, and graduate students, as summer classes had ended. It may also be that it took 4 weeks for people to start paying attention to the emails they were receiving. Therefore, as before a slight reduction in electricity consumption as a result of receiving the comparative electricity feedback was observed, but this was not sufficiently strong enough to support Hypothesis 2.

A Fixed-Effects (FE) test was also conducted. FE is a well-known way to analyze the impact of variables that change over time. Here, this was used to examine three effects: treatment, time, and treatment + time. Treatment was set as three groups: the control group, study group 1, and study group 2. Time was set as five time periods, each lasting one week: Time 1, Time 2, Time 3, Time 4, and Time 5. Table 5 shows the results and demonstrates that only the time effect was

statistically significant. Taking into account the LS Means Plot for both treatment and time, which plots least squares means for nominal and ordinal main effect interactions, only the time plot shows a significant degree of variability (Figures 9 and 10).

Table 5. Results by Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob>F
Treatment	2	2	8	0.0276	0.9728
Time	4	4	32	14.2961	<.001*
Treatment*Time	8	8	32	0.3313	0.9475

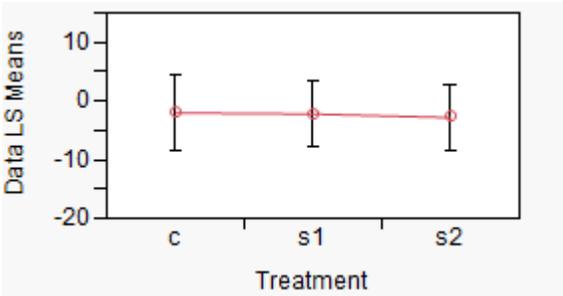


Figure 9. LS Means Plot for Treatment

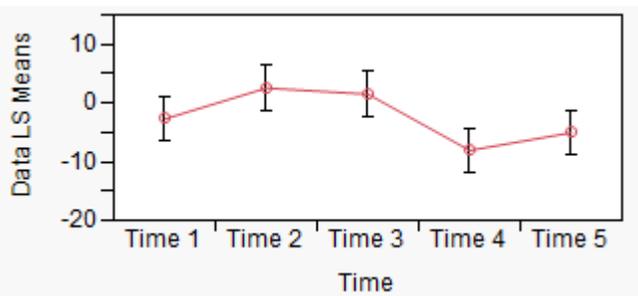


Figure 10. LS Means Plot for Time

(LS Means indicate the daily average electricity outputs)

To sum up, no null hypotheses were disproved by the results of this study. Even though study group 2 saved 4 times as much electricity as study group 1, the average reductions achieved by the two study groups remained very small. This is because the building occupants in study group 2 did save their electricity and consumed more energy during different weeks of the study period, which is why the result was not significant. However, the small savings in both study groups still represent important energy savings, largely because research buildings use so

much more electricity than other campus buildings such as residential buildings and student service buildings. It is also interesting to note that the final week of the study saw the greatest savings achieved by both study groups. It is possible that greater savings may have been observed in a longer study, but this cannot be also generalized to the general population without experimental support. It would also be interesting to discover whether long-term savings are achieved as a result of the study interventions having a lasting effect on the electricity usage behavior of the occupants of the buildings in study groups 1 and 2.

6. Responses from Building Occupants

During the experiment, the email queries received from some of the building occupants were particularly interesting. Since they had not been made aware of the purpose of this study, a number of the occupants of the buildings in the various groups had questions and sent emails requesting more information. Two people appreciated the sharing of the electricity consumption information. Most of the responses received came from faculty rather than staff or students, and this may indicate that they were paying more attention to the emails they were receiving containing the electricity use feedback. The interest expressed by the building occupants in becoming directly engaged in this experiment was a little unexpected. Overall, due to the attention they were clearly devoting to the feedback emails, the level of interest this indicates does suggest that more information could be gathered for each research building by soliciting suggestions from those working in the buildings.

Perhaps the most surprising responses were from occupants of the buildings in study group 1, who only received information on their own electricity use. One person specifically asked how much more electricity they were consuming compared to other similar buildings, and another person requested more detailed information because the electricity use feedback provided in the present study showed the electricity consumed only on a weekly basis.

Within the responses from study group 2, several building occupants suggested reasons why their building consumed more electricity than other comparable buildings. In particular, one person went into some detail to illustrate how differently their building's electricity system was being operated than those in other buildings; that particular building's electricity system consisted primarily of central heating and cooling, so building occupants had fewer

opportunities for electricity conservation. One person also complained about the electricity operating system in their building and asked for information on who had designed the building. There were a number of other useful and interesting responses from building occupants.

7. Research Contributions

This study makes a contribution to theory in that it has focused specifically on campus research buildings, which are typically the highest consumers of electricity in universities. Peschiera et al. (2010) demonstrated that a peer network designed to reduce electricity consumption can be formed in university residential buildings at the individual level and confirmed that electricity saving behaviors can be achieved by such a network. The present study also identified that a peer network in electricity consumption can develop in university research buildings at the building level which in this experiment resulted in 3,839 KWh of electricity savings, but the findings were not statistically significant. However, the present study provides a basis for future studies seeking to identify the most effective type of feedback to display to those working in university research buildings to encourage the adoption of electricity saving behaviors.

The present study explored the use of email as a feedback medium and found that this may be a good way to motivate people to save electricity if the comparative feedback sent to building occupants is carefully tailored by setting specific goal or providing incentives. Email has the potential to become a particularly cost effective way to promote energy-saving behaviors instead of renovating buildings or installing electricity saving devices, both of which entail considerable expense. Electricity users in university research buildings, namely faculty, staff, and students, tend to send and receive emails often and are used to receiving important information via this avenue.

The present study also highlights that efforts to encourage electricity saving behaviors should not be limited solely to students on university and college campuses. In this study,

efforts were made to engage faculty and staff, as well as students, in reducing the university's electricity consumption. Faculty and staff usually spend more time in campus research buildings than students because they have their offices and research labs in those buildings. In addition, in this experiment the administrative staff, who were responsible for providing electricity use feedback, actually played an important role in influencing the decisions of others on campus as information providers. Sharp (2002) found that groups combine to achieve the greatest institutional change when they have a shared vision and a sense of organizational alignment in their actions. The present study indicates that all electricity users in university research buildings can be involved in reducing electricity as a result of receiving comparative electricity use feedback.

8. Research Limitations

There are several limitations in the present study, which may be why the average reduction achieved by the different study groups was not significant. The first limitation is that the electricity use feedback was not provided sufficiently frequently to electricity users. Feedback is known to have an impact on motivating behaviors in electricity consumption, but the frequency with which that feedback is provided is also important (Seligman and Darley 1977). In the present study, weekly electricity use feedback was the best that could be achieved because most of the research buildings on the Virginia Tech campus had no real-time electricity meters installed so it was necessary to physically visit each building every week to read the electricity meter. Developing comparisons of electricity consumption between research buildings and sending email feedback also took some time. However, it would have been better to provide more frequent electricity use feedback for building occupants.

Another limitation is that there was no survey to check whether the individuals providing electricity use feedback were doing so in a timely fashion. There was also no survey of the building occupants to see if they actually read the emails containing the electricity use feedback. In the present study, the results and discussion were based on the assumptions that feedback providers would be fully responsible for their roles, and feedback receivers would read the electricity use feedback regularly. However, conducting a survey for both feedback providers and receivers could have provided more reliable results.

In addition, even though the greatest savings were achieved in both study groups in the final week of the experiment, the study could not be continued due to the major changes in building

occupancy that occur at the beginning of every Fall semester. The experiment ended in August, during the summer break, but in September many undergraduate students return to school, so if their electricity consumption is included, the results would be different from the previous month. Therefore, the data would not be directly comparable. Moreover, undergraduate students are not good subjects for this experiment because they have fewer opportunities for electricity conservation as they spend only limited time attending classes and labs in the campus research buildings. This experiment is limited to the original experiment period. Therefore, it is not clear if greater saving would be observed over a longer study.

Lastly, even though the selected buildings are in the same category, namely research buildings, the conditions of the buildings have different types of equipment in them. Some research buildings have more opportunities for efficient ventilation control, than other do. Some buildings have many have many pieces of energy intensive equipment, while others do not. This may have affected the reductions in electricity consumption in the various buildings in the present study. Dividing electricity consumption by square foot in each building might not be sufficient enough to make the selected buildings comparable in the present study. Related to this concern, more detailed information of each building should have been collected before the experiment.

If these limitations are taken into account when developing future studies, comparative electricity use feedback could have a potentially significant impact on energy consumption in university research buildings. Even though the present study's results were not statistically significant, they provide a foundation that future studies allowing for these limitations could build on to achieve further contributions to both theory and practice.

9. Future Research

There are three possible avenues for future research on this topic. Considering the limitations identified in the current study, similar experiments utilizing real-time electricity consumption meters could be conducted. If building occupants receive their electricity consumption via real-time electricity meters, it is possible that even non-comparative electricity use feedback will motivate people to reduce their electricity consumption. It has been reported that continuously monitoring a building's electricity systems can lead to reductions of as much as 25 percent in annual electricity bills (E source 2003). It is therefore reasonable to expect that greater electricity savings would be observed when building occupants receive electricity consumption data, whether or not it is compared to that of other buildings, in real-time.

Another opportunity for future research is to conduct a survey of feedback providers and building occupants after a similar experiment to provide more reliable results, as it would help check the implementation of the experimental protocol. Furthermore, based on the survey results, more desirable research methods could be derived for future research, leading to more convincing results and thus making a greater contribution to both theory and practice.

A future study could also provide comparative electricity use feedback by adopting more communication mediums, for example, posters, smart phone texts, and Internet social media. In the present study, only email was utilized to promote electricity conservation behavior. The results of the present study were not statistically significant because the email feedback might not be sufficient to promote and reinforce electricity conservation behaviors. Providing posters, texting with smart phones, and integrating Facebook would make users more conscious of their

electricity consumption, rather than simply including tips in the email feedback. However, it is still not clear how effective using other mediums would be for comparative electricity use feedback. Therefore, there is a need to study the effectiveness of comparative feedback via the application of other mediums in university research buildings.

Lastly, future studies should identify the amount of energy consumption that users have control over for each building and how much electricity is consumed as base load energy. Some of the buildings' electricity consumption is unavoidable because equipment must run 24/7 to support ongoing experiments, and this is why it is necessary to calculate base load energy consumption. A simple calculation of base load energy consumption for a building can be used in the future study. To obtain more accurate results for the future study, real-time meters can be installed to figure out base load consumption. This would make the future study have a clearer result of the impact of comparative electricity use feedback on energy consumption.

10. Conclusion

In the present study, two types of electricity use feedback were tested in university research buildings as means of promoting electricity saving behavior among building occupants. Non-comparative electricity use feedback and comparative electricity use feedback emails were sent to all those working in the buildings weekly for five weeks. Based on actual electricity consumption, the results showed that building occupants who received comparative electricity use feedback achieved a 4 times greater reduction in electricity usage than building occupants who received non-comparative electricity use feedback. However, this result was not statistically significant because the saving was not maintained over the study period. However, the present study is still critical because in terms of the reduction in kWh of electricity achieved per study building during the month-long study period, a large amount of electricity was saved.

While previous studies related to electricity use feedback have focused on university office buildings and residential buildings (Carrico and Riemer 2011; Jain et al. 2012; Peschiera and Taylor 2012; Peschiera et al. 2010; Petersen et al. 2007), this study investigated at campus research buildings, which are typically the highest consumers of electricity in universities. The present study also explored the use of email as a feedback medium and the results of the study indicate that an email may encourage energy conservation if the feedback is tailored properly.

Responses from building occupants highlighted the problem that several research buildings on the Virginia Tech Blacksburg campus are designed for centralized control of electricity. In these cases, it should be possible for campus staff to schedule occupancy to optimize efficient electricity usage, with staff conducting frequent checks to ensure that heating, ventilation, and

air conditioning (HVAC) systems are not set to overcool or overheat buildings. Many universities have not yet institutionalized a systemic commitment to environmentally sustainable campus operation, even though they realize the enormous potential for greater efficiency and the opportunity to reduce electricity consumption and, hence, lower operating expenses.

In the present study, the effectiveness of comparative electricity use feedback in university research buildings was not confirmed because of several limitations: infrequent feedback, no survey to check on the implementation, the relatively short study period, and the different types of research buildings with different types of equipment. However, in the light of these limitations, it is expected that future studies should result in more significant reductions in energy consumption for university research buildings.

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