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Introduction

Built in 1968, McGuinn Hall borders Beacon Street and sits in the southwestern corner of the main campus of Boston College. The building includes six floors of offices, classrooms, and lecture halls, and in addition houses the Social Work library in its basement. McGuinn is the home of the Boston College Psychology, Sociology, and Political Science departments as well as
the offices of the Graduate School of Social Work, the Graduate School of Arts and Sciences, and the Woods College of Advancing Studies (“Campus Guide: McGuinn Hall”, 2011).

McGuinn, being a highly populated and commonly visited building, uses plenty of energy to maintain its heating and cooling, electricity, and ventilation, among many other things. While some renovations have been completed in McGuinn in the years following its original construction, the renovations have been focused more on aesthetic changes as opposed to structural or energy efficiency improvements. McGuinn particularly poses energy efficiency issues not only because of the lack of renovations since its construction but also due to its unique design. While most campus buildings at Boston College reflect a Gothic style of architecture with plenty of stone siding and few windows, McGuinn’s architectural design differs from this pattern. McGuinn’s façade is virtually covered in windows on all four sides, and the great majority of these windows are single-paned. Single-paned windows more readily transmit heat and cold from outside the building to inside, which lowers the overall energy efficiency of the building and raises energy expenses for the university. In a growing environmentally conscious age, it is especially troubling to reflect upon the high energy use and extrapolated energy cost that the great number of windows and the low energy efficacy of the single-paned glass does for McGuinn.

For the GE 580 Team Project, our group decided to research the costs and benefits of different window treatments in order to gauge the energy efficiency and possible savings.
associated with such renovations. Beginning with collecting data on McGuinn’s current energy expenditures, our group then examined three separate avenues of window treatments to see how these would affect the total energy output of the building. Our group investigated the effects of: 1) changing all single-paned windows to more energy efficient double-paned windows, 2) applying energy saving films to the current windows, and 3) employing behavioral changes related to window use so as to mitigate energy loss. This paper will give a general background of McGuinn’s current energy use and in addition will delve into the particular methods of choice for each cost-benefit analysis. The cost-benefit analyses will help to explain the pros and cons of each type of window treatment and will help to guide facilities managers in the future to better gauge the energy improvement needs of McGuinn and Boston College as a whole.

❖ McGuinn’s Current Energy Use

McGuinn Hall’s high number of windows has a great impact on the energy use of the building, particularly in relation to the building’s heating and cooling costs. It is important first to understand how many square feet of window space there is on McGuinn in order to better assess the energy efficiency improvement needs for the building. To begin, our group measured the dimensions of the various types of windows on McGuinn. Using our best estimations, we counted 642 total windows ranging from 50 to 82 inches high and from 31.5 to 72 inches across. After calculations (shown in the table below), we estimated the approximate square footage of window space to be 122,377 ft².

<table>
<thead>
<tr>
<th>McGuinn Window Measurements</th>
<th>Number of Windows</th>
<th>Measurement in inches (height x in²)</th>
<th>ft²</th>
</tr>
</thead>
</table>

Table 1: Window Measurements and Total Square Footage of McGuinn Hall
These findings are important in that they show the major extent to which windows play a part in the structure of McGuinn. 122,377 ft² is a significant amount of area dedicated to window space, and is especially troubling to energy concerns since the majority of these windows are single-paned and more easily allow for cold and heat to be transferred between the outdoors and the interior of the building.

Afterwards, we contacted the BC Energy Manager John MacDonald and the Energy Management Specialist Bruce Dixon in order to get a better sense of the energy expenditures of McGuinn. Mr. MacDonald and Mr. Dixon provided the hard data of the amount of energy McGuinn consumes, provided in the tables below. In 2013 McGuinn went through 33,568 mBtu of steam energy for heating and cooling (powered by natural gas) over the course of the year, with energy levels peaking in the significantly warmer months of May through August. McGuinn averaged about a 3,050 mBtu expenditure of steam energy per month. As for electrical energy, McGuinn used 1,084,112 kWh during the 2013 year, with kWh also peaking during warmer months. The building averaged an output of 90,342 kWh per month over the year. Mr. Dixon noted that Boston College gets its electricity from a natural gas power plant contracted with NSTAR located in the Boston metropolitan area. This is a large energy expenditure for one singular building, and it is without a doubt related in part to the out of date single-paned windows and the poor window weatherization practices the building employs.
Table 2: McGuinn Energy Use – Heating, Cooling, and Electricity

<table>
<thead>
<tr>
<th>McGuinn Steam</th>
<th>mBtu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month</td>
<td></td>
</tr>
<tr>
<td>1/31/2013</td>
<td>2783.528</td>
</tr>
<tr>
<td>2/28/13</td>
<td>2334.734</td>
</tr>
<tr>
<td>3/31/13</td>
<td>2735.677</td>
</tr>
<tr>
<td>4/30/13</td>
<td>2702.208</td>
</tr>
<tr>
<td>5/31/13</td>
<td>2875.969</td>
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<tr>
<td>6/30/13</td>
<td>2936.589</td>
</tr>
<tr>
<td>7/31/13</td>
<td>3058.437</td>
</tr>
<tr>
<td>8/31/13</td>
<td>5407.066</td>
</tr>
<tr>
<td>9/30/13</td>
<td>2957.631</td>
</tr>
<tr>
<td>10/31/13</td>
<td>2988.938</td>
</tr>
<tr>
<td>11/30/13</td>
<td>2781.256</td>
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<tr>
<td><strong>Total mBtu per year:</strong></td>
<td><strong>33,568.066</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>McGuinn Electrical</th>
<th>kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month</td>
<td></td>
</tr>
<tr>
<td>1/31/13</td>
<td>84896</td>
</tr>
<tr>
<td>2/28/13</td>
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<tr>
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<td>91423</td>
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<td>11/30/13</td>
<td>83362</td>
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<tr>
<td>12/31/13</td>
<td>82078</td>
</tr>
<tr>
<td><strong>Total kWh per year:</strong></td>
<td><strong>1,084,112</strong></td>
</tr>
</tbody>
</table>

One final piece of important information is the cost of McGuinn’s energy use. Mr. MacDonald stated that on average McGuinn consumes around 1,126,969 kWh per year at a cost of $0.136 per kWh. With this information, it is possible to calculate the average cost to heat, cool, and provide electricity to McGuinn:
1,126,969 kWh x $0.136 per kWh = $153,267 per year to operate

With a price tag of $153,267 per year to operate, McGuinn’s energy efficiency issues should not be ignored. The poor window quality compounded by the sheer square footage of glass incurs large costs to the university and is detrimental to the environment. In order to lessen the building’s energy waste, consequential environmental degradation, and high energy costs, there need to be renovations to the building’s windows. This paper will look into the various forms that these renovations could take, as well as a cost-benefit analysis of the various options. After analyzing the available data, this study will conclude with final recommendations for what would be the best option for window renovations for McGuinn, taking into consideration energy efficiency, environmental impact, and long-term cost.

❖ Double Paned Windows

Glass itself is a very poor insulator. In any building, windows are going to account for the majority of energy loss. The poor insulation allows the hot air from the heaters or the cold air from the A.C. to escape the building. This escape means more energy needs to be expended to achieve the desired temperature. Double paned windows provide extra insulating benefits that mitigate this energy loss and thus cut energy costs of a building.

Two major factors make single paned windows more efficient, with the first being the extra layer of glass. By adding another pane, the heat has twice the material to pass through and more is kept in the building. Figure 2 demonstrates the ways in which the extra layer can prevent heat loss and solar heat gain.
The second way in which double paned glass prevents energy loss is the air that is situated between the two layers. Air is a much better insulator than glass. While the extra pane only slightly decreases heat loss, the layer of air is where double paned windows truly get their efficient nature. Substituting another gas for the air can further increase the efficiency of double paned windows. Two of the most commonly used gases to decrease energy loss are argon and krypton. The gas that fills this space and the distance between the two panes determine the majority of the insulating properties of a double paned window as shown in Figure 3.

Adding the layer of gas in between the panes greatly increases the costs of the windows however. Not only does the cost of production increase, but also so does the cost of maintenance. For these reasons, the group decided to focus on the market standard for double paned windows: a layer of air situated between the glass.
The cost of double paned windows varies greatly. The factors that determine the cost include the efficiency levels, the size, the window company, and the building that is receiving the new windows. In order to simplify data the group chose to look at numerous companies and costs and find an average price and efficiency level. The group wanted to ensure that for whatever windows were chosen they would meet the standards set out by the U.S. government via Energy Star. The results were that for McGuinn hall, the average cost for replacing all the windows would be around $850 per window. With every window replaced, these new double paned windows would be able to cut the building’s energy bill by 50%. Table 3 illustrates the costs and savings associated with installing new, double paned windows with McGuinn.

<table>
<thead>
<tr>
<th>Number of Windows</th>
<th>Cost per Window</th>
<th>Total Cost</th>
<th>Current Energy Costs</th>
<th>Projected Savings (with double paned windows)</th>
</tr>
</thead>
<tbody>
<tr>
<td>642</td>
<td>$850</td>
<td>$545,700</td>
<td>$153,267 per year</td>
<td>$76,633 per year</td>
</tr>
</tbody>
</table>

Table 3: Costs and savings associated of double paned windows (homeadvisor.com)

The results of this cost benefit analysis show that by updating McGuinn’s out of date windows, the building can save around $76,633. With the initial cost, however, these saving only provide a return on investment of a little of 7 years. While in the long run a 7-year return on investment is not bad, Boston College would prefer to see an ROI of about 2-4 years. That being said, this cost benefit analysis is not complete. It only shows the cost associated with energy in the building and it does not consider the societal costs of improper energy use. With carbon dioxide levels in the atmosphere already at an overly high level (around 400 ppm according to Bill McKibben), BC needs to do its part to burn as little fossil fuels as possible. By adding energy efficient window in McGuinn and other older buildings, BC can help reduce the adverse affects of global warming.

**Energy Saving Film**

Energy saving window film typically consists of a thin polyester film substrate that has a micro-thin, transparent metal coating applied to one side. This metal coating is applied using vacuum-based technologies such as vapor deposition or sputtering. A second layer of polyester film is laminated over the metal coating to protect the metal. A scratch resistant coating is
applied onto the side of this laminated composite that faces the building interior to protect the film during normal window cleaning. An adhesive layer is applied onto the film side that faces the glass and is protected by a removable release liner until just before the film is applied to the glazing system. Ultraviolet absorbers are added to the polyester film layers, the adhesive layer, or both to protect from UV degradation. Figure 4 below demonstrates how the film works:

![Figure 4: How Film Works](http://gjerdessolarshield.com/residential/faq.html)

Energy saving film rejects solar heat effectively by rejecting a greater portion of the sun’s heat than tinted or heat absorbing glass, rejecting up to 84% of solar heat gain (Florida Solar Energy Center). While window film is often valued in warm climates for their quick payback, payback is often affected just as much by electricity costs as climate. Therefore, use of energy saving window films should be considered in any climate with above average electricity costs. The figure (Figure 5) below shows the temperatures with film and without film.
Across all climate zones, energy saving window films offers a good return on investment due to the combination of solar performance and significantly lower material and installation costs. On average, it costs $3.00 per square foot for window film ("Energy Analysis for Window Films Applications in New and Existing Homes and Offices"). With these factors in mind, application of energy saving window films should be strongly considered in lieu of window replacement if existing window are functionally sound.

Furthermore, in a study conducted by the International Window Film Association, the energy saving effect of installing window film was compared to several traditional energy saving techniques such as updating HVAC systems, adding R-38 ceiling insulation, and air sealing and caulking ("Energy Analysis for Window Films Applications in New and Existing Homes and Offices"). The data shows installing window film on new homes and businesses is not an attractive energy efficiency measure. The reasoning is due to the window already using high performance glazing. Thus, the return on the investment will be minimal. But when considering older building such as McGuinn, the most effective method may be applying a cost effective window tint.

Figure 5: Temperature With and Without Film, ("Energy Savings Window Film Upgrade Cycle")
In existing offices, window film represents a significant opportunity for cost effective energy savings. Window tinting prices are significantly less than other energy saving solutions. Window tinting can help reduce a building’s energy costs by 5-15% and cut solar heat gain up to 75% (“Vista Window Films”). Thus, the annual energy costs savings window tinting provides allows a building to quickly recoup its window tint costs. Typically, the recovery span occurs in three years or less.

In addition, window film provides protection to patients, staff, and even the facility’s furnishings from exposure to ultraviolet radiation coming in through the windows. Window film can help with energy control and lowers the cost of energy. It can stop 80 percent of the solar energy coming through the glass (“Vista Window Films”). Window films have been designed, tested, and certified for protection of broke glass in bomb blasts, severe windstorms and whenever there’s any impact with a window wither from inside the room or from outside of the room. Window film can help reduce excess glare. The window film can darken the windows to cut back on too much light coming through during regular daylight hours, which will also avoid the alternative of closing blinds and turning on interior lights.

Two of the main negatives of energy efficient window film are warrant problems and choosing the wrong film. If you install solar window film on double-pane windows, there is the possibility you could void your warranty. Some types of film absorb all of the sun’s rays instead of reflecting them away. When the glass heats up, it expands, which can break the factory seal or break the glass. Thus, the window is no longer energy-efficient and may need replacing.

Next, newer, shiny window film brightens the room while keeping out the passive solar heat gains that raise the temperature. While this may be desirable in warmer climates, passive solar heat gain is beneficial in the cold climate of Boston. Conversely, dark window film blocks ultraviolet light by absorbing the entire spectrum. It blocks a significant amount of natural light and increases the need for indoor lighting.

Both of these issues are easily manageable through proper research. Below, I have found two companies that specialize in the design of energy efficient window film and tint. Both companies received good reviews and have worked on projects across the nation such as Dulles Airport and other corporate buildings.
In addition, when plugging in the specifics of McGuinn into the LLumar energy savings calculator, the following energy savings were calculated.

![LLumar Energy Savings Calculator](http://northamerica.llumar.com/choose-a-product/llumars-interactive-tools/energy-savings-calculator)

**Figure 6: LLumar Energy Savings Calculator** (http://northamerica.llumar.com/choose-a-product/llumars-interactive-tools/energy-savings-calculator)
**Energy Consumption Behavior**

In order to accurately conduct a cost benefit analysis of window efficiency in McGuinn Hall, our group felt compelled to seek further understanding of energy consumption behavior both at Boston College, and in today’s society. With a sad disregard for global climate concerns by a majority of even those educated on the issues, the subsequent implications of a populace unaware of how their actions negatively affect the environment are substantial. By considering the common practices of individuals at Boston College, specifically those of faculty and staff primarily located in McGuinn Hall, and reviewing average energy related costs associated with said standard behavior, we may come to understand how to improve energy efficiency short of installing new windows or treatments.

It is important to note that actions we take for granted often have more effect on the outside world than we comprehend. Although there are a myriad of ways buildings become more efficient, our group was assigned to look into specifically window options which gave us a distinct task, and luckily there is ample information out there considering our topic. We began our research by looking at one quote in particular: “Heat flows through a window assembly in three ways: conduction, convection and radiation. When these basic mechanisms of heat transfer are applied to the performance of windows, they interact in complex ways. Three energy performance characteristics of windows are used to portray how energy is transferred and are the basis for how energy performance is quantified” (“Understanding Windows”).

- **Insulating value.** When there is a temperature difference between inside and outside, heat is lost or gained through the window frame and glazing by the combined effects of conduction, convection, and radiation. This is indicated in terms of the U-factor of a window assembly.
- **Heat gain from solar radiation.** Regardless of outside temperature, heat can be gained through windows by direct or indirect solar radiation. The ability to control this heat gain through windows is measured in terms of the Solar Heat Gain Coefficient (SHGC) of the window.
- **Infiltration.** Heat loss and gain also occur by Air Leakage through cracks in the window assembly. This effect is measured in terms of the amount of air (cubic feet or cubic
meters per minute) that passes through a unit area of window (square foot or square meter) under given pressure conditions. In reality, infiltration varies slightly with wind-driven and temperature-driven pressure changes.

While the majority of our assignment dealt with the first two window characteristics in generating a cost-benefit analysis, the problem of infiltration and air leakage is equally tied to building construction features as it is to behavior. After contacting window companies, conducting both research in the field and in the books, one particular issue became apparent. The first day this spring we made it over to McGuinn to conduct window surface area calculations and inspect the interior, it became obvious that the occupants of the building were taking energy measures into their own hands.

Everywhere you looked there was an unlocked window here, a window fully ajar there. You begin to realize that although some major renovations have been made to make office spaces more aesthetically pleasing, these renovations have overlooked the necessity to update inner mechanics such as air conditioning system, and yes, the windows. This is a critical issue because when “The heating system of a building is usually on from October to May, rooms can sometimes be overheated. One way people try to deal with this is by opening a window. This is the most wasteful way to deal with this problem” (“Doing My Part”). During the winter, even a partly open window wastes a huge amount of energy. “To make up for the energy loss, the heating system must burn additional natural gas or oil, or use electricity to keep the building temperature at the proper set point. This additional energy consumption is responsible for the increase in GHG emissions” (“Doing My Part”). In short, this practice of opening windows is both detrimental to Boston College’s energy bill, as well as markedly impactful on our ecological footprint.

Moving beyond the question of window use behavior, we think it would be helpful to offer forth a few tips on how to reduce energy use here at Boston College, and specifically in McGuinn Hall for the staff who work in the building and furthermore, offer techniques used both in home and commercial settings that can help reduce this same energy use.

Faculty and Staff Can:
Adjust the Temperature

- When you are at work, set your thermostat as low as is comfortable.
- When you are out of the office, turn your thermostat back 10° to 15° for eight hours and save around 10% a year on your heating and cooling bills.

Find and Seal Leaks

- Seal the air leaks around utility cut-throughs for pipes ("plumbing penetrations"), gaps around chimneys and recessed lights in insulated ceilings, and unfinished spaces behind cupboards and closets.
  Find out how to detect air leaks.
  Learn more about air sealing new and existing homes.
- Add caulk or weather-stripping to seal air leaks around leaky doors and windows.
  Find out how to select and apply the appropriate caulk.
  Learn how to select and apply weather-stripping.

Take Advantage of Heat from the Sun

- Open curtains on your south-facing windows during the day to allow sunlight to naturally heat your home, and close them at night to reduce the chill you may feel from cold windows ("Fall and Winter Energy-Saving Tips").

Use Curtains Properly

- An investment in energy efficient curtains will save money during winter and summer months. Energy efficient curtains serve a dual purpose; they retain heat during the winter and reject heat in the summer, resulting in lower cooling and heating bills. You'll control how much sun is allowed to enter your home, and when, by adjusting the energy efficient curtains to be either open or closed.

Let It Flow

- Keep air vents clear of paper, files, and office supplies. It takes as much as 25 percent more energy to pump air into the workspace if the vents are blocked. Plus you might be able to get rid of your space heater! ("Energy-saving tips for everyone")
Recommendations and Conclusion

After completing our research and cost-benefit analyses, the issue of energy efficiency in McGuinn became even more apparent. While there are many options that McGuinn could explore to become more energy efficient, not all the options are realistic cost- or implementation-wise. Updating all single paned windows to double paned windows undoubtedly brings the highest energy efficiency improvements to McGuinn, with a 50% cut of energy costs and savings of $76,663 a year. However, this option is very costly (weighing in at approximately $545,700 for the renovations), and it is unlikely that Boston College would be willing to shell out this much money to renovate an old building such as McGuinn. While the environmental improvements are the most striking with this option, we found it to be unrealistic as a choice for Boston College due to its long return on investment and large initial costs.

Applying energy saving window films was the second option that we explored. We found that window tinting can help reduce a building’s energy costs by 5-15% and that by applying medium tint (the lowest and cheapest grade product), Boston College would save around $35,000 a year on energy costs. The environmental improvements are significantly lower for this option than compared with the double paned window option, yet the cost was considerably lower and the return on investment period would only be around 2-4 years. We deduced that this option, while not necessarily the most beneficial to the environment, would be the most realistic choice for Boston College. According to John MacDonald, our contact and the Energy Manager at Boston College, the university is typically looking to see a 2-3 year return on investment for projects such as these. With this option, McGuinn would still see reductions of energy use and overall costs, but would have a much quicker return on investment period.

That being said, our final recommendation for McGuinn’s window treatments and energy efficiency improvements is to invest in low-cost window films and couple this with behavioral changes of the staff and students present in McGuinn. The energy efficiency improvements of McGuinn via the window tinting could be vastly aided by behavioral changes by the staff such as closing windows, adjusting the temperature of rooms, and closing blinds at key points during the day. These extra behavioral adaptations would bolster the improvements given by the window tints and better assist McGuinn in raising its energy efficiency and lowering its heating, cooling, and electricity costs.
In conclusion, this project has helped to identify key issues in McGuinn’s energy use portfolio. Its lack of structural renovations and its window-filled façade have led to high energy costs and low energy efficiency in the building. While switching all windows from single paned to double paned would have the highest energy benefits, the costs and long return on investment are unrealistic for Boston College. Employing window tints and simple behavioral changes in the building will lead to improved energy efficiency, lower HVAC costs, and a far smaller carbon footprint, all at a much lower cost to the university.
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