

EVALUATING THE ENERGY SAVINGS OF HIGH PERFORMANCE BUILDING ENCLOSURE RETROFITS

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ABSTRACT

Building enclosure retrofits for multi-unit residential buildings can result in significant energy savings when energy is a priority. Studies suggest up to a 90% reduction in space heating energy consumption could be achieved through a high performance building enclosure. However, such savings have not yet been confirmed through field measurement and verification.

A high performance building enclosure retrofit was undertaken at a 13-storey multi-unit residential building in Vancouver, BC. The work was undertaken primarily as a renewals project, with energy conservation measures incorporated to also reduce energy consumption. The retrofit includes high performance windows (triple glazing, fibreglass frames), exterior wall insulation with low conductivity cladding attachment, and air sealing. Modeled energy savings predicted a 19% reduction in overall energy consumption, or a 68% reduction of in-suite space heating energy, realized through this retrofit.

Whole building air leakage testing was performed before and after the retrofit to measure air tightness savings. Metered energy consumption was analyzed to determine the actual energy savings resulting from the enclosure retrofit through measurement and verification (M&V).

This paper will detail the high performance enclosure retrofit undertaken at the case study building. M&V results are presented to show the actual energy savings resulting from the retrofit. Modeled savings are also compared to measured savings to assess the accuracy of the modeled predictions. Air tightness testing results are presented to show the air tightness improvements achievable through an enclosure retrofit, as well as the associated energy savings. Actual project capital costs and annual savings from the energy conservation measures are presented to show the payback period and financial viability of a high performance enclosure retrofit. The findings and lessons learned from this project will assist in planning for future high performance building enclosure retrofits to lower the energy consumption of the existing building stock.

INTRODUCTION

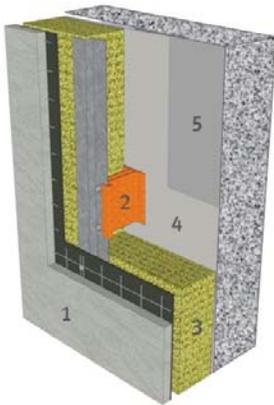
This paper summarizes the findings of a research study assessing the measured energy savings of efficient building enclosure renewals of mid- to high-rise multi-unit residential buildings (MURBs) and impacts on the performance of ventilation systems and indoor air quality (IAQ). The study is focused on monitoring and testing of a 13-storey building (GFA 56,800 ft², 5,275 m²) with 37 residential units, built in 1986 and located in Vancouver, British Columbia. Glazed windows and doors comprise 51% of the vertical enclosure area of the building. The building is ventilated using a pressurized corridor approach with a single make-up air (MUA) unit located on the roof.

In 2012 the owners of the case study building proceeded with a building enclosure renewals project to address aging building components, improve comfort, acoustics, and durability of the building, and reduce energy consumption. The building was selected to be part of a high performance energy retrofit demonstration and research project. It 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 primarily in the summer and fall of 2012, and it was completed in December 2012. Measurement and verification (M&V) of energy consumption, airflow and IAQ was performed through 2013. Phase 2 plans to address building mechanical systems, mainly focused on ventilation.

EXISTING BUILDING AND ENERGY RETROFIT

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. This wall provided an effective R-value of approximately R-4 hr-ft²-F/Btu ($R_{SI}=0.7 \text{ m}^2\text{-K/W}$) accounting for the exposed slab edges. As part of the enclosure retrofit, 3½” (89 mm) of semi-rigid mineral fiber insulation was added to the exterior of this assembly and floor slabs, installed between fiberglass cladding support clips with low thermal conductivity. This improved the effective wall R-value to approximately R-16 hr-ft²-°F/Btu ($R_{SI}=2.8 \text{ m}^2\text{-K/W}$). These low conductivity fiberglass clips significantly reduce thermal bridging through the insulation compared to traditional attachment methods; Figure 1 shows a graphic of this assembly. A liquid applied membrane was also used to seal discrete locations in the concrete and to provide improved air barrier continuity at joints and transitions.



1. New cladding stucco or metal panels
2. Furring (fibreglass spacer with 1” steel Z-girt and screws into existing concrete) to create rainscreen cavity
3. Insulation (3.5” semi-rigid stone wool board)
4. Vapour permeable coating at cracks and penetrations
5. Existing finished concrete

FIGURE 1: Exterior insulated rainscreen wall assembly for the retrofit building, incorporating low conductivity fiberglass cladding attachment clips to minimize thermal bridging.

The original windows were non-thermally broken aluminum frame windows with double glazed insulated glazing units (IGUs) with an effective U-value of approximately U-0.55 Btu/hr-ft²-°F ($U=5.9 \text{ W/m}^2\text{-K}$). These were replaced with fiberglass frame windows with low-e coated, argon filled, triple glazed IGUs that provide an effective window U-value of approximately U-0.20 Btu/hr-ft²-°F ($1.1 \text{ W/m}^2\text{-K}$).

The original roof of the building was replaced as part of the retrofit. It was replaced like-for-like and no thermal upgrade was included since the roof surface height could not be increased due to code requirements at doors and parapets. Also, as the roof is a relatively small fraction of the surface area of the building, it would result in low energy savings. Consequently the roof was R-9.5 hr-ft²-°F/Btu ($R=1.7 \text{ m}^2\text{-K/W}$) both pre- and post-retrofit.

The overall building enclosure improved from an effective R-value of R-2.8 hr-ft²-°F/Btu ($R=0.5 \text{ m}^2\text{-K/W}$) to R-9.1 ($R=2.1 \text{ m}^2\text{-K/W}$) as a result of the retrofit.

The building enclosure retrofit incorporated significantly improved air barrier detailing at penetrations. The improvement of these details limits the infiltration and exfiltration of air through the building enclosure, which can be a major source of energy loss. The new casement style operable windows also incorporate more robust gaskets and hardware which are significantly more airtight than the relatively poorly sealed slider style operable windows originally installed.

The building uses a make-up air (MUA) unit to provide ventilation. The MUA or ventilation system was not modified as part of the enclosure retrofit (Phase 1 work). Phase 2 of the work plans to focus on suite compartmentalization, direct ventilation into residential units, and heat recovery.

PREDICTED ENERGY EFFICIENCY IMPROVEMENTS

Whole building energy modeling was performed for the retrofit building to understand the end-use breakdown of energy consumption at the building, and to determine the impact of potential energy efficiency measures in the design phase. The energy model was calibrated to align with metered energy consumption to ensure that the model is representative of actual building energy consumption. The existing building (pre-retrofit) calibrated energy model is also used as the baseline case for M&V.

Historical metered energy data was obtained from the electric and gas utilities, BC Hydro and FortisBC. The utility data was weather normalized using regression to determine the typical annual energy use. To determine the weather normalized correlations, monthly energy consumption was plotted versus the monthly heating degree day (HDD) value. Various regression techniques were performed 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 methodology, the case study building has an Energy Use Intensity (EUI) of 221 kWh/m² per year.

The case study building's energy consumption was compared to a study on energy consumption in high-rise multi-unit residential buildings in southwestern British Columbia (RDH 2012). This study found that the average weather-normalized energy use intensity for MURBs in southwest British Columbia is 213 kWh/m² per year. The case study building's EUI is only slightly higher than the average from the study, and is therefore very representative of typical high-rise multi-unit residential buildings in southwestern British Columbia.

The case study building was modeled using the program DesignBuilder, an interface for EnergyPlus. The model was calibrated to the metered data by adjusting inputs in the model that are not certain based on seasonal trends in the data. For a residential building there are several inputs that can vary, such as lighting and miscellaneous electrical (plug) loads, and temperature setpoints.

Figure 2 and Table 1 show the modeled energy end-use breakdown at the existing (pre-retrofit) building, as well as the predicted (modeled) savings after the retrofit. 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 68% in the model. M&V will be important to compare actual savings to modeled savings, as the electricity savings could be affected by occupant behaviour such as opening windows during cold periods, negating some of the savings.

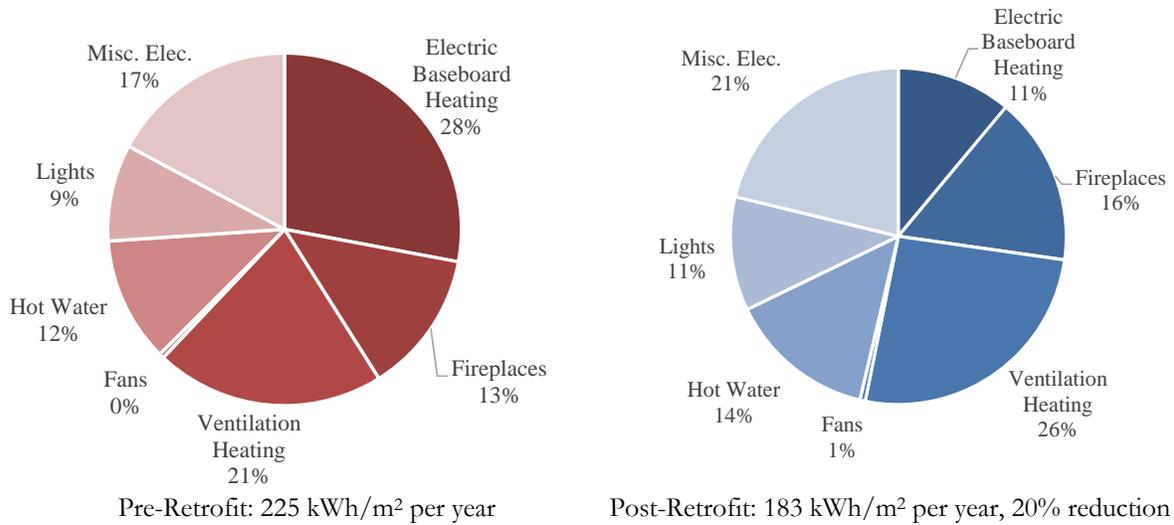


FIGURE 2: Simulated energy consumption by end-use, calibrated pre-retrofit (left) and modeled post-retrofit with enclosure measures (right), kWh/m² per year and percentage of total.

TABLE 1: Predicted energy performance based on calibrated energy model.

	Suite Heating (Electric)	Total Electricity	Total gas	Total Energy (Gas and Electricity)
Pre-Retrofit	63 kWh/m ² ·yr	123 kWh/m ² ·yr	103 kWh/m ² ·yr	225 kWh/m ² ·yr
Post-Retrofit	20 kWh/m ² ·yr	80 kWh/m ² ·yr	103 kWh/m ² ·yr	183 kWh/m ² ·yr
Savings	43 kWh/m ² ·yr (68%)	43 kWh/m ² ·yr (35%)	0 kWh/m ² ·yr	43 kWh/m ² ·yr (19%)

MEASUREMENT AND VERIFICATION

An important part of this project and the associated research study was to undertake M&V of energy savings. There are several standards for performing M&V of energy savings. For this project, the International Performance Measurement and Verification Protocol (IPMVP Volume 1 – EVO 10000-1:2012) was followed since it is one of the most widely used M&V standards, likely due to its use in LEED.

The IPMVP includes the following definition for M&V.

“Measurement and Verification (M&V) is the process of using measurement to reliably determine actual savings created within an individual facility by an energy management program. Savings cannot be directly measured, since they represent the absence of energy use. Instead, savings are determined by comparing measured use before and after implementation of a project, making appropriate adjustments for change in conditions.”

The IPMVP standard requires that an M&V plan be created prior to project implementation. At the case study building, an M&V plan was developed once the design and energy efficiency measures had been finalized. The M&V plan defined several important aspects of the M&V, such as the approach (calibrated simulation, calibrating an hourly energy model to monthly utility bills), the baseline period (2006 to 2011,

normalized based on heating degree days to determine an average weather year energy consumption), the reporting period (one year from project completion), adjustments (weather), and several other aspects of the process. Measured data was obtained from the gas and electricity utility meters.

ENERGY MEASUREMENT AND VERIFICATION RESULTS

Metered energy consumption was obtained from the electricity and gas utilities, BC Hydro and FortisBC. In the M&V plan, weather was identified as an independent variable that is expected to change regularly and impact energy use at the building. As such, the metered data was weather normalized following the same procedure as the pre-retrofit data (described above), known as a routine adjustment. Other independent variables that may impact energy consumption include occupancy changes and occupant behavior changes. Tracking and measuring changes in occupant behaviour are beyond the scope of this project, but will be considered qualitatively in the M&V analysis.

Once the one year period of data had been collected, the post-retrofit energy model was compared to the metered data, and calibrated such that the model and metered data align. This 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 energy savings for the retrofit project. This is important to understand how reliable energy modeling is as a design and prediction tool, and to inform and improve modeling for future projects. The calibrations were performed by adjusting model inputs that are not known with certainty. In this case, temperature setpoints, domestic hot water consumption, lighting, and miscellaneous electrical energy consumption were all inputs that were adjusted through the calibration process.

Figure 3 and Figure 4 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. While the overall metered building-level energy savings are accurate, it is important to note that the model calibrations and estimates of energy savings by end-use (e.g. electric baseboard savings) are estimates only, and would require significant sub-metering to know savings with certainty.

For the electricity consumption (Figure 3), 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 tend to 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.

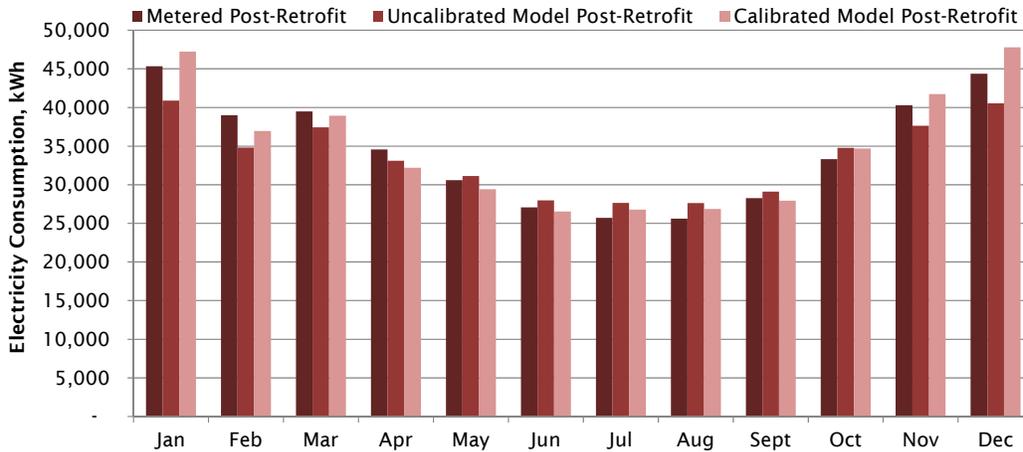


FIGURE 3: Metered, uncalibrated model and calibrated model post-retrofit electricity consumption, kWh.

Comparing the modeled and metered gas consumption data (Figure 4) 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 DHW consumption rate was increased to calibrate the model.

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.

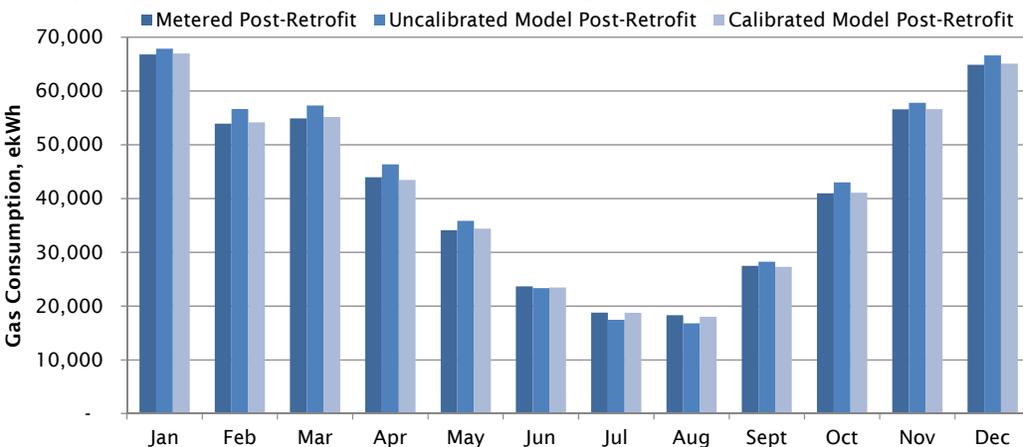


FIGURE 4: Metered, uncalibrated model and calibrated model post-retrofit gas consumption (DHW, fireplaces, make-up air heating), ekWh.

Table 2 shows the energy savings predicted by the initial model (“Uncalibrated Model Savings”) compared to the final model, calibrated to align with the metered post-retrofit data (“Calibrated Model Savings”). The electricity savings were lower than predicted, at 33% compared to the predicted 35%. No gas savings were modeled (since the impact on fireplace use was not known, no change was modeled), though the metered data shows a 2% savings in gas consumption. Overall, total savings was very close to the modeled savings, both 19% savings.

TABLE 2: Uncalibrated and calibrated model energy savings, ekWh (%).

	Electric Baseboard Heating	Total Electricity	Total Gas	Total Energy
Uncalibrated Model (Predicted) Savings	215,500 (68%)	215,500 (35%)	0 (0%)	215,500 (19%)
Calibrated Model (Actual) Savings	201,100 (63%)	201,100 (33%)	12,900 (2%)	214,900 (19%)

Figure 5, Figure 6 and Figure 7 show the calibrated pre- and post-retrofit energy models for electricity, gas, and total energy, respectively, showing final measured energy savings at the study building. Again, the electricity plot (Figure 5) shows a drop in summer electricity consumption, suggesting that there was some summer electric baseboard use that dropped following the retrofit. The gas plot (Figure 6) shows a greater drop in gas consumption during the shoulder season months, suggesting that owners are using their fireplaces less during these months.

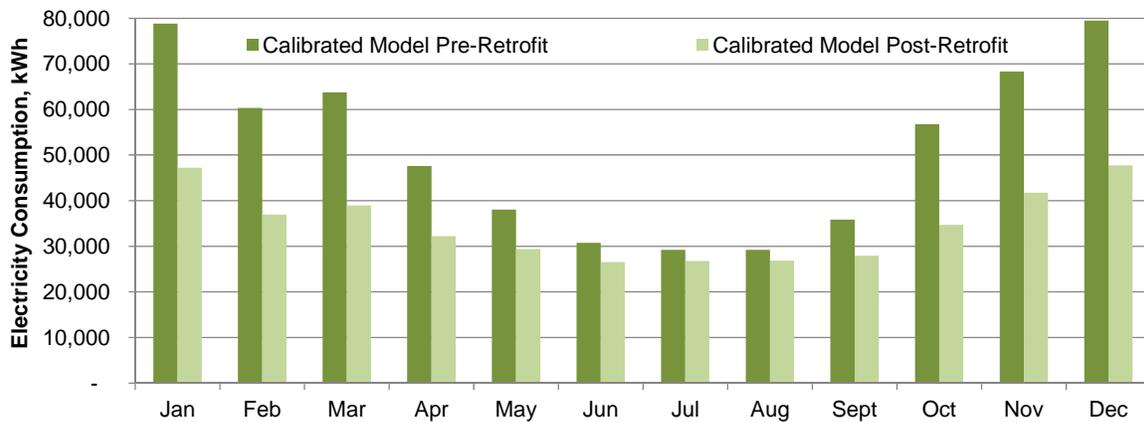


FIGURE 5: Calibrated model pre- and post-retrofit electricity consumption, kWh.

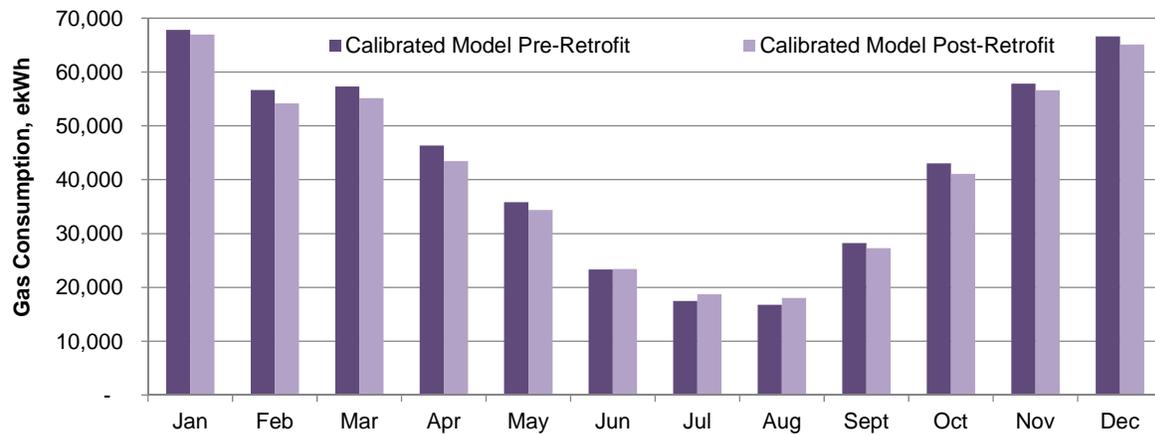


FIGURE 6: Calibrated model pre- and post-retrofit gas consumption, ekWh.

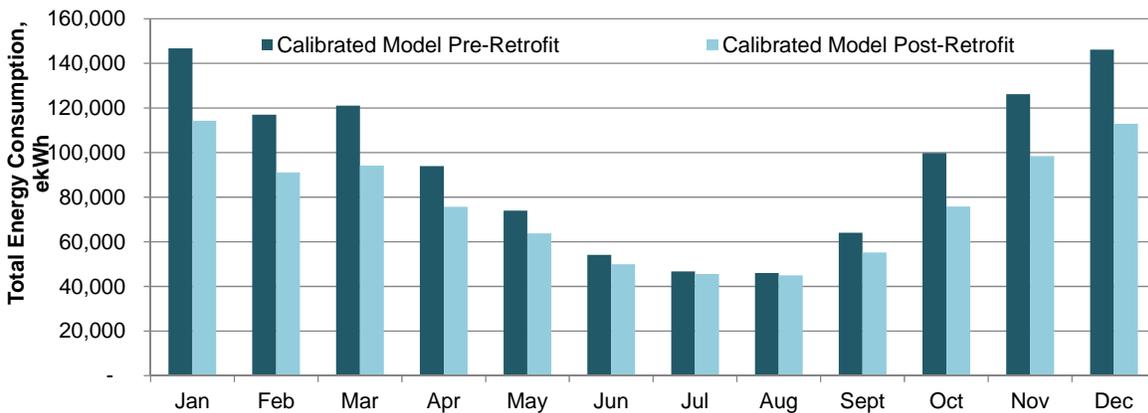


FIGURE 7: Calibrated model pre- and post-retrofit total energy consumption, ekWh.

Overall, the measured energy savings at the study building were 43 kWh/m² per year, a total of 221,000 ekWh. Using gas and electricity prices for Vancouver, BC that are current as of January 2014, this results in an annual savings of \$21,000 at the building, or \$570 per suite.

OTHER MONITORING RESULTS

Since this case study project was part of a larger research project to understand the opportunities for energy savings through retrofits of multi-unit residential buildings, additional testing and monitoring was performed throughout the one year M&V period. This included indoor environmental quality testing and monitoring, and airflow testing. These results are published in the paper “A Field Study of Airflow in Mid to High-Rise Multi-Unit Residential Buildings” (Ricketts and Straube, 2014). One significant finding was that measured airtightness dropped from a pre-retrofit rate of 0.71 cfm/ft² at 75 Pa, to a post-retrofit rate of 0.32 cfm/ft² at 75 Pa, an improvement of 55%.

CONCLUSIONS

The findings at the case-study building indicate that a significant improvement in the airtightness and thermal performance of a building enclosure can significantly reduce building energy consumption. Under phase 1 of this energy efficiency research and demonstration project for MURBs, the building enclosure renewal resulted in a measured 19% reduction in energy consumption, including a very significant 63% reduction in electric baseboard space heating in residential units. A total EUI reduction of 43 kWh/m² per year was measured.

The building enclosure renewal achieved a significant improvement in airtightness, about 55%. The reduction in incidental air leakage to suites can exacerbate IAQ issues resulting from poor ventilation system design. As such, it is important to consider the impact of building enclosure retrofits on HVAC equipment operation and ventilation rates and to consider the potential need for mechanical system retrofit measures.

An important finding of this work was comparing modeled to measured energy savings to assess the use of energy modeling to predict savings from building enclosure renewals projects. The results showed that overall savings were in line with the predicted savings, though the gas and electricity savings were slightly different. Gas savings were measured that were not modeled, likely due to the change in occupants' fireplace use. The measured electric baseboard heating savings were lower than predicted, which may be due to owners opening their windows, resulting in additional air infiltration. Additional work should be performed to assess whether upgrading the ventilation system can result in additional space heat savings if owners are less likely to open their windows during the winter and shoulder months.

ACKNOWLEDGMENTS

This project was completed with the support of the following funding partners: Homeowner Protection Office (HPO) branch of BC Housing, BC Hydro, FortisBC, National Resources Canada (NRCan), Enbridge Gas, City of Vancouver, City of North Vancouver, City of Surrey, City of New Westminster, City of Richmond.

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