Case Study – NE3 Window Replacement
Lessons Learned and Energy Performance Impact

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Burnaby, British Columbia
2016

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ABSTRACT

This case study aims to document and evaluate the impact of a windows upgrade on the energy performance of the NE3 building, built in 1971 at the Burnaby Campus of the British Columbia Institute of Technology (BCIT). The windows were donated by the local company Centra Windows.

The NE3 building, home of the BCIT Centre for Architectural Ecology, is a one story wood-frame construction over a concrete slab on grade. Most of its windows are single-pane with aluminum frame, and four are double-pane. The Centre for Architectural Ecology houses faculty and graduate students engaged in research activities on architectural acoustics. As such, for the implementation of the new windows an integrated effort to consider both energy and acoustical performance of the windows was made; addressing these two targets was central to this building upgrade. This study focuses on the energy impacts of the windows upgrade.

An energy model of the building was created to evaluate the energy impacts of the windows upgrade. To create the energy model, a careful take-off was conducted of the construction, the mechanical equipment, the occupancy, and other thermal and electric loads. The model was created using the industry standard software eQUEST. The model was tuned using utility data from the building and is used to estimate the expected monthly and yearly energy savings with the new windows.

The results from the energy simulation show that the window improvement might generate savings in the order of 1 to 2% of all the energy used in the building per year. It is recommended that the results of this study are corroborated with at least one year of actual energy performance data from the building after the windows replacement.

1. INTRODUCTION

1.1 Objective

This case study aims to evaluate the influence window upgrades of 27 windows installed in NE3 in the overall building energy performance. To achieve this goal, an energy model of NE3 is developed and properly calibrated with real data from the building. NE3 is home of the Centre for Architectural Ecology and it is well-known to develop research in building acoustics, so the implementation of the new windows was also analyzed from an acoustic performance perspective. Therefore, this case study also has the objective to document all the process and challenges that led to the implementation of the windows, including the integrated approach to analyze this particular windows upgrade and the methodology used in the installation of the windows.

2. NE3 – CENTRE FOR ARCHITECTURAL ECOLOGY

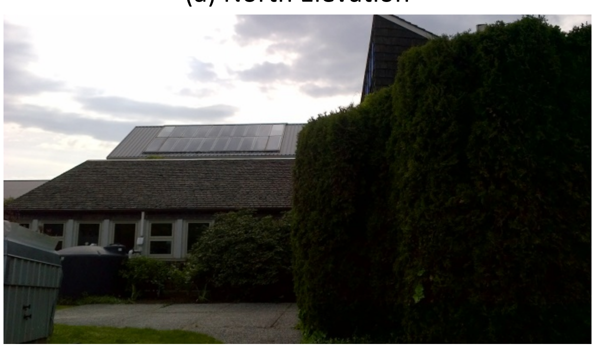
NE3 – Centre for Architectural Ecology is located at 3700 Willingdon Avenue, BCIT Burnaby Campus. This 648 m^2 (6,975 ft^2) wood-frame building was constructed on site in 1971 and since 2003 is the home to the Centre for Architectural Ecology. Nowadays, this research facility is dedicated to applied research and education under the direction of Dr. Maureen Connelly. When it comes to research areas, the centre is well-known to develop research in building acoustics, green roofs, and vegetated walls. Figure 2.1 shows the top view of the building.

Figure 2.1 – Top view of NE3 – Centre for Architectural Ecology

Figure 2.2 presents the building elevations.

(a) North Elevation

(b) South Elevation



(c) East Elevation

(d) West Elevation

Figure 2.2 – NE3 elevations

NE3 has two offices in the front part of the building and, in the back, presents the laboratory, where most of the experiments are done. The building also includes storage, a mechanical room and restrooms. Figure 2.3 presents NE3 floor plan.

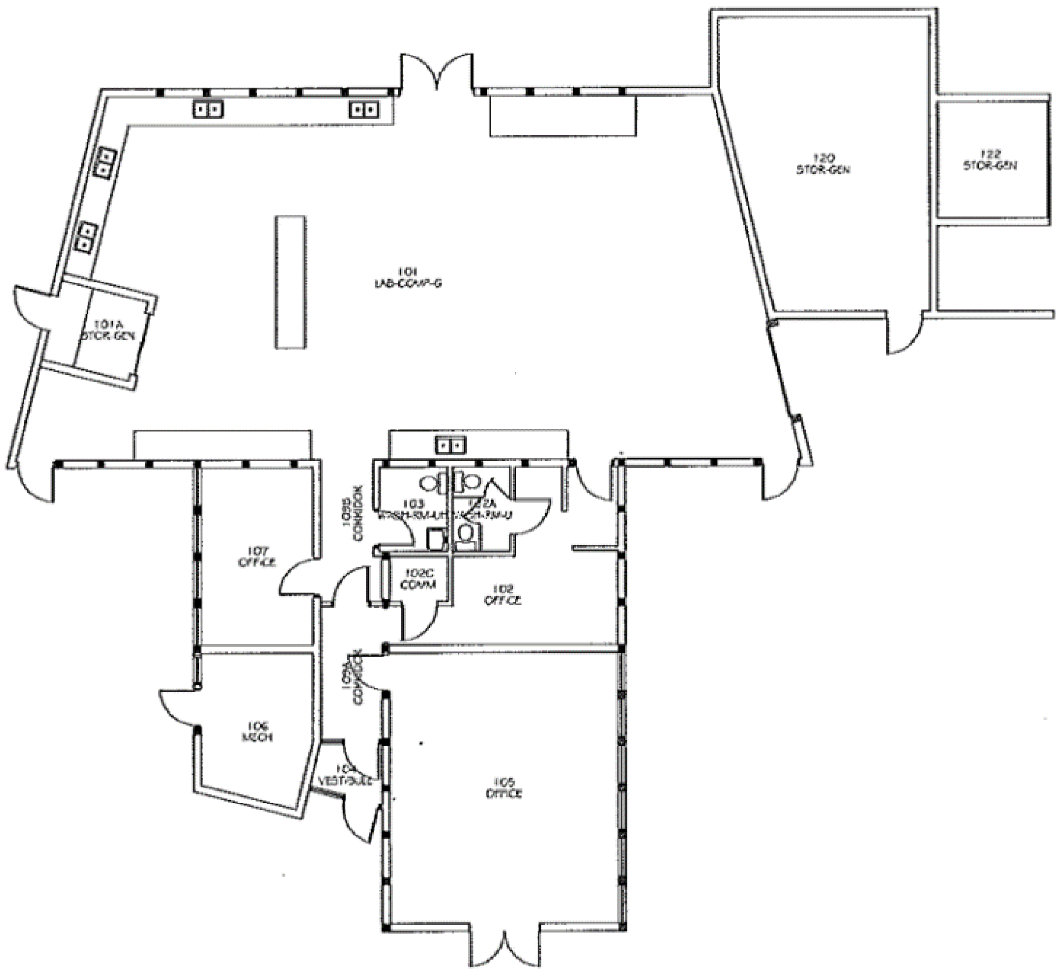


Figure 2.3 – NE3 floor plan

2.1 Construction

This section presents the construction aspects and the envelope characteristics of the Centre for Architectural Ecology. In terms of structure, NE3 has a concrete slab on grade serving as the foundation, wood studs walls and wood framing structure for the roof. The exterior walls are composed by the originals cedar shingles installed in 1971. The sloped roof is also made of the cedar shingles and the entry doors are typical glazed wood assemblies. In the interior, the floor finishes throughout the building are vinyl composite tiles and exposed concrete floor. The interior wall finishes are painted gypsum board and blocks.

The thermal insulation, made of fiberglass batts, is positioned inside the wood frame wall cavity. In the outside surface of the envelope, building paper serves as water resistive barrier (WRB) and air barrier. It is important to mention that the continuity of the air barrier is sometimes compromised along the assembly. For example, the connections between the building and the single-pane windows without proper sealants generate a certain amount of air leakage through the frame. Further, the air barrier is not continuous to the door frame, gaps exist where shingles are missing, and the shingle cladding has not been sealed to the door frames.

The poor connection to the air barrier results in air leakage through the enclosure and excessive energy consumption. Due to the absence of sealants and poor connection to the air barrier, currently, there is also the potential for water ingress at the junction between the frame and cladding. Figure 2.4 presents, after the removal of the window, the connection between the building paper and the window frame. It is possible to attest the part of the building paper (air barrier) is compromised, therefore, during the installation of the new windows the building paper was substituted by spun bonded polyolefin (Tyvek).

Figure 2.4 – Window frame and building paper

2.2 Windows and Energy Performance

The windows system has a critical participation in the building enclosure. Generally, it is the weaker chain in thermal efficiency in the whole building assembly. Figure 2.5 presents a graph where it shows the importance of each building element to the total thermal load of the building. The figure shows that the fenestration has a higher impact on heating and cooling load when compared with other building elements, like walls, roofs, floors and even the air infiltration. This kind of behaviour is usually found in cold climates, like the one presented in Vancouver, Canada.

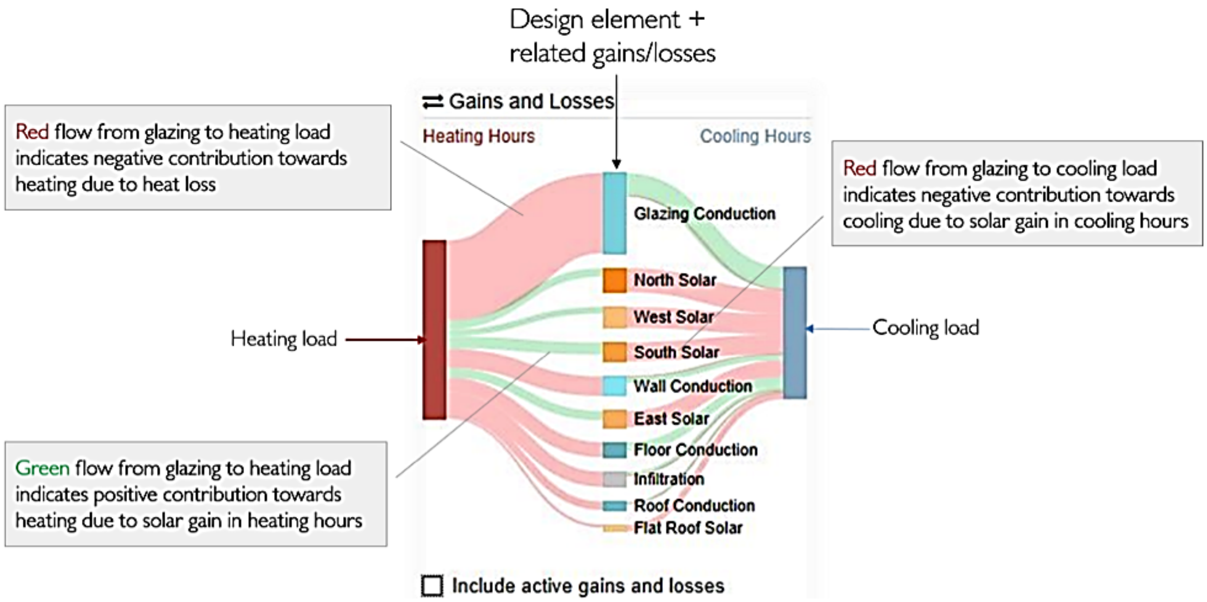


Figure 2.5 – Influence of the assembly components in the building total thermal load

(*http://www.sefaira.com/news/energy-flows-2-0-an-improved-approach-to-understanding-building-performance/*)

In the heating load, the windows present an even higher significance and represent a great portion of the total load. The heating and cooling load are basically supported by the mechanical system in order to achieve a desirable temperature (thermal comfort). It is important to mention that NE3 presents only heating system (further presented in section 5.2); cooling is provided by a window air conditioner in one particular office room and in the other rooms the cooling is achieved by opening windows and doors.

Two of the most important factors when it comes to energy efficiency and windows are the U-value (thermal conductivity) and solar heat gain coefficient (SHGC). The U-value represents the amount heat loss by conduction; lower values of thermal conductivity represent higher thermal performance. Solar heat gain coefficient (SHGC) is a factor that takes into consideration the amount of solar radiation transmitted by the fenestration. This coefficient affects both heating and cooling loads. Windows with lower SHGC aloud less solar radiation going into the building, this is reflected in less energy require for cooling the space in the summer and higher energy for heating the space in the winter. In the heating season (colder months), windows with high SHGC allow more heat going into space, serving as “free heating” and requiring less energy to the mechanical system to heat the space.

2.3 Windows – NE3

This section explains the differences between the old and new window systems used in NE3. In total, the building presents 27 windows; all of them were changed. Most of the windows are single-pane with aluminum frame, 23 in total. The rest of 4 windows are double-pane also with aluminum frame. When it comes to area of window per total wall assembly, NE3 presents 8.1% of window-to-wall ratio. This value is relative to the window area, which is going to be substituted, divided by the total wall area. Normally the window-to-wall ratio also includes the area of the doors, but for this study it is presented only the values for windows. After all, the windows are the only element in the building enclosure to be modified. The new windows are all double-pane with vinyl frame, low-e coating, argon-filled, U-value of 1.6 W/m²K, SHGC of 0.3, and visual transmittance of 64%. Figure 2.6 presents the 6 east-facing windows of NE3; the dimensions of those windows are 4’ 6’’ (137 cm) of height by 3’ (91 cm) of width.

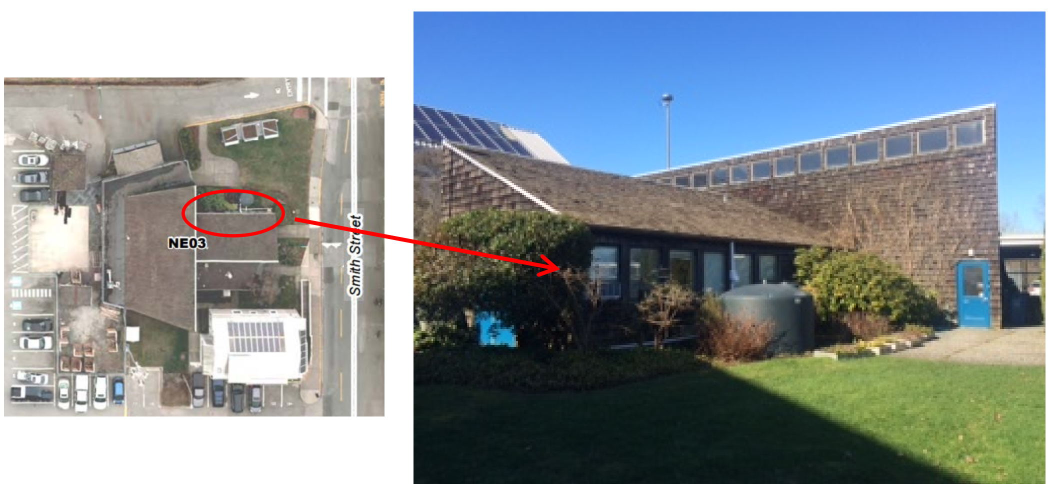


Figure 2.6 – East-facing windows

The values relative to U-value and solar heat gain coefficient (SHGC) for all the old windows were considered following the recommendations of ASHRAE Handbook of Fundamentals (2013). Table 2.1 shows the properties and dimensions for both the old and new east-facing windows.

Table 2.1 – East-facing window properties

	East-facing windows	
	Previous window	New window (Centra)
Number of windows	6	
Window height (ft)	4.5	
Window width (ft)	3.0	
Frame material	Aluminum	Vinyl
Number of panes	1	2
Gap thickness (mm)	No gap	13
Gap glass fill	-	Argon
Overall U-value (W/m²K)	5.8*	1.6
Solar heat gain coefficient (SHGC)	0.9*	0.30
Low-e coating	No	Yes
Visual transmittance (VT)	-	64%

* The values adopted in the model were estimated; using ASHRAE Handbook of Fundamental (2013) as reference.

Figure 2.7 presents the 4 west-facing windows of NE3; its dimensions are also 4’ 6’’ (137 cm) of height by 3’ (91 cm) of width.

Figure 2.7 – West-facing windows

Table 2.2 shows the properties and dimensions of the old and new west-facing windows.

Table 2.2 – West-facing window properties

	West-facing windows	
	Previous window	New window (Centra)
Number of windows	4	
Window height (ft)	4.5	
Window width (ft)	3.0	
Frame material	Aluminum	Vinyl
Number of panes	2	2
Gap thickness (mm)	13	13
Gap glass fill	Air	Argon
Overall U-value (W/m²K)	3.7*	1.6
Solar heat gain coefficient (SHGC)	0.76*	0.30
Low-e coating	No	Yes
Visual transmittance (VT)	-	64%

* The values adopted in the model were estimated; using ASHRAE Handbook of Fundamental (2013) as reference.

Figure 2.8 presents the 17 west-facing windows; the dimensions of those windows are 3’ (91 cm) of height by 3’ (91 cm) of width.

Figure 2.8 – South-facing windows

Table 2.3 shows the properties and dimensions of the old and new south-facing windows.

Table 2.3 – South-facing window properties

	South-facing windows	
	Previous window	New window (Centra)
Number of windows	17	
Window height (ft)	3.0	
Window width (ft)	3.0	
Frame material	Aluminum	Vinyl
Number of panes	1	2
Gap thickness (mm)	No gap	13
Gap glass fill	-	Argon
Overall U-value (W/m²K)	5.8*	1.6
Solar heat gain coefficient (SHGC)	0.9*	0.30
Low-e coating	No	Yes
Visual transmittance (VT)	-	64%

* The values adopted in the model were estimated; using ASHRAE Handbook of Fundamental (2013) as reference.

The windows upgrade will affect both the cooling and heating load of the building. The heating load is affected by the lower U-value (thermal conductivity) of the new windows, which directly implies in less heat loss by the window system. NE3 does not have an integrated mechanical cooling system, in the warmer months, the mechanical cooling is provided only for one room with the use of a window air conditioner. The rest of the building uses other mechanisms to achieve thermal comfort for cooling, like opening window and doors, fans and other types of adaptive behaviour. Even so, the cooling load would also be affected by the new windows; the lower solar heat gain coefficient (SHGC) would allow less heat going in the fenestration, requiring less mechanical cooling and also improving the thermal comfort of the users during the warmer months.

2.4 Infrared Camera

One technology used to evaluate the building thermal performance is the infrared (IR) camera. The use of thermal imaging for a home inspection, to observe thermal bridges, air tightness and other forms of building auditing are increasing with the development of this technology and, at the same time, is becoming more accessible to the wide public. Although people assume that the infrared (IR) camera measures the surfaces temperatures, this concept is not 100% accurate. This camera actually measures the intensity of infrared radiation (radiant energy) being emitted by the surface it is aimed at. The precision of these measurements depends on the emissivity and reflectivity of the surfaces adopted in the IR camera settings.

From the outside, surfaces/materials that are losing more heat show higher temperatures, surfaces with lower temperatures, one the other hand, are losing less heat. But when the infrared camera is used indoors the opposite behaviour is observed, surfaces with lower temperatures are losing more heat than the surfaces with higher temperatures. With this simple concept is possible to identify thermal bridges, air leakage, moisture intrusion, and other kinds of imperfections in the building enclosure. But special attention is needed when the pictures are taken outdoors, it is required to:

- Have a reasonable ΔT between indoor and outdoor temperature to actual have considerable heat transfer trough the envelope;
- Sun radiation warms the exterior walls and roofs, therefore, it compromises the surface temperatures observed by the camera during the day. So it is preferable to take pictures during the night after the heat provided by the sun radiation is dissipated;
- Water has a relatively high thermal conductivity, so if the surfaces are damped by the rain, for example, the surface temperature observed in the infrared picture it is not

representative of the actual material. Thereby, have dryer materials in the exterior is desirable.

NE3 was built in 1971, the airtightness of this building is not comparable with most of the modern buildings normally found today. The IR camera comes as a good alternative to evaluate its overall airtightness and visually identify the air-leakages. The infrared pictures were taken on February 25th, 2016 from 8:00 to 8:40 PM. In this particular day, outside temperature was around 8 °C (46.4 °F) and all the desirable conditions were presented. Figures 2.9 to 2.12 present the pictures taken with the IR camera.

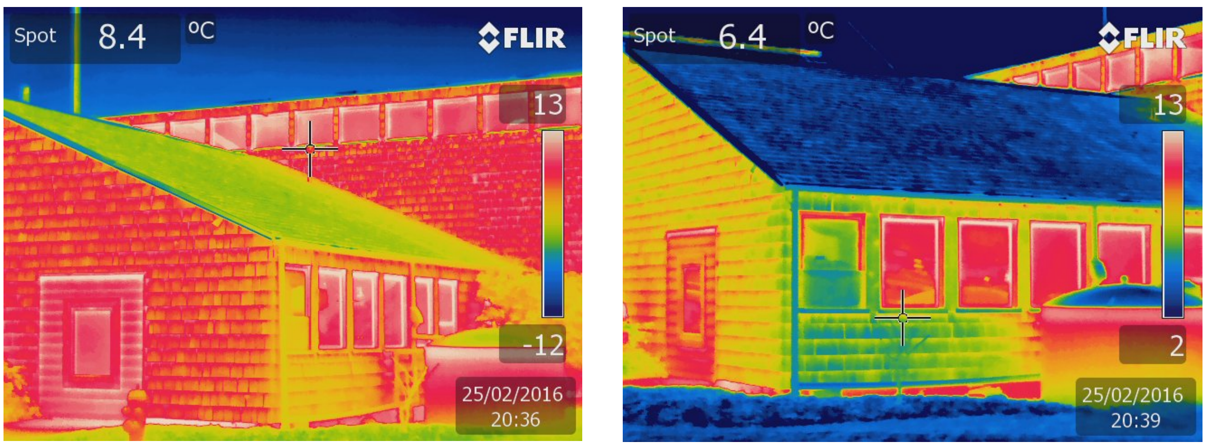


Figure 2.9 – Thermal images of the overall building

Figure 2.10 presents the thermal image of the windows to be upgraded, in the lower and upper part of the building respectively. Dealing with a thermal image of window surface is not as simple as dealing with the rest of opaque surfaces that are normally presented in the building envelope. The emissivity and reflectivity of the glass compromise the reading of surfaces temperature in the IR camera. In the thermal image, the surface of the glass reflects other surfaces, functioning similarly to a mirror. The windows with a low-e coating (low emissivity) present a more reflective surface than the ones without low-e coating. In the figure, is possible to see higher temperatures across the window frame, this is explained by both the higher conductivity of the aluminum window frame working as a thermal bridge and by the existence of air leakage across the window frame. Special mention needs to be taken to the area across the window air conditioner (figure 2.10), which does not present any kind of insulation and becomes a great area of heat loss.

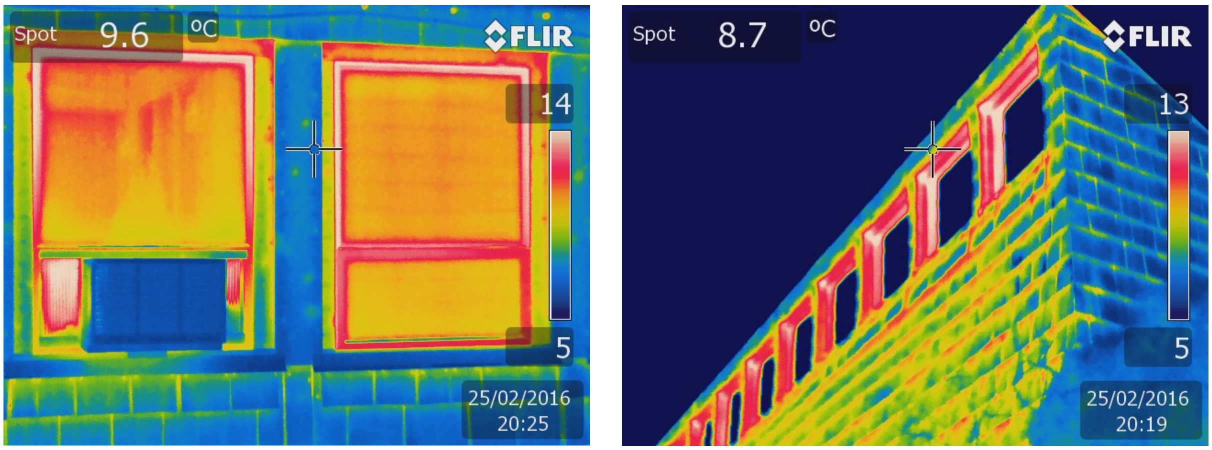


Figure 2.10 – Thermal images of the windows

Figure 2.11 presents thermal images of the wall and roof assembly. It is possible to observe in the upper part of the cedar shingles higher temperatures; this might indicate a certain amount of air leakage through the wall assembly. In the picture on the left, it is possible to detect that this particular part of the roof does not present zones with higher temperatures, indicating that the roof still presents a reasonable thermal performance.

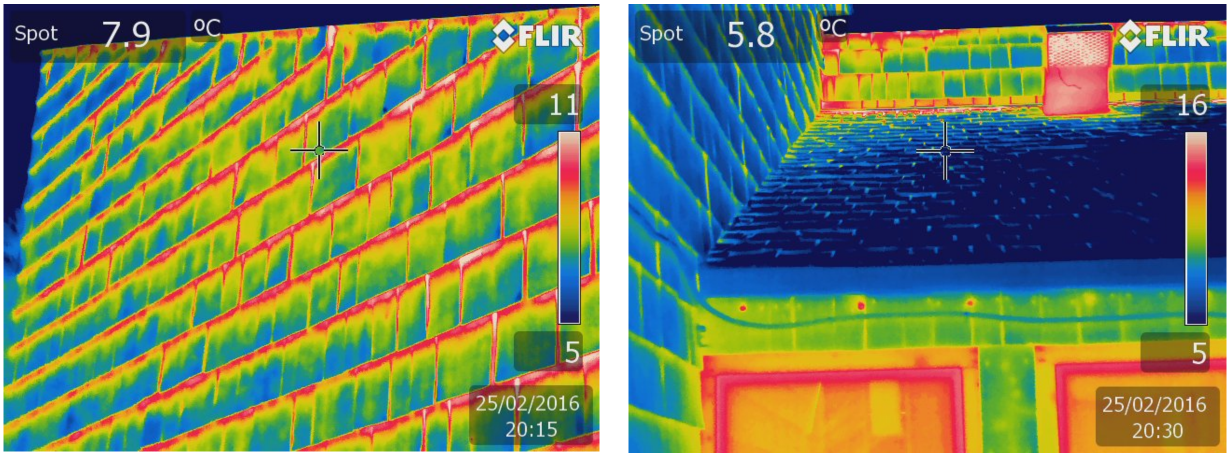


Figure 2.11 – Thermal images of the wall and roof assembly

Figure 2.12 presents the concrete slab, due to its higher thermal conductivity and no insulation the foundation acts as thermal bridge. This expression is used to an area of an object which has a significantly higher heat transfer than the surrounding materials resulting in an overall reduction in the thermal performance.

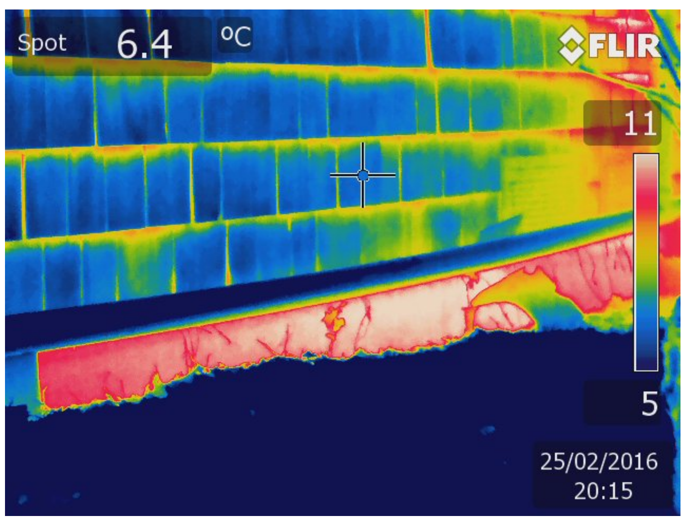


Figure 2.12 – Slab on grade thermal bridge

All the pathologies shown along this section by the IR pictures, like thermal bridging and airtightness, influence the overall energy performance of NE3. The improvement of the window will certainly affect the thermal performance of the window glass and IGU. But by this previous analysis with IR camera, it is possible to conclude that this window improvement would also impose a better performance to the window frame and airtightness.

3. CHALLENGES

This project presented particular challenges to be overcome during the process of planning, conception and execution. This section briefly describes the challenges and the process that led to the solutions adopted and used in the execution part.

3.1 Budget

The budget for this project was a constraint, a common theme for homeowners and constructors. All the support provided by Centra Windows was fundamental to the success of this project. Considerations for a cost-benefit analysis are presented in the next sections.

3.2 Triple vs. Double-Pane Window

One decision taken during the process of choosing the windows for NE3 was between the uses of triple or double-pane window. It is well-known that the thermal performance of a triple glaze window is usually higher than a double glaze. The reason for the improvement of the thermal transmittance of a triple glaze window is not because the extra pane (glass) by itself, but because the existence of an extra gap that can be filled by air or another type of gas. This is easily explained when the thermal resistance of the individual materials is analyzed, the thermal resistance of glass is almost null but the resistance of a layer of still air, on the other hand, is significantly higher.

The use of triple pane might have a significant impact on thermal performance. Those windows have considerably lower U-value and solar heat gain coefficient (SHGC). The higher performance is given by the extra gap and also because the extra pane that allow the use of an extra low-e coating in the window assembly. At the same time, triple glaze windows present some disadvantages, like being heavier than double-pane which makes it more difficult for installation. It is also more generally expensive than double-pane windows.

For this project, one preponderant aspect that led to the double-pane window to be chosen was the acoustical performance. Subsection 3.4 briefly exposes the considerations that led to this decision. Also, BCIT was interested in demonstrating a project that would be likely replicated by the average homeowner and selecting an excellent double pane window with a good U-value and SHGC seemed like the right approach.

3.3 Dealing with Hazardous Materials

Common in the 1970's construction, NE3 building used asbestos containing mud for the interior walls. At present time, when the hazardous effects of exposure to asbestos are well known, special care is needed to deal with the materials. During the implementation of the new windows, all the specifications prescribed by WorkSafe BC to deal with this kind of materials were respected and a removal/installation procedure was developed for the installation team to follow. A Notice of Project (NOP) was also submitted to WorkSafe BC. One example of the numerous steps included in the procedure is illustrated in Figure 3.1. Before the removal of the old windows, a layer of 6 mil polyethylene was sealed in the interior part. Figure 3.1 present this procedure and how windows were sealed.

Figure 3.1 – Positioning 6 mil polyethylene before the windows removal

The presence of hazardous materials (hazmat) is an important element of budget planning. However, it is important to note that in some low risk cases, the cost impact of dealing with hazmat can be relatively low compared to the overall budget. This was the case for the work in NE-03.

3.4 Acoustic vs. Energy Performance Trade-offs

As mentioned before, NE3 conducts a lot of research related with the acoustical performance of buildings. Therefore, this window improvement is/will also analyze from an acoustical perspective (but is outside the scope of this report). The acoustic performance was critical in the decision-making process of selecting the proper window. NE3, particularly, has shown acoustical problems in a specific low frequency, around 150 Hz. After the analysis of all the options of windows available and take into consideration this problem with that particular frequency, it was decided to use the double-pane window which appeared to have an acoustical advantage over the triple pane option. The chosen window also provides a desirable and high energy performance, especially when compared with the previous window assembly.

4. INSTALATION OF THE WINDOW

The installation of the window was made by Centra Windows; the company provided and manufactured the windows. The installation occurred from 25th of April to 3rd of May, 2016. The following section exposes the methodology adopted during the installation.

4.1 Methodology

Before explaining the window change per se, some concepts need to be introduced: rain penetration control, water shedding surface (WSS), water resistive barrier (WRB) and air barrier (AB). The correct installation and continuity of these control layers along the building envelope and windows guarantee that the window system will perform as expected. Deficiencies in those control layers might impose problems to the building assembly, like moisture accumulation, rain leakage, and lack of proper airtightness. All the methodology used in the installation of the windows is based on the concept of continuity of these control layers and the window applied. If properly installed, the service life and performance of the windows and the building itself is expected to be satisfactory.

As mentioned earlier, NE3 has asbestos boards installed in the interior walls. For that reason, the first step before the windows were removed was to place 6 mil polyethylene film (see figure 3.1). The rest of the methodology adopted during the installation is presented by table 4.1.

Table 4.1 – Windows installation methodology [1]

Step 1: Position a 6 mil polyethylene film in the interior wall, avoiding exposure to the asbestos in the interior wall board.	
Step 2: Take off the old window trim to remove the window entirely. Again, the removal procedure developed addressed the hazmat risk associated to this phase.	

Table 4.1 – Windows installation methodology [2]

Step 3: Put impermeable self-adhered membrane (SAM) in the window sill and corners. Permeable self-adhered membrane (SAM) is used for the window jambs. The shims are positioned and the new window is installed over it.	

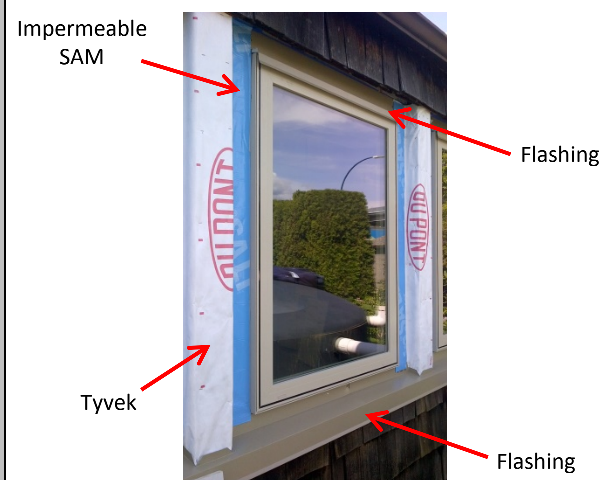
Phase 4: The windows are installed and properly sealed.	
Phase 5: Tyvek, flashing and impermeable SAM are positioned over the installed window.	

Table 4.1 – Windows installation methodology [3]

Phase 5: Window trim and cladding are positioned.	

The impermeable SAM in the window sill is a common practice to avoid water infiltration; it works as a water resistive barrier (WRB). With similar function, the permeable SAM is positioned in the window jambs. After the glazing is installed and sealed, the window flashing is placed over and below the window. The flashings work as a water shedding surface (WSS) and protect/relieve the window jamb and sill of the rain water loads (see figure 4.1).

Figure 4.1 – Window flashing

This installation also used Tyvek. The reason behind the application of this particular material is because the original building paper (1971) located in the in assembly was partly compromised. Therefore, this new layer of Tyvek assumes the function of previous building paper as a water resistive barrier (WRB) and air barrier for this perimeter between window frame and wall assembly. The methodology presented in this section follows the standard practice used in the industry.

5. ENERGY MODELING

5.1 eQUEST – Quick Energy Simulation Tool

The software used to perform the energy model is eQUEST, which is a building energy simulation tool developed by James J. Hirsch and Associates. The software is based on the older and widely known energy analysis program, DOE-2, from the Lawrence Berkeley National

Laboratory (LBNL). eQUEST gives a graphic user interface, wizard and industry standard defaults to the DOE-2.

eQUEST simulate all the energy use for a whole year in the studied building. The energy consumption is divided by its source, as gas and electrical energy. In this building, gas consumption is responsible for domestic hot water (DHW) and space heating (boilers). On the other hand, the electric energy consumption is related to space cooling (1 window unit), lighting, equipment/miscellaneous and auxiliary equipment. The 3D model made by eQUEST of NE3 is presented by figure 5.1.

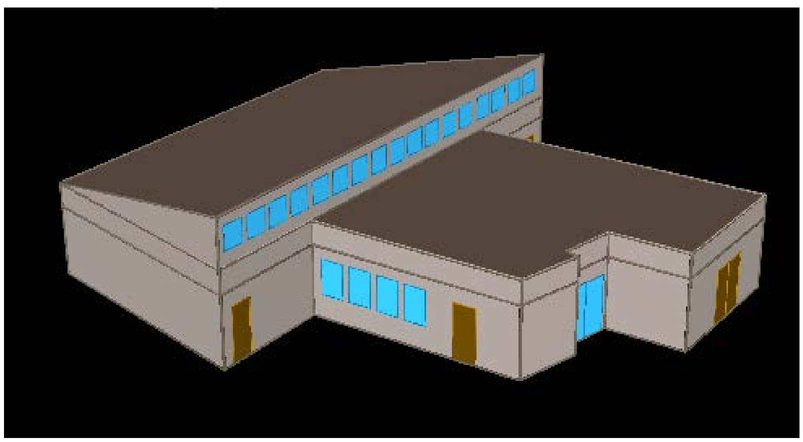


Figure 5.1 – 3D energy model of NE3 (eQUEST)

5.2 Assumptions and Limitations

In terms of energy modeling, the assumptions and considerations assumed in the software are fundamental to the accuracy of the model in comparison with the real building. All the assumptions made in the energy modeling are presented along this section.

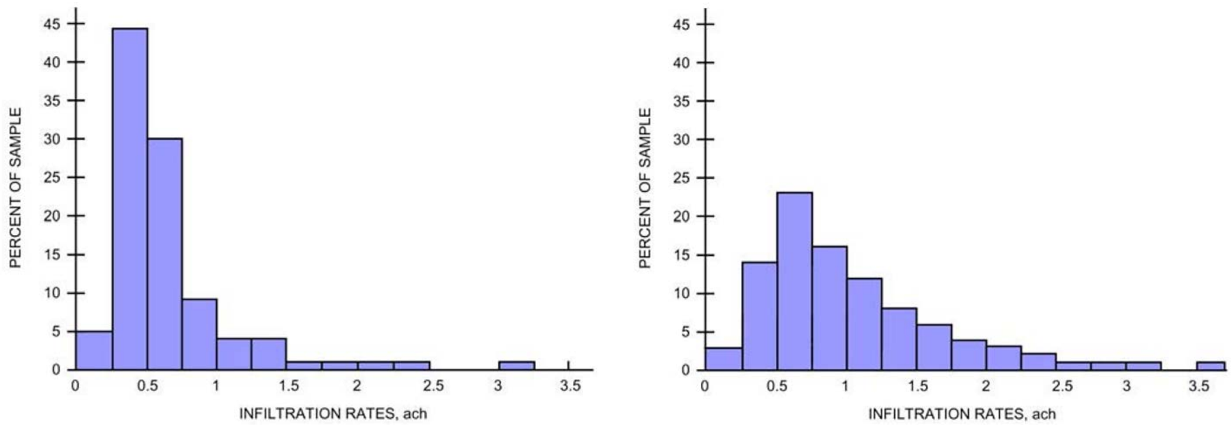
5.2.1 Schedule

The yearly schedule adopted for this project was divided in two periods. The first is related with the normal usage of buildings, it goes from January 2nd to July 14th and from September 1st to December 14th. The normal schedule during the week days are from 9:00 AM to 5:00 PM on week days. For weekends the buildings operates only Saturday from 10:00 AM to 3:00 PM. The second period is related with the low usage of the building (break period). It was considered from July 15th to August 31st and from December 15th to January 1st. During this period the building usage was from 10:00 AM to 3:00 PM, but for weekend the building does not operate.

5.2.2 Air-leakage

To estimate the air-leakage of a building the standard approach is to do a blower-door test. This option was initially taken into consideration for NE3, but after further deliberation it was consider unfeasible because the building presents asbestos in the wall assembly. The pressure differential in the assembly during the test would force the transport of asbestos particles to the environment which is highly dangerous; therefore, for safety reasons, it was decided not to do this test. But the brief infrared analysis presented in section 2.4 gives an overall idea of the of NE3 airtightness.

ASHARE Handbook of Fundamentals (2013) mentioned that the typical infiltration values in housing in North America vary by a factor of about 10, from tightly construction with seasonal average air exchange rates as low as 0.1 air changes per hour (ACH) to loosely constructed housing with air exchange rates as great as 2.0 ACH. Figure 5.2 presents histograms of infiltration rates in two different samples of North America housing (Grimsrud et al., 1982; Grot and Clark, 1979). Figure 5.2 *(a)* shows the average seasonal infiltration of 312 houses located in different areas in North America. The median infiltration value of this sample is 0.5 ACH. Figure 5.2 *(b)* represents measurements in 266 houses located in 16 U.S. cities. The median value of this sample is 0.9 ACH. The group of houses in the figure 5.2 *(a)* sample is based in new construction and more energy-efficient houses, whereas the group in figure 5.2 *(b)* represents older, low-income housing.



(a) New Construction *(b) Old Construction*

Figure 5.2 – Histogram of Infiltration Values (ASHARE Handbook of Fundamentals, 2013)

ASHARE Handbook of Fundamentals (2001) also presents tables that give air exchanges rates (ACH) as a function of the building airtightness and season, as presented by table 5.1 and 5.2.

Table 5.1 – Air exchange rate (ACH) as function of airtightness in winter (ASHARE Handbook of Fundamentals, 2001)

Winter										
Class	Outdoor Design Temperature (°C)									
	10	4	-1	-7	-12	-18	-23	-29	-34	-40
Tight	0.41	0.43	0.45	0.47	0.49	0.51	0.53	0.55	0.57	0.59
Medium	0.69	0.73	0.77	0.81	0.85	0.89	0.93	0.97	1.40	1.05
Loose	1.11	1.15	1.20	1.23	1.27	1.30	1.35	1.40	1.43	1.47

Table 5.2 – Air exchange rate (ACH) as function of airtightness in summer (ASHARE Handbook of Fundamentals, 2001)

Summer						
Class	Outdoor Design Temperature (°C)					
	29	32	35	38	41	43
Tight	0.33	0.34	0.35	0.36	0.37	0.38
Medium	0.46	0.48	0.5	0.52	0.54	0.56
Loose	0.68	0.7	0.72	0.74	0.76	0.78

For the energy model of NE3, it was considered an infiltration rate of 0.7 ACH for the whole building. Part of the overall air-leakage in a building is due to window and doors leakage. ASHRAE Handbook of Fundamentals (2013) reports that the windows and door have an impact in the infiltration rate in order of 6 to 22%. The new windows might impose more airtightness to the whole building enclosure when compare with the previous old window system. The IR analysis (section 2.4) showed that the window frame might present a certain amount of air-leakage. Therefore, in the further analysis, one scenario that it is taken into consideration is the improvement of the overall building airtightness in the order of 15%, using, instead of 0.7 ACH, 0.6 ACH approximately.

5.2.3 Equipment Loads

The Centre for Architectural Ecology does a number of researches, usually these experiments require, in some level, electrical energy. Estimating the amount of energy used in NE3 is a difficult task if you take into consideration that the energy demand varies with the needs and schedule of the researchers. Because of this, the miscellaneous loads were inferred using real data from building (calibration is presented in section 5.4) to calibrate the energy model. After the calibration, the office equipment load adopted is 1.75 W/ft². For the restroom and mechanical room, on the hand, the loads are considered to be 0.10 W/ft².

5.2.4 Lighting System

The lighting system has an important contribution to the energy consumption of office buildings and also affects both the heating and cooling load of the space. Less efficient lightings spend more energy to illuminate the space but at the same time provide some “free heating”. This might require less energy to heat the space or, on the other hand, more energy to cool down the space. The lighting system adopted for the energy model has a light density of 1.1 W/ft^2 for the office space, 0.9 W/ft^2 for the restrooms and 0.5 W/ft^2 for the corridor, storage and mechanical room.

5.2.5 Thermal insulation

Thermal resistance might decreases over time so the energy model considers a thermal insulation for the wall assembly of R-10, nominal value. This consideration follows the Building Enclosure Condition Assessment (BECA) performed by Boldwing Continuum Architects Inc. in the year of 2015 for NE3. That report concluded that the building assembly presents, approximately, an R-10 thermal resistance for the whole wall assembly.

5.3 Mechanical System

This section shortly explains the mechanical system used in NE3 and its representation in the eQUEST software. For heating, the building uses hydronic heaters; the heating coils use water heated by boilers. The building presents 3 zones (see figure 5.3), the zones on the front uses the uses hydronic base board heaters, the zone of the laboratory on the back uses two fans with hydronic heating coils to provide the heat for this particular space. Figure 5.4 shows the heaters used in NE3.

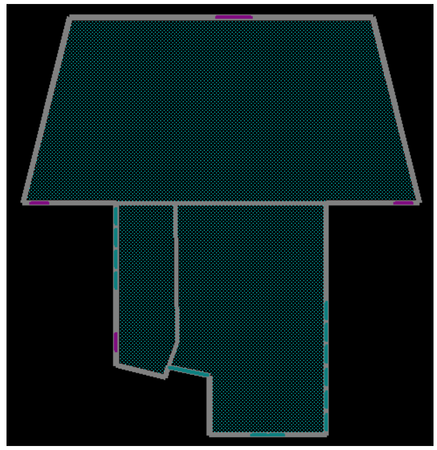


Figure 5.3 – Thermal zones in NE3 (eQUEST)

Figure 5.4 – Hydronic baseboard heaters in NE3

As mentioned previously, the building does not present a central system responsible for cooling. The main office, located on the west side of the building, presents a window air conditioner used in the cooling season. For the rest of the building, thermal comfort is achieved using adaptive behaviour, like using fans or opening windows and doors.

5.4 Calibration and Validation

After model the building, a calibration is needed to make sure that the model fairly represents the actual energy usage of the NE3. The real electrical consumption used for tuning the model was from the year of 2012 to 2015. All the data is available in the Factor 4 website (online) as the building has a real time smart metering. The data available sometimes presents gaps and it is discontinuous, the only year that presents the data for every month is 2014. The electrical consumption over the years has some variation; this behaviour indicates that the usage of the building varies with the demand, needs and experiments made by the users. Figure 5.5 shows the calibration of the energy model with the electrical consumption.

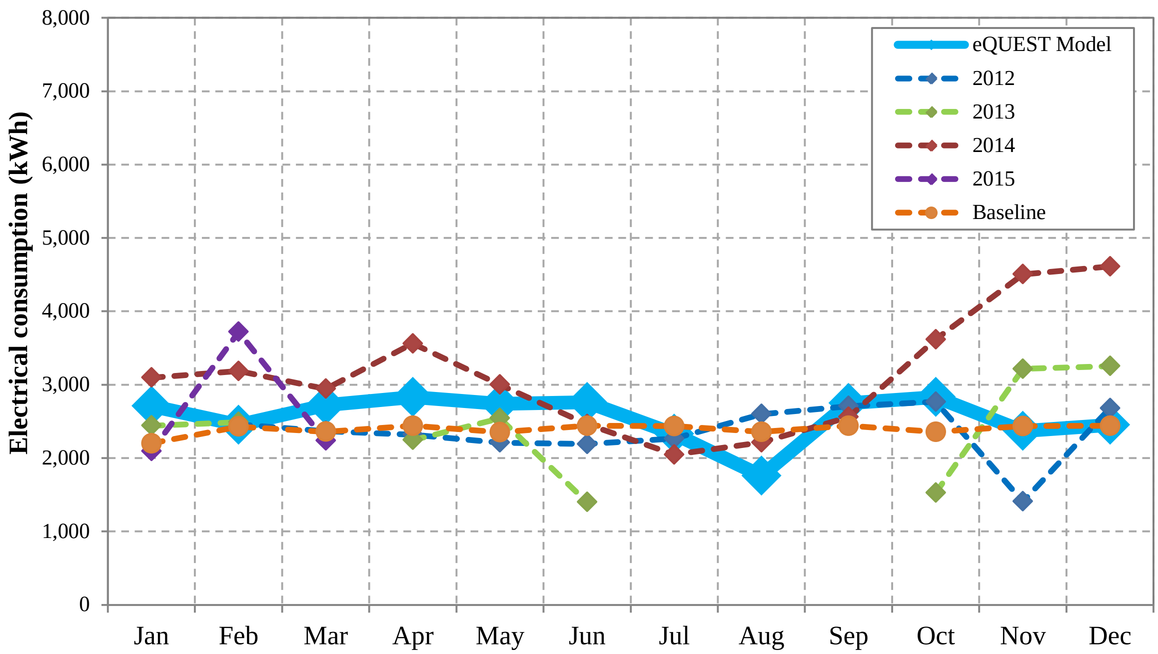


Figure 5.5 – Calibration of the energy model (electrical)

The gas consumption, on the other hand, was obtaining by periodic manual reading in the gas meter in NE3; the data are from March of 2013 to March of 2016. The readings vary with time but give a possibility to reasonably estimate the gas consumptions over a year. The method adopted to determine the monthly gas consumption uses averages of kWh/day for the periods close to the months to be calculated. Table 5.3 presents the gas consumptions from 2013 to 2016 and the values of kWh/day from the periods between the readings.

Table 5.3 – Gas consumptions from 2013 to 2016

	Gas meter/Readings (ft³)	Gas consumption between readings (ft³)	Energy between readings (MMBtu)	Energy between readings (kWh)	# of days between readings	kWh/day
25/03/2013	7,428,034	-	-	-	-	-
06/06/2013	7,464,216	36,182	36	10,604	73	145.3
16/07/2013	7,476,771	12,555	13	3,680	40	92.0
22/08/2013	7,477,044	273	0	80	37	2.2
10/06/2015	7,780,656	303,612	304	88,980	657	135.4
31/07/2015	7,788,214	7,558	8	2,215	51	43.4
31/08/2015	7,788,608	394	0	115	31	3.7
07/10/2015	7,797,270	8,662	9	2,539	37	68.6
02/11/2015	7,818,716	21,446	21	6,285	26	241.7
30/11/2015	7,827,248	8,532	9	2,500	28	89.3
08/12/2015	7,831,598	4,350	4	1,275	8	159.4
14/12/2015	7,835,402	3,804	4	1,115	6	185.8
21/12/2015	7,988,526	153,124	153	44,876	7	6,410.9
04/01/2016	8,254,836	266,310	266	78,048	14	5,574.8
10/01/2016	8,860,127	605,291	605	177,393	6	29,565.5
25/01/2016	8,870,058	9,931	10	2,910	15	194.0
23/02/2016	8,889,545	19,487	19	5,711	29	196.9
01/03/2016	8,894,495	4,950	5	1,451	7	207.2
14/03/2016	8,900,826	6,331	6	1,855	13	142.7

Table 5.4 presents the calculated monthly gas consumption. It uses the averages of kWh/day for similar periods of reading to calculate the monthly gas consumption.

Table 5.4 – Calculated Gas Consumption

	Gas Consumption (MMBtu)	Gas Consumption (kWh)
Jan	20.7	6,060
Feb	18.7	5,474
Mar	18.5	5,425
Apr	12.1	3,559
May	12.5	3,677
Jun	4.8	1,412
Jul	4.6	1,346
Aug	0.3	91
Sep	7.0	2,058
Oct	7.3	2,127
Nov	9.1	2,679
Dec	18.3	5,350

Figure 5.6 shows the gas consumption for both the energy model and the real data from NE3 (table 5.4).

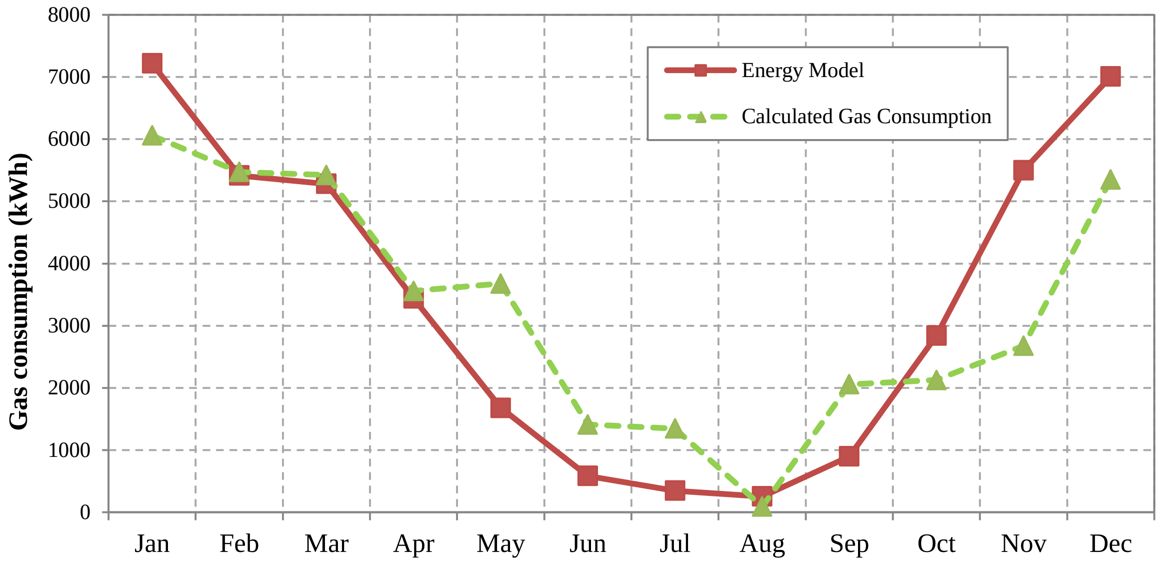


Figure 5.6 – Calibration of the energy model (gas)

Figure 5.5 and 5.6 show that the results from the energy model present reasonable alignment with the real energy consumption of NE3. After this validation, it is now is feasible to position the new window system on the model and evaluate its impact on the energy performance of the building.

6. ANALYSIS OF WINDOW UPGRADE IN NE3

After the previous calibration and validation of the energy model, this section analyzes the impact caused by the window upgrade in the energy performance of NE3. Three different scenarios/models are analyzed: the first with the old windows, the second with the new windows, and the third scenario, also with the new windows, but, with a decrease in the air-leakage of 15% caused by the more air-tight windows. Instead of 0.7 ACH as the value for infiltration rate for the building, in that third scenario it is used the infiltration rate of 0.6 ACH approximately. Figure 6.1 presents the annual results of energy consumption by end use.

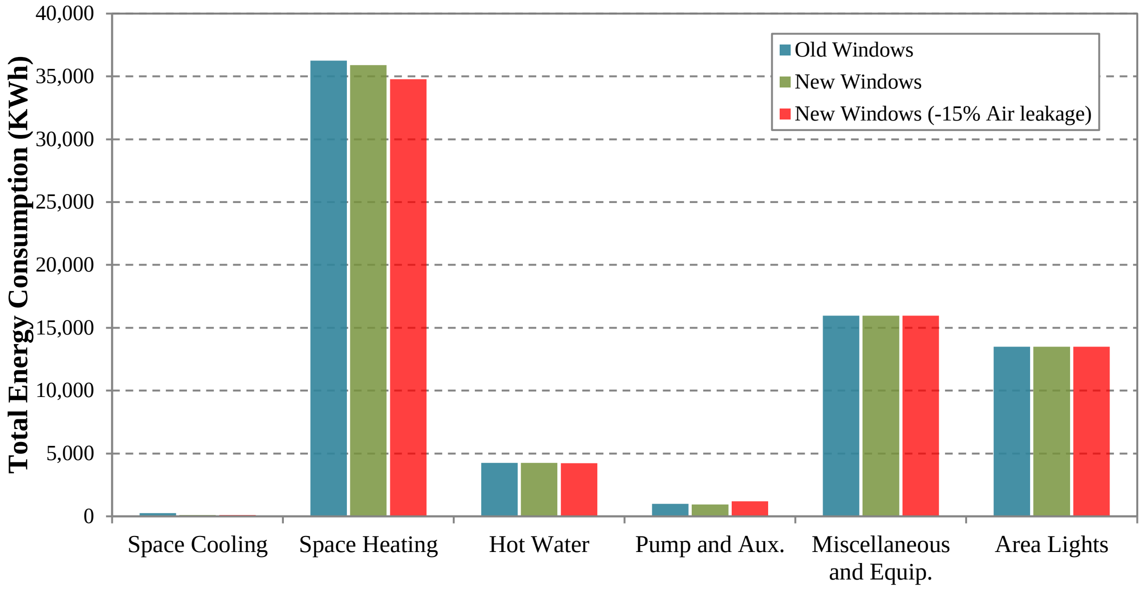


Figure 6.1 – Annual electrical consumption by end use

Looking at figure 6.1, it is possible to attest that the space heating forms the majority amount of the energy used in NE3. The energy spent for cooling the space is almost negligible. The total annual energy savings for heating is **0.9%** and **4.1%** for the second and third scenario respectively. In terms of total energy savings per year, the new window system provides **0.7%** of savings and the new windows with higher airtightness save **2.0%.** Table 6.1 presents the annual results and energy savings for each model.

Table 6.1 – Annual energy consumption

	Old Windows	New Windows			New Windows (-15% Air-leakage)		
	Energy (kWh)	Energy (kWh)	Energy savings (kWh)	Energy savings (%)	Energy (kWh)	Energy savings (kWh)	Energy savings (%)
Space Cooling	250	100	150	60.0	110	140	56.0
Space Heating	36,238	35,898	340	**0.9**	34,767	1,471	**4.1**
Hot Water	4,238	4,238	0	0.0	4,235	3	0.1
Pump and Aux.	980	950	30	3.1	1,200	-220	-22.4
Miscellaneous and Equip.	15,960	15,960	0	0.0	15,960	0	0.0
Area Lights	13,490	13,490	0	0.0	13,490	0	0.0
TOTAL	**71,156**	**70,636**	**520**	**0.7**	**69,762**	**1,394**	**2.0**

In terms of monthly energy consumption, figures 6.2 and 6.3 present the electrical and gas consumption analysis respectively.

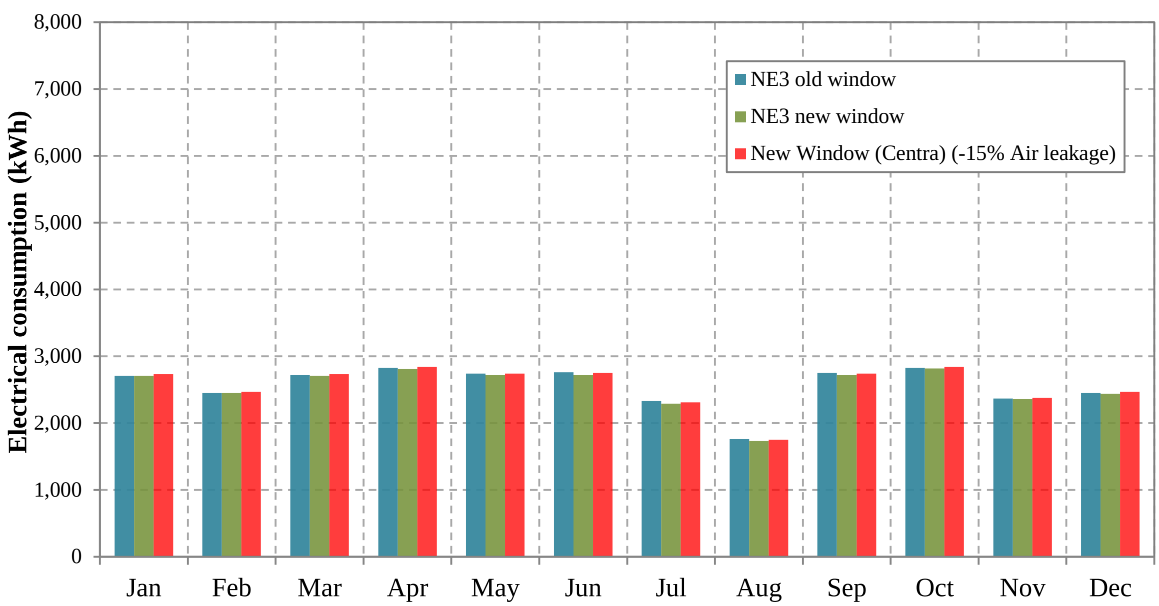


Figure 6.2 – Monthly electrical consumption analysis

Figure 6.2 shows slightly differences in the electrical consumption over the months. This variations is explained by the lower solar heat gain coefficient (SHGC) of the new window system, that allowed less solar radiation to goes through the window assembly, affecting the amount of energy used to cool down the space (note that this is theoretical only has a decision was note to re-install the AC unit in the one window). The model the with the new windows presents more saving in cooling compared with the model with improvement in airtightness because the building air-leakage during the warmer months provide some kind of “free cooling” for the space. The model with more airtightness does not have the outside air coming and cooling down the space. This particular behaviour is generated by the relative mild temperatures of the air during the summer in Vancouver.

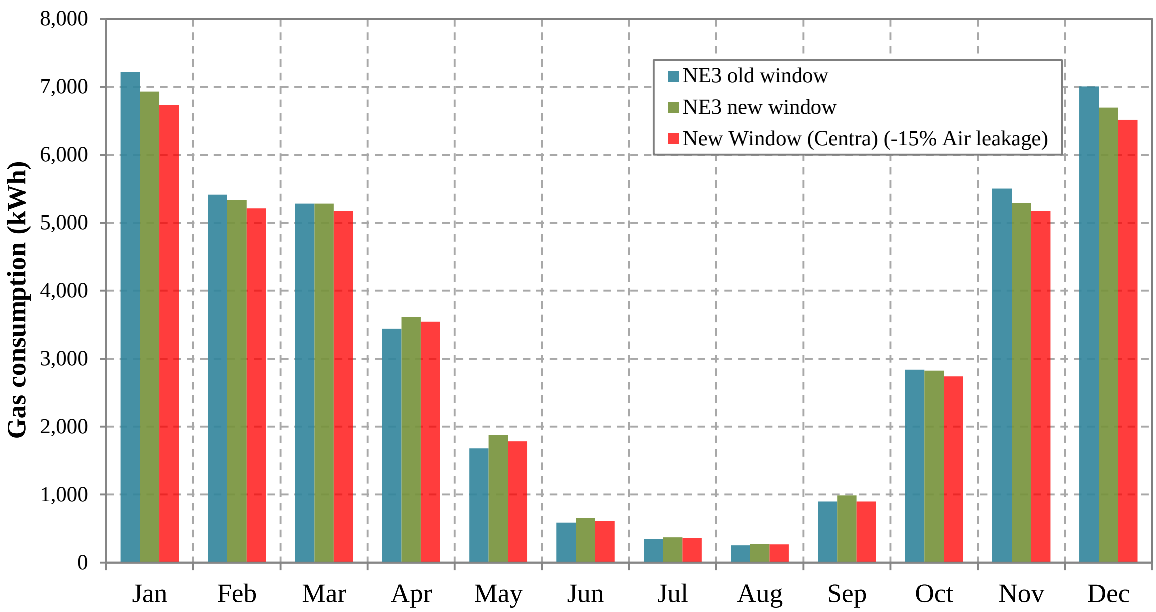


Figure 6.3 – Monthly gas consumption analysis

Figure 6.3 indicate that during the heating season the new window system generates some energy savings, especially the window with decrease in air-leakage.

7. CONCLUSION AND FURTHER WORK

Built in 1971, NE3 presents some deficiencies in terms of building enclosure and airtightness. The old windows system did not meet the current minimum requirements imposed by Canadian and local codes in terms of thermal conductivity and airtightness. From the energy modelling, it is observed an annual improvement of 0.7% in the energy consumption for the new windows, and, if it considered that the new windows would provide a higher airtightness, 2.0% of energy savings. This is not a significant increase in energy efficiency and is explained by deficiencies in the building enclosure, including poor airtightness as indicated by the infrared images. The low window-to-wall ratio of this building of 8.1%, reflects that for this particular building, the impact of windows performance on energy performance is expected to be low. The impact of the same window improvement in a building with proper airtightness, thermal insulation and higher window-to-all ratio would be expected to be much higher.

For further work, after this window upgrade the energy consumption of NE3 needs to be carefully followed. The future results in energy consumption can be analyzed and compared with historical data. All the information relative to energy performance after this modification might also be used to tune the energy model, with special care to deviations related the building schedule and usage.

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