Deep Energy Retrofits of High-Rise Multi-Unit Residential Buildings

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ABSTRACT

Multi-unit residential buildings (MURBs) comprise a significant portion of the housing stock in North American cities. Several studies have identified opportunities to reduce energy consumption at these buildings. Building enclosure retrofits present one of the largest opportunities for significant energy savings.

A previous study by the authors into energy savings achieved in MURBs as the result of full building enclosure renewals work found that, on average, a reduction of 8% of total energy consumption was realized through projects undertaken primarily to address moisture ingress damage, and not specifically for energy savings (RDH 2012). This study also highlighted that full building enclosure retrofits of existing MURBs have the potential for much larger savings, and when properly implemented along with HVAC upgrades, total building energy savings in the order of 20-50% and suite space heat savings of up to 90% can be achieved.

As a result of this research work, a pilot project was undertaken to perform an energy efficient building enclosure retrofit and HVAC upgrade of a 1980's vintage high-rise MURB in Vancouver, BC, predicted to yield a total energy savings of over 25%. This paper details the high performance enclosure retrofit that was completed. Modeled energy savings are compared metered energy use. A payback period of 5 years was calculated for installing triple glazed, fiberglass frame windows compared to code minimum windows.

The findings and lessons learned from this project will assist in planning for future high performance enclosure retrofits to lower the energy consumption of the existing building stock.

Introduction

Multi-unit residential buildings (MURBs) comprise a significant and growing proportion of the housing stock in cities across North America. These buildings constantly go through renewals to address aging systems, repair, and upgrade components. Renewals projects present a good opportunity to also consider energy efficiency at these buildings.

This paper summarizes recent findings of an ongoing research study assessing the effect of building enclosure renewals and energy efficiency upgrades on the energy consumption of mid- and high-rise MURBs. The study is currently focused on a pilot project 13-storey building with 37 residential units, built in 1986 and located in Vancouver, British Columbia. Glazed windows comprise 51% of the vertical enclosure area of the building. The building is heated with electric baseboards in suites, and it is ventilated using a pressurized corridor approach with a single make-up air unit (MAU) that heats and delivers outdoor air to the corridors.

In 2012, the owners of the building proceeded with a building enclosure renewal project to address aging building components (including water ingress and durability issues), improve comfort and durability of the building, and reduce energy consumption. The building was selected to be part of a deep energy retrofit demonstration and research project in partnership with several industry organizations. The pilot project is intended to serve as a model for sustainable, energy efficient and economical enclosure renewals of existing buildings. Phase 1 of this project, an exterior building enclosure retrofit, took place from May through December

2012. Measurement and verification of energy consumption, airflow and Indoor Environmental Quality (IEQ) was performed through 2013. Phase 2, which is currently in the planning stages, will address building mechanical systems, mainly focused on ventilation.

Energy Consumption Trends in Mid- and High-Rise MURBs

An earlier phase of this study looked at energy consumption end-uses and trends in mid- and high-rise MURBs in southwestern British Columbia. Weather-normalized site energy use intensity (EUI) data for this sample of buildings is presented in Figure 1, showing the proportions of natural gas, suite electricity, and common electricity at each building. All energy consumption presented in this paper is site energy.

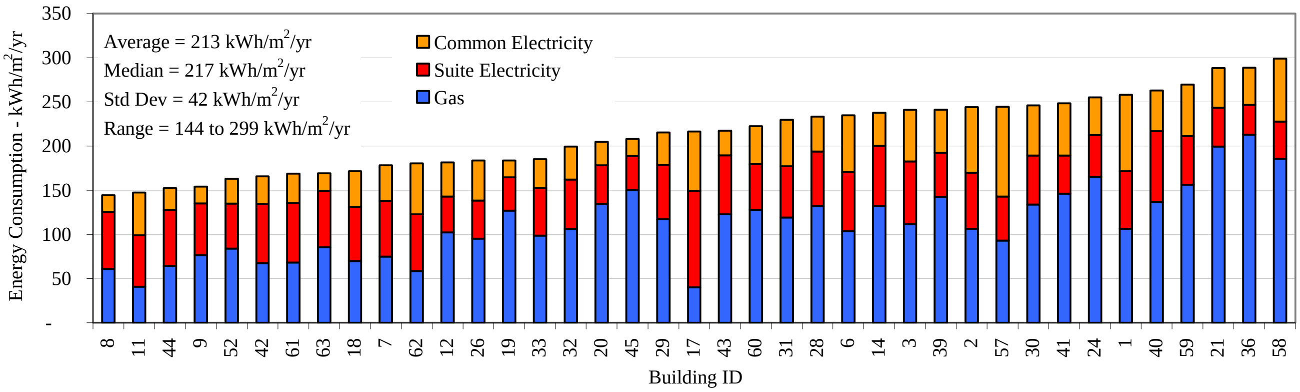


Figure 1. Annual average EUI for 39 MURBs in southwestern British Columbia, kWh/m^2 per year.

Average EUI for the study buildings is 213 $kWh/m^2/yr$, and ranges from a low of 144 kWh/m^2, to a high of 299 kWh/m^2. This energy data was collected over a period from 1998 through 2009. On a per suite basis, the average energy consumption is 21,926 ekWh/yr (combined gas, suite and common electricity consumption). This is lower on a per dwelling basis than an average single-family dwelling in southwestern British Columbia, which consumes 32,030 kWh/yr (BC Hydro 2007).

On average, 49% of the energy consumption at the study buildings is electricity, broken down to 28% electricity in suites and 21% electricity in common areas. Natural gas accounts for 51% of the energy used on average, broken down to approximately 25% for domestic hot water and 26% for make-up air ventilation heat and gas-fireplaces (only present in certain buildings).

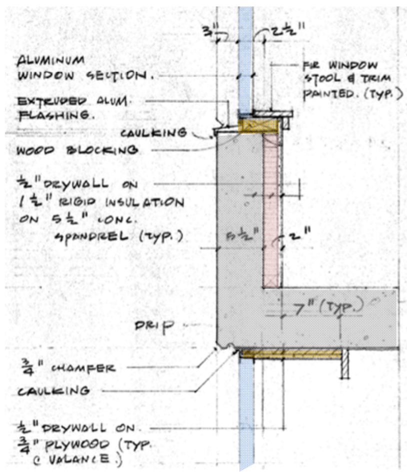
Additional results from this study are published in the research report "Energy Consumption and Conservation in Mid- to High-Rise Residential Buildings" (RDH 2012).

Pilot Project Building Characteristics and Retrofit Measures

This section details the existing building enclosure and mechanical systems at the pilot building, and the retrofit measures that were implemented to reduce energy consumption.

Building Enclosure

The original building consisted of exposed concrete walls with 1½" of rigid extruded polystyrene insulation installed between the steel furring and the interior gypsum wall board (Figure 1). This wall provided an effective R-value of approximately 4 hr•ft²•°F/Btu accounting for thermal bridging at the steel studs and exposed slab edges. The roof had 1½" of rigid polystyrene insulation, with an overall R-value of approximately R-9 (as there are no thermal bridging elements through the roof insulation).



Exterior

- Exposed concrete cladding
- Steel stud furring, with 1.5" rigid polystyrene insulation between steel studs
- Drywall

Interior

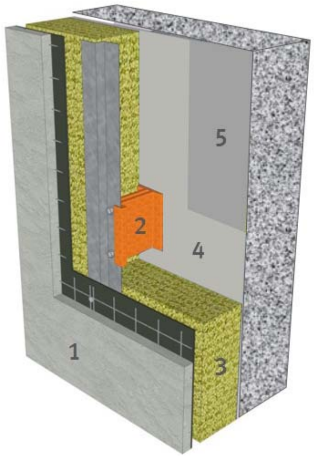
Figure 2. Existing wall assembly from original architectural drawings: exposed concrete slab edge and interior insulation between steel studs. Thermal bridging at the steel studs and concrete slab edge reduces the insulation performance to an overall effective R-value of R-4.

The original windows were non-thermally broken aluminum frame windows with double glazed insulated glazing units (IGUs) with an effective U-value of approximately 0.55 Btu/hr•ft²•°F. Significant air leakage occurred through the building enclosure; airtightness testing showed an air leakage rate of 0.71 cfm/ft² at a pressure difference of 75 Pa (Ricketts, 2014). This was likely due to several factors, such as the poorly sealed slider-type windows and gaps at other penetrations through the building enclosure.

Though the primary driver behind the enclosure retrofit was not energy efficiency, several energy conservation measures were incorporated into the project. The walls were insulated with 3½" of semi-rigid mineral fiber insulation added at the exterior, installed between low conductivity fiberglass clips to attach the stucco and metal panel cladding (see Figure 2). This improved the effective wall R-value to approximately R-16 hr•ft²•°F/Btu as the slab edges were also insulated. The low conductivity fiberglass clips significantly reduce thermal bridging through the insulation compared to traditional cladding attachment methods that use continuous metal girts that create a thermal bridge through the exterior insulation.

The existing windows were replaced with new fiberglass frame windows with triple glazed, low-e, argon IGUs that provide an effective window U-value of U-0.20 Btu/hr•ft²•°F.

Roof insulation was not added to the project due to dimensional constraints. Furthermore, limited energy savings were possible, since the roof accounts for a low proportion of heat loss at the building (determined through energy modeling).



Exterior

- New over-cladding (stucco and metal panels)
- Fibreglass spacer with 1” steel “z” girt and screws into existing concrete
- 3.5” semi-rigid mineral wool insulation
- Vapour permeable coating at cracks and penetrations
- Existing concrete backup wall assembly

Interior

Figure 3. Exterior insulated wall assembly retrofitted at the pilot project building. Exterior insulation continues past the slab edge, and low-conductivity cladding attachment system yields an overall effective R-value of R-16.

Airtightness improvements were made through the use of a liquid applied membrane to seal cracks in the concrete and to provide improved air barrier continuity at transitions (e.g. window to wall transitions). Design work included air barrier detailing around windows and at other penetrations. The new casement style operable windows also incorporate more robust gaskets and hardware that are significantly more airtight than the original slider style operable windows. After the retrofit, airtightness testing showed a building enclosure air leakage rate of 0.32 cfm/ft² at 75 Pa, an improvement of 55% compared to the pre-retrofit airtightness.

Heating and Ventilation System

The suites, lobby and corridors at the pilot project are heated by electric baseboards. Each suite has individual thermostat temperature control. Fourteen of the suites at the upper floors also have gas fireplaces. The net heating efficiency of the fireplaces is not known, though the labels indicate that the fireplaces are ‘decorative’ and not meant for heating purposes (see Figure 3); as such their heating efficiency is thought to be low, likely in the order of 40%. The building does not have a mechanical cooling system.

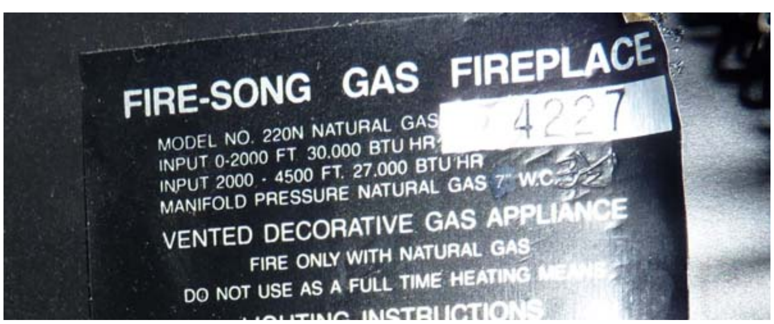


Figure 4. Fireplace label, indicating “decorative gas appliance” and “do not use as a full time heating means”.

The ventilation system at the pilot project building uses a pressurized corridor strategy, where air is heated by a gas-fired rooftop unit and distributed into the corridors of the building. This design intends for heated ventilation air to enter suites through door undercuts. Suites have bathroom and kitchen exhaust fans operated by the occupants. This strategy is illustrated in Figure 4, and is common in British Columbia.

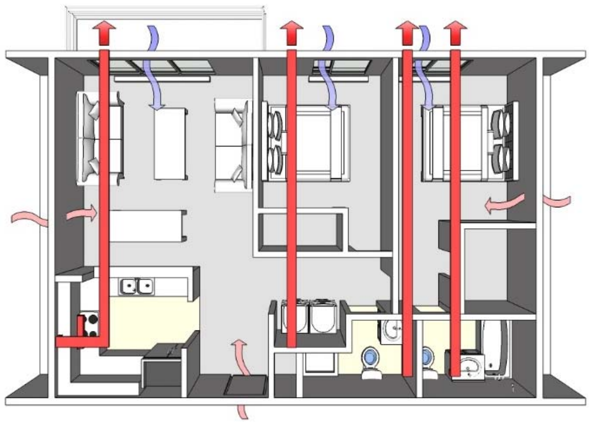


Figure 5. Suite ventilation in a MURB using a pressurized corridor system. Air enters the suite through make-up air from the corridors (through door undercut), operable windows, and infiltration from the outdoors. Air is exhausted through bathroom and kitchen exhaust fans operated by the occupants.

When a building enclosure retrofit is performed, and the enclosure becomes more airtight, ventilation becomes more important since the airtightness strategies reduce incidental infiltration. The pressurized corridor ventilation strategy is a common approach used in MURBs in British Columbia, even for new buildings, however industry professionals have questioned the effectiveness of this strategy in delivering adequate ventilation to the suites (Ricketts, 2014).

Testing was performed prior to the retrofit to determine the proportion of make-up air that enters the suites from the corridors at the pilot project building using a pressure neutral compartmentalized approach using multiple blower door fans (Ricketts, 2014). Figure 5 shows the results of this testing; only 20% of make-up air was measured to enter the suites through door undercuts. The balance of airflow was lost through elevator shafts, stairwells, and adjacent floors. While ventilation issues were identified early in the project planning stages, the owners elected to plan for ventilation upgrades following the building enclosure renewals project.

Several mechanical upgrades were considered for the pilot project. Since energy modeling predicted that the enclosure insulation, high performance windows and airtightness improvements would result in a significant drop in electric baseboard energy, an upgrade to the suite heating system (electric baseboards) was neither necessary nor cost effective.

Fireplace upgrades are being considered to replace the existing decorative units with higher heating efficiency models. However, this measure may also not be necessary given that the insulation improvements may result in a significant reduction in fireplaces use.

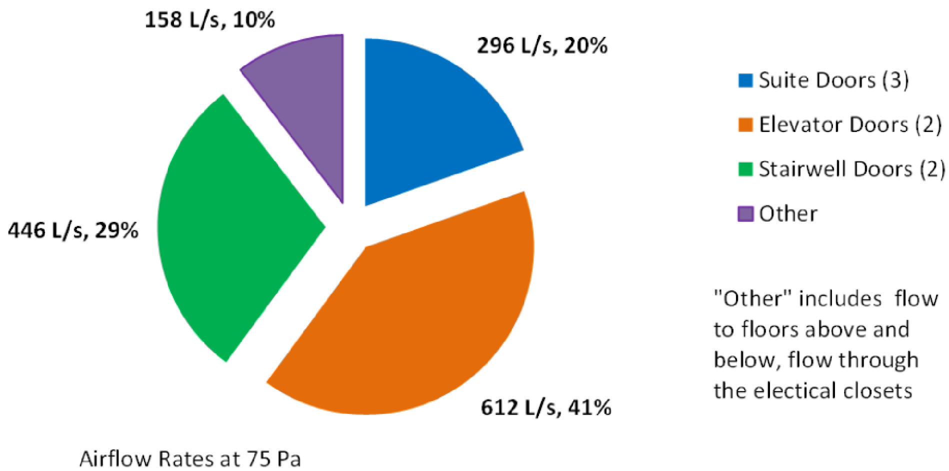


Figure 6. Airflow associated with corridor elements at the pilot project. (Ricketts and Finch, 2013).

Since significant airtightness improvements were made to the building envelope, and due to the poor ventilation performance of the pressurized corridor system, a ventilation upgrade should be performed at the building. A ventilation upgrade is planned for Phase 2 of the project, where in-suite Heat Recovery Ventilators (HRVs) will be installed, and the make-up air unit flow rate reduced to provide only minimum corridor pressurization. This work is planned for 2014, following one year of measurement and verification of energy savings from the enclosure retrofit. An upgrade to a higher efficiency make-up air unit is also being considered.

Pilot Project Energy Consumption

The pilot project building's energy consumption was compared to consumption trends from the sample buildings in the previous research work (RDH 2012). To determine the typical annual energy use at the study buildings from this research project, the utility data was weather normalized using regression, the same methodology used in the previous study. To determine the weather normalized correlations, monthly energy consumption was plotted versus the monthly heating degree day (HDD) value. Various regression techniques were assessed to determine the best relationship (RDH 2012). Consumption data for a typical weather year was then calculated based on average degree days in the Canadian Weather for Energy Calculations (CWEC) database (Environment Canada 2012).

Using this same methodology for weather normalizing the utility-metered energy consumption, the case study building has an EUI of 225 kWh/m^2 per year. This EUI is slightly higher than the average from the study, 213 kWh/m^2, and is therefore very representative of typical high-rise multi-unit residential buildings in southwestern British Columbia.

An energy model was developed for the pilot project building to further understand the end-use breakdown of energy consumption at the building, and to determine the impact of potential energy efficiency measures that could be incorporated as part of the building renewal. The energy model was calibrated to align with metered energy consumption to ensure that the model is representative of actual building energy consumption.

Figure 3 shows the modeled energy end-use breakdown at the existing (pre-retrofit) building, as well as the predicted (modeled) savings after the retrofit. Overall, 56% of energy consumption at the building is for heating (electric baseboards, fireplaces and make-up air).

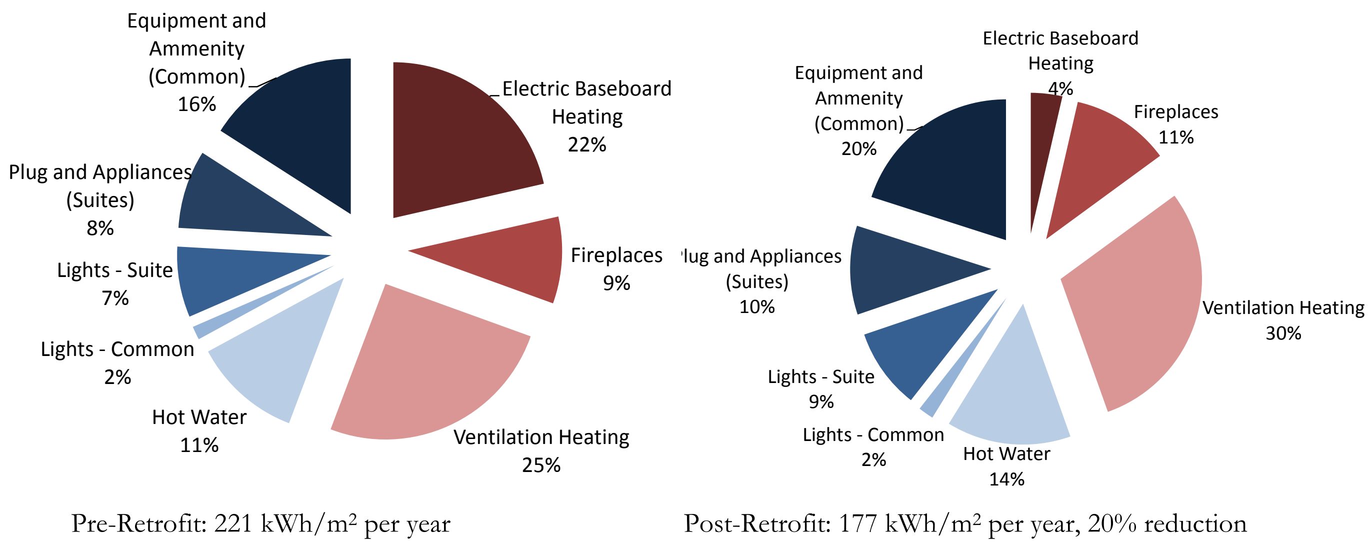


Figure 7. Simulated energy consumption by end-use, calibrated pre-retrofit (left) and modeled post-building enclosure retrofit (right).

Table 1 shows the electricity, gas and total modeled change in EUI. The energy efficiency improvements for the building enclosure are predicted to result in an estimated 19% total building energy savings. The electric baseboard space heating energy consumption is reduced by 87% in the model. Measurement and verification (M&V) will be important to compare actual savings to modeled savings, as the electricity savings could be affected by occupant behavior such as opening windows during cold periods, which would negate some of the savings.

Table 1. Predicted energy savings based on calibrated energy model, kWh/m^2 per year

	Suite Heating (Electric Baseboards)	Total Electricity	Total Gas	Total Energy (Gas and Electric)
Pre-Retrofit	48	118	103	221
Post-Retrofit	6	76	103	179
Reduction	42 (87%)	42 (36%)	0	42 (19%)

A cost-payback analysis was also completed in the design stages of this project to assess the financial feasibility of the energy efficiency measures. Since the project was being undertaken for reasons other than energy savings, the payback period considered only incremental costs for energy efficiency measures.

Payback was not calculated for wall insulation and air sealing measures since they were to be included in the project for durability and moisture control, regardless of energy savings. Using low-conductivity cladding attachment was an energy intervention, but it was cost-neutral when compared with the more typical metal girts that result in significant thermal bridging.

The triple glazed fiberglass frame windows had an incremental cost of approximately $60,000 above code-minimum double glazed aluminum frame windows, after an incentive received for the energy efficiency measure. This gave a calculated simple payback period of 6 years for the windows using 2012 energy prices.

Energy Measurement and Verification Results

M&V was performed for a period of one year (January to December 2013) following the completion of the retrofit. M&V was performed in accordance with the International Performance Measurement and Verification Protocol. The IPMVP approach selected to perform M&V is Option D – Calibrated Simulation, since this method allows for a better estimation of savings attributable to particular energy end-uses. Using this method, an energy model is calibrated to the post-retrofit utility bills to determine savings.

Metered energy consumption was obtained from the local electricity and gas utilities, BC Hydro and FortisBC. The metered data was weather normalized following the same procedure as the pre-retrofit data (described above). Other independent variables that may impact energy consumption include occupancy changes and occupant behavior changes. Tracking and measuring changes in occupant behavior are beyond the scope of this project, but will be considered qualitatively in the analysis.

Once the one-year period of data had been collected, the post-retrofit energy model was compared to the metered data, and it was calibrated such that the model and the metered data align. Calibrated models were within 5% of monthly metered energy consumption for most months, and within 1% difference annually; this comparison can be seen in Figure 7 and Figure 8. The calibration process was an important step in the research study as it helps to understand how effective and accurate the energy modeling tool was at predicting savings for the project. This is important because the reliability of energy modeling as a design and prediction tool for energy savings is not well understood. Furthermore, lessons learned from this effort will inform and help to improve modeling for future projects.

Figure 7 and Figure 8 show the metered electricity and gas consumption for the one year post-retrofit period, compared to the uncalibrated model (the model that was produced in the design stages to predict energy savings from the retrofit) and the calibrated model. The following observations are made from these two plots.

For the electricity consumption (Figure 7), the reduction in summer electricity consumption shows that there was some summer electric baseboard heating prior to the retrofit, which was nearly eliminated following the retrofit. It was observed that some owners keep their thermostats at a higher than typical setpoint, and therefore a setpoint of 23.5°C was modeled.

Electricity consumption in the winter months indicates that the building used more heating energy than was simulated in the model. This could occur due to occupant behavior such as open windows in the winter months, resulting in additional air infiltration that was not modeled. This suggests that despite the significant airtightness improvement at the building, owners may be opening their windows, negating some of the savings; this practice has also been observed on several visits to the building over the monitoring period. It is also important to note that the ventilation system has not yet been upgraded following the retrofit, likely creating a need for occupants to open windows for ventilation air. A ventilation upgrade is planned for Phase 2; additional research should be performed following Phase 2 to determine whether the owners will open the windows less often when adequate ventilation is provided to the suites, resulting in additional energy savings. Occupant control of thermostats could also affect the results.

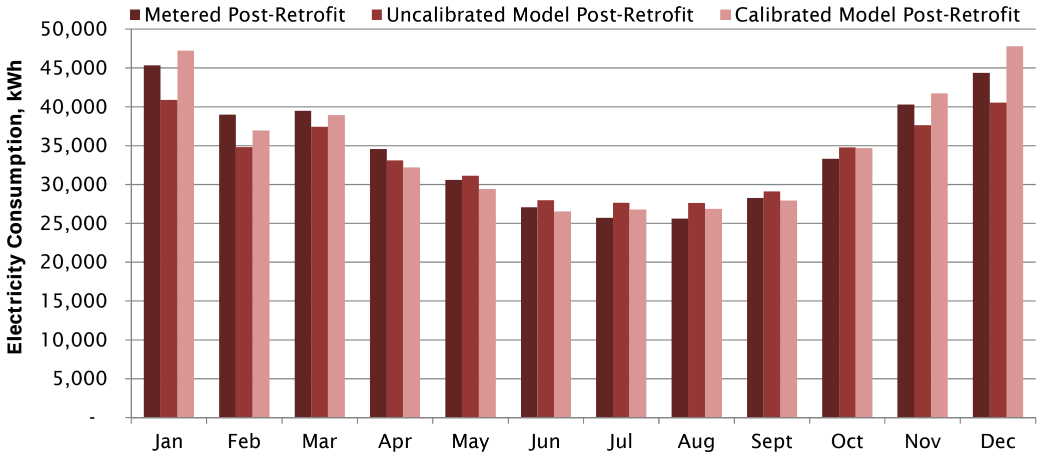


Figure 8. Metered, uncalibrated model, and calibrated model post-retrofit electricity consumption, kWh.

Comparing the modeled and metered gas consumption data showed higher metered gas consumption in the summer months, and lower metered gas consumption in the winter months. As such, two input changes were required to calibrate gas. In order to increase summer gas consumption, following the assumption that there is no fireplace or make-up air heating energy consumption in the summer, would require an increase in DHW consumption. Since the increase is relatively low (7% and 8% difference in July and August, respectively), it could be attributed to inaccuracies in the weather normalizing and modeling processes.

The decrease in gas consumption during the winter and shoulder months is likely due to a reduction in fireplace use following the retrofit, consistent with discussions with the owners that they use fireplaces less often. This change was not modeled in the original design model as it was dependent on occupant behavior. To calibrate the model, the monthly fireplace use schedule was adjusted month-by-month to calibrate the gas data to the metered data

Figure 8 shows the metered (weather normalized), uncalibrated model, and calibrated model gas consumption. Following the calibration, the modeled monthly consumption is within 2% difference of the metered data.

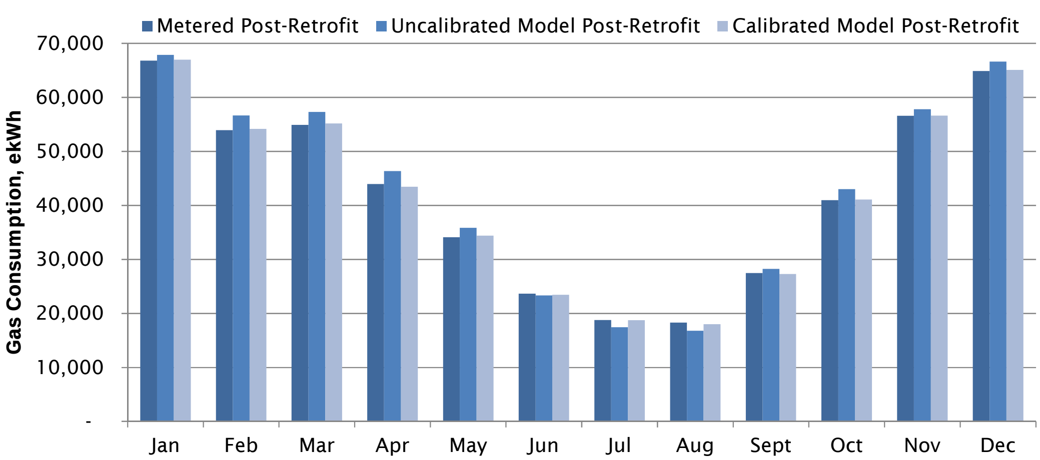


Figure 9. Metered, uncalibrated model, and calibrated model post-retrofit gas consumption (DHW, fireplaces, make-up air heating), ekWh.

Table 2 shows the energy savings predicted by the original design model compared to the final model that was calibrated to align with the metered post-retrofit data ("Metered Savings"). The electricity savings were lower than predicted, at 33% compared to the predicted 35%, as less electric baseboard savings were realized. No gas savings were modeled (since the impact on fireplace use was not known, no change was modeled), though the metered data shows a 5% savings in gas consumption. Overall, both modeled and metered total savings were 19%.

Table 2. Modeled and metered energy savings determined through M&V for a typical weather year, ekWh (%)

	Electric Baseboard Suite Heating	Total Electricity	Total Gas	Total Energy (Gas and Electric)
Modeled (Predicted) Savings	215,500 (68%)	215,500 (35%)	0 (0%)	215,500 (19%)
Metered Savings	201,100 (63%)	201,100 (33%)	12,900 (2%)	214,900 (19%)

Figure 9 and Figure 10 show the calibrated pre- and post-retrofit energy models for electricity and gas, respectively, showing final measured energy savings at the study building. Again, the electricity plot (Figure 9) shows a drop in summer electricity consumption, suggesting that either the baseline (lighting and miscellaneous) energy use changed, or there was some summer electric baseboard use (that was not modeled) that dropped following the retrofit. The gas plot (Figure 10) shows a greater drop in gas consumption during the shoulder season months, suggesting that owners are using their fireplaces less during these months.

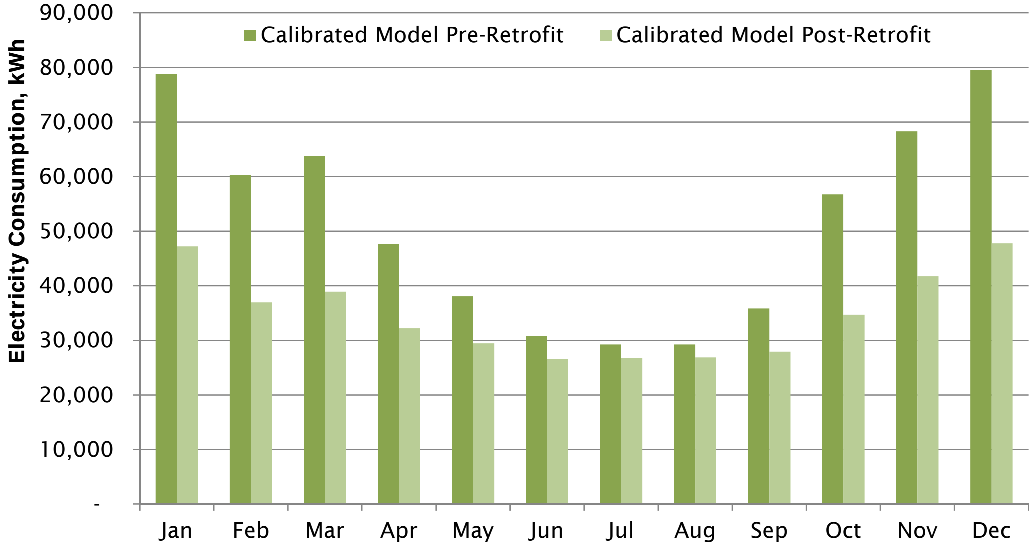


Figure 10. Calibrated model pre- and post-retrofit electricity consumption, kWh.

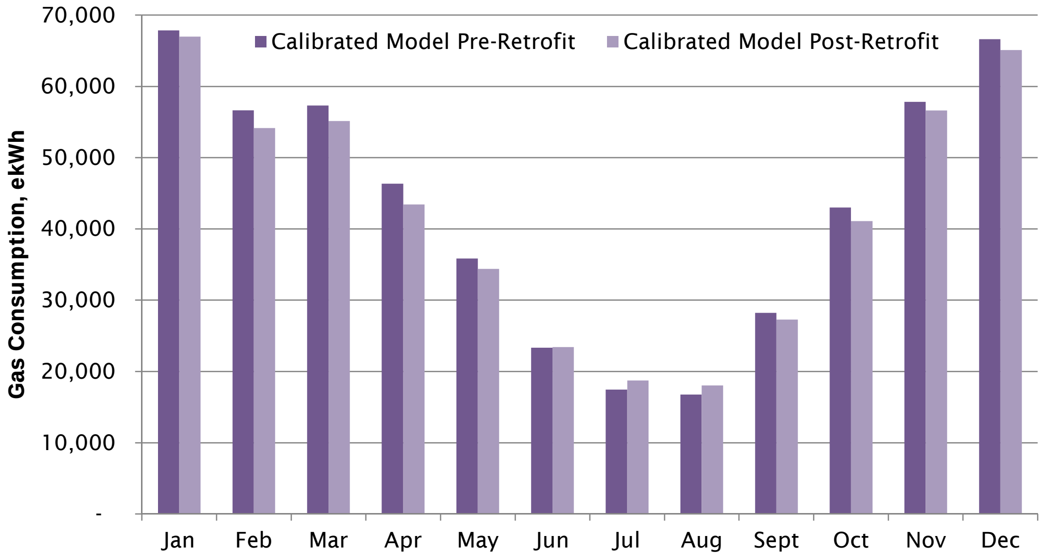


Figure 11. Calibrated model pre- and post-retrofit gas consumption, ekWh.

Overall, the measured energy savings at the study building were 43 kWh/m^2 per year, a total of 214,900 ekWh. Using gas and electricity prices for Vancouver, BC current as of May 2014, this results in an annual savings of $30,700 at the building, or $830 on average per suite. The majority of these savings will be seen by the owners directly on their electricity bills.

The incremental cost of the windows compared to code-minimum windows was priced at $88,100, or $60,000 including an incentive that was received for the energy upgrade. Considering the incremental costs and savings from the installed compared to a code minimum window yields a payback period for the windows of 7 years, or 5 years including the incentive.

Summary and Lessons Learned

The findings at the pilot building indicate that a significant improvement in the airtightness and thermal performance of a building enclosure can yield considerable energy savings. Under Phase 1 of this demonstration project, the renewal resulted in a measured 19% reduction in total energy, including a 63% reduction in electric space heating in residential units.

The main drivers behind the owners' decision to proceed with this retrofit project were to address localized water performance issues, to improve the comfort of the space, to upgrade the aesthetics of the building, and improve property value. While energy savings were a secondary consideration, incorporating energy efficiency measures at the time of renewals allowed for significant savings to be realized at low incremental capital cost. This project serves as a model for sustainable, energy efficient and economical renewals of existing buildings.

The building enclosure renewal achieved a significant improvement in airtightness, about 55%. An important consideration at the pilot project building and other similar renewal projects is the need for ventilation system upgrades. The impact of building enclosure retrofits on HVAC equipment operation and ventilation rates should be assessed as part of these projects.

Acknowledgements

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