Cost-benefit analysis of outfitting the windows of the Henry Hicks Arts and Administration building with more efficient models to improve Dalhousie University campus sustainability

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ABSTRACT:

With its prominent clock tower and classic design, the Henry Hicks Arts and Administration building, which was built in 1955, is probably the university's most recognizable and symbolic structure. Despite its importance to the university, the Henry Hicks or H&H building is behind in some of the maintenance measures necessary to keep the building in good condition. One of such measures would involve replacing the building's inefficient single-glazed windows with a more efficient window type. According to Marvin Windows and Doors, windows should be replaced every 20 years. This means that the H&H building is 30 years overdue for a window upgrade. However, the university works on a budget and is reluctant to take any reconstructive measures that are not cost-effective. This study weighs the costs and benefits associated with replacing the single-glazed windows with three types: the Kohler Energlas Plus, Marvin's Clad Ultimate Double Hung and Marvin's Casemaster. Each window is compared to the current type to measure energy savings, and carbon dioxide emission savings. These benefits were weighed against the costs associated with the installation using information provided through interviews with the assistant director of Facilities Management and two of the university's main window manufacturers, Kohler Windows and Marvin Windows and Doors. Although the study results suggest that window replacement cannot prove to be cost effective within 5 years (the university's standard for cost-effectiveness), the upgrading of windows would produce significant savings in energy costs and carbon dioxide emissions. It is recommended that in order to promote campus sustainability, Dalhousie replace the windows despite this drawback considering that the windows are due for replacement anyhow. With this said, Dalhousie should choose the Energlas Plus window produced by Kohler Windows and wood rather than vinyl stripping. This window type was not only the most efficient but would be able to reach the point of cost-effectiveness within 17.7 years of installation (sooner than the other proposed window types).

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INTRODUCTION

Overview

The problem that we have chosen to investigate is that the windows of the Henry Hicks Arts and Administration (H&H) building are of low quality and are allowing heat to escape readily from the building. Consequently, Dalhousie is burning more oil to heat the building, spending more money to pay for the oil, and creating more pollution than they would be if the current windows were replaced with windows that are more energy efficient. One source of evidence for this comes from a previous study conducted in by the Dalhousie Facilities Management (1983). These researchers concluded that the old windows, which are still in place today, are highly inefficient and allow large amounts of energy to be wasted (Dalhousie Facilities Management, 1983).

A review of current literature also indicates that single glazed windows are highly conductive, thus allowing a substantial amount of energy to be wasted. Current literature also suggests that more efficient windows are widely available (see "Literature Review" below). The qualitative analysis of this project will involve interviewing window suppliers to determine if the windows presently available would reduce energy costs for Dalhousie. Although the replacement of the windows of the H&H building was determined to save both money and energy over several years, the windows were not replaced as the university must operate on a five-year financial plan, which does not allow enough time for the benefits of replacing the windows to outweigh the initial costs (Dalhousie Facilities Management, 1983). Our project is intended to assess the current feasibility of this situation.

The problem of the inefficient windows affects many people in different ways. The comfort of those using the building may be affected by the quality of the windows, and students' tuition rates are affected by amount of fuel used for heating. In addition, Dalhousie would have to obtain immediate funding for the installation and purchase of the new windows if the current widows were replaced. Finally, diminishing the environmental impact of heating the H&H building and increasing Dalhousie's sustainability would affect the university's reputation as well as the health of many living organisms.

Our investigation into the possibility of upgrading the windows on campus will focus upon the H&H, and on Dalhousie's energy production, which takes place at the Facilities Management building on the Dalhousie Campus. Our project will be completed by April 8th, 2005, which means that approximately two months are available for this investigation to be carried out. Further limitations/delimitations and temporal boundaries of this project are described below.

Goal

To assess the feasibility and environmental impact associated with replacing the current windows in the H&H building with more energy efficient types in an effort to promote sustainability on campus.

Objectives

1) Identify potential replacement windows which are i) energy efficient and ii) cost-effective.

2) Assess the performance of these windows in light of the university's economic, environmental, aesthetic standards.
3) Make a recommendation to Dalhousie Facilities Management based on the study's findings.

Background

Located on the Studley Campus of the university, the H&H building is a symmetrically designed, stone building with an elaborate clock tower prominently displayed at its center. Built in 1955, this building is probably the structure most commonly associated with Dalhousie University as it is often photographed for the university's publicity shots. The H&H has significant symbolic value to the university community and its importance should be reflected in the building's upkeep. Maintaining the building properly will ensure that it building can remain a fixture on the campus for years to come. Perhaps the most important update that should be done to the building in order to bring it into the 21st century involves replacing its windows. Unlike some of the more modern buildings on campus (for example, the Marion McCain Arts and Social Sciences building and the new residence Risley Hall) the H&H is outfitted with old-fashioned, single-paned windows which are a notoriously energy inefficient design. Over the years, facilities management has considered replacing the older windows with newer, more efficient ones but the last study conducted to investigate this possibility proved window upgrading to be an uneconomical decision at the time. Since this 1983 study, "[t]he window industry has witnessed revolutionary changes" (Elmahdy & Cornick, 1990) including vast improvements in the selection and costs of windows. Consequently, it is time that the possibility of window upgrades to the H&H building be revisited and reassessed taking into consideration the current figures and new technologies.

Due to the aforementioned changes in the window industry over the past two decades, window selection has greatly expanded and as a result, choosing windows is a complicated and involved process. According to the National Research Council of Canada, however, there are several main factors which contribute to a window's performance that should be considered in the selection process:

> *"In addition to controlling heat flow, sound transmission, and air and rain leakage, windows are expected to transmit light without causing glare, to bring in fresh air without causing drafts and letting in insects, to be airtight but easy to operate, to bring in solar heat (in housing) in winter but not in summer."* (Rousseau, 1988)

When choosing a window type it is important that these criteria are considered and the benefits of the various factors are evaluated in light of climate, budget and appropriateness for building. For example, because the H&H is a historical property, it is important to maintain its historical quality to ensure that it remains "appealing and harmonious with the surroundings" (Rousseau, 1988). Windows can also be selected on the basis of less tangible qualities such as psychological or environmental reasons. Windows have been shown to enhance "mood, motivation and productivity" (Menzies & Wherrett, 2004) which are valuable qualities in a university setting. Although considerations when it comes to window selection are many, this study concentrates primarily on the assessment of window quality in terms of energy efficient and thus heat flow will be the main factor of interest.

Heat flow can include both the flow of warm air inside from outside when it is hot outdoors and the flow of warm heated air from inside to outside; both scenarios result in energy inefficiency. When heat radiates through windows on hot days it requires more energy to air-condition the space and maintain a comfortable temperature. Conversely, when heated air escapes from inside to outside during the cooler days, more energy is needed to reheat the space in order to maintain its optimal temperature of 70ºF during the heating season at Dalhousie (Personal communication with Peter Howitt, January 27, 2005). According to Menzies and Wherrett, "windows are responsible for a disproportionate amount of unwanted heat gain and heat loss between buildings and the environment" (2004). A window's capacity to limit this heat exchange between the indoors and the outdoors is determined by the thermal resistance of the window or its U-factor (Rousseau, 1988). Double-glazed or triple-glazed windows, in which there are two or three panes of glass sandwiched together with a layer of air or inert gas between each pane, have more thermal resistance than do single paned windows like the type found in the H&H. This is because the layer of air between the panes impedes the flow of heat, while the glass itself does almost nothing to prevent the heat flow exchange (Rousseau, 1988). Over the years new technologies which can further increase a window's thermal resistance have been developed. Such innovations include low Emissivity coatings and the injection of gases other than air between the panes (Rousseau, 1988) but these will be examined in greater detail later on.

Experts in the field of energy efficiency have estimated that anywhere from 3 per cent (in the USA) to 7 per cent (in Sweden) of total energy consumption is lost through windows (Menzies & Wherrett, 2004). Because so much energy is escaping from inefficient windows, more energy must be generated to compensate for the loss and to maintain indoor temperatures at their optimal levels. In the case of Dalhousie, which uses oil as fuel, more oil must be burned in order to produce this energy. The burning of fossil fuels releases damaging greenhouse gases into the atmosphere which are responsible for global warming as well as other pollutants which contribute to air pollution and poor air quality in general. The selection of windows can provide architects with "a major opportunity to conserve energy" (Menzies & Wherrett, 2004) and therefore simultaneously cut the university's oil costs and reduce the campus's contribution to overall environmental degradation. Furthermore, choosing energy efficient windows is an environmentally-responsible decision that can help the Dalhousie University move towards its ultimate goal of sustainability as defined by the Halifax Declaration and the Talloire Declaration.

According to architect Avi Friedman "[o]ne of the most effective ways you can control heat losses is through the careful selection of windows." Friedman suggests that in this selection process, a consumer's choice of frame material and type of glazing (2003) are the most important determinants of energy efficiency. In terms of frame selection, wood is the frame material that offers the best insulation followed by vinyl frames and thermally broken metal frames (Friedman, 2003). In general, however, frames are "the weak point in the window design," (Menzies & Wherrett, 2004) the type of glazing is probably the biggest determinant of efficiency. As mentioned above, double-glazed or triple glazed windows are much better at preventing heat exchange from inside to outside than are single-paned windows (Rousseau, 1988). The benefits of multi-glazed windows, however, can be further enhanced by coating the glass with a low emissivity or low E coating. This coating "allow[s] high proportion of the visible light in the solar spectrum to be transmitted but block[s] much of the other wavelengths responsible for solar heat gains, thus improving thermal efficiency" (Menzies & Wherrett, 2004). It has also becoming increasingly common to purchase windows, which have low conductivity gases such as argon or krypton injected into the space between the panes. This adjustment furthers slow the process of heat loss and gain (Menzies & Wherrett, 2004).

A window's performance in terms of energy efficiency can be assessed by looking at four main properties: its U-factor, air leakage (AL), Solar Heat Gain Coefficient (SHGC) and visible transmittance (VT) (Efficient Windows Collaborative, 2004). Perhaps the most relevant of these properties to this study at hand is the U-factor, the measure of a window's thermal resistance in Btu/hr-st-°F (Efficient Windows Collaborative, 2004). As a general rule, the lower the U-factor the better the window is at resisting heat flow and at insulating (Efficient Windows Collaborative, 2004). Another measurable property of window energy efficiency is air leakage (AL = leakage in cfm/sf). Air leakage determines the extent of heat loss by measuring "the cubic feet of air passing through a square foot of window area" (Efficient Windows Collaborative, 2004). The other two determinants of a window's efficiency are the Solar Heat Gain Coefficient which is the "fraction of incident solar radiation admitted through a window" and the visible transmittance measure which "indicates that amount of visible light transmitted" (Efficient Windows Collaborative, 2004). In order to simplify the research, however, this study will concentrate on the U-factor property, as heat gain and heat loss are the main issues of concern to campus facilities management.

With the support of Dalhousie University facilities management, this study will attempt to weigh the costs and benefits of three windows, the Kohler Engerglas Plus, the Marvin Clad Ultimate Double Hung, and the Marvin Casemaster. Each of these windows is a double glazed window with argon fill and low E coating, however vary in their different closing mechanisms and in the inherent differences that exist between manufacturers. The research will involve gathering information and opinions from the facilities management department as well as consulting window producers to gain expert knowledge on window types and respective efficiency ratings, and an extensive cost-benefit analysis that measures the price of installing new windows against the dollar savings in energy that could be incurred.

LITERATURE REVIEW

It is a widely accepted belief that the world is in the midst of a period of rapid climate change. Many believe that the anticipated global warming associated with climate change results in heat-waves, melting glaciers, and the shifting of climate zones. "The gases we continue to release will have impacts on the world of our children, grand-children, and great-grand children for years to come" (Dauncy & Mazza, 2001). If these predictions are accurate, then it imperative that we take action as soon as possible to minimize the potential consequences. Through the creation of the Kyoto Protocol, which aims to reduce the amount of greenhouse gases in the atmosphere, world governments are recognizing the need to change our practices and reduce our impact on the environment. The Canadian government is committed to reducing Canadian emissions by 6 per cent to pre-1990 levels (David Suzuki Foundation, 2002). However, the government cannot be solely responsible for the improvement of the Canadian environment – companies, institutes, and individuals must also play a role. Dalhousie University is no exception.

In 1983, members of the facilities management team at Dalhousie University conducted a study in order to determine whether it was economically feasible to replace the single-paned windows of the H&H with the more energy efficient double-glazed type. The results of the study, however, were not encouraging. At the time, oil prices were so low that the predicted savings to be incurred from the reduced energy use were not significant enough to offset the steep start-up costs associated with replacement. The cost-benefit analysis determined that the cost of upgrading the building's windows to storm (double-glazed) windows would be $94 000 so with the cost of oil at $0.88 per gallon, the university would save a $5 800 per year (Dalhousie University Facilities Management, 1983). Thus, the choice to replace the windows would only begin to pay off for the university after 16 years. The study cites "[a]lthough there is a substantial saving to be had by the addition of storm windows the cost will be high because of the large size, offering a particularly poor payback" (1983). As a result of these findings, facilities management temporarily put the plan to replace the H&H windows on hiatus.

Over the two decades since Dalhousie's investigation into window replacement, however, there have been significant advancements in window efficiency technology (Elmahdy & Cornick, 1990). This revolution in the window industry has resulted in numerous relevant studies comparing the various window types. One such study was conducted by the Efficient Windows Collaboration in 2004. The study calculated the annual cost of heating and cooling a new 2000 square foot house with 300 square feet of windows using six different cases involving six different window types and technology combinations:

Double glazing, clear glass, aluminum frame with thermal break
Double glazing, low E coating (low solar gain), argon gas fill and aluminum frame with thermal break
Double glazing, clear glass, vinyl/wood frame
Double-glazing, low E coating (low solar gain), argon gas fill, vinyl/wood frame
Double-glazing, low E coating (high solar gain), argon gas fill, vinyl/wood frame

Triple glazing, low E coating (moderate solar gain), argon gas fill, insulated vinyl frame. (Efficient Windows Collaborative, 2004)

Of the six cases, the triple glazing had the highest thermal resistance and the first window type (double-glazed, no argon fill) exhibited the lowest thermal resistance (Efficient Windows Collaborative, 2004). The results indicated that it cost $255.80 more annually to heat and cool in "Case 1" than in "Case 6". The windows associated with the highest heating and cooling costs were "Case 2" ($1157.14) and "Case 1" ($43.20) respectively. While the windows associated with the lowest heating and cooling costs were "Case 6" ($880.88) and "Case 5" ($17.49) respectively. The best overall savings occurred in "Case 6" ($909.31) and the most costly heating and cooling was in "Case 2" ($1175.51) (Efficient Windows Collaborative, 2004). Because Nova Scotia has a cool climate, preventing heat loss is more important than concerns involving air conditioning costs and heat gain. The data seems to suggest that when it comes to minimizing heat loss and reducing annual heat cost, triple glazing is better than double-glazing, a low E coating with high solar gain is an asset and that insulated vinyl frames offer the best results. Although these findings are based on the data gathered on a home and thus study will evaluate a large, university building, the results provide some insight into the performance levels of the various window types which can probably be extrapolated to benefit the Henry Hicks Arts and Administration building.

The findings of the above study were reached using efficiency-measuring models which take into account the space's size, the window area, the U-value, AL, Solar Heat Gain Coefficient and VT values. Karlsson, Karlsson and Ross, however, have developed a different model for rating the energy balance of windows in mid-Swedish climate which is a climate more similar to that of Canada's (2001). For their study, Karlsson, Karlsson and Ross gathered a set of 34 different windows of the 17 of which may or may not have had the gas fill, 2 were ordinary, 9 had the low emissivity coating and 6 were solar-control windows. Of the remaining window with gas fill there were several double and triple glazed varieties (2001). Their model determined that with the Stockholm climate, the uncoated double glazed windows have a lower energy balance than the coated version of the double glazed window and that all the low emissivity coated double-glazed units have better thermal performance than the uncoated triple-glazed windows (Karlsson, *et. al*, 2001). The window which yielded the best energy savings, however, was the triple-glazed unit with two tin-oxide coated panes and argon gas filing (Karlsson, *et. al*, 2001). Through the model Karlsson, Karlsson and Ross reached the conclusion that "the gas-filled and coated DGUs [double-glazed units] may be the most cost effective choice, even when compared with high performing TGUs (triple-glazed units)" (Karlsson, *et. al*, 2001). This study is a helpful resource as achieving cost-efficacy is the primary objective of the facilities management department which is often subject to financial constraints.

In addition to assessing which window types are most energy efficient and cost-effective, studies have been conducted in order to uncover people's attitudes towards windows and window replacement. Menzies and Wherrett conducted interviews of 28 architects from all over Scotland and handed out questionnaires to the occupants of the buildings that would be assessed (2004). From their conversations with the architects, the researchers were able to determine that “sustainability is not a major factor in the selection of windows. Costs are often assumed to be higher for environmentally sustainable products [...]” (Menzies & Wherrett, 2004). Most of the architects consulted considered comfort and productivity to be of greater importance in the window selection process than sustainability (Menzies & Wherrett, 2004). The poll of occupants, however, shows that it is possible for “environmentally sustainable and energy-efficient windows can also have high levels of comfort and productivity, where the building and window designs work together “(Menzies & Wherrett, 2004). The research of Menzies and Wherrett helps emphasize the role that architects and occupants opinions play in their acceptance of environmentally-friendly technology and policies and that pre-conceived notions about green technology can act as a barrier to its implementation.

The valuable role that windows play in environmental sustainability and energy conservation is illustrated in the increasing body of research done on the topic of window performance and efficiency. These studies have suggested that some window types outperform others and that improvements in efficiency since the first double-glazed windows were released on the market have been achieved. Furthermore, this research helps emphasize the need to revisit the issue of window replacement in the Henry Hicks Arts and Administration building. Considerable progress in terms of new window technology and efficiency modeling has been made and this sustainability issue should be revisited in light of the new findings.

In 2000, students participating in the WATgreen campus sustainability initiative at the University of Waterloo conducted a similar research project designed to assess the most energy efficient window system for the university residences. While our research will consider window performance in terms of each entire window unit (for example, Marvin’s Ultimate Double Hung Window), the WATgreen project assessed each of the elements of an *integrative window system* including glazings, frames, landscaping, orientation, window type and so on (Holdner *et. al.*: 2000) separately and then determined which components should be combined in order to maximize energy efficiency. Despite these differences in approach, the WATgreen study results do provide some insight into window efficiency in a university setting. The WATgreen study recommends soft coat glazing (Low E^2), with vinyl frames and either a slider or awning style window design (Holdner *et. al.*: 2000) but the report implies that the University of Waterloo’s perspective of cost-effectiveness was too rigid for these recommendations. Consequently, the WATgreen researchers suggest that “in order to receive payback on an investment and have that investment be worth the effort, a policy with flexible payback-times on investments is more logical” (Holdner *et. al.*: 2000).

METHODS

Qualitative methods

The qualitative research element of this study involved interviews with the university's primary window manufacturers (Marvin and Kohler), Piercey's: The Building Material People, as well as with Peter Howitt, the Assistant Director of Facilities Management.

It was necessary to interview Peter Howitt, the Assistant Director of Facilities Management, as he is the faculty member in possession of documents pertaining to campus energy use as well as the study on window efficiency that was conducted in 1983. Furthermore, Peter Howitt is knowledgeable in terms of which windows are presently installed in the Henry Hicks, their efficiency, and their maintenance. The interview was done in person to facilitate communication (Palys, 2003); furthermore Howitt provided books and information packages to contribute to our research. His expert knowledge of Dalhousie Facilities, as well as his educational background in mechanical engineering, has contributed valuable information concerning the windows in the Henry Hicks building. The interview consisted of 23 open-ended questions (see *Appendix C*) although the structure of the interview was altered slightly to create more natural conversation. Peter Howitt has been consulted about his participation in this study and he has verbally consented to the use of his name and his answers for the purpose of this research project.

Marvin Windows Inc. and Kohler Windows are two of Dalhousie University's main suppliers of windows. For this reason, it was important that they be consulted for this research as it is from their product lines that the Facilities Management selects the campus building windows. Representatives from Marvin and Kohler were interviewed over the telephone and their recommendations were taken into consideration. The interview consisted of 9 open-ended questions about the product line and the product performance (see *Appendix C*). The windows named by each company (the window type they typically recommend, the most energy efficient type they sell along with the most cost-effective type they sell) were evaluated based on their performance and cost (see *Quantitative methods*) and compared to the performance and cost of the single-glazed window variety which is currently in the H&H. In other words, separate cost-benefit analyses was done for three Marvin windows, three Kohler windows and the single-glazed type and these analyses compared to determine whether a window upgrade would be feasible and/or beneficial in light of the university's standards.

It was also necessary to contact Piercey's as they are Kohler's primary supplier. From Piercey's we obtained the costs of the windows, as well as quotes for the installation costs. Based on the recommendations made by Piercey's we were also able to determine which window type would be the most effective for a large, non-residential building.

Quantitative methods

The university operates under budgetary constraints, which means that changes must deliver returns on the investment within 5 years of their onset in order to be considered by the university management.

Thus, in order to determine whether the proposed window replacement is economically-feasible for the university, a cost-benefit analysis was conducted. The first step of this analysis involved determining the appropriate equations for carrying out the calculations. This was done by referring to the previous energy efficiency analysis conducted by Dalhousie Facilities Management (1983), and then modifying the equations according to principles outlined by Incropera and DeWitt (2002). Secondly, the total number of outdoor windows in the H&H building were counted and the dimensions of each window type were measured (see table 1; results).

The next step was to obtain numerous values needed to calculate the difference in energy efficiency between the current windows and those proposed to replace them. These values include the R-values for both the current and the proposed window types, the average temperature difference between the inside and outside of the H&H, as well as the length of the heating season (see table 3; *Appendix F*). These values were then converted into comparable units using the appropriate conversion factors (Incropera, and DeWitt, 2002). The window measurements and the relevant values provided by Peter Howitt and the window manufacturers were entered into the following equation to determine the change in energy spent in one year:

Δ ***Energy spent per year (in J/yr)***

$$= [(\text{Current U value J/m}^2 \text{ x }^{\circ}\text{K x s}) - (\text{Proposed U value J/m}^2 \text{ x }^{\circ}\text{K x s})] \text{ x } (\Delta \text{ T }^{\circ}\text{K}) \text{ x (seconds of heating/yr) x (window area m}^2)$$

<u>*Oil savings*</u>

Through facilities management records, the amount of energy (kWh) currently required to heat the H&H was determined. This value was then converted from kWh to its dollar value knowing that 1 kWh is equal to 3412 BTU; because it is known that 1 lb of Bunker C is equal to 40,000 BTU (Unit Converter, 2004), the volume of Bunker C could be calculated, and the price of this volume was found knowing the corresponding volume. The change in litres of oil burned per year was calculated using the following formula:

Δ ***Litres of oil consumed per year***

$$= (\text{J/year saved}) \text{ x } (9.4781 \text{ x } 10^{-4} \text{ Btu/J}) \text{ x } (1 \text{ Gallon/180000 Btu x 0.5 efficiency}) \text{ x } (1 \text{ m}^3/264.17 \text{ gal}) \text{ x } (1000\text{L/m}^3)$$

Knowing the cost of oil per gallon, we were able to then calculate the change in dollars spent on bunker-C oil in a year using the formula below:

Δ $ spent on oil

= (energy savings J/yr) x (9.4781 x 10^{-4} Btu/J) x [(\$ cost of oil/gallon)/ (E per gallon of oil/ gallons x overall efficiency)]

Infiltration calculation

In order to acquire an accurate picture of the costs and benefits associated with replacing the windows, it was necessary that we determine the difference between the amount of energy lost through air escape from the cracks around the current windows and the amount of energy expected to escape to the outdoors for the proposed windows. This was achieved using the values from table 3 (below) and the following formula:

Δ $ spent on oil

= (Current Heat Transfer - Proposed Heat Transfer) x (Δ T °F) x (heating hrs/yr) x [(Cost of oil/gallon)/ (Btu per gallon of oil x overall efficiency)]

Total yearly financial savings

To determine total dollar savings from replacing the current windows with each of the proposed window products, the following formula was employed:

Total $ savings

= $ savings from reduced conduction + $ savings from reduced infiltration

Emission savings

The costs to the environment that are associated with inefficient windows were also calculated in terms of savings in carbon dioxide emissions per year. These values were determined under the assuming that the university emits 3.09 t/KL of combusted bunker-C oil per year. The savings borne on the environment by converting the H&H current outdoor windows to energy efficient models was assessed as follows:

Total savings in CO_2 emissions

= kilolitres of oil saved per year x 3.09 T of CO_2 /kL of Bunker C oil burned

Cost of Window Replacement

To determine the costs associated with the window replacement, we consulted Piercey's: the Building Material people, Marvin Windows and Doors, Peter Howitt and contracting agency, C.M. Campbell Electric Limited. From these sources we were given various estimates on the cost of window replacement. The breakdown of expenses and the various quotes can be seen in below (table 2; results). These estimates were subsequently multiplied by the yearly savings in oil purchases to determine when the cost of the window replacement would equal the financial savings in these oil purchases. The savings from each window type were compared to both the lower and upper estimates associated with the cost of replacement. The findings are described in below (figure 4; results).

Limitations

The biggest limitation associated with this study stems from the fact that a similar study has been done prior (in 1983) and the proposed window upgrade was proven not to be cost-effective. The university is fuelled by a specific type of low-grade oil (Bunker C), the price of which has not changed significantly since the 1983 study was done. This is compounded by the fact that the price of labour has increased since the time of the prior study so the installation of double-glazed windows is, in the short term, negatively in the study's favour. Therefore, we are largely limited by the University's view of cost-efficiency over the short term, rather than the long-term benefits of more energy efficient windows. Also, another limitation is the various types of windows available. The technology surrounding the advancement in window efficiency has improved over the years so our study is limited by what windows could be installed. Further, the various window types available in the Halifax region limit this study. Another limitation may be the potential constraints of pre-existing building codes. This is a factor that would be investigated if the university approved the window upgrades, but if the study does prove to be cost-effective then installation must agree with building codes and standards. Another limitation to the study is the amount of time given to complete the project because the project time constraint is only one semester.

Delimitations

This study is delimited by only using the H&H to conduct the study. By focusing only on this one building we are delimiting the study because we will only be concerned with the energy efficiency of the existing windows in the H&H. The study is also delimited by the fact that it will be predominantly a quantitative study based on calculations of energy-efficiency and cost-benefits analyses. Because the study is trying to investigate the amount of money that could potentially be saved by Dalhousie by installing double-glazed windows, the validity of the study is heavily weighted on quantitative calculations. Another delimiting factor in this study is that there will only be a focus on the three types of windows that have been identified by the window manufacturers as most effective. As noted, window technology has been greatly advanced since the last study was done in 1983, but due to time constraints the study can only investigate the three window options.

Although there is likely an infinite number of variables that could potentially influence a window's performance, such as the window moldings and the window's Solar Heat Gain Coefficient, this study will conduct the cost-benefit analysis using a simplified cost-benefit analysis model which was suggested by Peter Howitt. This model relies chiefly on a window's R-value and U-value as indicators of the window's energy efficiency.

The building has four main sizes of windows which are classified above as extra large, large, medium and small. Although not all the windows fall into these size categories the study was delimited to include only these windows because it would be impossible to measure every window in the building. The windows in the clock tower, for example, are excluded from the research as it is not possible to access them. To simplify the study further, the windows above and in the doors were also excluded from the research as it was assumed that the incessant opening and closing of the doors would make any energy savings gained from window upgrades redundant. Also, in a few of the buildings' windows, the glass had been replaced by air-circulation vents or air conditioners—these windows were also excluded from the study.

In selecting the appropriate equations for calculating the amount of energy saved by the window replacement, the heating effect of people within the H&H building was excluded, as well as the heating effect of sunlight. These factors were excluded due to the complexity involved in incorporating them into the final estimates. The necessary computer modeling programs were not accessible given the time and resources constraints. Furthermore, these results are based on the assumption that oil prices will remain constant over the next forty years. Oil price projections vary substantially and these price fluctuations were not incorporated in this project due to their controversial nature.

RESULTS

Interview with Peter Howitt

This research project was suggested by Peter Howitt, the assistant director of Facilities Management at Dalhousie based on his expert knowledge of the campus and the university's needs. Howitt provided us with a package of information on window efficiency in addition to a previous study on window efficiency in the H&H. He also responded to our questionnaire found in Appendix B, which offered us details regarding costs of energy generation on campus, as well as fuel type and price, Howitt was also very helpful in familiarizing us with University protocol concerning the priority of maintenance activity, which largely depended on the demand for maintenance and available funds. The history of buildings and previous maintenance endeavours was also well documented by Howitt; he indicated that the windows in the H&H building were single glazed and had not been replaced in their fifty year history. Howitt also spoke of current window initiatives at Dalhousie, he told us that Marvin supplied some of their new windows that were installed in the Faculty of Arts and Social Science building, the Computer Science building, Risley Hall, and the new Management building. All of these windows were said to have double glazing, Argon, and E thermal break.

The previous study that Howitt gave us on energy efficiency in the H&H building was very useful (see Appendix F, Table 3), particularly in the realm of delineating the subtle values that would have been exceedingly difficult to detect otherwise. These values include the R-value of the current windows, which was 0.88 Btu/hr x area x ºF, the temperature range for average outside temperature and average indoor temperature, which were 40°F and 70°F respectively. Additionally, there was a value for heating hours per month, which was 722 hrs, and a value for energy produced per gallon of Bunker C combusted, which was 180,000 BTU/gal; the efficiency of the heating system was also indicated at 50%. Finally the value for current infiltration was offered which is the energy lost because of gaps between the window and the moulding, this value was estimated to be 2380 UNITS.

Interview with window manufacturers

During the phone interview with Bob Stevens from Marvin Windows and Doors (see *Appendix C*), he identified the Clad Ultimate Double-Hung Window as being both supplier's most cost-effective choice as well as being their recommendation for university buildings (question 1 and question 7, *Appendix C*). The company website describes this window was being "highly versatile, cost-effective [...] resulting in a high window performance, energy efficient window that is unmatched in beauty and function" (Marvin Windows and Doors, 2005). This window features "one-lite Low E II with argon insulting glass" (Marvin Windows and Doors, 2005) which ensures energy efficiency. According to Stevens, this window has a U-value of approximately 0.32 and an R-value of nearly 3.13 Btu/hr x area x ºF (question 2 and question 6, see *Appendix*

C). The Casemaster window was named as the most energy-efficient product that Marvin Windows and Doors sells (question 4, *Appendix C*). Although the Casemaster window glass has the same R-value and U-value as the Clad Ultimate Double-Hung window, the Casemaster glass is more tightly sealed to the frame with a double-weather strip, which increases its energy efficiency.

In 2004, Dalhousie's new residence (Risley Hall) was built and outfitted with Kohler brand single hung, non-operating Energlas Plus windows with double-glazed glass, a low E coating and argon fill. Non-operating or "fixed" windows were chosen because they cannot be opened thus heat exchange with the outdoors is minimized and maximum energy efficiency is achieved. The company reports that Energlas Plus windows are the most energy efficient product that they offer. Energlas Plus windows have an R-value of 8.0 and a U-value of 0.12 Btu/hr x area x °F, which makes them the most efficient window product that will be assessed in this study.

Number and size of windows

The field work conducted to determine the total window area of the H&H revealed approximately 8000 square feet of window area that can be included in the heat transfer calculations. The number and sizes of these windows are displayed in table 1.

Table 1: Measurements of window dimensions according to general type and total outdoor window area.

General window size	Width of glass (feet)	Height of glass (feet)	Number of windows in H&H	Total area (feet ^{2})
Smallest (basement)	4.58	4.25	51	992.72
Medium-small (top floor)	4.54	5.71	72	1866.48
Medium-large (1st and 2nd floors)	4.54	8.33	134	5067.63
Large (stairwells)	4.58	14.25	2	130.57
Total	N/A	N/A	258	**8057.3**

The four different sources that we approached provided estimates that ranged from approximately $300,000 to nearly $700,000 (Table 2). The factors upon which the estimates were based varied between contractors, and can be seen in table 2.

Table 2: The Estimated window replacement costs provided by various contractors

Expense type	Piercey's the Building Material People	Marvin Windows and Doors	Peter Howitt, Dalhousie Facilities Management	C.M. Campbell Electric Limited
Average price of each window	$550	Included in installation fee	Included in installation fee	Included in installation fee
Installation fee	$500/ window	$55 per foot ²	$2 500/ window	$900 (Includes removal, frame installation, weather proofing, finish-work, materials)
Workers pay	$35-$45/ hour	—	—	$50/ hr (Includes vacation, pension, benefits, contractor mark-up, scaffolding, masonry and so on)
Hours work	2.5 hr/ window	—	—	8 hr/ window
Total estimated cost for material and installation	$296 700	$443 150	$645 000 (allows for scaffolding, masonry, finish-work and so on)	$335 400

The main results from the calculations can be seen in figures 1 through 4 below. Figure 1 shows that the Energlas Plus window would save nearly $17,000/year in oil purchases to heat Dalhousie University. Although similar in financial savings, the Clad Ultimate Double Hung and Casemaster windows would provide approximately $1000 less savings per year than the Energlas Plus window type.

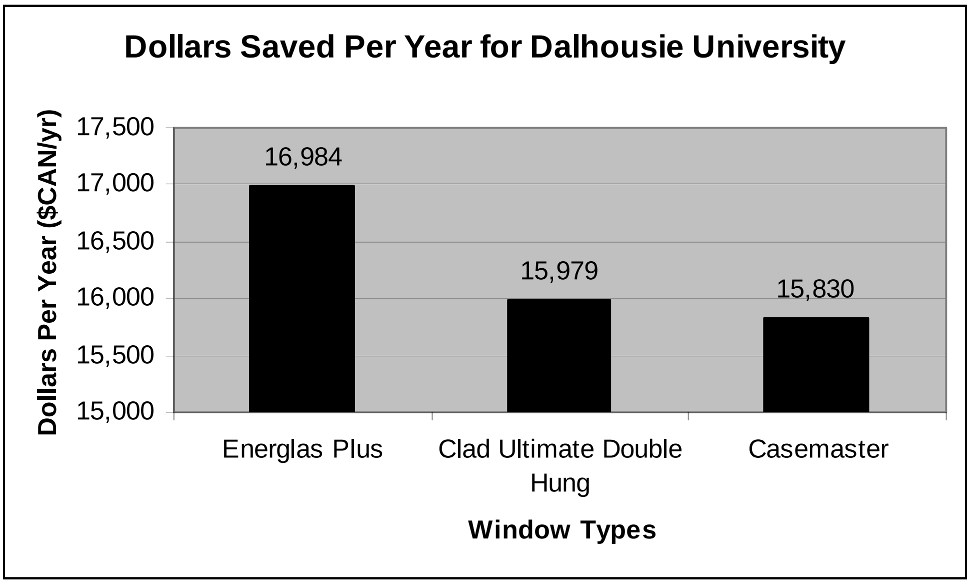

Figure 1. The relationship between the amounts of money saved each year for Dalhousie University and the replacement of the current windows in the H&H building with each of the windows proposed.

The replacement of the current H&H windows with Energlas Plus windows would result in a savings of 54,489 litters of bunker-C oil for Dalhousie University per year. The savings that would be acquired by replacing the current H&H windows with Clad Ultimate Double Hung or Casemaster window would be approximately 5,000 litres less than that saved by choosing the Energlas Plus windows as the replacement option.

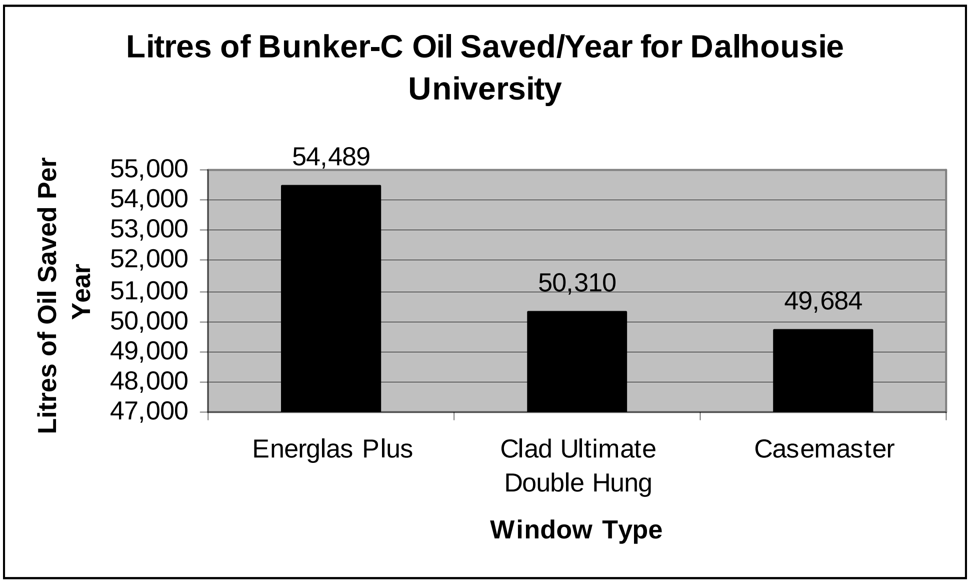

Figure 2. The relationship between the amounts of bunker-C oil saved per year and the type of window chosen to replace the current windows of the H&H building.

Figure 3 indicates that the emission of nearly 170 tonnes of carbon dioxide would be avoided if Dalhousie replaced the current windows in the H&H building with Energlas Plus windows. Similarly, choosing the Clad Ultimate Double Hung or Casemaster windows would also reduce carbon dioxide emission. However, the reduction would be roughly 10 tonnes greater if the Energlas plus windows were chosen to replace the current windows of the H&H building.

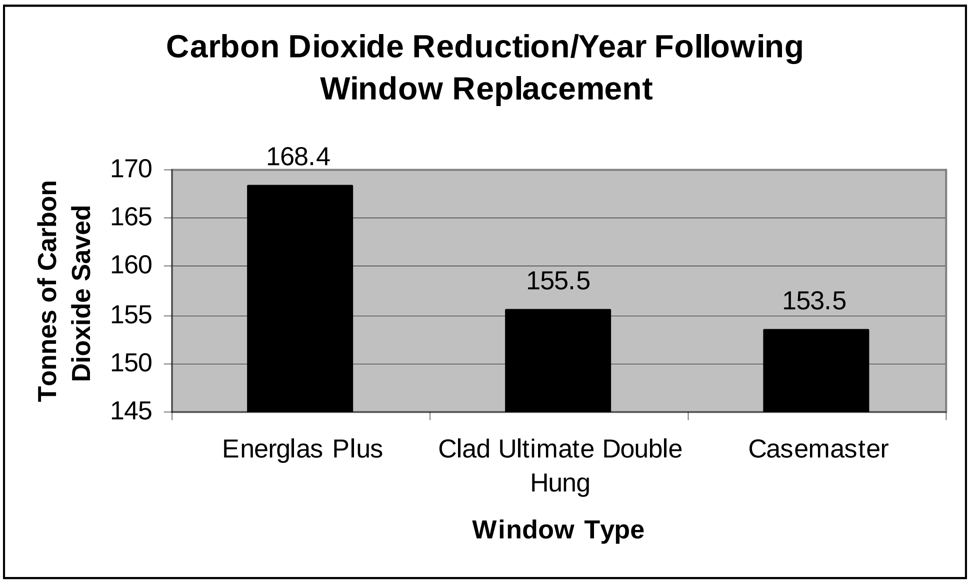

Figure 3. The relationship between the amounts of carbon dioxide emissions saved per year and the type of window chosen to replace the current windows of the H&H building

Following the proposed replacement of the current H&H windows, between 17.7 and 40.8 years would be needed before the initial cost of replacing the windows would be balanced by the financial savings in oil purchases (Figure 4). The shortest payback period would result from the replacement of the current windows with Energlas Plus windows. The Clad Ultimate Double Hung and Casemaster windows would also generate similar payback periods no more than two years greater than replacement with Energlas plus windows.

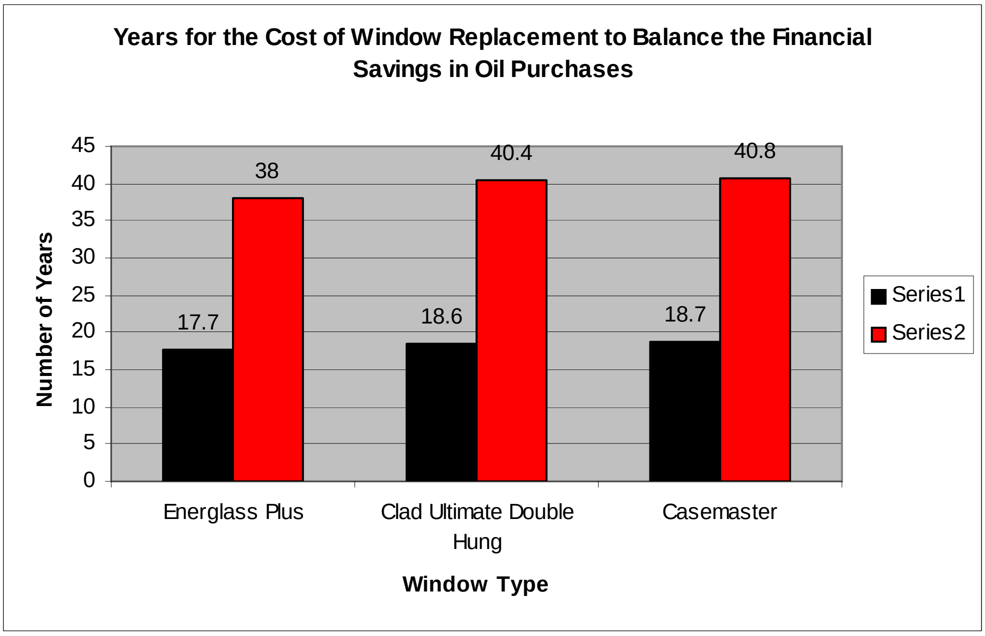

Figure 4. The relationship between number of years before the financial savings in oil purchases would balance the initial cost of replacing the current windows in the H&H and the three window types under investigation. Series 1 represents the estimated payback period based on the lowest installation quote. Series 2 represents the estimated payback period based on the highest installation quote.

DISCUSSION

Our goal was to assess the feasibility and environmental impact associated with replacing the current windows in the Henry Hicks Arts and Administration building with more energy efficient types. Efficient windows are necessary because currently Dalhousie is spending more money on energy, more money on oil, and creating more emissions than necessary. Improved windows could greatly reduce these financial and environmental costs.

Given the results of this research we are recommending that Dalhousie replace the current H&H windows with Kohler's Energlas Plus fixed-unit window. As the results tables show, this window consistently out-performs the other two models examined. It will have the greatest impact on CO_2 reduction because it is the most energy efficient window. As it is a fixed unit, it is easier for the building temperature to be regulated therefore using less Bunker-C, saving Dalhousie thousands of dollars per year. Additionally, the Energlas Plus window has the shortest pay back period estimates in both our shortest-term and longest-term projections. In light of these findings we feel that Kohler would be the most beneficial for Dalhousie in terms of both the environmental and financial aspects.

We further recommend that Dalhousie use wooden frames for the windows. Wood has a low ability to conduct heat and will be the best insulating material. Vinyl and Aluminium, the two other available materials for framing, both have significantly higher environmental costs. It is very toxic to both produce and destroy vinyl. While it outperforms wood in terms of durability, the pollutants created by its production are of extreme concern. Aluminium is inefficient because of its ability to conduct heat. The energy necessary to compensate for the heat transfer of aluminium renders it a poor choice for Dalhousie. However, should Dalhousie replace the windows and use wooden frames it is essential that they maintain proper upkeep by staining the frames at least once every 5 years to ensure they do not rot.

While the replacement of the H&H's single-glazed windows with any of our examined window models would be an improvement, the Kohler Energlas Plus is certainly Dalhousie's most cost-effective option. The current windows are already overdue for replacement and it is in Dalhousie's best interest to replace them with a high quality, durable model.

Our findings are in keeping with the original window study conducted on the H&H which also recommended that Dalhousie replace the windows with a double-glazed window with a wooden frame. The projected pay back period in that study was 16 years, while the lowest projected pay back period in this study was 17 years. Had Dalhousie implemented the suggestions made in 1983, the window replacements would have been paid back by this point. Furthermore, had oil prices projections been incorporated into the calculations, it is possible that the payback period would be reduced.

Our findings are also consistent with the research of Karlsson, Karlsson and Ross which concluded that gas filled, double-glazed units were the most cost-effective for cooler climates. Halifax is subject to very cold winters and it would appear that our findings are comparable that those of Karlsson, Karlsson and Ross.

However, replacing the windows remains a symptomatic solution to the problem of emissions creation; the root of this problem lies in the low grade Bunker-C that Dalhousie uses. A more significant reduction in emissions could be achieved if Dalhousie switched to a cleaner burning fuel, or an emissions free source of energy such as wind or solar power. The replacement of the windows in the H&H is vital but to be truly effective a change in energy source is also imperative.

CONCLUSION

Upon signing the Talloire and Halifax Declarations, Dalhousie University indicated a written agreement to reduce green house gas emissions and promote sustainability on campus. Although it is recognized that the shortest payback period of 17 years does not fit within Dalhousie's five year cost-effective definition, it is felt that Dalhousie is disallowing more long-term feasibility assessments from being implemented. In order to live up to their commitments to the Declarations previously stated, as well at the Kyoto Accord, there must be a redefinition of what is deemed cost-effective. The fact is, the windows in the H&H are overdue for replacement and it only makes sense that Dalhousie replaces them with models that will reduce the cost spent to compensate energy lost through the poor quality, single-glazed models currently in place. As a university, it is felt that Dalhousie withholds an opportunity to set a moral and environmental precedent in implementing logical changes that are in agreement with the Declarations signed.

For further research it is recommended that attention be paid to a cost-benefit analysis that takes into consideration the cost of other fuel types as an alternative to the Bunker C Dalhousie currently uses to provide energy to the buildings on campus. Because Bunker C is of such a low grade quality, it is important to acknowledge the significantly elevated levels of green house gas emissions Dalhousie is emitting because of it usage of this fuel type. Also, in order to receive more accurate installation costs, many window providers require a contractual agreement before specific costs can be generated, therefore further research can be conducted to acquire more precise installation fees. Another recommendation includes an investigation of how Dalhousie would use the money saved through the installation of more energy efficient window in the H&H.

This study has a significant amount of catalytic validity as it is noted there are numerous buildings on campus constructed around the same time as the H&H that are also in need of window replacement. The hope is that this study can be used for future feasibility assessments for other buildings on campus. It is apparent that this study presents a significant investment for Dalhousie, however in relative terms, Dalhousie will be spending a larger proportion on future energy costs, also factoring in that labour costs will not decrease and oil prices will not be getting any lower. More attention must be paid to the long-term benefits of installing the windows recommended from this study beyond the five year cost-effective period if any progress is going to be made on fulfilling Dalhousie's commitment towards sustainability.

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APPENDIX A

Definitions of terms

(All definitions of terms were found at the following website:
http://www.efficientwindows.org/glossary.cfm)

Air-leakage (air infiltration): The amount of air leaking in and out of a building through cracks in walls, windows, and doors.

Casing: Exposed moulding or framing around a window or door, on either the inside or outside, to cover the space between the window frame or jamb and the wall.

Conduction: Heat transfer through a solid material by contact of one molecule to the next. Heat flows from a higher-temperature area to a lower-temperature one.

Double glazing: In general, two thicknesses of glass separated by an air space within an opening to improve insulation against heat transfer and/or sound transmission. In factory-made double glazing units, the air between the glass sheets is thoroughly dried and the space is sealed airtight, eliminating possible condensation and providing superior insulating properties.

Fixed window: A window with no operating sashes.

Frame: The fixed frame of a window, which holds the sash or casement as well as hardware.

Glass: An inorganic transparent material composed of silica (sand), soda (sodium carbonate), and lime (calcium carbonate) with small quantities of alumina, boric, or magnesia oxides.

Glazing: The glass or plastic panes in a window, door, or skylight.

Heat loss: The transfer of heat from inside to outside by means of conduction, convection, and radiation through all surfaces of a house.

Insulating glass: Two or more pieces of glass spaced apart and hermetically sealed to form a single glazed unit with one or more air spaces in between. Also called double glazing.

Insulation: Construction materials used for protection from noise, heat, cold or fire.

KWH: KiloWatt Hour. Unit of energy or work equal to one thousand watt-hours.

Low Emittance (Low E) coating: Microscopically thin, virtually invisible, metal or metallic oxide layers deposited on a window or skylight glazing surface primarily to reduce the U-factor by suppressing radiative heat flow. A typical type of low E coating is transparent to the solar spectrum (visible light and short-wave infrared radiation) and reflective of long-wave infrared radiation.

Operable window: Window that can be opened for ventilation.

Pane: One of the compartments of a door or window consisting of a single sheet of glass in a frame; also, a sheet of glass.

R-value: A measure of the resistance of a glazing material or fenestration assembly to heat flow. It is the inverse of the U-factor ($R = 1/U$) and is expressed in units of hr-sq ft-°F/Btu. A high-R-value window has a greater resistance to heat flow and a higher insulating value than one with a low R-value.

Single glazing: Single thickness of glass in a window or door.

Solar heat gain coefficient (SHGC): The fraction of solar radiation admitted through a window or skylight, both directly transmitted, and absorbed and subsequently released inward. The solar heat gain coefficient has replaced the shading coefficient as the standard indicator of a window's shading ability. It is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits, and the greater its shading ability. SHGC can be expressed in terms of the glass alone or can refer to the entire window assembly.

Triple glazing: Three panes of glass or plastic with two air spaces between.

U-factor (U-value): A measure of the rate of non-solar heat loss or gain through a material or assembly. It is expressed in units of Btu/hr-sq ft-°F (W/sq m-°C). Values are normally given for NFRC/ASHRAE winter conditions of 0° F (18° C) outdoor temperature, 70° F (21° C) indoor temperature, 15 mph wind, and no solar load. The U-factor may be expressed for the glass alone or the entire window, which includes the effect of the frame and the spacer materials. The lower the U-factor, the greater a window's resistance to heat flow and the better its insulating value.

Weatherstripping: A strip of resilient material for covering the joint between the window sash and frame in order to reduce air leaks and prevent water from entering the structure.

Window: A glazed opening in an external wall of a building; an entire unit consisting of a frame sash and glazing, and any operable elements.

APPENDIX B

Interview with Peter Howitt

1. *Which building/s should we focus the project on?*
   Your choice.
2. *Is there a window supplier that Dalhousie prefers to use?*
   Marvin, storm windows.
3. *What type of windows, frames and weather-stripping do they current have?*
   Original, single glazed.
4. *How many windows are in these buildings?*
   Count them.
5. *What size are the windows?*
   Measure them.
6. *What direction do the windows face relative to the sun?*
   Varies.
7. *When were the windows last replaced?*
   Never.
8. *How often (on average) do the windows have to be replaced?*
   On demand.
9. *What are the regulations on maintaining the historical design of the building?*
10. *What is the current R value of the windows?*
    See report.
11. *What is the current U value of the windows?*
    Inverse of R value on report.
12. *How much energy escapes through windows currently being used?*
    See report.
13. *How much money is spent heating the buildings each year?*
    Approximately $3.5 million.
14. *How many kilowatts of energy are spent heating the buildings each year?*
15. *What are the emissions produced by each unit of energy generated?*
    Look it up.
16. *What type of oil is Dalhousie using?*
    Bunker C.
17. *How much are we paying for oil?*
    $0.22 / L.
18. *What is the annual budget on building upkeep? On windows?*
    Depends on demand.
19. *What windows are installed in the newer buildings (McCain and management, for example)?*
    Double glazed, Argon, E thermal break.
20. *What is the price per kilowatt of the energy generated on campus?*
    $0.065 / KWh electricity.
21. *What temperature is meant to be maintained in university buildings?*
    20-21°C.
22. *What are facilities management chief concerns when it comes to switching to more energy efficient windows?*
    Competitive issues, what produces the best savings with available dollars.
23. *Who are the best people to contact for answers to questions that we are unable to answer?*
    Me

APPENDIX C

Interview with window retailers

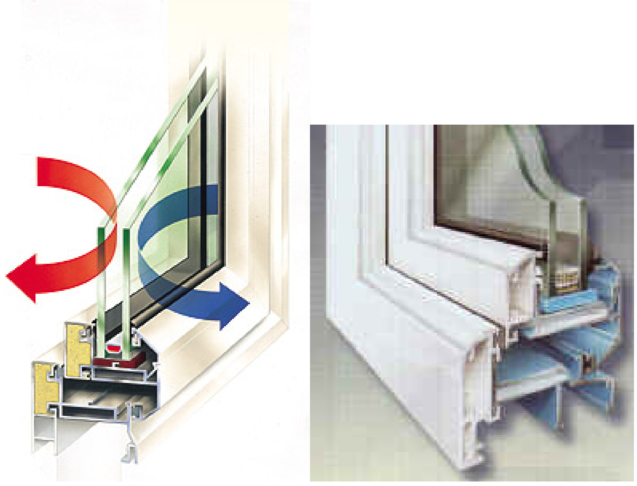
I am a student at Dalhousie University doing an investigation into possible replacement of Dalhousie's older windows with more energy efficient types. The results of this study will be forwarded to Dalhousie Facilities Management and the proposal taken into consideration. Currently, we are trying to assess whether or not window replacement would be feasible from a cost-benefit standpoint. Marvin/Kohler was named as a primary window supplier to Dalhousie University. Would you mind if I asked you some questions about your non-residential product line?

> *Who am I speaking with and do you mind if I use your name and the information that you provided me with in my group's research project report?*
>
> *What type of window would you typically recommend for large, non-residential buildings such as a university?*
>
> *What is the R value, U value and Solar Heat Gain Coefficient for this window?*
>
> *What are the rates (costs) for that product?*
>
> *What is the most energy efficient type of window that Marvin/Kohler carries?*
>
> *What is the R value, U value and Solar Heat Gain Coefficient for this window?*
>
> *What are the rates (costs) for that product?*
>
> *What is the most cost-effective window product that Marvin/Kohler sells? i.e. "most bang for your buck"?*
>
> *What is the R value, U value and Solar Heat Gain Coefficient for this window?*
>
> *What are the rates (costs) for that product?*

APPENDIX D

Photos

a) Henry Hicks Arts and Administration building



b) Double-glazed cross-sections

c) Single-glazed cross-section

APPENDIX E

Proposed window types

Energlas Plus Double Hung window by Kohler Windows

b) *Clad Ultimate Double Hung by Marvin Windows and Doors*

c) *The Casemaster casement window by Marvin Windows and Doors*

APPENDIX F

Rough calculations and values

Table 3. Values used in the heat transfer calculations in metric and/or English units

VALUES FOR CONDUCTION CALCULATIONS						
Value	English			Metric		
R-value (current)	0.88 Btu/hr x area x °F			—		
R-value (proposed)	Type 1	Type 2	Type 3	—		
	3.8	3.03	2.94			
U-value (current)	1.136 Btu/hr x area x °F			6.452 J/m^2 x °K x s		
U-value (proposed)	Type 1	Type 2	Type 3	Type 1	Type 2	Type 3
	0.283 Btu/hr x area x °F	0.33 Btu/hr x area x °F	0.34 Btu/hr x area x °F	1.494 J/m^2 x °K x s	1.874 J/m^2 x °K x s	1.931 J/m^2 x °K x s
Window area	8057.29 feet^2			748.5 m^2		
Average temperature Inside	70 °F			—		
Average temperature outside	40 °F			—		
Δ T (between outdoors and indoors)	30°F			16.67 °K		
Heating time /year	8.5 months x 722 hrs/month			220923200s/heating season		
Price of bunker-C oil	$0.88/ gallon					
Energy / G oil burned	180 000 Btu/ gallon					
Current infiltration Rate	2380 Btu/hr x °F			13513.51 W/ m^2 x °K		
Assumed proposed infiltration	0			0		

1) Energlas Plus

Conduction calculations

Δ Energy spent per year (in J/yr) = [(6.452 J/m^2 x °K x s) - (1.494 J/m^2 x °K x s)] x (16.67 °K) x (22093200 s/yr) x (748.5 m^2)
= 1.367 x 10^{12} J/year

Litres of oil consumed per year = (1.367 x 10^{12}J/year) x (9.4781 x 10^{-4} Btu/J) x (1 Gallon/180000

Btu x 0.5 efficiency) x (1 m^3/264.17 gal) x (1000L/m^3)
= 54 489 L/ year

Δ $ spent on oil = (1.367 x 10^{12} J/yr) x (9.4781 x 10^{-4} Btu/J) x [($0.88/gallon)/ (180000/ gallons x .50)
= $12 700/ year

Infiltration calculation

Δ $ spent on oil = (Current Heat Transfer- Proposed Heat Transfer) x (Δ T °F) x (heating hrs/yr) x [(Cost of oil/gallon)/ (Btu per gallon of oil x overall efficiency)]
= (2380 Btu/hr x °F) – (0 Btu/ hr x °F) x (30°F) x (722 hr/month) x 8.5 months/ year) x ($0.88/gal)/ (180000) x (0.50)]
= $4 283/ year

Total savings

Total $ savings = $12 700/year+ $ 4 284/ year
= $16 984/ year

2) Clad Ultimate Double Hung

Conduction calculation

Δ Energy spent per year (in J/yr) = [(6.452 J/m² x °K x s) - (1.874 J/m² x °K x s)] x (16.67 °K) x (22093200 s/yr) x (748.5 m²)
= 1.262 x 10^{12} J/year

Δ Litres of oil consumed per year = (1.262 x 10^{12}J/year) x (9.4781 x 10^{-4} Btu/J) x (1 Gallon/180000 Btu x 0.5 efficiency) x (1 m^3/264.17 gal) x (1000L/m^3)
= 50 310 L/ year

Δ $ spent on oil = (1.262 x 10^{12} J/yr) x (9.4781 x 10^{-4} Btu/J) x [($0.88/gallon)/ (180000/ gallons x 0.50)]
= $11 695/ year

Infiltration calculation

(same as above)
Δ $ spent on oil = $4 283/ year

Total savings

Total $ savings = $11 695/year + $ 4 284/ year
= $15 979/ year

3) The Casemaster

Conduction calculations

Δ Energy spent per year (in J/yr) = [(6.452 J/m² x °K x s) - (1.931 J/m² x °K x s)] x (16.67 °K) x (22093200 s/yr) x (748.5 m²)
= 1.246 x 10^{12} J/year

Δ Litres of oil consumed per year = (1.246 x 10^{12}J/year) x (9.4781 x 10^{-4} Btu/J) x (1 Gallon/180000 Btu x 0.5 efficiency) x (1 m^3/264.17 gal) x (1000L/m^3)

= 49 684 L/ year

Δ $ spent on oil = (1.246 x 10^{12} J/yr) x (9.4781 x 10^{-4} Btu/J) x [($0.88/gallon)/ (180000/ gallons x 0.50)]
= $11 547/ year

Infiltration calculation

(same as above) **$ spent on oil =** $4 283/ year

Total savings

Total $ savings = $11 547/year + $ 4 284/ year
= $15 830/ year