Reducing Energy Waste via Occupant Behavior: The Role of the Individual in Climate Change Solutions

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Abstract

This study aims to achieve energy waste reductions via the rewiring of human habits as opposed to using technology. In public spaces like university campuses, individuals often remove themselves from the energy conservation equation, viewing energy use as the responsibility of the organization. This attitude plays a part in the high levels of wasted light that are common in these public settings. By studying the ways in which human behavior can be altered, this thesis attempts to identify origins of waste on the CU-Boulder campus while finding ways to reduce such waste with minimal financial investment. In the first part of this thesis, I conducted a literature review to determine which strategies have had noteworthy success in reducing energy waste by targeting occupant behavior. This review revealed that the most effective strategies that rely on occupants incorporate (1) monitoring and energy-use feedback, (2) the establishment of social norms, (3) education and informative interventions, and (4) the manipulation of design elements. Upon identifying these four primary strategies, the second part of the thesis reveals how they are implemented on the CU campus and whether they have been successful. I found that our campus has energy conservation initiatives in place rooted in all of the listed strategies, yet recorded waste was still high, notably in public restrooms. Though it is encouraging that existing interventions are in place to target energy waste on campus, this study highlights the limitations of such initiatives. I made use of light/occupancy loggers to see how energy waste was impacted by multiple sign designs posted around campus, and found that none of these held a significant impact on occupant behavior. In addition, I found that most energy waste from lights occurs after business hours, when such interventions are obsolete. These results suggest that to target the bulk of energy waste, strategies implemented on campus should prioritize after-hours waste. Even so, energy conservation during business hours need also be tailored to more effectively influence university occupants if the campus is to achieve zero-waste goals. That said, targeting occupant behavior at CU would require new, more extensive, inclusive, and creative strategies, as recommended at the end of this paper.

Preface & Acknowledgements

The inspiration for this research originated from an interview I conducted for a career exploration project. While speaking with Michael P. Vandenbergh, my dad's colleague from Vanderbilt University's Climate Change Research Network, I learned about a study that explored energy-conscious behavior and social norms. In this study, light status (on/off) upon entry to a public restroom significantly affected the decision of the next user to flip the switch upon their own exit. Professor Vandenbergh wondered whether these results could be replicated in campus lecture halls, and this got me thinking about what interventions actually work to change habits and small daily decisions like turning off lights. Within the education sector, there is potential for significant waste reduction that aligns with the growing generational care for the environment and sustainability. I aim to reduce the value-action gap that I encounter on campus day-to-day because surveys have suggested that students cohesively want to reduce their carbon footprint, yet they overlook easy opportunities to do so.

First, I would like to thank my advisors, Eric Pedersen, Dale Miller, and Amanda Carrico, for guiding and supporting me through this process. Second, I would like to thank Michael Vandenbergh for inspiring the project and for connecting me to some relevant literature. Similarly, I would like to thank Jennifer Cole for sharing valuable and extensive research now embedded in my literature review. Third, I would like to thank Joe Branshaw, Lead Electrical Engineer, Michelle Gabrieloff, Energy Outreach Program Coordinator, and Ellen Edwards, Energy Manager, for providing crucial information related to campus energy and lighting projects. Fourth, I would like to extend my gratitude to Carl Schader, a good friend who performed some necessary coding to help with my data analysis. Lastly, I am thankful to have gained access to study locations in Duane Physics and McKenna Language thanks to Building Managers Doreen Williams and Timothy Lim. Thank you to all of my family and friends for believing in me through this all.

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Introduction

Environmental values are seldom conveyed in action – many people overlook opportunities for positive impact in recycling and composting, turning off appliances, using public transportation, etc. Turning the lights off when leaving a room is one of these simple, single second actions that contributes to climate change but is so easily forgotten or dismissed. While seemingly minute given the scale of climate change challenges, reducing wasteful actions like this can contribute drastically (in aggregate) to emission reductions and cost savings. Importantly, these actions are applicable across multiple sectors (residential, commercial, industrial, etc.) and engage consumers to take on climate change mitigation at an individual scale. While top-down approaches that target large enterprises and institutions are promising given the scale of impact, bottom-up approaches to climate solutions can help overcome financial, geographical, and accessibility barriers. This thesis explores the varying efficacy of these bottom-up, demand-side energy conservation initiatives on campus, in hopes of optimizing these strategies to lower the university's footprint. Upon reviewing empirically based strategies that encourage pro-environmental behavior, this thesis focuses on monitoring, design, education, and social norms. By installing HOBO UX90-006 Data Loggers that monitor room occupancy and indoor light levels, I will evaluate how well existing energy conservation initiatives at CU-Boulder drive pro-environmental decision-making. That said, I seek to answer the following questions: (1) which strategies are most effective in inducing pro-environmental action, and (2) which strategies have been implemented at CU, and how effective have they been. I hypothesize that interventions that incorporate social norms will carry the strongest influence given the demographic of the study population – young adults are especially susceptible to social pressure. By determining which strategies change occupant behavior the most, the results of this study may guide CU's future energy-saving initiatives. Additionally, by undertaking experimental trials, I will measure waste by focusing on the light on/no occupancy ratio collected by the loggers, representative of the total waste in each room. These measurements will give insight into the efficacy of existing campus initiatives in encouraging people to turn off the lights when leaving a public space. The next sections will outline the scope of the issue I am targeting – wasteful consumption of light and environmentally unconscious decision-making – and will provide evidence of strategies that have been shown to induce pro-environmental behavior. The literature review will also share details about existing and past campus initiatives that target energy conservation. My methods section will outline my strategies for measuring energy waste, for targeting and introducing certain interventions into spaces, and for choosing test locations. Finally, my results will share collected data and corresponding analyses, and I will provide a follow-up discussion which will contextualize these results, suggest opportunities for further research and conservation, and describe limitations of the research results.

Background

This section serves to contextualize the issue that this thesis targets. By offering a holistic review of energy waste and an overview of the psychological factors that influence behavior, the role of both of these elements in climate change mitigation becomes undeniable. The first part of this background will deliver details about waste derived from the education sector. Next, primary factors that shape or hinder behavioral intentions will be discussed, and the behavioral wedge will be introduced. Finally, the literature review will answer my first research question by identifying key strategies that have worked to induce pro-environmental behavior. This will be the basis for evaluating CU-Boulder energy conservation initiatives that implement the strategies discussed in the literature review.

Electricity Waste in the Education Sector

Every year in the US, 40 billion dollars are wasted on electricity for empty rooms in the household sector alone, equivalent to wasting half of our national coal usage (Laskey, 2013). All societal sectors contribute to this wasteful use of resources to a varying degree, and this use exerts stress on the environment without any applied benefit to consumers. For example, the service sector (which includes government, education, retail and more) accounts for 13% of national energy use (Lawrence Berkeley, 2013). Among this consumption of resources, electric lighting is responsible for 19% of total global electricity production, spiking to as much as 31% in the education sector where the management of natural resources, including energy and water use, is usually addressed in a 'laissez-faire' manner that allows students and other occupants to consume freely (Bonnet, 2002; Chappells, 2012). The subsequently high demand is reflected in the $10 billion spent on energy by American campuses every year, with some large universities using levels of electricity and water comparable to medium-sized cities (Bonnet, 2002; Goldstein, Cialdini, & Griskevicius, 2008). Within the US, colleges and universities use an average of 18.9 kilowatt hours (kWh) and spend an average of $1.10 per square foot on electricity annually, contributing to an estimated consumption of 279 billion kWh for lighting in the commercial and residential sectors (Dietz et al., 2009; Gardner & Stern, 1996). Wasteful energy use in academic buildings is avoidable because study spaces, lecture halls, residence halls, public restrooms, offices, and other areas often remain illuminated even when unoccupied, yet this waste could be minimized by incentivizing simple behavioral change (Chappells, 2012). While occupancy sensors can save 20%–26% of energy used for lighting compared to manual switches alone, behavioral incentives offer a less expensive – and subsequently more feasible and globally-accessible – alternative that can lead to immediate and free-standing reductions to annual energy bills (Gardner & Stern, 1996; Sioshansi, 2011).

Actions taken by individuals will be increasingly crucial as climate change progresses. According to the Deep Decarbonization Pathway Project (DDPP), a 5.5% annual decrease in per capita energy use will be necessary in order to meet an established target of 80% reduction to annual per capita carbon dioxide (CO_2) emissions by 2050 (Vandenbergh & Stern, 2017). This will be a growing challenge in the face of development, which consistently correlates with affluence in the shape of increases in airplane travel, average home size, and adoption of technologies like refrigerators, microwaves, televisions, computers, cell phones (Vandenbergh & Stern, 2017). All of these luxuries coincide with inevitable carbon demands, increasing our footprint and straying us further from the DDPP stated goal. Turning off the lights is considered to be a pro-environmental behavior because it reduces demand for energy from the environment and subsequently alters the dynamics of ecosystems positively (Groot & Steg, 2009). Because of the simplicity of this action among other pro-environmental behaviors, and given how often this action is overlooked, I predict that the reviewed strategies will demonstrate some effect on occupant behavior on campus.

Psychological challenges of behavior change

The knowledge that exists about how humans make decisions helps to illustrate the root of environmental problems, while simultaneously identifying methods to restructure patterns of human behavior to help eliminate waste. Psychology explains what individuals find most rewarding, pressuring, or impactful. This information can be used to encourage resource-conservative actions in areas of concentrated energy demand including universities, hotels, office buildings, and other publicly accessible settings. In these locations, individual behavior is especially challenging to target because employees, students, and other occupants have no direct financial incentive to reduce energy use, so they tend to remove themselves from the equation. These psychological challenges responsible for non-adoption of pro-environmental actions like turning lights off are summarized as anonymity, psychological distance, and loss of social cohesion (Baussan, 2015; Frey & Meier, 2003; Spence, Poortinga, & Pidgeon, 2011). When environmentally significant behaviors are performed anonymously, individuals may inherently feel that they can or should dismiss the responsible behavior due to the absence of consequences or rewards, leading to the free-rider problem (Odorzynski, 2016). By allowing for habits and problems to grow to scale, these social dilemmas increase and perceptions of individual impact shrink. Additionally, as societies grow and become more heterogeneous, social cohesion declines – the perceived social and moral responsibilities to others decreases and individuals lose trust that others are cooperating, leading their own motivation to dwindle (Baussan, 2015). Lastly, psychological distance acts as a barrier to behavior when individuals do not directly feel or understand the impacts of climate change on a regular basis. In other words, climate change becomes a phenomenon "outside of immediate attention" that facilitates "environmental numbness," and this poses a real barrier to mitigation practices in everyday life (Gifford, 2011). By examining what factors work best to convert this sense of numbness into motivation, I aim to target social norms on campus to create lasting impact. Through norm formation, cultural diffusion, and cooperation at a societal level, lifestyle changes that highlight efficiency could predictably contribute to 13% emissions reduction over the long term (Lawrence Berkeley, 2013). The growing affluence of the population renders such opportunities increasingly essential to counterbalance overconsumption trends (Sussman & Gifford, 2012). The growing consumption of energy observed in developed areas defies the decreasing cost of electricity and reflects an unsustainable combination of institutional growth and consumer behavior (Bonnet et al., 2002). With both of these factors at play at CU, evaluating energy conservation interventions will help to determine the best ways to change the norm on campus.

The Behavioral Wedge

Despite the need, behavioral strategies are often neglected due to the "value-action gap" – an observed lack of correlation between an individual's beliefs and behavior (Bhavani & Mohan, 2014; Cole & Van Boven, 2017). Though this pattern is observed in daily behavior, voluntary behavior change has been produced with improved information, social marketing, consumer pressure, and improved infrastructure (Kouchaki & Jami, 2013; Syme, Nancarrow, & Seligman, 2000). Energy reduction initiatives like these can target the "behavioral wedge," a proportion of emission cuts achieved by individual-scale adoption of pro-environmental actions. Though some behavioral interventions have failed as a consequence of inadequate design, other private and public initiatives have demonstrated noteworthy success, as in the cases of seat belt use, recycling, smoking, and adoption of low-emission technologies in households (Vandenbergh & Stern, 2017). While social marketing strategies aim to develop an ethic of sustainability and have demonstrated success in some areas, initiatives which incorporate design elements and education programs can be more effective in university settings where the demographic is largely made up of young adults (Chan et al., 2012; Farrow, Grolleau, & Ibanez, 2017).

Pro-environmental actions vary in technical potential (the level of energy savings achieved if 100% of non-adopters were to adopt an action), and in their behavioral plasticity (percent of non-adopters that can realistically be expected to adopt an action) (Dietz et al., 2009). That said, initiatives that aim to reduce the behavioral wedge should target actions with high technical potential and behavioral plasticity to ensure that enough people will adopt the change and that enough benefit will accrue from such changes. The resulting “wedge” of emission cuts could be generated by individuals simply making a habit of turning the lights off (Dietz et al., 2009).

In a survey administered by the Fall 2018 Environmental Psychology course at CU, survey respondents were asked how often they participated in various activities, one of which was “turning off the lights when leaving a room.” On average, respondents self-reported a score of 4.35 on a numeric scale for which 5 indicated “I always perform this action.” Despite high self-reported compliance, logger measurements suggest inconsistency with this report as control data recorded high levels of waste over the course of a week. That said, by studying what incentivizes people to act in environmentally-conscious ways, individual-scale mitigation efforts can become a part of climate change prescriptions; there is power in changing the public perspective about climate change from an issue handled solely by politicians, scientists and activists to one that is addressed by citizens themselves.

Literature Review

A focus on daily energy-saving behavior is becoming increasingly crucial. The International Energy Agency has predicted that energy used for lighting will grow 80% globally from 2006 levels by 2030 (Chappells, 2012). In the past, behavioral studies which motivate changes to occupant behavior have achieved energy savings from 5 to 30% (Dwyer, Maki, & Rothman, 2015). When it comes to energy saving habits, studies show a “foot-in-the-door effect;” attention towards basic actions such as turning off lights and computers can lead to larger scale and more consequential changes such as environmentally conscious travel mode choices (Nosek, 2012). In developed areas where technology is often accessible yet energy consumption is high, occupant behavior reflects a large portion of end-use behavior (Sioshansi, 2011). For example, the Bullitt Center in Seattle is considered one of the most energy-efficient buildings in the world with a measured energy consumption of approximately 376.6 kWh per square foot annually (Sioshansi, 2011). Nearly 33% of this consumption is directly attributable to occupant behavior, of which 16% is caused by electric lighting (Sioshansi, 2011). Though energy efficiency is achieved through the use of technology, energy conservation often requires an effort that may compromise safety, aesthetics, comfort, convenience, and/or performance (Sussman & Gifford, 2012). By investigating strategies that implement monitoring, education, design, and social norms on university campuses, a significant contributor to greenhouse gas emissions can be identified and, in turn, minimized.

The elimination of overconsumption via the rewiring of habits demonstrates the power of the individual in facing the global threat of climate change. By incentivizing environmental consciousness in human behavior through education programs, the establishment of social norms, the monitoring of energy use and the use of design elements, a tremendous saving potential can be realized globally. To illustrate this with concrete data, every 1,000 kWh saved by turning appliances off equates to $100 off one's utility bill (Gardner & Stern, 1996). An educational framework to target wasted energy use is necessary because people, and students in particular, engage in a range of energy-unconscious behavior. For example, Tufts University estimates that if students simply turned off their computers for six hours each night, $87,000 and 572 tons of greenhouse gas emissions would be saved (Marcell, Agyeman, Rappaport, 2004). Tulane University, which has a significantly larger student population compared to Tufts, conducted a similar study and found that if students were to turn off their computers, Tulane could save up to $300,000 a year ("Managin Energy Costs," 2003). Developing this habit – with appliances, lights and other electronics – can play a major role in mitigation efforts while helping on financial parameters. That said, behavioral change must be realized via the rewiring of habits. This study will attempt to determine which strategies are effective in doing so in hopes of motivating resource-conscious behavior.

Strategy 1 – Monitoring

Monitoring energy consumption allows for more thorough evaluation of energy efficiency and waste. This data is essential for pursuing energy savings measures that target occupant behavior (Cole & Van Boven, 2017; Swim et al., 2009). Oftentimes, a barrier to energy savings in public settings is the inaccessibility to information regarding occupant levels of consumption. Energy feedback allows for the relationship between one's actions and a given outcome to become more salient (Carrico & Riemer, 2011). Some universities have installed loggers that measure the energy used by specific appliances. This feedback, however, is typically used to address possible modifications to lighting, cooling systems, and insulation rather than to promote behavioral changes (Rewthong et al., 2015). Even so, studies have shown that monitoring a building's energy systems can bring about a 25% cut to annual energy bills (Gardner & Stern, 1996). For example, in a study that used group-level feedback presented monthly to employees via e-mail, a 7% reduction in energy use was measured. In contrast, the information-only control group increased its use by 4% (Carrico & Riemer, 2011). The energy savings realized from the feedback program saved an estimated $32 for every dollar spent, equivalent to about $5 per ton of carbon saved (Carrico & Riemer, 2011). In a residential study, a group of households was presented with daily feedback on electricity use, and researchers measured 11% less energy use in households that received feedback with information as compared to information alone (Carrico & Riemer, 2011). Even in the US Capitol, a new online tool called "My Green Office" that reports feedback to participants achieved a 74% reduction to the institution's carbon footprint only 18 months after its launch (Bin, 2012). In universities, these feedback-based strategies seem to be effective as well. One example is New Zealand's peak load warning system used at the University of Canterbury. This system functions by flashing orange lamps in every building when demand levels are reached or exceeded (Gardner & Stern, 1996). Though this system costs an initial $3,500 for installation, the university measured a payback period of only two months, with annual energy savings of about $21,000 (Gardner & Stern, 1996). While this intervention seems simple, consistent feedback to consumers has proven to be effective and is one of the ways that CU Boulder has tried to lower its energy consumption. Although it may be unfeasible to provide real-time feedback to students and faculty on campus, monitoring strategies can still prove effective - studies still show an association between relatively infrequent feedback reports and behavior change (Carrico & Riemer, 2011). Even so, efforts to make feedback more accessible and public are key and have been shown to be especially effective at reducing energy use in individuals who value energy conservation and/or desire to reduce his or her own usage (Carrico & Riemer, 2011). When surveyed, over 92% of CU students indicated a desire to lower their carbon footprint, so feedback strategies may hold great potential on this campus (Swim et al., 2011). At another university, students noted that the installation of meters with publicly displayed feedback in suites would be most effective in promoting environmentally-conscious behavior second to monetary incentive (Cole & Van Boven, 2017). This demonstrates the power of energy feedback as a way to motivate behavior change made possible by monitoring.

Strategy 2 – Education

While monitoring sets the stage for energy conservation strategies by increasing awareness of energy use, education about sustainability has demonstrated similar significance in altering behavior. The information deficit model (IDM) assumes that information creates knowledge, sparks attitude change, which, in turn, leads to action, and this is the basis for the efficacy of educational strategies in promoting pro-environmental behavior (Ehret, Sparks, & Sherman, 2016). Educational interventions include those that raise awareness, that provide information about what to do and why, public education campaigns, and others (Staats, Van Leeuwen, & Wit, 2000). Such strategies can increase individual awareness about environmental problems, enhance knowledge of environmental stress caused by behavior, and change perceptions of the advantages of behavioral alternatives (Groot & Steg, 2009). At the University of Toronto, Canada, students were provided with tool-kits that included resources and strategies for energy conservation actions with details about the environmental impact of specific behaviors, persuasion strategies, and an assortment of visual prompts which promoted sustainable behavior (e.g. stickers, posters, e-mail communications) (Chan et al., 2012). This interactive education in dorms was linked directly to lowered energy consumption. In China, the establishment of a Liberal Studies program that includes a sustainability module has demonstrated a clear increase in environmental knowledge. Upon completing the module, over 50% of students indicated changing their environmental behavior (Marcell, Agyeman, Rappaport, 2004). Unfortunately, these types of resource-based interventions are limited by specific institutions and the funds each allocates to environmental programs (Goldstein et al., 2008). Still, informational strategies like these have been shown to be effective, especially when they fulfill the following conditions: the targeted behavior change is easy, the primary barrier to behavior change is information, and the information is consistent with a person's values (McKenzie-Mohr, 2000). While turning off the lights likely meets all these criteria for most of CU's student body, this thesis focuses on this simple act because this type of change in habit would lead to emission cuts without sacrificing the well-being of individuals (Vandenbergh & Stern, 2017). By becoming more educated, individuals can become motivated to change their behavior. For example, when it comes to lighting, understanding the inefficiency of incandescent light is the first step to encourage transition to compact fluorescent lamps (CFL) or light-emitting diodes (LED) (which lose less energy to heat). Because LED bulbs require much less wattage than the CFL, they are more energy-efficient and longer lasting. Additionally, the operating life of a LED is unaffected by turning it on and off, while the lifetime of CFLs are reduced the more they are switched on and off. That said, the most efficient use of CFL lighting would mean turning off lights only when an individual is leaving for more than 15 minutes (Office of Energy Efficiency & Renewable Energy). This suggests that LEDs are the best option for lighting in the given context, and when used in conjunction with occupancy, daylight, or vacancy sensors, this technology could render waste practically obsolete. Even so, many obstacles render the widespread installation of these technologies unfeasible. Equipped with this knowledge, any individual can be motivated to act in a pro-environmental manner by heightening his or her awareness of his or her own impact.

Among education strategies, peer education may carry particular salience when it comes to pro-environmental activity because it combines education with the establishment of social norms. In particular, educational campaigns that target behavioral changes by modifying perceptions of normative actions within a community appear to carry the most influence upon group behavior. By using peers to motivate behavior change in conjunction with information, individuals are exposed to injunctive norms, leading them to believe that “other people in the group approve of this,” and to descriptive norms, leading peers to think “others are doing this” (Carrico & Riemer, 2011; Cialdini & Schultz, 2004). These educational strategies – most notably personalized information campaigns and energy programs advertised through community groups or informal social networks – carry an active role in reversing the value-action gap (Vandenbergh & Stern, 2017). Despite the studied relationship between social pressures and energy reduction, there are currently no established applications of peer education for the purpose of electricity conservation. In other domains such as food and safe sex choices, peer-based educational strategies have demonstrated noteworthy influence (Carrico & Riemer, 2011). This thesis will evaluate CU Boulder's implementation of education programs that target energy conservation. In particular, my review will look into the Eco-Visit Program hosted by the campus Environmental Center – a personalized in-home visit aimed to educate and inform homeowners and students alike with the help of peer educators.

Strategy 3 – Social Norms

Though education establishes necessary knowledge about sustainability, environmental consciousness can also be established through social norms. In the workplace where energy use is easily observed, individuals have noted feeling pressured to conserve energy, indicative of a vulnerability to normative influence (Carrico & Riemer, 2011). Social norms, defined as shared rules of conduct sustained by approval and disapproval that can have significant impacts on behavior (Faarrow et al., 2017). Norms are distinguished from habits, conventions, and legal rules in how they relate to public action; they may be especially salient in encouraging pro-environmental behaviors that are dependent upon collective action. They have been shown to initiate behavior change in studies where individuals are provided with information about common behaviors within a population (Vandenbergh & Stern, 2017). For example, fear of disapproval by neighbors or community members coincides with levels of lawn care (Swim et al., 2011). Similarly, in a study conducted in hotels, a standard environmental message which communicated the importance of environmental protection was much less effective in changing towel re-use behavior compared to a descriptive norm that informed guests that a majority of others participated in the program (Goldstein et al., 2008). In particular, the descriptive norm message yielded a 44.1% higher towel reuse rate (Goldstein et al., 2008). That said, messages that target normative aspects of energy conservation like this may hold much more influence on individual decision-making as compared to those that appeal to self-interest and social responsibility (Cialdini & Schultz, 2004). Sharing information about descriptive norms in a university setting would subject students to normative influence, and such strategies would likely be particularly effective in these settings given the average age of participants. Research on youth conservation programs has recorded noticeable gains in self-efficacy, social competence, and civic responsibility that is unique among the younger population (Swim et al., 2011).

The theory of planned behavior (TPB) identifies three key players that often shape behavioral intentions: attitude, perceived behavioral control, and subjective norm (Abrahamse & Steg, 2009). Subjective norm refers to the perceived social pressure to perform or refrain from a behavior (Abrahamse & Steg, 2009). Voting, diet choices, and environmental conservation are all examples of behaviors that have been shown to be swayed by these key factors (Abrahamse & Steg, 2009). While positive behaviors can come about from such perceived pressure, norms can likewise create obstacles to pro-environmental activity. For instance, when individuals find that their attitude or behavior is acceptable to the majority, their thinking can evolve into: "Well everyone does it," and they continue to perform undesirable behavior with little remorse (Crompton, 2008). Even so, if the strategies discussed work to shape social norms in pro-environmental ways, positive shifts can be actualized.

In an attempt to measure the influence of social norms on pro-environmental behavior, a study observed occupant light use in public restrooms and demonstrated that participants were 32.4% more likely to turn the lights off if they were off when they entered (Dwyer et al., 2015). When evaluating gender as a variable, the study suggested that women were far more receptive to social norms: 30.9% of women turned off the lights in a light-off initial status compared to only 9.6% of men (Dwyer et al., 2015). This study shows how individual choices can lead to shifts that can, in turn, drive societal gains. Additionally, changes that occur from norm formation can create intrinsic benefits, including a sense of competence, frugality, and participation (Swim et al., 2011). When pro-environmental behavior is pursued with intrinsic goals in mind, individuals become more motivated and persistent in behavior change (Crompton, 2008). Intrinsic motivation to commit to energy-saving behavior is not only becoming part of an ethos in small environmental groups, but throughout society at large, even in corporate culture as enterprises increasingly recognize the necessity of energy efficiency in the 21st century (Farrow et al., 2017; Martinez Patino et al, 2017). These broad environmental shifts hold tremendous potential, and their growing outreach promotes social cohesion that further motivates change.

Strategy 4 – Design

Design elements can also act to promote environmentally-conscious behavior by appealing to subconscious preferences. For example, identifying characteristics of light switches that attract users' attention can encourage energy-saving behavior in public settings (Farrow et al., 2017). A study which used different switches showed that simple, oversized, push-button on/off designs affected occupant behavior the most as they were perceived as easily identifiable, suitable for the context of use, safe, hygienic, and comfortable to use (Farrow et al., 2017). Past demonstrations of successful energy conservation from design have been observed in varied locations including streets and stairways. Sidewalk improvements, safe street crossings, street trees and lighting have all been associated with energy-saving travel behavior as more individuals decide to walk or bike (Farrow et al., 2017). Similarly, decorating stairwells was shown to correlate with increased stair usage in office buildings (Farrow et al., 2017).

Design elements in objects can also influence water and energy saving. For example, size and integrated user support in kettles were influential features in promoting energy conservative behavior (Farrow et al., 2017). The design of signs can influence behavior too. A study conducted in university classrooms found that lights were off for 52% of observations with a large sign, compared to 38% with a small sign and 11% with no sign (Moglia, Cook, & McGregor, 2017). This study revealed that the most important elements for targeting behavior change with signs include (1) the convenience of the target behavior, (2) the specification of this behavior, (3) the proximity of the sign to the behavior, and (4) the language used in delivering the message (Moglia et al., 2017). Similarly, interventions that manipulate design variables to achieve behavior change will be most effective when recipients of interventions recognize the relationship between their values and behavior, and when behavior is considered easy (Groot & Steg, 2009). An intervention's audience must understand why they should do something, the impact of their behavior, and how to best go about making the specified change in behavior (Groot & Steg, 2009). Equally, prompts should specify information regarding the target behavior, be considered important to the audience, be located near the place where the activity would take place, and be attention-grabbing (Moglia et al., 2017). In implementing a combination of these criteria, energy conservation initiatives can be tailored to suit psychological preferences.

Language is a significant element in design because it can convey different values and norms with underlying psychological factors. For example, studies show that the most effective language for changing behavior will communicate potential to achieve gains as opposed to potential losses (Carrico & Riemer, 2011). Another sensitivity exists between promoting guilt as opposed to shame when making use of guilt appeals in messages. While shaming language results in reflections of one's personal characteristics, guilt creates judgements of one's behavior (Swim et al., 2011). Equally, language must make the distinction between guilt for one's own behavior and for that of the groups. While some messages with guilt appeals may prove to be ineffective for more defensive recipients, these appeals have still been shown to carry influence (Swim et al., 2011).

Language can also be manipulated to appeal to the Schwartz Theory of Basic Human Values. According to this theory, human values are rooted in two overarching value orientations: self-enhancement vs. self-transcendence and openness to change vs. conservatism. Messages that convey self-transcendent values generate altruistic attitudes, encouraging individuals to prioritize collective well-being. Conveying such values in environmental campaigns has been tied to pro-environmental behavior, generally considered to be morally right. For example, when evidence of the impacts of climate change on health and well-being is presented, self-transcendent values drive increases to pro-environmental behavioral norms by increasing feelings of personal responsibility for behavior (Swim et al., 2011). Similarly, when people believe energy consumption has negative environmental consequences that harm others, they feel a stronger obligation to solve the problem by reducing their own use (Abrahamse & Steg, 2009). This moral obligation was observed in an experimental energy conservation campaign that used different types of messages to appeal to energy consumers. In the experiment, the control group received no message, the second group received a self-enhancement cost-saving message, and a third group received a self-transcendent message relating to public health (De Dominicis, Schultz, & Bonaiuto, 2017). The last of these interventions averaged 5.9% lower energy demand relative to the control group, compared to a slim 2% reduction associated to the self-enhancement message (De Dominicis et al., 2017). The similar use of self-transcendent elements in signs has been shown to deter behavior like littering in places like sport stadiums, cafeterias, movie theaters, parking garages, and high schools (Moglia et al., 2017). That said, linking altruism with pro-environmental behaviors with the aid of design elements can be both realistic and simplistic.

The specific objective of this thesis – to increase the number of lights turned off by university occupants – integrates many of the characteristics of successful design interventions: the targeted action is easy, the relationship between environmental values and the action is clear, there is no confusion about how to perform the action, and the impact of the behavior is evident. The different signs used during this experiment provide specific information about the target behavior, they demonstrate significance to the audience (especially via norm-conveying signs), and they were deliberately placed next to light switches to be located near the place where the behavior would take place. The designs of the signs vary in their attention-getting features, so it is expected that the more visually-appealing, norm-conveying signs will carry the most influence on energy use. Lastly, the act of flipping a switch does not clash with egoistic values as there are little to no personal costs at stake (Groot & Steg, 2009). This is the basis for my hypothesis and for my prediction that demand-side interventions can be used for small-scale yet important conservation.

CU Boulder Initiatives

CU Boulder has long held the reputation of an environmental steward in the education sector. Recognized as one of the top universities for sustainability in the country, CU acquired a Gold rating by the Sustainability Tracking, Assessment and Rating System (STARS) in August 2018, marking the third such rating since 2010 ("CU Boulder earns STARS," 2018). Overall, CU Boulder ranks 11th among US research universities in its STARS scores ("CU Boulder earns STARS," 2018). The university continues to make strides to reach Chancellor DiStefano's goal of becoming "nothing less than the global leader in sustainability" ("Energy Awarenenss," 2015). While many technologies have been installed around campus and are crucial to energy savings, CU has also implemented strategies focused on education, design, monitoring, and social norms.

Utility and Energy Services is a division on campus responsible for the design, operation, and maintenance of campus electricity infrastructure. Their goal is to provide the campus community with reliable, cost-effective utilities in an environmentally-responsible way (Utility and Energy Services, 2017). One of the division's initiatives is to monitor campus-wide utility distribution, including real-time monitoring of energy consumption and utility performance (Utility and Energy Services, 2017). Furthermore, the university makes such data accessible to the public via the EnergyCAPs website. On this website, energy costs are divided into categories, with electric consumption being the highest and most expensive. The website offers holistic time-series data and data about all consumption by building, all while offering an engaging user interface. Data from the website reveals that electricity costs for CU amounted to more than $14 million in the last 12 months (EnergyCAP Online). Although this program holds tremendous potential for the implementation of feedback-based initiatives, the website currently has limited outreach as it requires pro-activity on the part of university occupants to log into the site to view data. A system through which this data could be displayed real-time in lecture halls or office spaces may prove to be more effective and influential.

A few strategies on campus target social norms in the student body. In 2002, CU launched a campaign that aimed to integrate conservation into everyday life ("CU Boulder Energy Conservation," 2002). Using the tag name, "Turn off the juice," the campaign designed by the CU Environmental Center implemented design strategies with signs and stickers that targeted students, faculty, and staff at the university ("CU Boulder Energy Conservation," 2002). This strategy mirrors that of BC Hydro, a Canadian utility company which prides itself in sustainability. At this organization, a "Turn It Off" campaign used posters and stickers posted on manual switches and electric appliances. While only one aspect of the company's initiative, total electricity consumption was reduced by 12% reduction in 2 years (Bin, 2012). Similarly, as part of the CU campaign, 15 thousand campus light switches displayed the "turn off the juice" slogan in restrooms, offices, lecture halls, hallways, and all university spaces. Additionally, the campaign established an Energy Conservation Hotline that connects occupants to maintenance staff to report energy wastes around campus. To Robin Newsome-Suitts, CU-Boulder's Chair of the Campus Resource Conservation Committee at the time, this plan and its focus on behavior was seen as a direct and immediate initiative to achieve necessary emissions reductions before technical improvements could be made in the future ("CU Boulder Energy Conservation," 2002). More recently, the university continues to design and distribute signs and stickers that remind occupants to turn off the lights when they leave the room. These features, in combination with technological improvements, led to average savings of 23% in Regent Hall in only 4 months. The initiatives in Regent Hall diverted approximately 57,000 pounds of CO annually, equivalent to saving the university $22,000 ("CU Boulder Energy Conservation," 2002). The CU Buffs Live

Green Pledge is another program meant to target social norms as part of the Greening CU initiative. By voluntarily signing the pledge, students join their peers in one shared commitment: lower personal carbon footprint. Paired with a rewards program for additional incentive, this pledge encourages responsibility for one's own actions while being part of a collectively committed community.

Technologically, CU has the opportunity to fund many projects geared towards efficiency. For example, a lighting upgrade in Norlin Library in 2002 installed ballasts (devices which limit the amount of current in an electrical circuit) and T-8 lamps (energy-efficient fluorescents with a rated lifespan of 84,000 hours). These installations led to a 15% reduction to monthly energy use and the conservation of 80,000 kWh annually, or $42,000 ("CU Boulder Energy Conservation," 2002). The university has a blueprint for every new building that includes the installation of occupancy sensors and, more frequently, vacancy sensors. The sensors pair with the N-light, a switch with a simple "On" and "Off" push-button design. The N-light is a networked digital lighting control system that provides both energy savings & increased user configurability by integrating time-based, daylight-based, sensor-based manual lighting control schemes ("nLight Network Lighting Control," 2014). In some sense, this technology takes the occupant's decision out of the equation. While it has led to tremendous energy savings so far, it is only eligible for new and upcoming constructions. Because the older buildings on campus still contribute high levels of waste, occupant behavior is better suited to managing energy use. In these places, the installation of conduit wiring would be necessary for the n-Light to become compatible, and this would require that the whole lighting system be upgraded. This would entail retrofitting old infrastructure which is unfeasible given the current budget. Additionally, such costs are not likely to be paid back by the energy savings in any reasonable frame of time given the slim 10 cents per 1000 watts paid for electricity by the university. Although sensors may not be possible in all buildings, the campus has been replacing bulbs with LEDs since 2007. As an estimate, only 60% of bulbs are currently using this technology, indicating room for improvement and further savings in the near future at an affordable cost. To help illustrate potential savings, the UK had yet to replace 440 million light bulbs to LEDs in 2008, and, had this change been made, £1.2bn or over $1.5 billion of national savings would have accrued (Bhavani & Mohan, 2014). Even in the US, LED products made up only 12.6% of installations in common lighting applications in 2016 (Bhavani & Mohan, 2014).

CU's Environmental Center has also pursued feedback and informative interventions, one of the most established being the ECO-Visit program. This free service allows for students to gain feedback on energy and water usage, with tips and information about efficient behaviors and ways to conserve. The main goal of the program is to help students reduce their energy bills and ecological footprint with easy and fun tools and information. This form of energy conservation outreach is advertised as a service "for students by students" ("SCORE/ECO-Visits," 2015). The program uses peer education (in the form of free pizza for attendees) and is led by 2 students who perform efficiency installations, including CFL light bulbs and weather-stripping ("SCORE/ECO-Visits," 2015). The student leaders also have a conversation with residents to discuss targeted, personalized ways to conserve and reduce their energy bills. In one year, the Environmental Center will host 200 off-campus ECO-Visits in student residencies. While this is notable, there is little data that exists on the long-term effectiveness of the program in changing occupant behavior. Participants are only held to verbal commitments of improvement, and Environmental Center uses a follow-up phone call to confirm whether the commitment is upheld. Though this data is valuable, measures based in self-reports can be unreliable and inaccurate. Misinformation from self-reports is often high, especially given that occupants might feel guilty to admit to breaking commitments. Moreover, considering the size of the student body, the outreach that this program has is limited, and more rigorous post-visit data is necessary to ensure that this kind of program is effective long-term.

Lastly, CU has introduced the Positive Impacts Points (PIPS) program to provide students with financial incentives to encourage pro-environmental behavior. The program uses quick-response (QR) codes and a smartphone application to reward students for environmentally-friendly behavior such as re-using a water bottle, riding a bus and/or bike, recycling, etc. By allowing students to record their own behavior, users build up points and receive rewards for their choices in the form of ski passes, fitness class passes, gift cards, event tickets, etc. Such a strategy could be particularly effective because it reintroduces a major motivator for behavior: money. Financial incentives have long been recognized as powerful tools for steering decision-making, and this tool is equally influential in the environmental sphere. On a large scale, environmental technologies (such as renewable energy) accrue ever more investment as their price points become competitive and profitable. On a small scale, energy reductions can be achieved quickly when energy users themselves are financially motivated. For example, when BC Hydro integrated energy usage rates into employee performance reviews and used this data to determine annual bonuses, this created a potent motivation for participants and helped to achieve substantial energy reductions (Bin, 2012). The success of this technique may be particularly effective among university students, who are pressed for money. That said, PIPs and its influence on student behavior could shape norms and encourage more regular participation in actions that are often dismissed. Unfortunately, this program has yet to accept the placement of QR codes on light switches as the opportunity for users to free-ride (receive reward without behavior compliance) is too high.

Methods

To evaluate whether the university is successfully targeting occupant behavior on campus, I focused on existing interventions which aim to conserve energy. Among the strategies implemented on campus, this thesis focuses on the Environmental Center's distribution of energy conservation signs, and makes use of CU's monitoring software to provide energy usage feedback to occupants in my own sign design. These conditions will be compared in order to tailor energy conservation methods on campus and to forgo ineffective strategies. By testing multiple sign designs, I discerned whether signs that convey social norms carry more influence than those that do not, I assessed whether size of sign plays a role in efficacy, and whether energy consumption feedback contributes to changing occupant behavior. In evaluating each sign, I determined whether these interventions incorporate the strategies discussed: education, design, social norms, and monitoring. With permission from Building Managers, tests were conducted in a public restroom in Duane Physics (DUAN), and in a small classroom in McKenna Language (MKNA). I selected MKNA as my lecture hall location because it has yet to be technologically renovated, electricity accounts for 34% of all energy costs of the building, and the daily average cost for energy has risen 8.3% from the previous academic year (EnergyCAP Online). The building is equipped with conventional flip switches, and has very small lecture halls that are convenient for studying individual decision-making (compared to large halls). In my second location, DUAN Physics houses innovative technology, including timed light switches and the N-light push-button design. Even so, much of the building is ineligible for installation of these technologies due to cost barriers from existing infrastructure. There was no technologically advanced light design in the public restroom I used for conducting tests; the room was equipped with a conventional flip-switch. In this building, electricity is responsible for 56.7% of all energy use, and daily average cost for energy has risen 4% from the previous academic year (EnergyCAP Online). The restroom I chose has high levels of occupancy, so I predicted waste to be high. Because there is great psychological distance between occupants and the problems that arise from energy waste in both DUAN and MKNA, occupants likely feel less responsible for energy use and have less confidence in peers' responsibility, leading to weakened self-efficacy. Additionally, there are currently no planned or ongoing energy projects in either of these locations. Although all new buildings on campus will incorporate technologies that render occupant behavior obsolete, there is still vast waste generated from the technology-ineligible buildings on campus.

The HOBO UX90-006 light/occupancy logger used for this project is equipped with two sensors, an occupancy sensor which functions with infrared detection, and a light sensor. With this data, I was able to measure energy waste by examining the ratio of light on/unoccupied occurrences. These devices track with a high level of accuracy, taking note anytime the status in the room changes. The loggers collected data beginning on January 21st until March 10th, exclusively on school days (Monday-Friday) to best represent the behavior of students and faculty. The data was further divided between business hours (8am-5pm) and after business hours (5:01pm-7:59am) so as to isolate the time of primary energy waste generation. I collected control data to determine initial waste levels in both locations. Thereafter, I manipulated the independent variable in each location by introducing a different sign each week (refer to Appendix).

While the first sign in each location was chosen at random, the signs were alternated between locations to isolate the effect of each one. For example, if sign A was in Location 1 and sign B was in Location 2 in week 1, the signs would be reversed in the following week. Four of these signs were designed and distributed by the Environmental Center (signs A-D). Three of them (signs A-C) have identical messages, but are printed in three different sizes. The smallest sign (sign C) measures 2 in. by 1.5 in., the medium sign (sign B) measures 6 in. by 2.88 in., and the largest sign (sign A) measures 8 in. by 3.88 in. The purpose of including these three signs is to determine whether size rather than design plays a role. This in part replicates the set-up of the study that revealed lowest levels of energy waste corresponding to the largest sign (Moglia et al., 2017). The message on signs A-C dates back to CU's "Turn Off the Juice" campaign in 2002, and gently reminds occupants to "Please, turn off the lights when you leave & you can turn off climate change". The fourth sign, sign D, combines elements of social norm and design, and it is the largest of all signs used. This second design was created by the Energy Outreach Program in the Environmental Center and displays a message that invokes both descriptive and injunctive norms. The message writes: "92% of CU students want to lower their carbon footprint. Turning off the lights helps. Be part of the solution." This language inherently transmits self-efficacy and the perception that others would both approve of such action and perform it themselves. In addition to the more elaborate and targeted message, this sign measures 11 in. by 17 in. Given these qualities, I predicted that this sign would carry the most influence between signs A-D. Finally, I designed my own sign, sign E, based on the research I conducted for the literature review. This sign was printed at an intermediate size, measuring 8 in by 10 in. The message reads: "In December, MKNA used 4,544.00 kWh of electricity (1,136 kWh less than 2017). Still, that's enough to fully charge your phone daily for 2,272 years. You can make a difference: turn off the lights when you leave! #NETZEROCU." Similarly, the sign posted in DUAN reads: "In December, DUAN used 276,820 kWh of electricity, a 69,348 kWh improvement from 2017. Even so, this building contributed to 1,797 megatons of greenhouse gases in 2018, 114 more than 2017. You can help: turn off the lights when you leave the room! #NETZEROCU." The signs fit the following criteria: it (1) is attention-getting, (2) conveys self-efficacy, (3) provides energy usage feedback, (4) incorporates social norm, (5) is clear, and (6) shares a stated goal.

The light on/unoccupied measurements from the loggers will be compared for each condition using statistical tests, and a T-test will reveal whether significant differences exist in waste generated during business hours and after business hours. If a statistically significant difference is calculated, design, informative interventions, social norms, monitoring/feedback, or a combination of these likely have an effect on behavior. This information will be helpful for future university investments.

Results & Analysis

Among the strategies studied for this project, I hypothesized that design elements present in signs D and E would correlate with lowest energy waste. This correlation would be attributed to the social norms conveyed in the sign messages, the attention-grabbing features of the signs, and/or the energy-use feedback. Specifically, I predicted that my own design (sign E) would be most effective, and that the Environmental Center's design (sign D) would be second most effective. With this in mind, I hypothesized that the smallest of the four signs (sign C) would have the lowest level of influence.

During the first week of research, I collected control data in both locations with no experimental conditions present. This data revealed vastly different levels of energy waste in the two settings. In the DUAN public restroom, control data measured minimum waste amounting to

3.15 days out of 5, or 75.68 hours. In other words, the loggers recorded that the lights were on with no occupancy for a *minimum* of 82.60% of the time during the control week. The logger recorded occupancy for only 16.21% of the time. If we assume that typical fluorescent lights are used in this room and that these consume 32 watts per hour, 2.42 kWh of light were wasted in a single public restroom. Additionally, given that each kWh of energy consumption equates to .366 kg of CO_2, this room wastefully emitted .88 kg of CO_2 in a single school week. Alternatively, in the small MKNA classroom, the minimum waste amounted to just 0.04 days out of 5, or .945 hours, and energy waste was recorded 5.08% of the time, at minimum. This could in part be attributed to higher levels of occupancy, measured at 25.42%. In comparison, this classroom wastes approximately 0.03 kWh in a week, emitting a slim 0.011 kg of CO_2.

In the following weeks, energy waste was compared across multiple conditions. Results were recorded for five signs, and waste levels were compared during and after business hours. The impact of each condition on energy waste is displayed below.

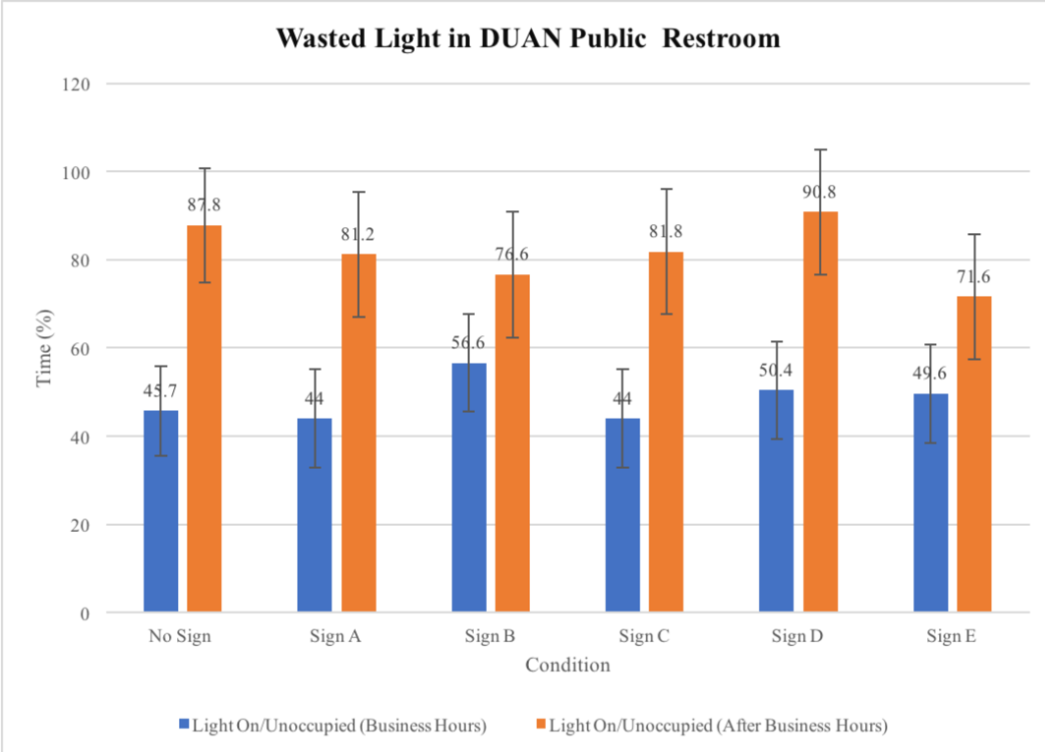

Figure 1: Energy Waste in DUAN Public Restroom. As in Figure 2, confidence intervals are broad due to limited data. Although all conditions are attributed to very similar levels of waste, there is a remarkable difference in waste originating during business hours compared to after hours.

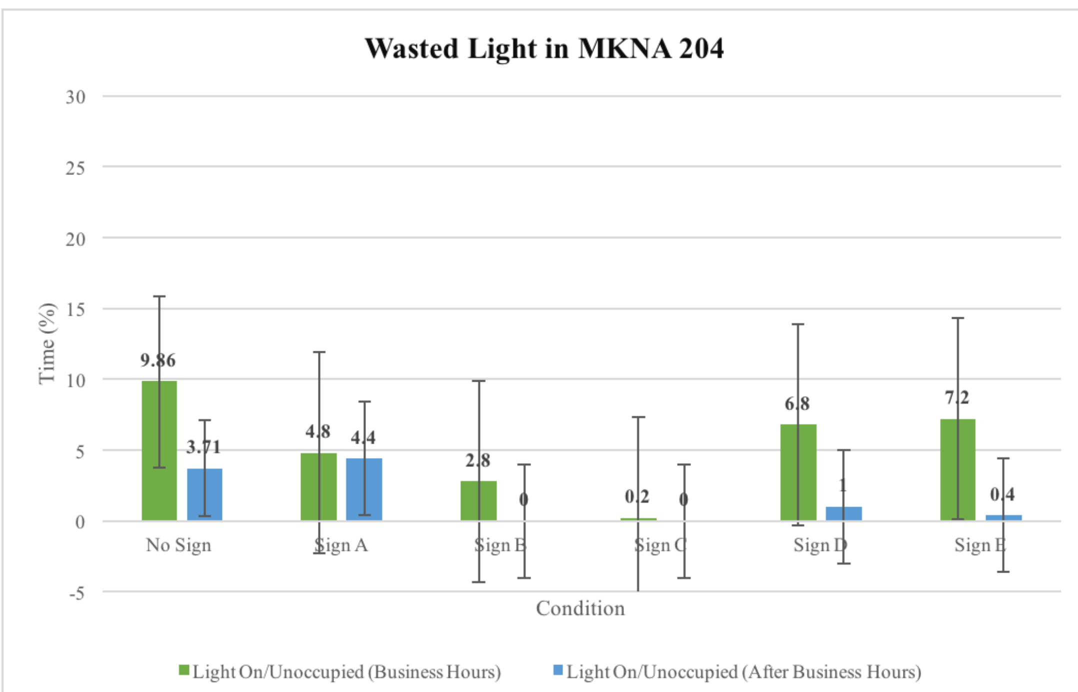

Figure 2: Energy Waste in MKNA classroom. Note the difference in scale of the y-axis on this chart. Confidence intervals are broad given the number of data points for each condition. In this Figure, sign C can be seen to be the most effective, and waste after hours is minimally lower than waste during business hours. The presence of any one condition is better as compared to the control during business hours, but this was not the case after-hours.

Overall, waste in MKNA remained much lower than in DUAN - a difference that could be attributed to room type and usage. I conducted a paired sample T test for each location to determine whether the difference between energy waste during and after business hours was significant. In the DUAN public restroom, the mean level of waste during business hours (.48 or 48% of the time) was much lower than waste after hours (.82 or 82% of the time) ($t = 8.51$, $p < .001$). In the MKNA classroom, this difference was more difficult to measure given the tremendously low levels of waste, and the opposite pattern was revealed. During business hours, mean waste (.05 or 5% of the time) was higher than after hours (.02 or 2% of the time) ($t = 1.775$, $p = .088$). The statistical significance of this pattern is marginal, suggesting that further study is required.

After collecting experimental data for each sign in MKNA, I conducted a univariate analysis of variance (ANOVA) to compare light waste during business hours across conditions, including the no-sign control condition. In this lecture hall, no condition was deemed to be more effective than the next [F (5, 26) = 1.11, p= .378]. Here, the F-value tests the effect of each condition and is based on the linearly independent pairwise comparisons among the estimated marginal means. A larger F-value represents greater dispersion between two variances, so the smaller value measured here is indicative of the groups being fairly similar. During the control week, the mean level of waste was recorded to be 9.9% of the time. In comparison, with sign A, energy waste was recorded 4.8% of the time, 2.8% of the time with sign B, 0.2% with sign C, 6.8% with sign D, and 7.2% with sign E (see Figure 2 in Appendix). I performed a linear contrast to compare the waste in the control week to the mean of all other sign conditions combined (i.e. to test whether the presence of any sign, relative to the no-sign control, had a significant effect). The difference in level of waste during the control week as compared to when conditions were present was not significant, with a contrast estimate of .055 (*p* = .11). Even so, I recorded the mean difference (MD) between the control week and all other conditions. The MD with sign A was calculated to be .051, indicating that waste was reduced by 5.1% as compared to the control. With sign B, MD was slightly higher (.071). Sign C looks to have created the largest impact, with MD equal to .097, indicative of a 9.7% reduction to waste. Sign D and E had the smallest mean differences, equal to .031 and .027, respectively. This suggests that the alternate hypothesis was more realistic in the present study: sign C was the most effective at reducing energy waste. Using sign C as a baseline for comparison, a MD of -.046 was recorded for sign A, indicating a 4.6% increase in energy waste when sign A was used instead of sign C. Sign B was less effective than sign C with a 2.6% increase to waste. Sign E was furthest from the waste levels recorded with sign C, with a MD of -.07 or a 7% increase in waste. Sign D was close behind sign E, measuring a MD of -.066. Although no one condition was responsible for statistically significant difference in energy waste, further study is required given that energy waste was still highest with no conditions present and that a difference in waste was recorded each week. This could indicate that no one sign is more effective than the next, but that having some intervention in place does make a difference. Otherwise, these findings may suggest that new and different signs altogether must be designed to better incorporate the studied strategies.

Next, I used an ANOVA test to compare levels of waste across conditions after business hours in MKNA. Again, the difference in energy waste between groups was not significant, but further study is necessary given the low level of confidence [F (5, 26) = 1.08, p= .394]. During the control week, the meal level of waste was 0.37, in other words, light waste was recorded 3.7% of the time. With sign A, waste was recorded 4.4% of the time. With signs B and C, waste levels were extremely close to zero (1.735E-16 and 3.469E-16, respectively). Sign D corresponded to waste 1% of the time, and sign E recorded mean waste 0.4% of the time. A linear contrast was conducted to compare the waste during the control week compared to the experimental weeks. The contrast estimate was calculated to be 0.026, but the difference in these two groups was not significant (p = .186). Compared to the control week, sign A recorded a MD of -.007, sign B of .037, sign C of .037, sign D of .027, and sign E of .033. When comparing to the most effective sign, sign C, sign A was less effective with a MD of -.044, sign B was immeasurably less effective, recording a MD of 1.735E-18, sign D reported a MD of -.010, and sign E measured a MD equal to -.004. This shows that sign B and C were most effective after hours, although waste levels for this time were close to zero. Given that these differences are so minimal, it is most useful to observe overall patterns, displayed in Figure 2 (refer to Appendix). The days with no intervention in place were second highest in recorded waste, and light waste after-hours was practically eliminated with all signs except A. Given that sign A was the first condition to be placed in MKNA, this pattern could be indicative of learned behavior. The same audience was present throughout the course of the study, and these occupants may have recognized the continuous stream of targeted interventions, leading them to act pro-environmentally with any condition present.

The same tests were run for the DUAN public restroom, and the high level of waste recorded in this location was conducive to better comparison across conditions. During business hours, sign A corresponded to energy waste occurring 44% of the time, sign B to 56.6%, sign C to 44%, sign D to 50.4%, and sign E to 49.6%. The first ANOVA for this location was run with data collected during business hours. As with the classroom location, the effects of all conditions and the difference in their efficacy were not significant [F (4, 20) = .847, p = .512]. If sign C is used as a baseline for comparison given that it was the most effective at this location, sign A had a MD of 0.000 (these two signs had the same exact impact). Sign B had a MD of -.126, sign D had a MD of -.064, and sign E's MD was equal to -.056. The similarity between all conditions is apparent in Figure 3 (refer to Appendix). After performing a linear contrast to compare the levels of waste during the control week with all other experimental weeks, the calculated contrast estimate was .074, indicating no significant difference between the groups (p = .298).

A final ANOVA test was conducted for the DUAN public restroom after business hours, when waste was measurably higher. Again, the effects of all conditions were insignificant [F (4, 20) = .926, p = .469]. With sign A, waste was recorded 81.2% of the time, 76.6% with sign B, 81.8% with sign C, 90.8% with sign D, and 71.6% with sign E. In the after-hours period, sign E had the most positive impact on energy waste, and will thus serve as the baseline for comparison. Compared to sign E, sign A's MD was -.096, sign B was -.050, sign C was -.102, and sign D was -.192. That said, sign D seemed to be the least effective, followed by sign C. This is inconsistent with the patterns observed in the MKNA location. A final linear contrast test for this data set revealed a contrast estimate of -.033, indicating no significant difference between the control week and the experimental weeks (p = .557). Thus, the most prominent and significant discovery was in the inefficiency and high level of waste that originates after business hours in the public restroom.

Discussion

This study aimed to determine the feasibility of achieving energy waste reductions by changing individual behavior through cost-effective interventions. By carefully tracking occupancy and light status in two campus locations, I determined where waste reduction was most imminent, and observed whether waste could be reduced using certain demand-side interventions. By recording levels of energy waste, I evaluated the effectiveness of current interventions used on the CU campus, while offering an alternative that combines the empirically-tested evidence discussed in the literature review. That said, the goal of this study was to tailor energy reduction efforts on university campuses without expensive technological investments. This gives insight into climate change solutions and whether or not individuals can be depended upon for related goals.

A few conclusions can be drawn from this study regarding occupant behavior and the source of energy waste. First, while I assumed that some signs would carry more influence than others, this did not appear to be the case. Even so, energy waste was reduced in the lecture hall with the presence of an intervention as compared to when no conditions were present. Additionally, waste in the lecture hall was much lower as compared to the public restroom. This could be attributed to the fact that in a lecture hall, occupancy is more evident and public than a restroom. Thus, the last occupant leaving the classroom probably feels more responsibility to turn the lights off in the absence of students and faculty. Despite the bathroom for this study only having 3 stalls, occupants may be hesitant to turn the lights off because this might require checking for vacancy. Especially when a public restroom has multiple stalls, I predict pro-environmental behavior to be even less likely as it is not habitual to check for others upon one's own exit. That said, although levels of waste in restrooms are very high, it may not be feasible to depend upon occupants to lower the waste since they do not seem to feel as personally accountable for that location's energy usage. Some restroom occupants might even think turning the lights off is disrespectful towards future occupants who walk into a dark room. That said, the strategies tested in this study could be more effective in single-user public restrooms where the decision inherently lies on one individual at a time.

The difference between business hours and after-hours waste in the public restroom was the most significant result of the study. In the DUAN restroom where waste remained high throughout the course of the study, I observed after-hours waste levels that were nearly twice as much as those collected during business hours. After classes, no individual is responsible for making sure that energy supply is shut down for the day. One solution might be to install vacancy sensors, which, as compared to an occupancy sensor, would depend on an occupant to manually turn on a light and on the sensor's detection of vacancy to turn the lights off. Vacancy sensors are particularly effective in public restrooms because, unlike occupancy sensors which supply 30 minutes of light at minimum, the lights are turned off immediately when vacancy is detected. The thirty-minute interval of light supplied by an occupancy sensor is inherently wasteful because occupants are often present for shorter intervals of time. Because the campus has no means with which to install the more effective vacancy sensors in older buildings like DUAN and MKNA, the most feasible solution to after-hours waste is to identify and designate individuals who are willing to turn the lights off after business hours.

To target this same issue, Cornell University has launched the "Lights Off Cornell" campaign to minimize wasted electricity throughout campus by engaging student volunteers to turn off the lights after hours in academic buildings ("Light Off Cornell"). The volunteers use a "Lights Off Cornell" smart phone application to record data to help estimate energy and financial savings ("Light Off Cornell"). It was estimated that such a program could not only help to eliminate unnecessary light usage, but could save the university $60,000 per year. This project is run by a committee of students and managed by the Office of Energy and Sustainability, now part of the University's Climate Action Plan. Such a program could easily be replicated at CU's Environmental Center, especially if studies were conducted to identify prime locations for energy waste generation after hours. Another solution follows Stanford University's footsteps, where the Stanford Energy Systems Innovations (SESI) project transformed the university's energy supply from 100% fossil-fuel-based power plants to grid-sourced electricity and an electric heat recovery system (Sullivan, 2016). This new system, along with Stanford's solar power procurement, has reduced campus emissions by 68% from peak levels (Sullivan, 2016). If renewable energy could be used to supply energy to CU's older buildings not fit for the N-light and vacancy sensors, then the waste that occurs would not be of much, if any, concern.

Although comparisons between conditions were deemed statistically insignificant, it is important to recognize the patterns observed. In both locations, sign C seems to have reduced energy waste the most. This may indicate that the size of the sign rather than the message could be most important, but sign C was the smallest of the set. The positioning of this sign directly above the switch may have played a part in its positive impact on waste. Another pattern that warrants further study is in the relationship between room type and level of energy waste. Although MKNA's classroom had remarkably little waste, this is not likely to be the case in all lecture halls around campus. It would be helpful to know what style of lecture hall correlates to highest levels of waste. Additionally, further study could define the relationship between waste and time of day to determine whether this is consistent across lecture halls, public restrooms, and other university settings.

In total, the measured waste from this study shows clear inefficiencies that could be dealt with simply and inexpensively. In 33 days of week-day data collection in 2 locations, a total of 659 hours of light was wasted on empty rooms, contributing to the high levels of electricity consumption in both buildings. As noted on my designed sign, the DUAN physics building consumed 276,820 kWh of electricity in December, and that was a 69,348-kWh improvement from 2017. Even so, this is no grounds to assume a consistent trend. One month later in January, usage was recorded at 375, 197 kWh, and this was 20, 389 kWh more than the previous year (EnergyCAP Online). DUAN consumed in one month the equivalent CO_2 emissions that approximately 50 cars would produce in an entire year. In MKNA, a similar pattern was observed where December usage was 1,136 kWh less than 2017, but in January, energy demand was 48 kWh higher than 2017. The resources on campus, like the EnergyCAP website used to collect the above-mentioned data, should be instrumental in achieving the campus-wide commitment to sustainability.

While the data collected in this study is valuable and can be used to tailor energy conservation on campus, a few limitations must be taken into consideration. First, the size of the study and the resulting data set were limited in size. Ideally, this test would have been conducted in more than 2 locations. I would like to replicate the performed experiment in many more locations to identify characteristics of restrooms and lecture halls most receptive to the interventions. I would conduct the study in lecture halls with higher initial levels of waste, and with a diverse set of light switch designs. Furthermore, the restroom used for this study was a women's restroom, and it would be interesting to determine whether any differences in behavior are attributed to gender. Another limitation is inherent in the study not being purely controlled - the changes that occurred week to week were not accounted for. For example, the study did not account for changes in the occupant audience. Given that the experiments occurred during the spring semester, data was likely pooled from a consistent population, but this is not easily confirmed. Lastly, if time permitted, it would have been helpful to collect baseline data with no interventions between each sign to further isolate the effect of each condition and to ensure that no one condition had a lasting effect as opposed to each sign having the same one.

More than a quarter of energy use in non-residential buildings is used for lighting (Lawrence Berkeley, 2013). Similarly, the US economy was calculated to be consuming energy at 39% efficiency in 2012, its lowest rate ever. This level of annual energy waste in the US is enough to power the UK for seven years (Lawrence Berkeley, 2013). By studying streetlights alone, it was determined that 22,000 gigawatt-hours a year are wasted on unused lighting. Under conservative measures, this would amount to $2.2 billion a year, which is enough to fund a mission to Mars annually (Filmer, 2013). Undoubtedly, the waste of light in buildings adds a significant amount of inefficiency (Lawrence Berkeley, 2013). In 2009, Boston University conducted a study to determine potential improvements if individuals on campus turned off their lights ("Turn Off the Lights"). By turning off the lights when exiting a room, an individual can reduce his or her greenhouse gas emissions by 0.15 pounds per hour ("Turn Off the Lights"). Taking this data into account, Boston University estimated that if everyone on campus turned off one light, for one hour a day, for one year, 733, 475 kWh of electricity use, or 1, 161,000 pounds of CO_2, could be diverted annually ("Turn Off the Lights").

On a broader scale, the data presented in this study is important for its focus on a sector that is often not at the forefront of climate change discussions and solutions. In 2005, US institutions of higher education accounted for approximately 121 million metric tons of CO_2 equivalent, making up 2% of total annual US greenhouse gas emissions (equivalent to 25% of California's emissions) (Sinha et al., 2010). Purchased electricity, stationary combustion, and commuting account for approximately 88% of such emissions, and much of the waste generated from these sources is avoidable. More than ten years later, many universities are seeing rising trends in energy use as they expand and advance, and the new, innovative technologies that prioritize long-term sustainability are seldom the priority. Additionally, many universities, including our own, do not have the budget to incorporate the needed technology. Studying occupant behavior to target the demand for energy is a strong alternative. Simple strategies can and should be pursued since the origin of most energy waste comes from unused lights, and also given the insufficiency of many existing interventions on campus.

The strategies discussed in the literature review warrant further study in university settings. Here, the force of social norms carries extensive power as college students aim to fit in and be part of the majority. Given that CU has already put in place programs and initiatives rooted in the discussed strategies, it is clear that energy conservation must be tailored further to render such interventions more influential and effective. First, I recommend that studies be conducted on light switch designs to determine whether uncommon designs can be installed at similar prices while being more effective than the conventional flip-switch. Similarly, it would be helpful to retrieve data on the N-light system currently being installed in new CU buildings to calculate the impact of such changes. Next, I recommend that the university try additional monitoring and feedback strategies. Although we have a great service, EnergyCAPs, that provides access to students and faculty, the website is hardly used and thus should be broadcasted in other ways. Future research related to monitoring might include a survey which asks CU students and faculty whether or not they are aware that such a website exist, and whether or not they access this data. The survey could determine whether students are even interested in such feedback, or whether they find another method of information delivery more effective. That said, energy feedback has consistently been found to correlate with energy reduction in past studies. Broadcasting the EnergyCAPs data in a more public manner would be interesting and would likely correlate with positive impacts on the university's energy use. Next, the existing study on social norms in public restrooms should be replicated in a university setting to determine whether differences exist between the general population and a student-based one (Dwyer et al., 2015). This would entail manual manipulation of light status after every individual entry to see whether a light-off status upon entry is more often tied to a light-off status upon exit. This would determine whether university students are influenced by social norms and the decisions of those around them, which I predict they would be. In addition, data should be collected to determine the total outcome and outreach of CU's Eco-Visit education program and the PIPs Rewards program. For example, it would be helpful to meter and monitor the energy use of the ECO-Visit participants to determine whether the education program has a short-term or long-term, if any, effect on household energy consumption. Lastly, studies of occupant behavior could be divided among variable demographics to determine whether age, financial class, or other factors play into this complex approach to energy conservation.

Conclusion

Energy efficiency is an ongoing activity that requires constant attention and re-evaluation given the evolving body of knowledge in climate science and conservation. In this thesis, I found that the initiatives currently in place to target occupant behavior and encourage pro-environmental decisions are far from achieving energy savings shown in other case studies. Given that many of the existing interventions are limited in their outreach and effectiveness, tremendous energy savings could be achieved if these were revised to become more public and community-based. No condition in the present study significantly reduced waste, but it is possible that other methods may carry much more influence on an audience of university occupants. Many strategies discussed in my literature review have yet to be tried on our campus, so further study could be worthwhile given the high levels of waste that I recorded. Equipped with an understanding of the main culprits of waste and the types of locations where such waste is most prominent, the university can further improve and tailor energy conservation initiatives. The instruments currently in place provide an excellent starting point which CU can build on to achieve greater and lasting energy waste reductions.

As we learn more about the scope of climate challenges, the role of the individual becomes apparent and undeniable. As behavioral norms adapt to the growing affluence of the population, it is essential to incorporate efficient behavior patterns that counterbalance the overconsumption trends in developed areas. Especially in public spaces where actions and decisions are not tied to financial rewards or repercussions, targeting occupant behavior is a challenge that still has many unanswered questions and warrants further study. Current energy conservation initiatives on campus are limited in their effectiveness and outreach, yet simple solutions can be put in place to achieve immediate, cost-free energy savings. Interventions that combine the strategies discussed in my literature review should be explored further to tailor energy conservation initiatives on our campus. Given CU's zero waste goal, one should not look beyond such an important potential source for energy waste reduction. The people on our campus and in our community are motivated to reducing their impact, and we must bridge the gap between these existing values and the behavior that does not always coincide. Given that prior studies have created note-worthy reductions to energy waste, I am confident that similar results can be replicated here and established throughout the education sector. The solution may lie beyond any campaign or sign design. Instead, we must depend on a combination of known factors to get to the root of how humans make decisions, and this requires exploratory initiatives to determine what might be most effective. The combination of this university's tightknit communities and CU's commitment to eliminating waste mean this is only the beginning of energy conservation for our campus. This university is renowned for its environmental ingenuity, and thus it is necessary that we are leaders in furthering the energy conservation initiatives for CU and universities around the world. As time progresses and psychological distance from the root issue of climate change decreases, it will become apparent that we all carry a strong role and responsibility in resolving one of today's largest threats to our well being and future. It is only a matter of time before we realize the inevitability of our participation, and CU's establishment in the environmental community gives opportunity to set precedent for other universities to follow. Armed with motivation, knowledge and community, the outcome is bright.

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Appendix

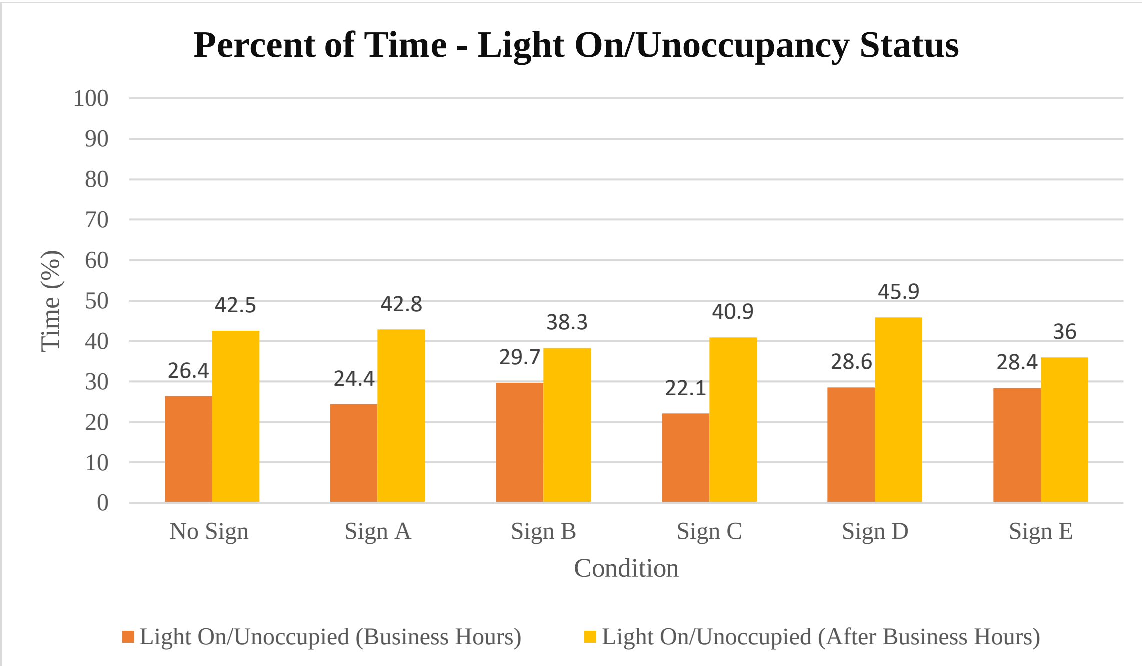

Figure 1: Combined waste in both locations – During and after business hours. This figure combines data from both locations for a holistic review of waste patterns around campus across multiple room types. Given that waste levels in DUAN were significantly higher, this figure is skewed by that data set. Even so, the significant difference between waste during and after hours is shown.

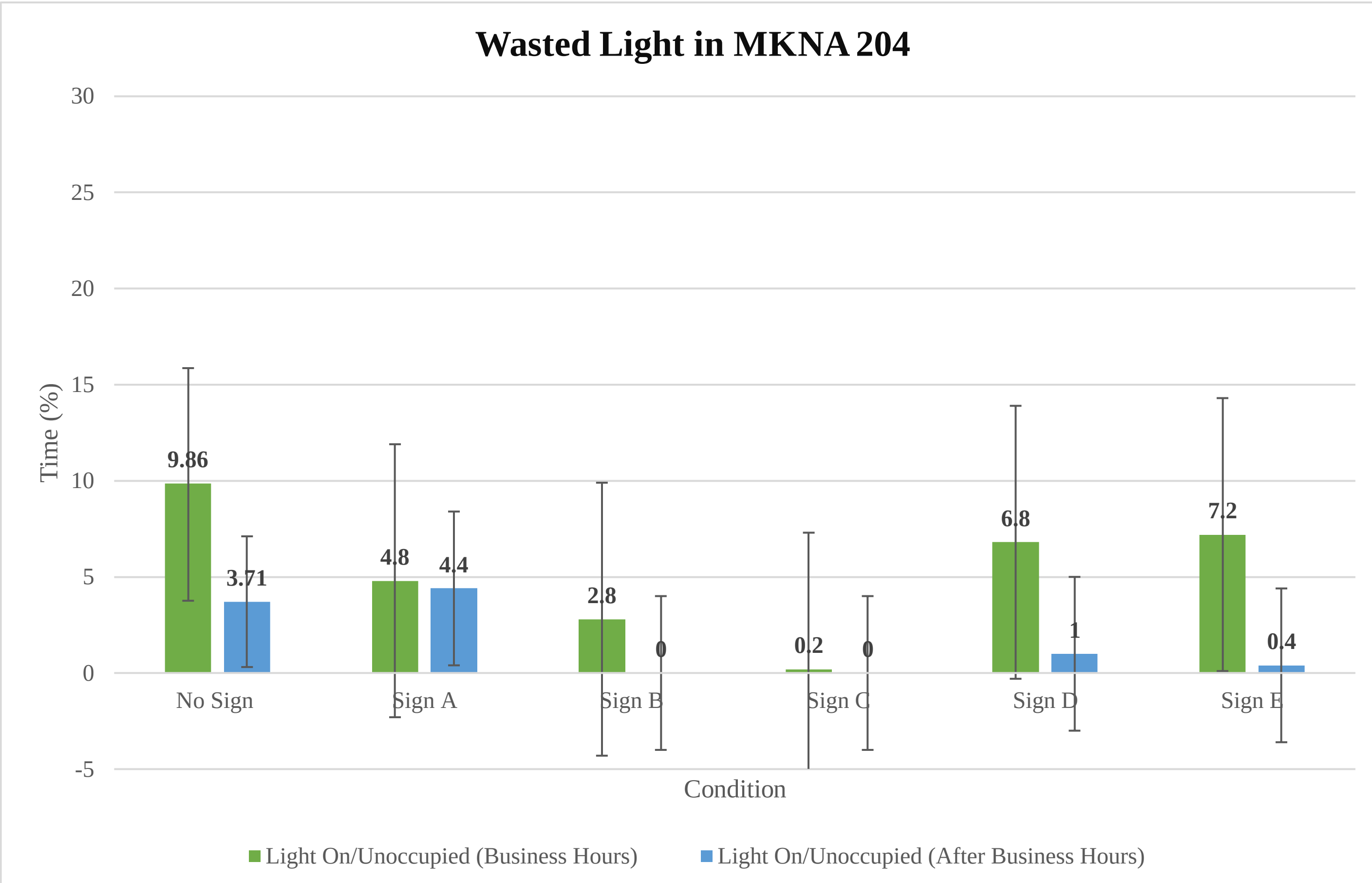

Figure 2: Energy Waste in MKNA classroom. It is important to note the difference in scale on this chart compared to Figure 1 and 3. Confidence intervals are broad given the number of data points for each condition. In this Figure, sign C can be seen to be the most effective, and waste after hours is minimally lower than waste during business hours. Additionally, the presence of any one condition is better as compared to the control during business hours, but this was not the case after-hours.

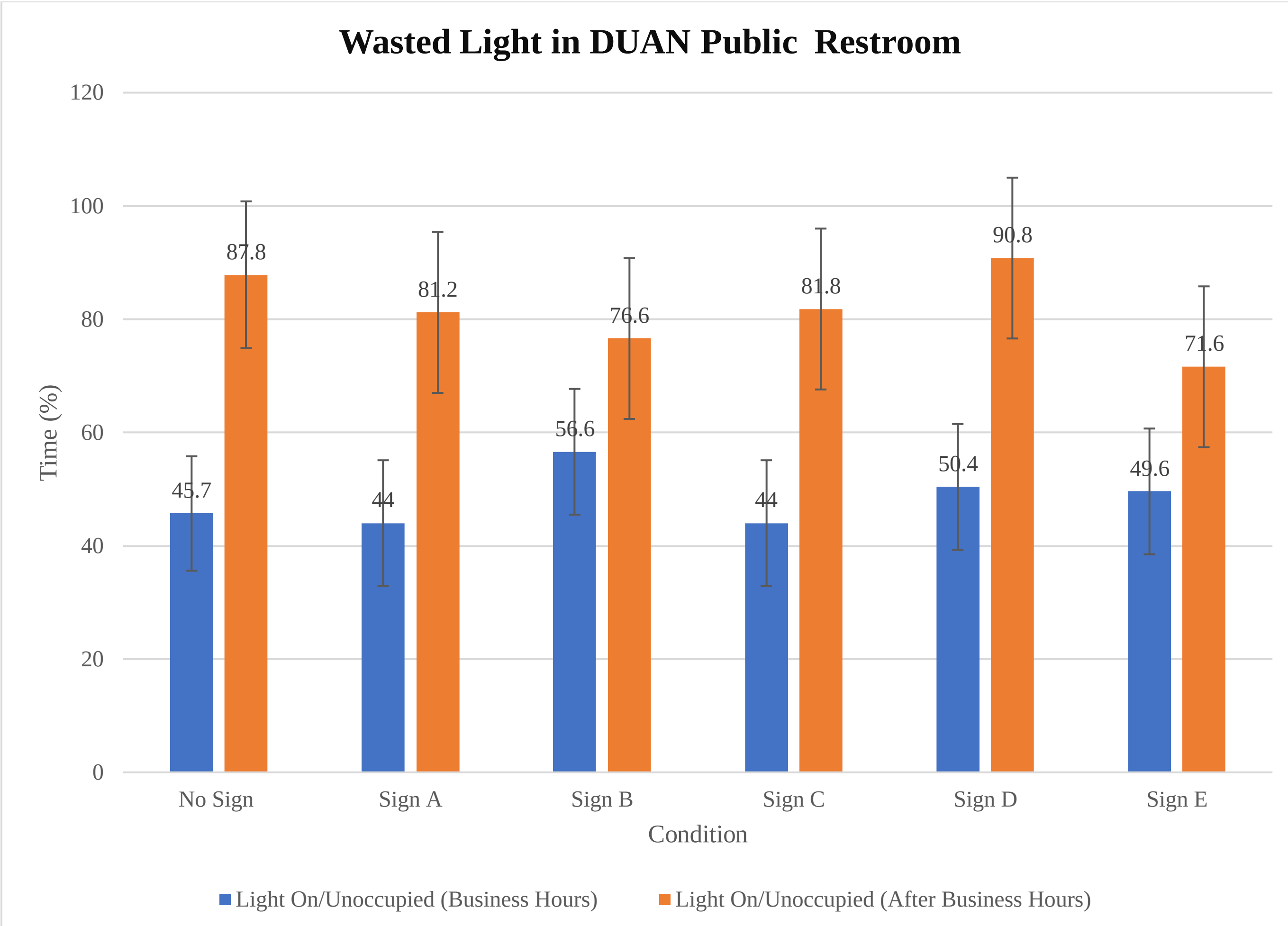

Figure 1: Energy Waste in DUAN Public Restroom. As in Figure 2, confidence intervals are broad due to limited data. Although all conditions are attributed to very similar levels of waste, there is a remarkable difference in waste originating during business hours compared to after hours.

Figure 4: Sign E for DUAN public restroom. This sign was designed based on empirical studies which discuss successful design elements. The sign includes energy feedback, is attention-getting, includes a stated and shared goal, and also includes elements of education.

Figure 5: Sign E for MKNA classroom. This sign was designed based on empirical studies which discuss successful design elements. The sign includes energy feedback, is attention-getting, includes a stated and shared goal, and also includes elements of education.

Figure 6: Sign A-C. This sign was designed by the university and printed in multiple sizes. All sizes were tested in this project, from small to large to determine whether such a difference carries influence on occupant behavior. The sign design was also chosen because of its simplicity and corresponding lack of elements including social norm messaging and information. Even so, this sign does convey self-efficacy.

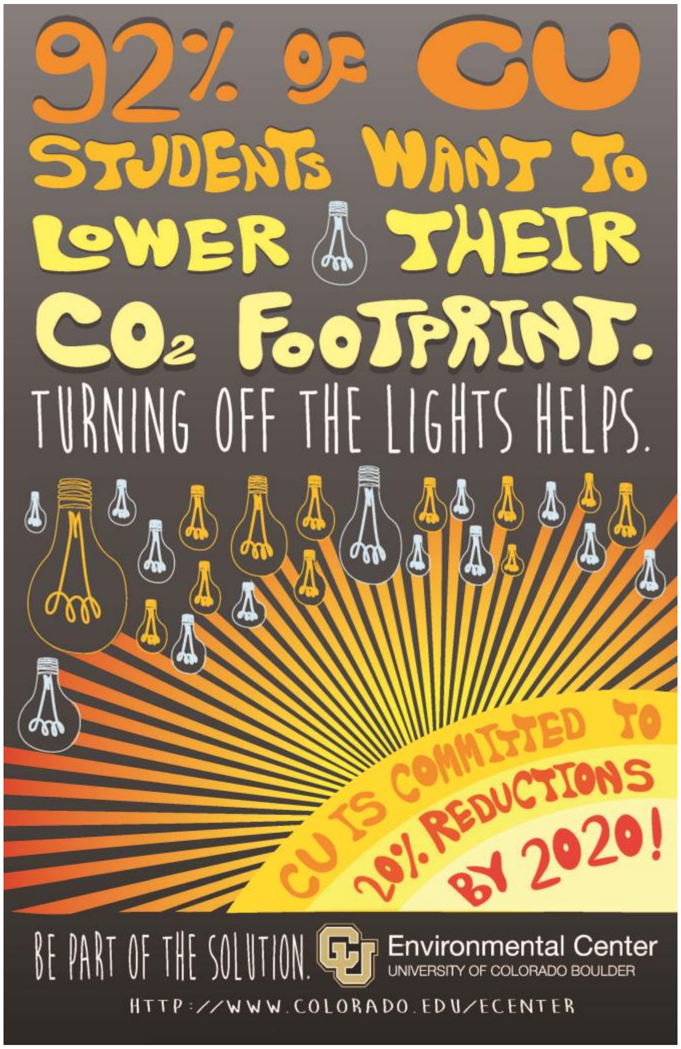

Figure 7: Sign D. Shown in the middle of this set of three, sign D was designed by the Environmental Center with a goal of creating something more eye-catching and effective than sign A-C. The message displayed conveys social norms and self-efficacy in an attention-getting manner.