Elevator Energy Audit:
An Analysis of Elevator Energy Efficiency at Boston College

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Abstract

· As more and more efforts go into climate change mitigation, it is our responsibility as the consumer to reduce our consumption of energy and our toll on the environment. However living in an industrialized society can pose challenges to conservation as it becomes easier to take resources like energy for granted. We decided to research a narrower field of energy consumption and determine more about the elevator usage on Boston College's campus. Often elevators are used in place of stairs out of convenience and ease, but in doing so, a large amount of energy is expended that could have been avoided under some circumstances. With our research, we hoped to determine possible options for reducing energy consumption with elevator use on campus. We hoped to determine how often people use elevators, how much energy the elevators in Maloney Hall and the Commonwealth Avenue Garage consume, and how many elevators are on campus. Ultimately, we hope to determine how people can be incentivized to use the stairs as well as discover alternatives to using elevators. We installed a monitoring device on an elevator in Maloney Hall and one in the Commonwealth Avenue Garage. We also created and distributed an online survey to better understand the Boston College community's habits in regards to taking the stairs or the elevator. A brief in-person survey was also done which confirmed the results from the online survey. Lastly, we staged an intervention by placing signs around the elevators to encourage the use of stairs. Through these efforts, it was determined that time and physical exertion were the two most common reasons people elected to take the elevator over the stairs. It was also learned that most people when they are considering their energy consumption do not factor in their elevator usage. Through the monitoring, we were able to determine that the Maloney elevators are substantially more efficient than the Commonwealth Avenue Garage elevators, and that during the intervention, there was a 21% reduction in energy usage from the elevator. With these findings, we recommend that Boston College continue to pursue their efforts to reduce community member's elevator usage by continuing with the interventions and by installing more efficient elevators and better stairwell placement during new construction projects

Introduction

As greenhouse gases are emitted at increasing levels across most of the world, global climate change has become one of the most pertinent political issues of the 21st century. As long as fossil fuels are the primary source of energy worldwide, nations will continue to emit dangerous amounts of greenhouse gases while depleting nonrenewable resources. It is crucial that renewable energy alternatives are implemented on the supply side of the equation; however, if nations are to successfully mitigate the effects of climate change, they must also be aware of ways in which they can decrease the energy consumption of consumers. As more companies have invested in energy efficiency technology, engineers have gained a better insight into how our large buildings consume electricity. Moreover, a number of manufacturing revolutions in the construction industry have led to the production of more energy-efficient heating and air-conditioning systems, lighting fixtures, and kitchen equipment. Nevertheless, elevators and escalators have received little attention from this perspective (De Almeida, 2011).

As of 2013, elevators accounted for approximately 1.2 billion kWh of energy consumption in the U.S. alone. In other words, the U.S. elevator energy use is comparable to the total energy use of Connecticut, Utah, Ireland or Denmark (Sachs, 2015). Research has shown that the amount of energy consumed by elevators and escalators can account for approximately 5-25% of the total energy consumption of a building (Adak, 2013). Furthermore, the number of elevators installed in commercial buildings is set to rise significantly in the coming decades. Some of the current trends contributing to a rise in elevator installation and use include further urbanization in developing countries, growing awareness of accessibility issues, an ageing population in many western countries as well as a rising demand for convenience (De Almeida, 2011). Traditionally, the energy use of elevators has been perceived as relatively small (less than the amount of the service contract). However, as more monitoring capabilities have come online in the last decade, researchers have been able to more closely monitor the electricity consumption of elevators. Thus, an elevator energy audit of Boston College has the potential to expose more energy-intensive elevators while also providing suggestions to decrease the overall consumption of elevators on campus.

Boston College currently has a total of 74 elevators that help approximately 14,100 enrolled students, 758 full time faculty, and 2,509 administrative, professional, and support staff reach all corners of the campus (BCOIR, 2013). Among these, there are two main delineations in the mechanics of the elevators. Approximately 46% of the elevators on campus are considered hydraulic elevators. These elevators are relatively inexpensive but limited to low-rise service (Sachs, 2015). A large hydraulic cylinder is placed beneath the elevator cart. In order to lift the cart, a hydraulic fluid such as petroleum is used to drift the cylinder upward to its destination. Some examples of hydraulic elevators on BC's campus include the Commonwealth Avenue Parking Garage, Voute Hall, and Lyons Hall. The remaining 54% of elevators on campus are comprised of traction elevators. These models are frequently used for mid-rise to high-rise buildings and can be found in Maloney Hall, Gasson Hall, and Stokes Hall. Traction elevators generally have counterweights that weigh about as much as the car plus about 40-50% of its rated load. They are lifted by steel cables or, more recently, by flat, plastic-coated steel wire belts (Sachs 2015). Beyond the physical lifting of each elevator car, elevator systems consume a significant amount of energy for lighting, ventilation and controlling operations.

While it is necessary to research the overall efficiency of an elevator for an energy audit, it is also important to analyze the motivations of their users. In other words, what does it take to convince people to take the stairs rather than an elevator? A number of physicians and public health officials have have tested this question and concluded that "there is strong evidence that point-of-decision prompts are effective in increasing the use of stairs" (Soler, 2010). According to one study performed at the Maastricht University in the Netherlands, the use of prompts increased the amount of stair-takers over a four week timeframe by approximately 8.2% (Nieuw-Amerongen 2011). As part of this energy audit, we found it necessary to also test the he hypothesis that signage promoting stair usage will achieve its goal among the BC population.

No previous energy audit has been conducted on elevators at Boston College. Moreover, no survey has been conducted to determine the campus's elevator usage habits. Based upon this current lack of knowledge regarding energy use of elevators at Boston College, there is much room to optimize practices, increase efficiency, and encourage stair use among students and faculty.

No matter how large or small the movement is, sustainability initiatives have the potential to reduce greenhouse gas emissions and promote a greater quality of life for all. Improving the energy efficiency of elevators on campus and reducing their overall usage has the potential to drastically reduce the amount of electricity that is consumed at Boston College. In doing so, BC can aim to more closely align their consumption habits with their mission statement on sustainability: "Boston College recognizes that there are limits to the world's resources...the university is committed to conserving resources and reducing the impact that its services and activities place on the environment" (IMP, 2009).

Thus, the primary goal of this project is to better understand the energy consumption of Boston College's elevators in order to offer suggestions for a reduction in electricity usage. Specific objectives for this investigation will include the following:

1. **Conduct an on-campus survey for students and faculty members to better understand their conceptions of elevator and stair usage.** The results from this survey will help to explain the current motivations behind using an elevator over a stairwell. Consequently, more concerted efforts can be taken to attempt to motivate more stair use to reduce the amount of electricity consumed by elevators on campus.
2. **Collect energy monitoring data from two of the most frequently used elevators on campus (Maloney & Commonwealth Avenue Parking Garage).** This data will provide BC with a greater insight into the energy consumption between hydraulic and traction elevators, the total energy consumption of a given elevator, the financial and environmental cost of running an elevator, and the weekly trends of elevator usage on campus.
3. **Perform an experiment with signage promoting stair use on campus.** In doing so, the university will be able to gauge whether or not students and faculty are responsive to environmental cues that prompt them to avoid elevator use.
4. **Provide recommendations to BC's Facilities department to reduce the overall amount of electricity consumed by elevators on campus.** After interpreting the results of our experiment, suggestions will be sent to the Facilities Department so

that BC can attempt to further influence student behavior towards stair-usage as well as make individual elevators more energy efficient.

Materials & Methods

Surveys to Better Understand Boston College Community

To better understand the elevator usage of the Boston College community, we developed a survey to be distributed throughout the community. We submitted a final IRB request on March 26, 2016 and received approval on March 28, 2016. To establish a basis for the participants in our survey, we reached out to every department in the Morrissey College of Arts and Sciences as well as members of the Lynch School and the Connell School of Nursing. When emailing each department, we focused on emailing department heads or those who were office managers for the department. Every email briefly outlined the background of the researchers explaining that we were seniors in an Environmental Seminar class conducting a research assignment. Our area of interest was outlined within the email as well as a short overview of some of the research questions we hoped to answer. We also shared our ultimate goals of our research within the email explaining that we hoped to inform the Boston College community about the energy from elevator usage as well as promote greater energy efficiency of elevators around campus. The link to the survey was included within the email as well as a request for distribution of the survey to their department. We decided to reach out to department heads and office managers because we did not have the listserv information for each department. We also reached out to individual groups on campus, such as the Band's Program and EcoPledge, and asked if they would distribute our survey to their members; the same information was shared with various groups on campus as was shared with department heads.

The survey (appendix 1) contained 23 different questions for the participant to answer. The beginning questions focused on getting background information about the participant such as their role as a community member (student, faculty, staff) as well as their living arrangements such as what floor they lived on (this was targeted for students), and their physical activity. The

next series of questions asked about their habits surrounding their elevator usage. We asked questions like how frequently they use the elevator and framed the potential answers as a percentage of the time they use the elevator (100%, 75%, 50%, etc. of the time). We tried to further break down their elevator usage by asking how often the participant used the elevator in different environments like academic building and dorms. A separate question was asked to determine how frequently the participant used the elevators within Maloney Hall and the Commonwealth Avenue Garage to get to Middle Campus as this was the area we were targeting with our intervention. Finally, we asked the participant how energy conscious they were and if they ever consider their energy consumption when they use an elevator. We also asked if the participant had a physical disability which required them to take the elevator. If the participant answered with yes, their data was excluded from the survey analysis as we wish to change the behavior of those on campus who have the ability to take the stairs. The survey was distributed on April 1, 2016 and was active until April 21, 2016.

The questions in the online survey were analyzed using frequency tables. Because of the goals of our survey, which were to gain insight into elevator and stair use habits in order to better instruct elevator efficiency and encourage stair use, analysis of subgroups was not relevant for most questions. When subgroups analysis was relevant, data was analyzed using the subgroups of students, faculty, class year, self-identified elevator and self-identified stair users. Due to the fact that the sample was not randomly selected and had a relatively small number of respondents, we did not do significance testing.

In-person surveys were also completed and included within the IRB exemption request. Four people were randomly selected as they exited the elevators and stairwell in Maloney Hall and asked to participate in the survey. They were asked an open-ended question about why they chose to use the stairs or take the elevator as well as a series of questions to get more background information on the participant such as whether or not they were a student, their year, and where they lived.

In addition to the online survey, we also conducted a sample survey conducted in person of people using the elevators and stairs in Maloney respectively in person. All respondents were travelling to the fourth floor in Maloney. This survey consisted of demographic information and

an open ended survey question asking about what their reasons were for taking the stairs or elevator just then. The sample included four people in total: two had just used the stairs to go up and two had just used the elevators to go up.

Gathering Elevator Electricity Consumption Data

Because there are 74 elevators on BC's Chestnut Hill Campus and we only had access to one three-phase monitoring device, we did not have the ability to monitor each elevator over the course of the semester. Alternatively, Maloney Hall and the Commonwealth Avenue Garage were chosen for monitoring because they are two of the more popular elevators for students and faculty that migrate between Lower Campus and Middle Campus. In order to measure the quantitative energy use of elevators in Maloney and the Commonwealth Avenue Garage, we used an electrical monitoring system programmed by the Energy Director of Facilities at Boston College, John MacDonald. Our group was in close contact with MacDonald throughout the entire project to ensure the monitoring system was properly installed for the timeframes we preferred.

The ultimate goal in gathering elevator electricity consumptions data was to highlight weekly consumption trends, compare the consumption difference between hydraulic and traction elevators, and to assess the financial and environmental impact of elevator use. Data was collected across the three-day increment of Monday, Tuesday, and Wednesday. Because Boston College generally holds class on a Monday/Wednesday/Friday and Tuesday/Thursday schedule, repeating measurements for three days accounts for any differences in class schedule and the associated results of faculty habits. Hence, we monitored the energy consumption of a single elevator over a three-day period in Maloney and the Commonwealth Avenue Parking Garage. In addition, the energy consumption was monitored in Maloney while signs encouraging stair use were hung across campus. The monitoring device is able to compile the electricity input into the elevator's power junction over 30-second intervals. Each elevator uses three-phase power because of the heavy load they require. In other words, a three-phase power system is typically used for larger, commercial electrical loads because it uses less conductor material to transmit

the same amount of electrical power. Thus, the monitoring system displayed the average kW for each of the three channels on the elevator in 30-second intervals. It is important to note that the energy being monitored was used solely to run the mechanical components that lift and descend the elevator; in other words, the data did not include energy consumption information for lighting, ventilation and controls. Photograph 1 displays setup of the monitoring system in the Maloney elevator room; moreover, Table 1 below demonstrates a sample portion of the feedback we received from the monitoring system:

Photograph 1. Energy monitoring software connected to three-phase elevator circuit

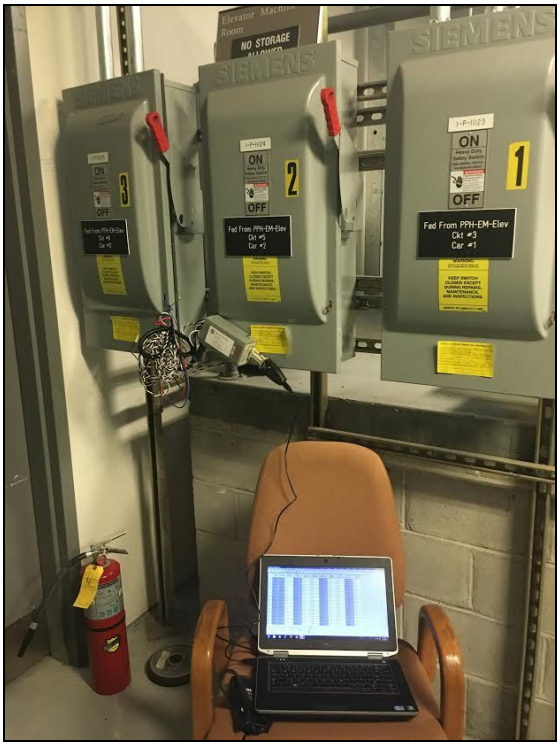
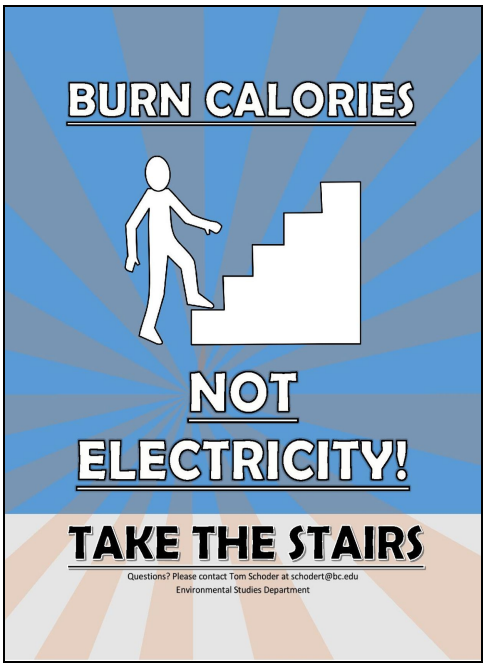


Table 1. Sample data gathering from three-phase monitoring device

Record	Record	Record	Chan 1	Chan 2	Chan 3
Number	Date	End Time	Avg. KW	Avg. KW	Avg. KW
1	4/18/2016	12:00:00 AM	0.259	0	0

Signage Encouraging Stair Use

In order to determine whether or not the BC student and faculty population could be influenced by point-of-decision prompts on elevators, a poster was placed on the first floor kiosk of Maloney Hall. During this same week, the poster was reformatted to create a flyer which was posted in public areas around campus. In conjunction with the kiosk poster in Maloney, the flyers aimed to increase the awareness of the energy consumption linked to elevator usage. While alternative methods to influence behavior were explored (stairwell beautification in Maloney, door delays on Maloney elevators), signage options were the most feasible given the semester timeframe and physical resources. Consequently, the control energy consumption of elevator #3 in Maloney between February 29 and March 2 was compared with the total energy consumption of elevator #3 while the sign and flyers were featured on campus between March 18 and March 21. Photographs 2 and 3 show the flyer and the kiosk poster.



Photograph 1. (left) Design of poster and flyer that was presented around BC's Chestnut Hill Campus.
Photograph 2. (right) The poster featured in the Maloney 1st floor kiosk on March 18.

Finally, using the survey responses and energy monitoring data, a series of recommendations could be gathered for BC's facilities department. In analyzing both qualitative and quantitative data points, a more holistic picture of BC's elevator energy use is formed.

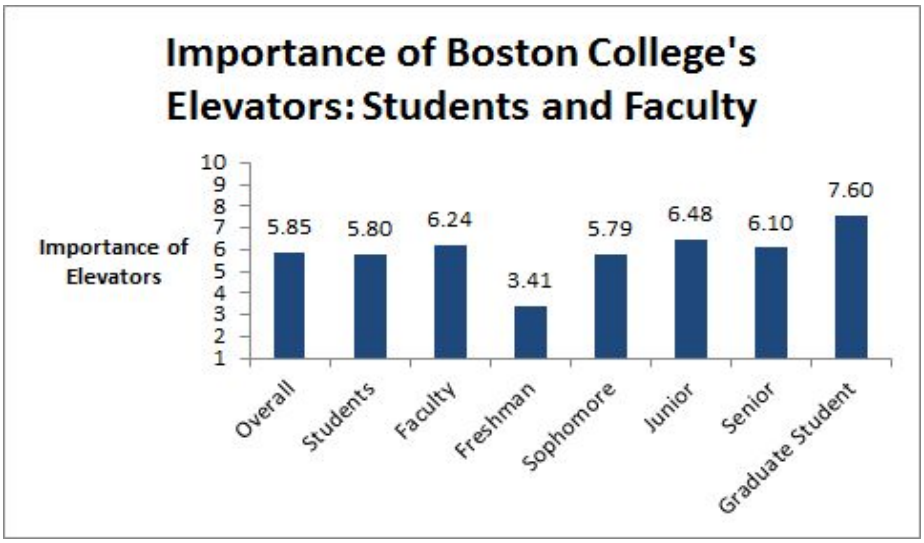
Isolating the trends in the energy monitoring data and the campus's behavioral motivations for elevator use not only provides BC with information on how to reduce energy consumption, but it also has implications for other schools seeking to lower their carbon footprint.

Results

Survey Results

The survey asked a question regarding how important elevators on Boston College's campus were to them. This was done in order to gain insight into people's opinions towards elevators in their daily lives, which could contribute to whether or not they can be encouraged to use stairs. Looking at all of the respondents for the survey, they expressed an average level of expressed importance for elevator's on Boston College's campus. On a scale of 1 to 10, with 1 being "not important at all" and 10 being "extremely important", the average was 5.85. As seen

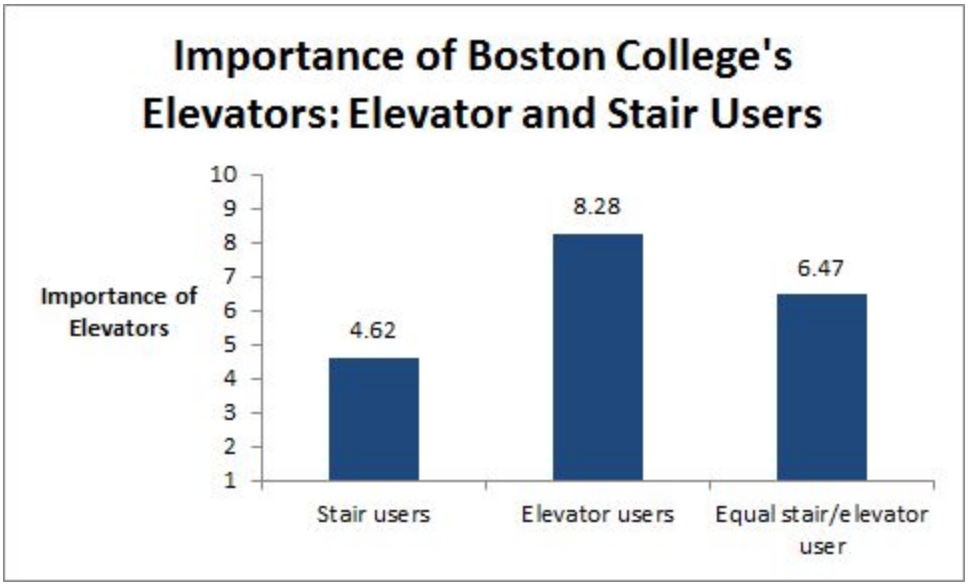
Table 2: Importance of Boston College's Elevators: Students and Faculty



in Table 2, faculty member's considered elevator's to be slightly more important than student's considered them, at 5.80 to 6.24. By class level, Freshman ranked the importance of Boston College's elevators lowest, at 3.41, while Graduate Students ranked it the highest at 7.60. We also examined differences in importance for self-identified elevator, stair, and equal

elevator/stair users. Table 3 shows that stair users report that Boston College's elevators are less important to them than they are for elevator users. These results make sense considering elevator's would likely be more important to people who use them more frequently.

Table 3: Importance of Boston College's Elevators: Elevator and Stairs Users



In order to gain insight into the reasons why people choose to take elevators as opposed to stairs, the survey included to multiple choice question asking respondents to think of the last time they took the elevator and what their reason for it was. The question was multiple choice and respondents were able to select multiple answers. There was also an option to select "Other" and write-in a different reason than the ones listed. The most common reasons given for taking the elevator as opposed to the stairs were that it would require taking too many flights of stairs (68) followed by the physical exertion it would take to use the stairs (58), and time, because they believe the elevators to be faster than the stairs (48) (Table 4).

The open ended responses given under the "Other" option, of which there were 41, were coded into six different categories. The option for companion's decision includes responses that reported taking the elevator because the person they were travelling with decided to take it. Open ended responses that related to any type of sickness or injury fell into the injury/illness category, which may or may not overlap with the multiple choice disability response. Other open ended responses mentioned the weather, carrying or moving heavy objects, and the relative

convenience of the location of elevators versus the inconvenience in the location of stairs on Boston College's campus. The results suggest that there are multiple reasons behind people's decisions to take the elevator or stairs. The open ended questions have further insight into these reasons with responses not included in the multiple choice section, such as the impact of poor, cold, or rainy weather on elevator use, the decision of travelling companions, and carrying or moving heavy loads.

Table 4: Reasons for Taking the Elevator

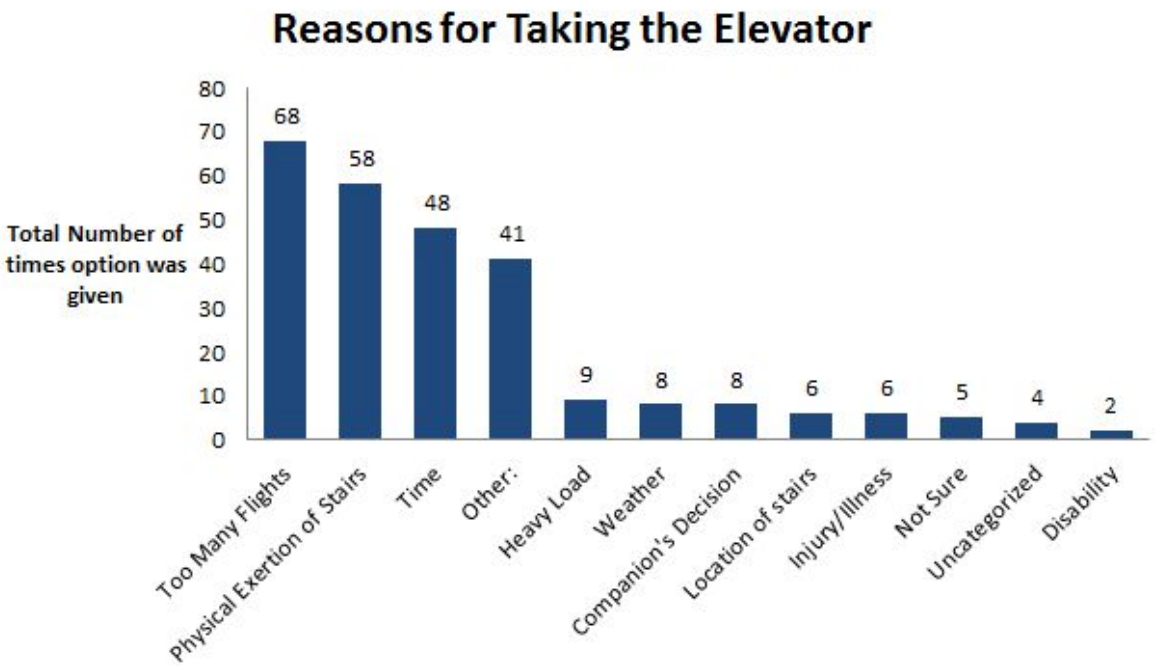
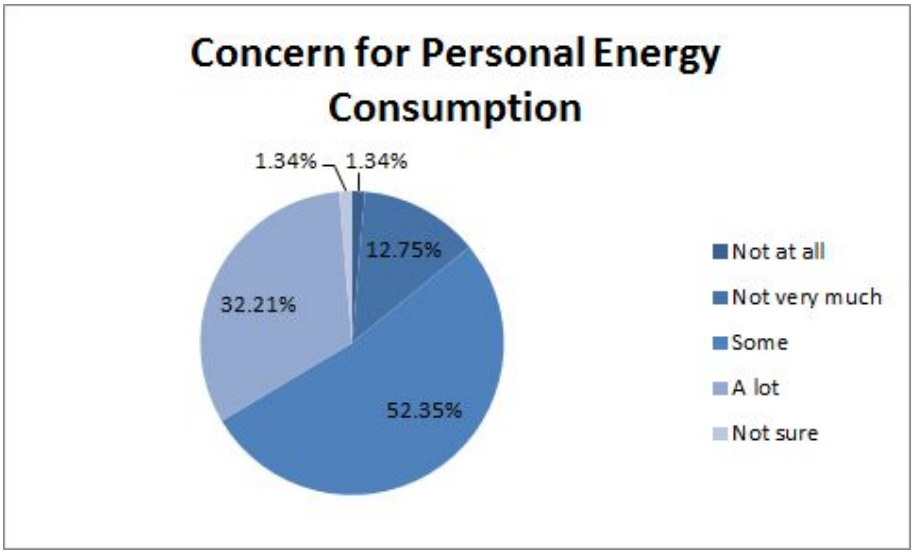
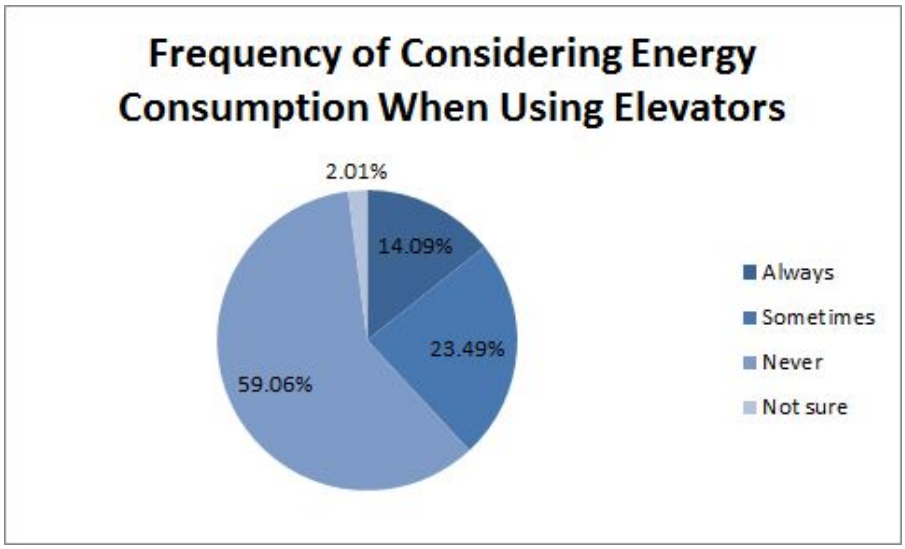


Table 5: Concern for Personal Energy Consumption



The survey asked respondents about their general concern for their own energy consumption, the results of which are displayed in Table 5. A majority of respondents said that they had at least some concern for the amount of energy that they use (52.35%). Very few responded that they had either not very much concern (12.75%) or that they were not at all concerned (1.35%) for their personal energy consumption. These results suggest that most respondents have at least some concern for how much energy they use on a day to day basis.

Table 6: Frequency of Considering Energy Consumption When Using Elevators



Besides generalized energy consumption, the survey also asked specifically how frequently they considered the energy consumption that comes from using elevators. The results of this question can be found in Table 6. The majority of survey takers replied that the had never considered the energy consumption of elevators (59.06%), followed by 23.49% who said that they sometimes considered it, and 14.09% who responded that they always considered energy consumption when using elevators.

Table 7: Frequency of Elevator Use by Location

Location of Elevators	Frequency of Elevator Use as Opposed to Stair Use					
	100% of the time	75% of the time	50% of the time	25% of the time	0% of the time	Not sure
All on campus building	8.05%	15.44%	24.16%	29.53%	22.15%	8.05%
Academic buildings	6.04%	10.74%	18.79%	32.89%	30.87%	0.67%
Dormitory buildings	12.75%	5.37%	8.72%	12.08%	51.01%	10.07%
Comm. Ave and Maloney	13.42%	25.50%	18.79%	22.15%	19.46%	0.67%

In addition to opinions regarding elevators and energy consumption, the survey also measured how frequently respondents reported using elevators as opposed to stairs in various locations on campus (Table 7). This helps to measure which locations on campus are most high traffic for elevator use, which can help to determine which locations are best suited for stair use encouragement. As expected, the Commonwealth Avenue and Maloney Hall elevators were the highest traffic locations, with 13.42% reporting they used the elevators there as opposed to the stairs 100% of the time and 25.50% reporting they used them 75% of the time. Dormitory buildings were the locations with the lowest reported use of elevators, with 51.01% reporting they used them 0% of the time.

Table 8: Frequency of Elevator Use in Comm. Ave and Maloney

Comm. Ave and Maloney Elevator Trip (Up/Down)	Total Number of Times Used Per Day				
	More than 5 times	2-4 times	1 time	Never	Not sure
Elevators Going Up	0.67%	26.85%	40.94%	30.20 %	1.34%
Elevators Going Down	0.67%	18.12%	30.87%	48.99 %	1.34%

As previously discussed, the Commonwealth Ave and Maloney Elevators appear to be the highest traffic elevators on the Boston College campus. The survey delved deeper into specifically the use of these two elevators by asking the total number of times in a typical day the respondents took both elevators up and the total number of times they took both elevators down (Table 8). In term of using the Commonwealth Ave and Maloney Elevators to go down, a large percentage at 48.99% reported that they never used them to go down, followed by 30.87% who said they used it once per day to go down. Comparatively, many more reported using the elevators to go up: 26.85% reported using either 2-4 times per day to go up and 40.94% reported using it just 1 time. Only 30.20% reported never using the Commonwealth Ave and Maloney Elevators to go up, which is 18.79% less than those who reported never using them to go down.

Table 9: Flights of Stairs Required Before Choosing the Elevator by Direction of Trip

Direction of Trip	**Number of Flights of Stairs Required Before Choosing to Take the Elevator**			
	5 or More	3-4	1-2	Not Sure
Up	40.94%	53.69%	2.01%	3.36%
Down	67.11%	14.77%	1.34%	16.78%

The survey also tried to gain insight into how the number of flights of stairs and the direction of the trip, either up or down, affects people's decision to take either the stairs or the elevators. The results are displayed in Table 9 and suggest that there is a relationship between both the direction of the trip and the number of flights of stairs. For trips that are going up, a majority of respondents replied that at 3-4 flights they would choose to take the elevator at 53.69%. Comparatively, for trips going down, only 14.77% responded that they would choose to take the elevator at 2-4 flights of stairs. The Maloney and Commonwealth Avenue elevators are both require at least flights of stairs to travel between upper and lower campus.

In Person Survey Results

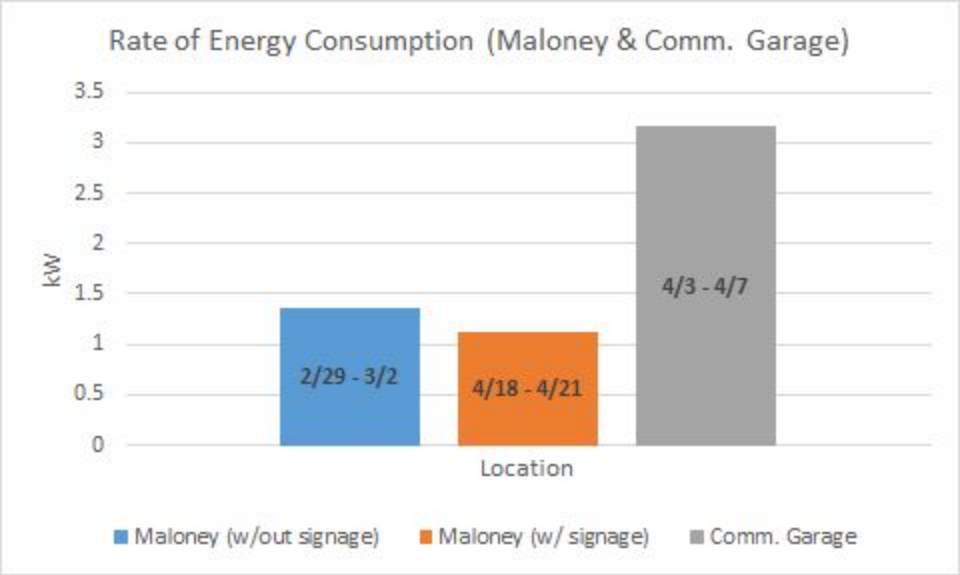
Both the stair and elevator users surveyed in the in person survey gave similar responses to why they made their choice to what was revealed through the online survey. Both the first and second respondent mentioned that they believed the elevators in Maloney were faster than taking the stairs when they were going to the fourth floor. The first respondent also mentioned that she had been with friends who had chosen to take the elevator, mentioning that taking the elevator is just part of her routine when going to class with her roommates. The second respondent mentioned that taking the elevator was just easier than taking the stairs.

The stair user's responses differed from each other. The first respondent mentioned how they tried to take the stairs as often as they could in order to try to stay healthy. They also mentioned how it helped them to reach their fitness goals to take the stairs at Boston College when they could. On the other hand, the second respondent did not mention the health benefits of stairs having an impact on their decision. Instead, they stated that the ground floor lobby in Maloney had been crowded with people waiting for the elevator, so they decided to take the stairs instead of waiting.

Elevator Energy Monitoring Results

After receiving the monitoring data from John MacDonald for Maloney Hall and the Commonwealth Avenue Parking garage, some general conclusions can be made about the energy consumption of traction and hydraulic elevators. The monitoring data must be interpreted in terms of the energy consumed (kWh) and the power deriving from each individual three-phase channel (kW). While kilowatt-hours illustrate the total amount of energy that was consumed over a given time period, kilowatt units describes the rate at which energy is used. Thus, kilowatt units offer a simple way to compare the consumption rates across different segments of time. Graph 1 below displays the kilowatts averages for Maloney Hall without signage, Maloney Hall with signage, and the Commonwealth Avenue Parking Garage without signage. The data was collected over three day intervals between Monday and Wednesday.

Table 10. Rate of Energy Consumption (kW) across Maloney and Comm. Ave. Garage



The graph demonstrates a couple of significant findings. First off, the rate of energy consumption for elevator #3 dropped from 1.35 kW without the signage to approximately 1.12 kW with the signage. It may be impossible to draw a direct cause and effect relationship with these data given the multitude of variables at play including the weather; nevertheless a 21% reduction in overall energy consumption is significant. If the Maloney elevator energy consumption data under control conditions (without signage) were extrapolated to the entire year for all three elevators, the building would reduce its energy use by 7,450 kWh and Boston College would save approximately $968.50. Another finding from the above table is the high amount of energy consumption per ride for a hydraulic elevator such as the Commonwealth Avenue Parking Garage. The hydraulic elevator consumes 234% more electricity compared to the control data for Maloney without signage. Over a three-day period, the Commonwealth Avenue Parking Garage consumed 227.63 kWh of energy compared to just 97.50 kWh of energy in Maloney without signage. Despite consuming more energy than its traction elevator counterpart, the Parking Garage elevator was only in use 21% of the time (15 hours 7 min.) from Monday through Wednesday. The Maloney Hall elevator was in use about 45% of the time (32 hours 24 min.). Tables 12 and 13 illustrates this discrepancy in use between the elevators.

Tables 12 & 13. Representation of the percentage of time each elevator is actively running

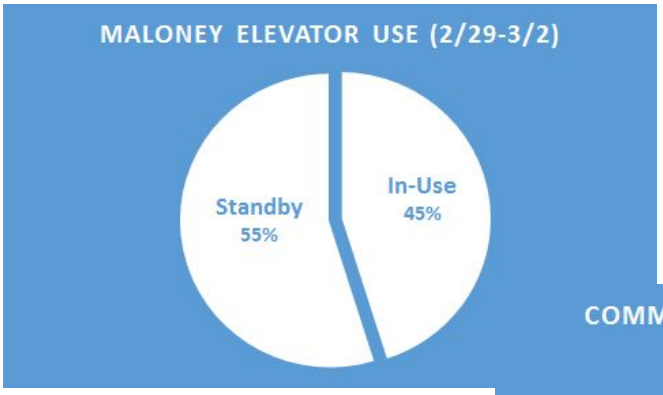


Table 12.

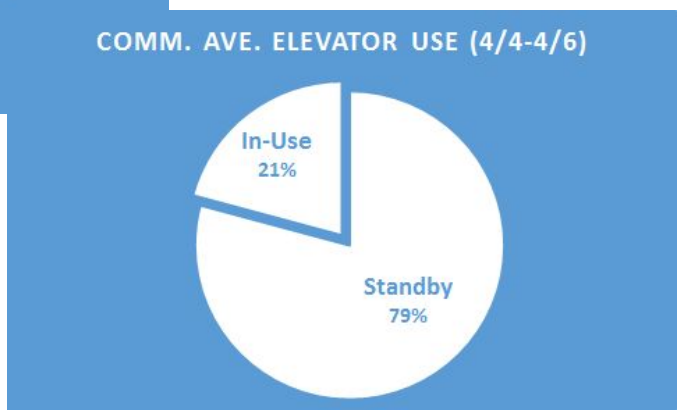
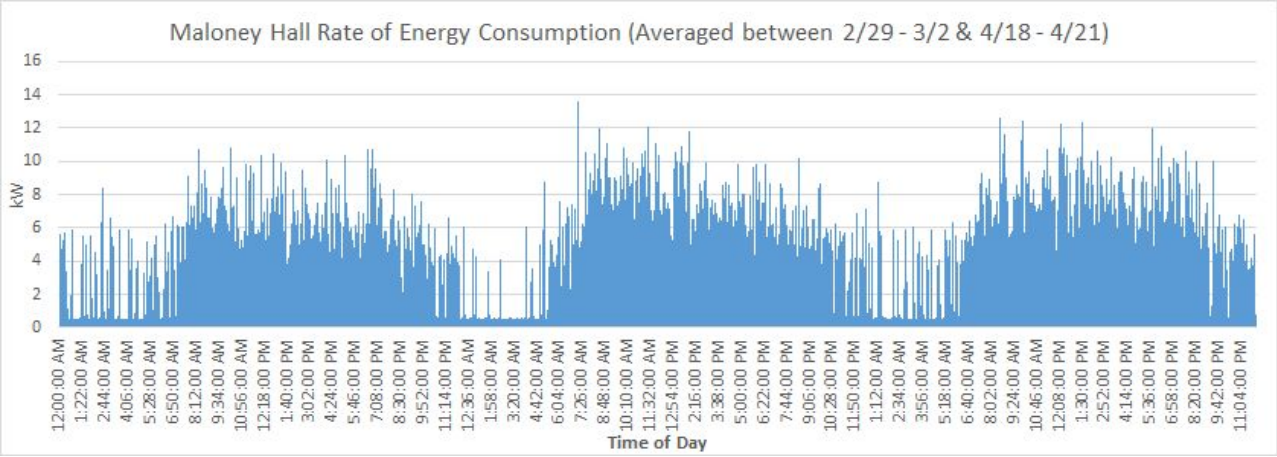


Table 13.

The elevator energy monitoring data also provides insight into the trends of elevator use based on the time of day. The daily trends between Monday and Wednesday show significant upticks in energy consumption between the hours of 7AM to 10PM; however, the consumption outside of this timeframe is rather minimal. Because Maloney's elevators use a counterweight system, it requires the most energy to lift a full car from the first floor as well as descend a nearly empty car from the top floors. Table 14 shows the energy trend from Monday to Tuesday.

Table 14. Averaged rate of energy consumption (kW) between 2/29-3/2 & 4/18-4/21)



Discussion

Survey

The survey given out to the Boston College community yielded results that were within the expectations of the researchers. When asked on a ten point scale about how much the participant cared about elevators on campus, the results averaged to a 5.85. This suggests that members of the BC community, on average, see elevators as a convenience rather than as an integral part of their BC experience. We interpret this result as meaning that most community members simply decide to take the elevator out of convenience and could take the stairs in many instances when they elect to take the elevator. We also found that most participants answered that they take the elevators most often because there are too many flights of stairs to comfortably reach their destination. More than half of the participants answered that they took the elevator when they had to ascend three to four flights of stairs. The next most common reason people chose to take the elevator was that it would take too much physical exertion to reach their destination. Another key finding of our survey was that there is a difference in the habits of

participants whether or not they are ascending or descending. About 40% said that they would decide to take the elevator if they were going up five or more flights of stairs while 67 % said they would take the elevator down if they had to travel five or more floors. This was then compared to the 55% of respondents who said that they would take the elevator up if they had to travel between three or more floors while only 15% said that they would take the elevator down if they were travelling at least three to four floors. This suggests that convenience and physical exertion play a large role in the user's decision to use the elevator. With this information, we recommend that if BC's decides to further address the use of elevators on campus, they have the potential to be most successful if they target people who use the elevator to travel downwards. We believe that there is a lower threshold to overcome than to convince people to ascend multiple flights of stairs.

Another area of interest we were interested in discovering was whether or not participants were conscious of their energy use and monitored, or at least thought about, their personal energy consumption. We found that nearly a third of respondents considered themselves to be concerned out their energy footprint. However, 60% of respondents said that they never factored in the energy used by the elevator into their own understanding of their energy use. This suggests that there is a disconnect between participants and their use of the elevator. Most participants do not consider the energy that is consumed by their initial press of the call button.

The completion of the in-person surveys helped to confirm our results from our distributed survey. After speaking with the various participants, the results suggest that speed and ease of use are important components in the decision making process to choose the elevator over the stairs. In addition, habits and travelling companions could also have a substantial impact. However, speaking with the participants that chose to take the stairs provides an interesting juxtaposition. This suggests that some people believe the stairs are faster than elevators, depending on how busy the elevators are. This finding brings in another variable into people's decision making and that is what others in their environment elect to take the elevator or stairs. This can persuade someone to take the stairs if they believe it is faster or to take the elevator if that is what their walking companion decided.

Elevator Monitoring Data

From our monitoring of the Maloney elevator, we were able to do a comparison of the effect of our intervention before and after we put up signage. We found that during the phase sign posters promoting the use of stairs, the overall energy consumed by the elevator decreased by 21%. However, it is important to note that there are external factors that may have affected our data collection. Weather may have played a role in both monitoring periods and had the potential to influence users to walk outside to class or travel to class through Maloney. Without another study, we will not be able to directly correlate the reduction of energy with our intervention. That being said, our findings do show that staging another intervention to reduce the community's use of elevators has a high chance of success.

We also set up a monitoring system on the elevators in the Commonwealth Avenue Garage in order to establish how frequently they are used as well as how their energy consumption compares to the elevators in Maloney. With our data, we discovered that the elevators in the Commonwealth Avenue Garage consume more than 234% more energy than the elevators in Maloney Hall. We also found that the Commonwealth Avenue Garage elevators are used far less frequently than those in Maloney. The elevators in the garage are on standby for 79% of the time while the elevators in Maloney are on standby for 55% of the time. This suggests that more of the BC community uses Maloney more frequently to travel to Middle Campus than the elevators found in the Commonwealth Avenue Garage. Understanding which elevator is on standby for a greater period of time is important in determining which elevator system to target for improving efficiency of standby power such as the light and ventilation.

Using the Electricity Facts (appendix 2) handout shared with us by John MacDonald, we determined that the average amount of CO2 released in Massachusetts is 837.82lbs of CO2 per 1 MWh. We then took the data from the Maloney elevators and assumed that the amount of energy consumed by the elevators, within the three days of data before the intervention, could be extrapolated to the entire year. With this assumption, we calculated that the total energy consumed by the elevators in Maloney per year was 35,476 kWh. This translates to 29,722.5 lbs of CO2 per year from elevator use alone. If Boston College maintained the reduction of elevator

usage by 21% throughout the year, they could save $968.50. While this may be a small monetary incentive, there are also environmental benefits to consider such as the reduction in carbon emissions. BC may only save $968.50, but they also save 6241.7 lbs of CO2 from being released into the atmosphere per year.

Limits of Our Investigation

Due to the nature of our research method, our survey results come from a voluntary response sample. The participants in our survey may over represent the members of the Boston College community who are mindful of their energy consumption as well as those who are predominantly stair-users and underrepresent those who are indifferent towards their energy consumption and stair-use. This has the potential to introduce skew to the results. It is also important to note that our survey results are dependent on the honesty and subjectivity of the participants. Our findings are best used to speak on the behalf of the greater Boston College community and should be more closely considered when applying to larger, different communities. There were also a total of 149 responses made up of 132 students, 16 faculty members, and 1 visitor. Therefore the survey participants only represent a small fraction of the entire Boston College community and only allude to the habits of the Boston College community as a whole rather than proportionally represent all members.

In regards to the data from the elevator monitoring system, there are external variables that may have influenced the findings. Nothing was done to change the stairwell closest to the elevators in Maloney Hall. The stairwell has no windows, carpeting, pieces of art, or music. The stairwell is painted a muted tone of beige and is not considered aesthetically pleasing. While leaving the stairwell unchanged for both parts of the monitoring process, the baseline and with the intervention of the signs, gives a better understanding of the impact of the signs, it introduces a larger initial barrier to overcome. The monitoring was done throughout the spring semester of 2016 from February to April. The changing seasons may have had an effect on elevator usage in Maloney as well as the Commonwealth Avenue Garage because both systems are largely used by students to get to Middle Campus from Lower Campus for class, so as it became more pleasant outside, more people may have chosen to walk or take the stairs outside. With the same

consideration, unpleasant weather such as rainy days or unusually cold days may have influenced more members of the community to come to Maloney or the Commonwealth Avenue Garage to take the elevator. Though once participants were inside Maloney, they had the ability to make the decision to take the stairs inside the building or the elevator.

Recommendations

Reducing Energy Consumption with New Design

On average, elevators make up 2-5% on a building's energy use, but considering the nature of elevators, there are moments when they make up 50% of a building's energy consumption (Sachs, 2015). While reducing the energy elevators consume may have a minor impact on the overall energy consumption of the building, it can have a more profound impact on the money saved over time. There are two methods Boston College can take in an effort to reduce the monetary impact of elevators. They can make financial investment in the elevator system and make renovations to existing elevators and install efficient elevators in new buildings. While more efficient elevators may have a greater initial cost, it is important to consider the lifelong costs of elevators in terms of energy consumption as well as later maintenance. Some new elevator systems do not require an elevator penthouse which can reduce cost. Systems like gearless elevators use permanent magnetic motors which reduces energy consumption. Beyond the costs of installing very efficient elevator systems, smaller investments could be made such as installing new components like the controls that have the potential to improve the user experience and reduce energy. Systems can be modified to reduce the energy that is consumed when the elevator is idle. Taking measures to reduce the energy consumed while the elevator is on standby can have a profound effect on the overall energy consumption and does not have a high investment cost. Simple steps can be done such as turning the lights and ventilation off within an elevator cab when it is unoccupied (Sachs, 2015).

Another measure Boston College could take to reduce elevator usage is having well-designed stairwells. Studies have found that elevator usage has been connected to the proximity of the elevators to the stairs. If elevators are closest to the building entrance and the stairs are farther away, people are more likely to take the elevator. This can be observed in Boston College's Vanderslice Hall. When undergoing new construction projects, Boston College should consider placing the stairs closer to the entrance of a building and tuck the elevator away from immediate sight. Studies have also found that stairwells are more likely to be used if they are naturally lit. To reduce the environmental impact of elevator, the design of the stairwell should be well-thought-out so it is aesthetically pleasing for its users in all future construction projects (Ruff *et al.*, 2014).

Reducing Energy Consumption with Current Structure

Other efforts Boston College can take to reduce elevator usage is to try to change the habits of the BC community. With further research, the efficiency of all of the elevators across campus can be assessed, and the most efficient elevators could be labeled as such. It is recommended that these more efficient elevators should be at least 10% more efficient than the baseline efficiency. This could be used to make the user more conscious of their energy consumption, and if they are unable or unwilling to change the frequency with which they use elevators, they now have the knowledge to try to use the most efficient elevator which would consume less energy. This strategy should be done with categorical ratings rather than just a single label with just one threshold. This will allow elevator efficiency to improve within the system as time and new innovations will allow for greener models (Sachs, 2015). Another method Boston College could use to reduce elevator usage is to continue putting up signs near the elevator that encourage taking the stairs. This would have a positive health benefit for the community by reducing the risk of chronic diseases. However, further studies will need to be complete in order to determine the overall effectiveness of this intervention within the Boston College community (Ruff *et al.*, 2014). Other studies have been complete that indicate that environmental changes surrounding the elevator can increase the number of people who elect to

take the stairs. This can be done by having a dynamic set of informational posters rather than just one (Boutelle *et al.*, 2001). It has been found in other research that people are more likely to take the stairs if they are visually appealing (Ruff *et al.*, 2014). While natural light is preferred, current stairwells can incorporate music and artwork. If the artwork is changed on a semi-regular basis and the music is changed daily, stair use has been found to increase (Boutelle *et al.*, 2001). If further work shows that intervention does not reduce elevator usage, than Boston College can promote the use of the Maloney elevators over the use of the Commonwealth Avenue Garage elevators. This would reduce overall energy consumption as the Garage elevators consume more than 200% more energy than those in Maloney.

Another approach that was found to decrease elevator usage was increasing the elevator travel time. This intervention could be done with all current infrastructure and would just need to be programed into the elevator mechanisms. This was done is a study by increasing the amount of time it took for the elevator doors to open. The delay was added to the elevator door closing mechanism, and this increased the elevator travel time by 26 seconds. This reduced elevator usage by 33%. The study then reduced the door delay to 21 seconds, and they did not see a change in the already reduced elevator usage (Houten *et al.*, 1981).

Boston College must decide whether or not there are benefits to changing already existing elevators. If renovations are going to be made, then they should be done to high traffic elevators with low efficiency to most offset the financial investment. However, there are simpler, cheaper interventions that can be done if there is serious interest in reducing the overall energy consumed by elevators on campus (Sachs, 2015).

Conclusion

We now have a better understanding of the impacts of elevator use on Boston College's campus. Through the energy auditing process, we have a better understanding of both the environmental impacts, through carbon emissions, as well as the financial implications of elevator energy expenditures. By use of the survey conducted on members of the Boston College

community, we gained insight into the motivations for elevator use as well as the frequency of elevator use in different locations throughout campus. As we expected, both time and physical exertion play an important role in encouraging elevator use. Other factors were revealed such as the importance of the decision of companions in a group and routine of taking the elevator versus the stairs. The survey participants from the Boston College community reported considering energy use of elevators at low rates, which means that bringing their energy use to light could help to encourage stair use. This was part of the inspiration behind the point of use signs in the Maloney first floor entrance, which we now understand likely had some impact on encouraging stair use. Further implementation and study throughout the Boston College campus is suggested to further study its effects. This, along with other structural and mechanical changes, can be applied to current elevators and future construction and remodelling on the Boston College campus in order to help facilitate energy reduction from elevators through efficiency and encouraging stair use.

Acknowledgements

We would like to thank our professor, Tara Pisani-Gareau, and our mentors John MacDonald and Bruce Dixon for their continued guidance and support throughout the semester. We would also like to thank those who took the time to fill out our survey and provide us with valuable data.

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Appendix 1:

Boston College Elevator Use Survey: Online

Boston College

Earth and Environmental Sciences

"A Study of the Boston College Community's Use of Stairs and Elevators"
Researchers: Thomas Schoder, Lucy Alexander, and Margaret Cahill
Faculty Advisor: Professor Tara Pisani-Gareau (tara.pisanigareau@bc.edu)
Adult Consent Form

You are being asked to participate in a research study titled "A Study of the Boston College Community's Use of Stairs and Elevators." This is a voluntary survey about elevator use on Boston College's campus. You were selected to participate in this project because you are a member of the BC community as a student, staff, or faculty member. The survey include multiple choice questions and short answer responses about your habits in regards to elevator and stair usage.

The purpose of this study is to better understand the motivations behind elevator usage as well as stair usage through the surveying of 500 members of the BC community.
The survey will be conducted online and should take approximately 10 minutes.
There are no direct benefits to participating in this survey, but you may feel gratified for your contribution to knowledge in this field. You will not be compensated for taking this survey. There are no costs to you for participating in this survey.

The principal investigators will exert all reasonable efforts to ensure that your responses and identity are kept confidential. Survey responses are recorded anonymously and are secured with Cloud Lock. Please note that regulatory agencies, the Boston College Institutional Review Board, and Boston College internal auditors may review research records.

Participation is voluntary. There will be no consequences and your relations with Boston College will not be affected if you choose not to participate. It should be noted that there may be unknown risks associated with completion of the survey. You are free to withdraw for the survey or skip questions at any time. If you have questions or concerns regarding this research you may contact the Principal Investigator, Margaret Cahill, at cahillmq@bc.edu.

If you have questions about your rights as a research participant, you may contact the Office for Research Protections, Boston College, at 617-552-4778 or irb@bc.edu.
This study was reviewed by the Boston College Institutional Review Board and its approval was granted on [insert approval date]. If you agree to the statements above and agree to participate in this study, please press the select the "yes" button below.

1. How much do you care about your personal energy consumption?
a. A lot
b. Some
c. Not very much
d. Not at all
e. Not sure

2. Regarding your physical activity, do you consider yourself:
a. Very active
b. Active
c. Less active

3. Where do you live?
a. Upper Campus
b. College Road
c. Lower Campus
d. Newton Campus
e. Off Campus

4. Are you a Boston College Student?
a. Yes
b. No

5. If yes, what year are you?
a. Freshman
b. Sophomore
c. Junior
d. Senior
e. Graduate Student

6. If no, are you:
a. Boston College Faculty
b. Visitor

7. Do you identify as:
a. Male

b. Female
c. Other

The next several questions are going to ask you about your use of elevators on campus.

8. How important to you are elevators on Boston College's campus on a scale to 1 to 10 with 1 being not important at all and 10 being extremely important?
a. 1,2,3,4,5,6,7,8,9,10

9. On a typical day, how often do you use elevators on Boston College's campus?
a. 100% of the time
b. 75% of the time
c. 50% of the time
d. 25% of the time
e. 0% of the time
f. Not sure

10. How often do you use elevators, instead of stairs, in academic buildings on Boston College's campus?
a. 100% of the time
b. 75% of the time
c. 50% of the time
d. 25% of the time
e. 0% of the time
f. Not sure

11. How often do you use elevators in your dorm (if you live on campus)?
a. 100% of the time
b. 75% of the time
c. 50% of the time
d. 25% of the time
e. 0% of the time
f. Not sure

12. If you live on-campus, what floor is your dorm located on?
a. 1,2,3,4,5,6,7,8

13. How often do you use elevators to get from lower to upper campus using the Maloney and/or Commonwealth Ave garage elevators?

a. 100% of the time
b. 75% of the time
c. 50% of the time
d. 25% of the time
e. 0% of the time
f. Not sure

14. When you take the elevator, do you consider your energy consumption?
a. Always
b. Sometimes
c. Never
d. Not Sure

The next two questions are about the Maloney and Commonwealth Ave Garage elevators.

15. In a typical day, how often do you take the Maloney or Commonwealth Ave Garage elevators up?
a. More than 5 times
b. 2-4 times
c. 1 time
d. Never
e. Not sure

16. How often do you take the Maloney or Commonwealth Ave Garage elevators down?
a. More than 5 times
b. 2-4 times
c. 1 time
d. Never
e. Not sure

The following questions are about your general elevator use on Boston College's campus.

17. Overall do you consider yourself to be more of an elevator user or stair user.
a. Elevator
b. Stair
c. Neither because I use both stairs and elevators equally

18. Think about the most recent time that you took an elevator on the Boston College campus. What made you choose to take the elevator as opposed to the stairs? (Select all that apply)

a. Time, because I believe elevators are faster than stairs
b. It takes too much physical exertion to take the stairs
c. I have a disability which requires I take the elevator
d. I had to go too many flights of stairs
e. Other (space to write another reason)
f. Not sure

19. What are your reasons for taking elevators as opposed to stairs? Select all that apply
a. Time, because I believe elevators are faster than stairs
b. It takes too much energy to take the stairs
c. I have a disability which requires I take the elevator
d. Other (space to write another reason)
e. Not sure

20. How many floors would you have to walk **up** in order to decide to use the elevator?
a. 1-2
b. 3-4
c. 5 or more
d. Not sure

21. How many floors would you have to walk **down** in order to decide to use the elevator?
a. 1-2
b. 3-4
c. 5 or more
d. Not sure

22. Do you have any condition that limits your ability to climb stairs?
a. Yes
b. No

Boston College Elevator Use Survey: In Person

Boston College
Earth and Environmental Sciences

"A Study of the Boston College Community's Use of Stairs and Elevators"
Researchers: Thomas Schoder, Lucy Alexander, and Margaret Cahill
Faculty Advisor: Professor Tara Pisani-Gareau (tara.pisanigareau@bc.edu)
Adult Consent Form

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The purpose of this study is to better understand the motivations behind elevator usage as well as stair usage through the surveying of 500 members of the BC community.

The survey will be conducted in person through the use of an iPad or other smart device and should take approximately 2 minutes.

There are no direct benefits to participating in this survey, but you may feel gratified for your contribution to knowledge in this field. You will not be compensated for taking this survey. There are no costs to you for participating in this survey.

The principal investigators will exert all reasonable efforts to ensure that your responses and identity are kept confidential. Survey responses are recorded anonymously and are secured with Cloud Lock. Please note that regulatory agencies, the Boston College Institutional Review Board, and Boston College internal auditors may review research records.

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If you have questions about your rights as a research participant, you may contact the Office for Research Protections, Boston College, at 617-552-4778 or irb@bc.edu.

This study was reviewed by the Boston College Institutional Review Board and its approval was granted on [insert approval date]. If you agree to the statements above and agree to participate in this study, please press the select the "yes" button below.

The following questions will ask you about your elevator and stair use on Boston College's campus.

1. What were your main reasons for choosing to take the elevator, as opposed to the stairs, just now?
a. Open ended question

2. Where do you live?
a. Upper Campus
b. College Road
c. Lower Campus
d. Newton Campus
e. Off Campus

3. Are you a Boston College Student?
a. Yes
b. No

4. If yes, what year are you?
a. Freshman
b. Sophomore
c. Junior
d. Senior
e. Graduate Student

5. If no, are you:
a. Boston College Faculty
b. Visitor

6. Do you identify as:
a. Male
b. Female
c. Other

Boston College Stair Use Survey: In Person

Boston College
Earth and Environmental Sciences

"A Study of the Boston College Community's Use of Stairs and Elevators"
Researchers: Thomas Schoder, Lucy Alexander, and Margaret Cahill
Faculty Advisor: Professor Tara Pisani-Gareau (tara.pisanigareau@bc.edu)
Adult Consent Form

You are being asked to participate in a research study titled "A Study of the Boston College Community's Use of Stairs and Elevators." This is a voluntary survey about elevator use on Boston College's campus. You were selected to participate in this project because you are a member of the BC community as a student, staff, or faculty member. The survey include multiple choice questions and short answer responses about your habits in regards to elevator and stair usage.

The purpose of this study is to better understand the motivations behind elevator usage as well as stair usage through the surveying of 500 members of the BC community.

The survey will be conducted in person through the use of an iPad or other smart device and should take approximately 2 minutes.

There are no direct benefits to participating in this survey, but you may feel gratified for your contribution to knowledge in this field. You will not be compensated for taking this survey. There are no costs to you for participating in this survey.

The principal investigators will exert all reasonable efforts to ensure that your responses and identity are kept confidential. Survey responses are recorded anonymously and are secured with Cloud Lock. Please note that regulatory agencies, the Boston College Institutional Review Board, and Boston College internal auditors may review research records.

Participation is voluntary. There will be no consequences and your relations with Boston College will not be affected if you choose not to participate. It should be noted that there may be unknown risks associated with completion of the survey. You are free to withdraw for the survey or skip questions at any time. If you have questions or concerns regarding this research you may contact the Principal Investigator, Margaret Cahill, at cahillmq@bc.edu.

If you have questions about your rights as a research participant, you may contact the Office for Research Protections, Boston College, at 617-552-4778 or irb@bc.edu.

This study was reviewed by the Boston College Institutional Review Board and its approval was granted on [insert approval date]. If you agree to the statements above and agree to participate in this study, please press the select the "yes" button below.

The following questions will ask you about your stair and elevator use on Boston College's campus.

7. What were your main reasons for choosing to take the stairs, as opposed to the elevator, just now?
a. Open ended question

8. Where do you live?
a. Upper Campus
b. College Road
c. Lower Campus
d. Newton Campus
e. Off Campus

9. Are you a Boston College Student?
a. Yes
b. No

10. If yes, what year are you?
a. Freshman
b. Sophomore
c. Junior
d. Senior
e. Graduate Student

11. If no, are you:
a. Boston College Faculty
b. Visitor

12. Do you identify as:
a. Male
b. Female
c. Other

Appendix 2:

Electricity Facts
TransCanada Power Marketing Ltd.
BOSTON COLLEGE
January 2016

Competitive Suppliers are required by the Massachusetts Department of Public Utilities to provide customers with an information disclosure label. The purpose of the label is to ensure that customers are presented with consistent information by which to evaluate services offered by Competitive Suppliers and Distribution Companies.

Generation Price Average price per kWh at different levels of use. Prices do not include regulated charges for customer service and delivery	Average Use per Month	1,000 kWh	10,000 kWh	20,000 kWh	40,000 kWh
	Average Price per kWh	Please refer to your Purchased Power Agreement for contract prices. Your average electricity price may vary by time of use. See your most recent invoice for your monthly use.			

Contract	Please refer to your Purchased Power Agreement for prices and terms for Generation Service.

Power Sources
This electricity product in the period **7/1/14 to 6/30/15** was assigned generation from the following sources:

Power Source	Known Resources	System Power	Total
Biomass	0.0%	0.0%	0.0%
Coal	0.0%	0.0%	0.0%
Hydro: Large	76.5%	0.0%	76.5%
Hydro: Small	0.0%	0.0%	0.0%
Imported Power	0.0%	0.0%	0.0%
Landfill Gas	0.1%	0.0%	0.1%
Low Impact Hydro Institute*	17.6%	0.0%	17.6%
Municipal Trash	0.0%	0.0%	0.0%
Natural Gas	0.0%	0.0%	0.0%
Nuclear	0.0%	0.0%	0.0%
Oil (inc. Diesel & Jet)	0.0%	0.0%	0.0%
Other	0.0%	0.0%	0.0%
Other Renewable	0.0%	0.0%	0.0%
Solar	0.0%	0.0%	0.0%
Wind	5.8%	0.0%	5.8%
Total	100.0%	0.0%	100.0%

Air Emissions
Carbon dioxide (CO_2), nitrogen oxide (NO_x), and sulfur dioxide (SO_2) emission rates from these sources, relative to the regional average, and to the emission rates of a new generating unit.

	TCPM Resource Portfolio (lbs/MWh)	New England Average (lbs/MWh)	TCPM Portfolio as % of Regional Average	New Unit (lbs/MWh)
CO_2	0.0	837.82	0%	760
NO_x	0.0	0.78	0%	0.06
SO_2	0.0	0.87	0%	0.02

Labor Information	94% of the electricity from Known Resources came from power sources with union contracts or that used replacement labor during disputes between **7/1/14** and **6/30/15**. It is not known what percentage of the electricity from System Power came from power sources with union contracts.

Customer Service	For questions about your invoice, please call 508-871-1850, option 3. For all other inquiries, contact your business representative directly or call TransCanada toll-free at 1-877-634-2928.

**Low Impact Hydro Institute (LIHI) certification means that these plants meet or exceed rigorous criteria in eight key areas: river flow, water quality, fish passage and protection, watershed protection, threatened and endangered species protection, cultural resource protection, recreation, and facilities recommended for removal.*