ASSESSING THE ECONOMIC AND ENVIRONMENTAL CASE FOR WINDOW RETROFITS IN SINGLE FAMILY HOMES

Amy Chitilian[1], Kim Pressnail[2], Ekaterina Tzekova[3]

ABSTRACT

To assist designers and homeowners in making better thermal retrofit choices, this study evaluates the potential economic and environmental benefits of various window retrofit options in Ontario. Two homes in Toronto with identical layouts were modelled: a historic 1879 home and a 1992 home built to the Ontario Building Code (OBC) 1990. The pre-retrofit, 1879 solid masonry home had original single-glazed windows. The 1992 home was built according to the 1990 OBC, with sealed double-glazed windows that had reached the end of their service life. Using HOT2000 modelling software, this study modelled the pre-retrofit and various retrofit window options to determine the heating and cooling loads. Various retrofit scenarios were evaluated including a window upgrade to the 1990 OBC standard (R=0.34m^{2}K/W), an upgrade to a higher performance double-glazed window (R= 0.77m^{2}K/W), and an upgrade involving high-performance triple-glazed units (R= 1.40m^{2}K/W). Economic and environmental evaluations were also carried out. Since both homes were in need of window upgrades, the cost of bringing the existing windows up to the 1990 OBC standard was used as the base cost. Thus, only the incremental capital costs of higher performing replacements were measured against the projected incremental energy cost and carbon savings over and above the base cases. The results indicate that even high performance windows are economically justifiable in both the historic home and the 1992 home on this basis. In the case of the 1992 home, the cost of achieving carbon savings over a 25 year service life of the windows ranged from $13 to $47 per tCO2e depending upon the retrofit window selected. Assuming energy costs remain constant, the return on investment for high performance windows was found to be 13% for the historic home, and 22% for the 1992 home. While the paper considered homes located in Toronto ON, the methods used in this study can be applied to any cold-climate city located in regions considering a carbon pricing policy.

1. Read Jones Christofferson, 144 Front St. West, Suite 500, Toronto, ON, Tel. (647) 988 5449

2. University of Toronto, 35 St. George St., Toronto, ON, Tel. (416) 978 1501

3. The Atmospheric Fund, Toronto, ON Tel. (416) 393 6383

NOMENCLATURE AND ABBREVIATIONS

OBC – Ontario Building Code

RSI – Thermal Resistance SI (m^2K/W)

ACH – Air Changes Per Hour (airtightness)

U – Overall Heat Transfer Coefficient SI (W/m^2K)

INTRODUCTION

As awareness of climate change increases and energy prices rise, the need to thermally retrofit residential buildings grows. In low-rise home retrofit projects, window retrofits are often contemplated. However, window replacements are usually considered to be too expensive when the total cost of installing new windows is judged against the potential energy savings. Yet, if the windows need to be replaced because they have reached the end of their useful service life, or if interior spaces are uncomfortable because of poorly performing windows, then why should the entire cost of window replacement be weighed against the energy costs savings? It follows that, if the windows need to be replaced, only the incremental cost of installing windows that are better than replacement windows that meet the existing building code should be weighed against the associated incremental energy savings.

When better windows are installed, both heating and cooling energy is saved. In Canada, approximately 60% of all of the energy used in homes is for space heating. (Natural Resources Canada, 2007). However, the effect of thermal retrofits on space cooling energy needs to be considered as well. Even though in Canada space cooling accounts for only 5% of home energy use, space cooling costs are significant. Cooling costs are significant because the cost of electricity, the primary energy used to cool most homes in Ontario, is expensive relative to the cost of natural gas, the primary energy source for heating homes in Ontario. In 2016, peak electricity costs in Toronto were 18¢/kWh while delivered natural gas costs in Toronto were approximately 33 ¢/m^3 or about 3¢/ekWh. (Ontario Energy Board , 2016). Thus, during peak rate periods, the cost of energy required for cooling is roughly six times greater than the cost of providing heat using natural gas.

In June 2016, Ontario released a new climate change action plan which will limit greenhouse gas pollution. The plan includes a carbon cap and trade system that places a price on carbon andlimits the amount of greenhouse gas emissions that can be produced by the economy. The economy can then trade between members and all funds raised by the government can be reinvested into green technology (Government of Ontario , 2016). This type of carbon pricing is expected to cause natural gas prices to rise relative to electricity prices since only 9% of Ontario's electricity is derived from burning fossil fuels (IESO, 2017). In January 2017, the price of natural gas in Toronto rose by 3.35 ¢/m^3 to accommodate the carbon cap and trade policy, which will further increase energy bills (Enbridge , 2017). More recently, the government of Ontario cut electricity bills by 25% in 2017 (Government of Ontario, 2017). Thus, forecasting energy prices, particularly electricity, is challenging.

Beyond saving energy and ultimately energy costs, better performing windows result in a more comfortable indoor environment. With better solar control and improved glass surface temperatures, better windows can result in the avoidance of wide temperature swings, reductions in peak sizing of air conditioning systems, and major reductions in lighting energy and annual space conditioning (Straube, 2010). Further,

upon installation, new windows can lead to improved airtightness and an improvement in thermal comfort as cold drafts are reduced.

Although the benefits of higher performance windows are many, in the analysis presented here, only the direct energy savings are considered. This study provides a detailed analysis of glazing retrofits in a single family Toronto home. In order to provide reasonable advice for those homeowners looking to replace their existing windows, two types of model homes were used. The first is an 1879 historic home, with little to no insulation within the envelope (RSI value of walls – 0.57). The second is a 1992 home built to the 1990 Ontario Building Code (OBC), with a reasonably insulated envelope (RSI value of walls – 3.25). The homes were chosen because both require window replacements, as the windows have reached the ends of their service lives (i.e. more than 25 years old). Both homes were modeled using HOT2000 with the original windows in place. The upgrades were later applied, to analyze the cost/benefits of the window replacements.

ENERGY MODELLING

HOT2000 modeling software was used to model the two homes. The first home was an 1879 historic double-wythe clay brick masonry home with original single glazed windows. The second home modelled was a 1992 home built to the Ontario Building Code 1990. For simplicity and comparison purposes, the homes had identical footprints and layouts. Both homes were modeled by varying key parameters in HOT20000 using Toronto, ON weather data. The chosen occupancy for the homes was 2 adults and 2 children, who were assumed to be in the home for 50% of the time. In the heating season, the homes were heated to 21°C during the day and 18°C at night. During the cooling season, the homes were cooled to 25°C.

The modelled homes had four exterior walls with a total of 17 windows distributed as five windows on the south elevation and four windows on the remaining north, east and west elevations. The windows on the north and south facades measured 700mm by 1800mm (27.5” x 71”), and 700mm by 1200mm (27.5” x 47”) on the east and west. For domestic hot water heating, the homes had an electric heater with a conventional tank, with a volume of 303 L and an energy factor of 0.79. Both homes were heated with a high efficiency condensing natural gas furnace with a steady-state efficiency of 89%. Table 1 lists the HOT 2000 input parameters for the two original homes. The parameters used in the 1992 model home conform to the 1990 OBC, Table 9.25.2.A **(Government of Ontario, 1990)**.

Table 1: HOT2000 Input Parameters for the Two Original Homes

Parameter	1992 Home	Historic Home
Airtightness	**4.55 ACH @ 50 Pa**	**16.41 ACH @ 50 Pa**
Roof RSI (nominal)	**5.4**	**2.6**
Wall RSI (nominal)	**3.25**	**0.57**
Slab on ground RSI	**0.75**	**1.76**
Window Tightness (L/sm^2)	**3.72**	**1.86 (A1)**
Volume of Home	**451 m3**	**451 m3**
Building Envelope Surface Area	**444 m2**	**444 m2**
Window to Wall Ratio	**0.194**	**0.194**

Since window upgrades often improve air tightness, it was assumed that the retrofits improved the airtightness of the historic home. Therefore, in Upgrade 1, the airtightness was improved by 15%, to 14.0 ACH_{50}, and by 25% in upgrade 2 and 3, to 12.3 ACH_{50}. Since the 1992 home already had sealed double-glazed windows (A1 air tightness), the base case involved a direct replacement of the existing grade of windows. Upgrade 1 and Upgrade 2 were considered to be A2 air tightness and A3 air tightness, respectively. Details of the upgrades are summarized in Table 2.

Table 2: Window Thermal Specifications

Scenario	Description	RSI value	U value	SHGC	Air Tightness
Historic Original	**Single-glazed, clear, wood frame**	**0.17**	**5.88**	**0.8**	**16.41 ACH_{50}**
Historic Upgrade 1 (Base Case)	**Double-glazed, 13 mm air filled, wood frame**	**0.34**	**2.94**	**0.6**	**14.0 ACH_{50}**
Historic Upgrade 2	**Double-glazed, low-e 0.35, 13 mm argon filled, wood frame**	**0.77**	**1.3**	**0.28**	**12.3 ACH_{50}**
Historic Upgrade 3	**Triple glazed, low-e 0.35, argon filled, wood frame**	**1.41**	**0.71**	**0.24**	**12.3 ACH_{50}**
1992 Original (Base Case)	**Double-glazed, 13 mm air filled, vinyl frame**	**0.28**	**3.57**	**0.6**	**4.55 ACH_{50} with A1 windows**
1992 Upgrade 1	**Double-glazed, low-e 0.35, 13 mm argon filled, vinyl frame**	**0.77**	**1.3**	**0.28**	**4.55 ACH_{50} with A2 windows**
1992 Upgrade 2	**Triple glazed, low-e 0.35, argon filled, vinyl frame**	**1.41**	**0.71**	**0.24**	**4.55 ACH_{50} with A3 windows**

MODELLING RESULTS

The window upgrades significantly reduced the space heating and the space cooling requirements of both homes although the results vary slightly due to the initial envelope conditions of the models as well as the differing air tightness and ventilation requirements. In Figure 1, it is clear that the heat loss through the original windows compared to the model total heat loss is much greater in the 1992 home (46%) compared to the historic home (35%). This is because low performance windows have a greater effect on the 1992 home, which has a higher wall RSI value and lower heating requirements overall. Also, the percentage of heat loss through the windows of the historic home is significantly reduced through upgrades (8% heat loss through windows) compared to the 1992 home (18% percent heat loss through windows). This is because the historic home, with thermally inefficient walls, loses more than twice as much heat in total compared to the 1992 home (353,205 MJ and 153,792 MJ, respectively).

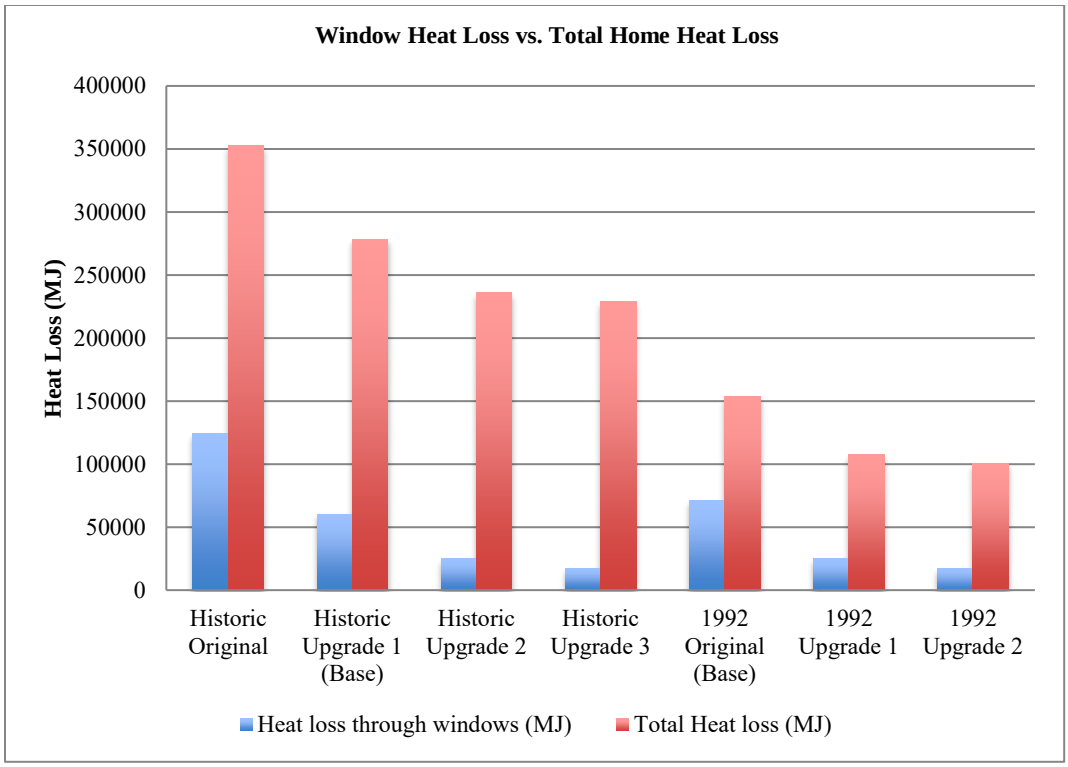

Figure 1: Window Heat Loss and Total Home Heat Loss for Each Model

Figure 2 shows the resulting heating energy required for the historic and 1992 homes when the upgrades were modelled. In the case of the historic home, the Upgrade 1 was considered to be the "base case" for comparison purposes. In the case of the 1992 home, the original home was considered to be the "base case." As the R-value of the windows is increased from the base 0.34 m^2K/W for the historic home and 0.28 for 1992 home, there is a diminishing return on the percentage of heating energy saved as the window R value is increased to 0.77 and then to 1.41 m^2K/W. This is due, in part, to the inverse relationship between the energy transferred and the thermal resistance offered by the retrofit windows. In the case of heating, it is also due to the decreasing solar heat gain coefficient (SHGC) which reduces the solar heating of the home in the winter. However, this is partly off-set, because a lower SHGC means that the cooling load is reduced as unwanted solar energy during the cooling season is excluded.

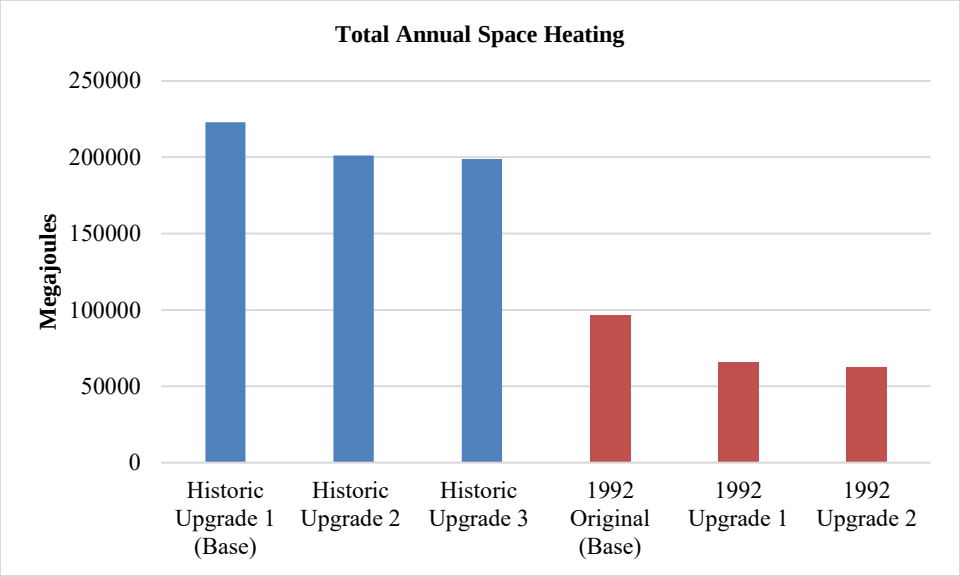

Figure 2: Total Annual Space Heating Loads

Figure 3 shows the resulting space cooling energy required for the historic and 1992 buildings when the upgrades were modelled. Once again, as the R-value of the windows is increased from 0.34 m^2K/W for historic and 0.28 m^2K/W for 1992, to 0.77 m^2K/W, and finally to 1.4 m^2K/W, there is a diminishing return on the amount of cooling energy saved. These cooling loads are very small in comparison to the heating loads shown in Figure 2. However, due to the much higher cost of cooling, the upgrades have a significant impact on the economic justification of higher performance windows. The 1992 home has slightly higher cooling loads because the base case windows were more thermally inefficient compared to the historic upgrade 1 windows.

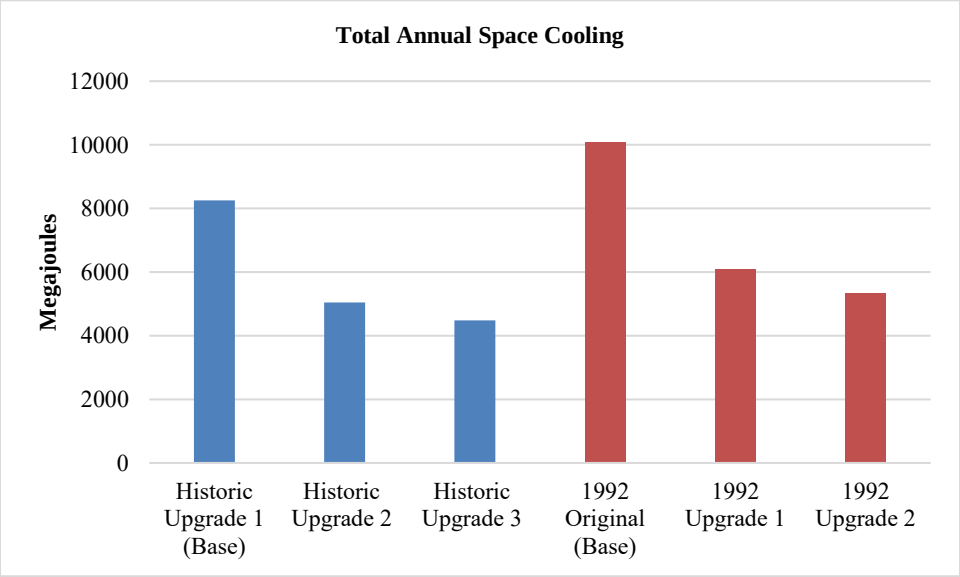

Figure 3: Total Annual Space Cooling Loads

ENERGY COSTING AND ENVIRNMENTAL ANALYSIS

It follows that, as Canada moves towards reducing the reliance on fossil fuels, natural gas costs will continue to rise. Thus, homeowners will look for ways to reduce home heating costs. Home energy retrofits, including window and envelope retrofits, will be one way of countering high energy bills.

Carbon Costing

To estimate carbon use, the amount of natural gas and electricity used to heat and cool each model home, was converted into carbon dioxide equivalent values. While the carbon savings do not appear significant when evaluated on a per-home basis, once multiplied to reflect all homes within a region undergoing a retrofit, the impact on the environment would be substantial. Additionally, when evaluating the effect of the windows over a 25-year lifecycle, the very high performance windows will result in carbon savings of approximately 32 tonnes in the historic home and 45 tonnes in the 1992 home. Figure 4 depicts the annual carbon dioxide equivalent emissions savings of each model over and above the base cases. It follows that the 1992 home experiences greater savings than the historic home because greater air tightness can be achieved and because the base case windows in the 1992 home had a slightly lower R value. Figure 4 also reveals that low carbon electricity means that saving electricity in cooling doesn't save much carbon.

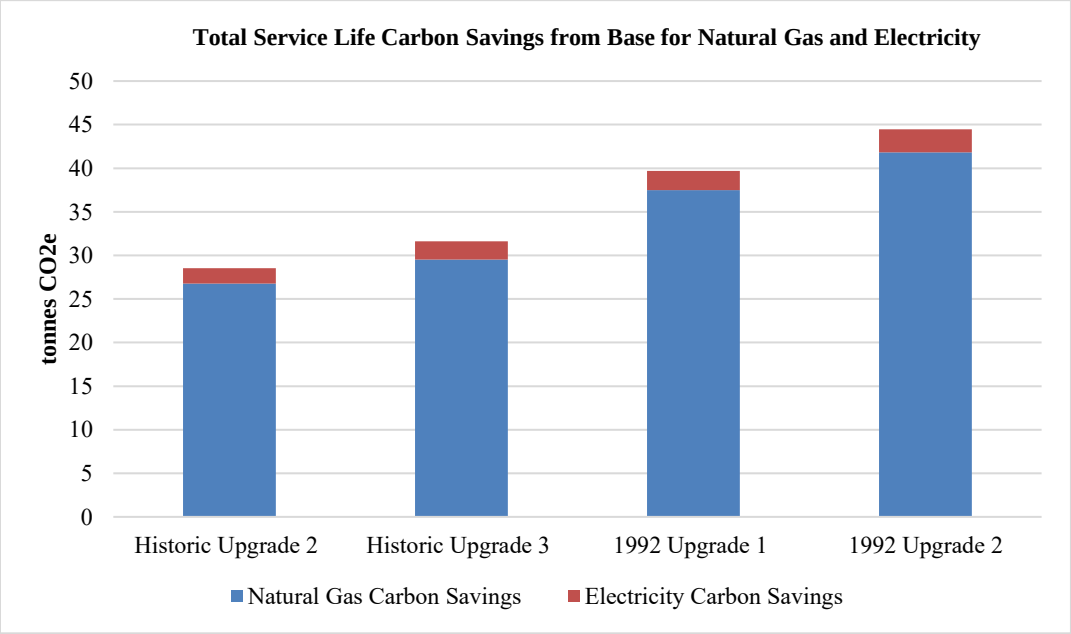

Figure 4: Carbon Dioxide Equivalent Emissions for the Historic Home and 1992 Home Given Various Retrofits

In 2017, the Federal Government of Canada announced that carbon is valued at $18/tonne and is forecasted to increase (Macleans, 2017). The value of the carbon saved in 2017 is shown in Figure 5. These values are associated with carbon emissions and are meant to provide a monetary indication of the impact of the value of carbon in the economy, not as a direct cost savings to the consumer. However, carbon emission costs will have an impact on the average household costs which are expected to increase annually by $150 per household (Macleans, 2017). It is expected that the revenues generated from carbon taxes may be used to subsidize proactive sustainable technologies, rather than providing incentives for retroactive programs

that mitigate existing pollution. The annual incremental carbon savings in 2017 for the economies for the various retrofit upgrades are shown in Figure 5.

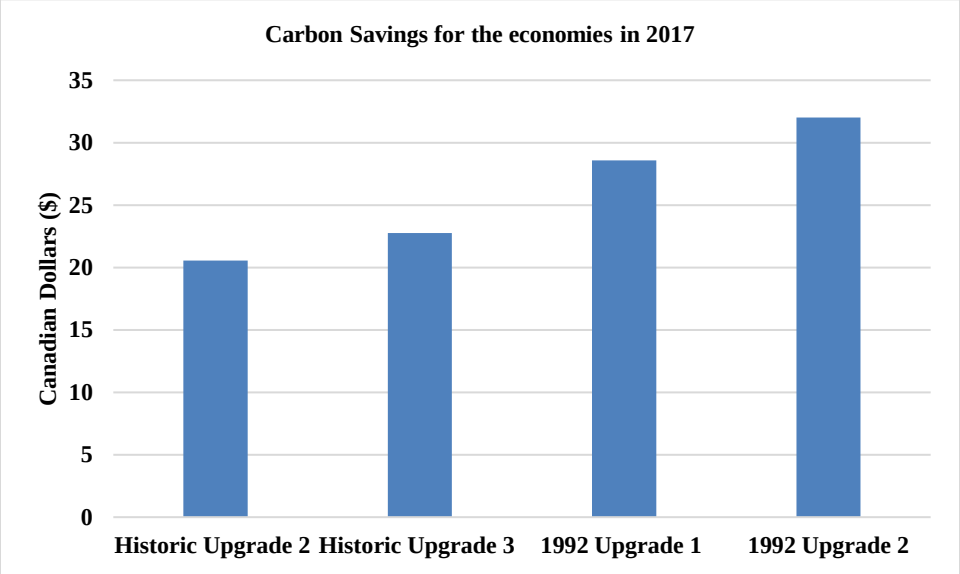

Figure 5: Carbon Savings of Model Homes in 2017 Priced at $18/tonne Trading Price

Energy Cost Changes

In order to evaluate the economic case for window retrofits, natural gas and electricity costs had to be considered. Figure 6 shows the effects of changes in the delivered cost of natural gas that occurred between 2016 and 2017 on home heating costs. These changes occurred as the delivered price of natural gas increased from approximately 29 ¢/m^3 to 32 ¢/m^3 in response to implementation of the carbon tax (Enbridge, 2017). In the analysis that follows, 2017 delivered natural gas costs are used. However, it should be noted that future increases in natural gas costs can be expected as carbon pricing unfolds.

To estimate the costs of electricity used to cool and to ventilate the buildings, 2017 electricity costs were used. These costs reflect the very recent changes brought about by the government of Ontario which has led to the reduction in electricity bills by 25% in 2017 (Government of Ontario, 2017). Given the volatility in the political climate, forecasting energy prices, particularly electricity, is challenging. While the Ontario government has committed to only increasing electricity costs by a small amount over the next 4 years, it is possible that future electricity costs may rise substantially. Since forecasting future electricity costs is uncertain, using 2017 prices is the only approach possible.

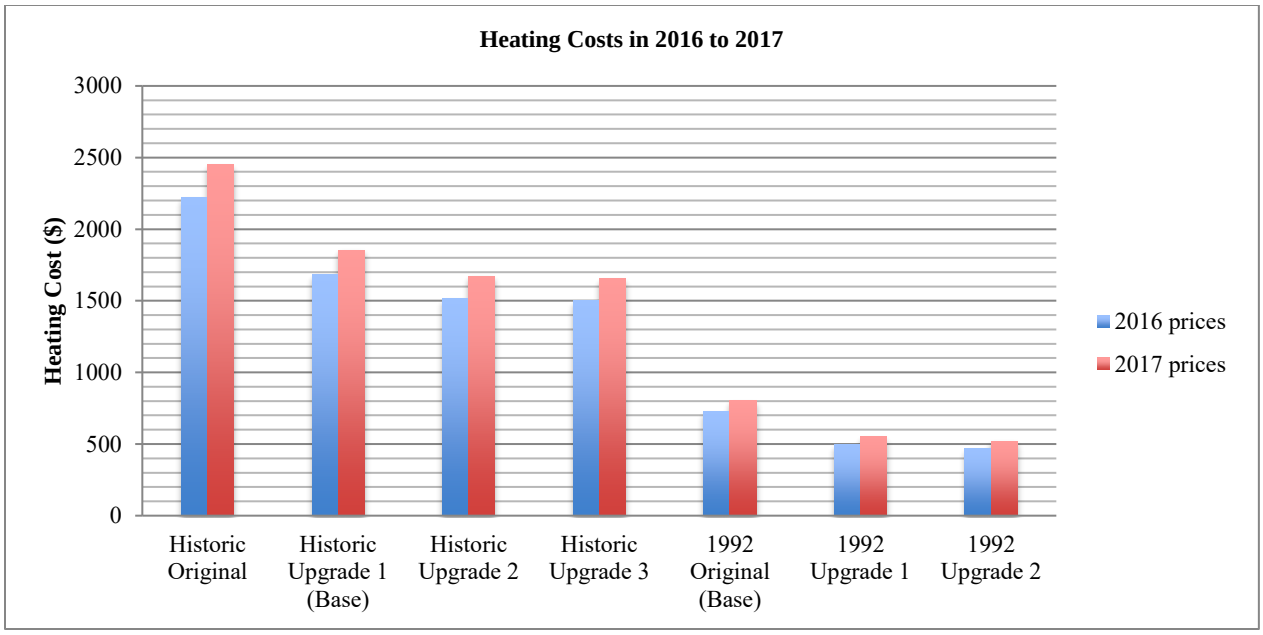

Figure 6: Natural Gas Heating Costs in 2016 and 2017

WINDOW COSTS AND SAVINGS

After completing the HOT2000 simulations, window product quotations were sought. Since both homes required window replacements, installation costs were not included in this cost analysis. Assuming that the installation costs would be the same for each retrofit option, only the material costs were considered. In the case of the 1992 home, vinyl windows were specified. Quotations were obtained from 3 separate window manufacturing companies, and these quotes were averaged to obtain the material costs for each upgrade option. For the case of the historic home, in order to satisfy architectural requirements, wood frames were specified. Only one quotation was obtained and used for wood windows. Table 3 provides details of the quotations obtained.

Table: 3 Window Descriptions and Material Costs

Building and Option	Description	Average Total Material Cost
Base Historic Home Upgrade 1	Insulated Dual Air Filled, Wood Frame	$12,310
Historic Home Upgrade 2	Insulated Dual Low-e Argon Filled, Wood Frame	$12,930
Historic Home Upgrade 3	Insulated Triple Low-e Advanced Glass, Argon Filled, Wood Frame	$14,920
Base 1992 Home	Insulated Dual Air Filled, Vinyl Frame	$9,970
1992 Home Upgrade 1	Insulated Dual Low-e Argon Filled, Vinyl Frame	$10,470
1992 Home Upgrade 2	Insulated Triple Low-e Advanced Glass, Argon Filled, Vinyl Frame	$12,080

The incremental material cost of window replacements above the base case was calculated for each upgrade option and compared to the corresponding incremental energy savings using 2017 energy costs. To calculate

the return on investment, the energy cost savings were calculated using 2017 electricity and natural gas prices. However, since energy prices are expected to increase, the savings will increase annually leading to all upgrades becoming even more financially justifiable.

As shown in Table 4, the return on investment varied depending on the building and the retrofit option. The return on investment for the historic home ranged from 13% to 48%. The highest performing windows from an energy point of view were the most expensive and had the lowest return on investment. Similarly, in the case of the 1992 home, the return on investment ranged from 22% to 80%. The return on investment was higher in the 1992 home compared to the historic home because the vinyl window upgrades were less expensive than wood-framed windows. While the returns for both homes were very favorable, it should be emphasized that only the incremental material costs over and above the base case windows were considered. Installation costs were not included as these costs were assumed to be the same for all options including the base case window retrofit. This approach was used because the existing windows were at the end of their service life and needed replacement.

Table 4: Incremental Costs and Savings and Return on Investment for Various Retrofit Options

Model	Incremental Cost Above Base	Incremental Annual Savings Above Base	Return on Investment	Window Cost per Tonne of Carbon Saved ($/tonne)
Historic Upgrade 2	**$620**	**$300**	**48%**	**$22**
Historic Upgrade 3	**$2,610**	**$340**	**13%**	**$82**
1992 Upgrade 1	**$500**	**$400**	**80%**	**$13**
1992 Upgrade 2	**$2,110**	**$460**	**22%**	**$47**

An additional benefit of making homes more energy-efficient is the reduction of greenhouse gas emissions that occurs. The total carbon dioxide equivalent emissions savings over the expected 25 year life of the windows was previously shown in Figure 4. Upgrades to higher performance windows, as shown in Figure 4, result in substantial reductions in carbon dioxide over the 25 year service life of the windows. These savings in carbon can be expressed in terms of the cost to the home owner for upgrades per tCO2e saved. As shown in Table 4 above, the cost per tCO2e of the double-glazed, low-e, argon filled window upgrade (Upgrade 1) in the 1992 home is $13, which is below the current floor carbon price of $18/tonne set by the government of Canada. In terms of the cost of saving carbon, the other upgrades may not appear as attractive since they are above the carbon floor pricing. However, if energy prices and the trading cost of carbon continue to rise as expected, the case for providing economic incentives for the other upgrades may become more compelling. In expressing the cost to home owner per ton of CO2e, it is recognized that the home owners bears a cost for a societal benefit. However, this cost information is useful for evaluating the economic benefit of providing publically-funded incentives for thermal retrofits.

CONCLUSION

This paper has examined the economic and environmental case for improving the thermal performance of two model homes through window retrofits. When windows have reached the end of their effective service lives, choosing high performance windows during a retrofit has a strong economic case. Conservative returns on investment using 2017 energy costs and window capital costs for the historic home and for the

1992 home were 13% and 22% respectively. Given that energy prices, particularly the price of natural gas, are expected to rise as the cost of carbon is recognized in the economy, these returns on investment are considered to be conservative. However, it must be emphasized that only the incremental capital costs of the windows were used in the analysis because, in the case of both homes, the windows were in need of replacement. Thus, only the incremental costs of better windows, over and above a base 1990 standard, were used. Since installation costs were assumed to be the same for all of the retrofits, only the capital costs of the windows were included.

In addition to energy saving, improving windows in a home adds to the capital worth of the real estate. In one 2012 study, it was reported that a $10,000 investment in new windows, could improve the capital value of the real estate by as much as $8500 (Kane, 2012). This capital value improvement has not been considered here. Further, new, better performing windows reduce drafts, reduce the condensation potential and generally improve human comfort. Again, the value of improving durability and human thermal comfort has not been considered here.

Finally, given the modest $18 rate per ton of CO2e assessed by the Federal Government of Canada, it is clear that, at least in the case of one of the window retrofit options presented here, it would be more economical to save the CO2e through retrofit than it would be to pay for it. Higher carbon prices can be forecasted based on the historical rise of carbon taxes in British Columbia. As such, saving carbon will increasingly become a driver for change. A part of this change will inevitably include growing public incentives that encourage home owners to improve the thermal performance of their homes.

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