ENERGY EFFICIENT RETROFIT OF A HIGH-RISE MULTIFAMILY BUILDING

Brittany Hanam[1], Lorne Ricketts[2], Andrew Pape-Salmon[3]

ABSTRACT

The National Institute of Building Sciences estimates that over 70% of the buildings that will be present in 2030 already exist today. The sustainable and energy efficient renewal of existing buildings is paramount to reducing our environmental footprint and improving the operational affordability of buildings. Buildings constantly go through renewals as components including windows, cladding, roofing, and mechanical equipment reach the end of their service lives. Rather than choosing standard or code-minimum replacement components, high performance components and designs can reduce energy consumption at low incremental cost.

This paper presents a case study of an energy efficient building enclosure retrofit of a 13 story multifamily building in Vancouver, BC. Renewal work to the building enclosure included the addition of continuous exterior insulation with low conductivity cladding attachment, replacing the existing windows with triple-glazed fiberglass frame units, and air sealing. The overall effective R-value of the building enclosure (walls, windows and roof) was improved from R-2.8 hr-ft^2-F/Btu to R-9.1 hr-ft^2-F/Btu. Pre- and post-retrofit whole building airtightness testing showed a 55% reduction in air leakage.

Whole building energy modeling was performed to assess potential retrofit measures, to estimate energy savings and to complete a cost-payback analysis. Measurement and Verification (M&V) was performed following one year of post-retrofit operations. The retrofit resulted in a measured 19% overall energy savings, reducing in-suite electric baseboard space heating energy by an estimated 63%.

This paper will detail lessons learned through design, energy modeling, implementation, and M&V of an energy efficient building enclosure retrofit project. This case study provides a template for future building enclosure renewals projects to achieve cost-effective, energy efficient retrofits.

[1] Brittany Hanam, MASc, P.Eng., RDH Building Engineering Ltd., Vancouver, BC
[2] Lorne Ricketts, MASc, EIT, RDH Building Engineering Ltd., Vancouver, BC
[3] Andrew Pape-Salmon, P.Eng., MRM, RDH Building Engineering Ltd., Victoria, BC

1. INTRODUCTION

This paper provides a case study of a recent energy efficient building enclosure retrofit project. The case study building is a 13-storey multifamily condominium 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. It is ventilated using a pressurized corridor approach with a single gas-fired make-up air unit (MAU) located on the roof, which heats the air to room temperature. The building is heated using electric baseboards in the suites, corridors and lobby.

In 2012 the building owners proceeded with a building enclosure retrofit project to address aging building components, improve comfort, acoustics, and durability, 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, utility and government organizations. It is intended to serve as a model for sustainable, energy efficient and economical renewals of existing buildings. Construction of the exterior building enclosure retrofit, known as Phase 1 of the project, took place from May to December 2012. Energy measurement and verification (M&V) and other testing was performed through the calendar year 2013. Phase 2 is in progress to address building mechanical systems, mainly focused on ventilation.

The paper presents a summary of the retrofit work performed, as well as the energy modeling and M&V of energy savings. Lessons learned from the case study are presented to assist future building enclosure renewals projects in achieving cost-effective, energy efficient retrofits.

2. BUILDING SYSTEMS AND ENERGY CONSERVATION MEASURES

This section provides an overview of the retrofit project at the case study building. The original building consisted of exposed concrete walls with interior insulation and exposed slab edges (effective thermal resistance of approximately R-4 hr•ft²•°F/Btu). The original windows had non-thermally broken aluminum frames with double glazed insulated glazing units (IGUs) (U-value of approximately U-0.55 Btu/hr•ft²•°F). Significant air leakage occurred through the building envelope; airtightness testing showed an air leakage rate of 0.71 cfm/ft² at a pressure difference of 75 Pa.

The building is heated by electric baseboards in the suites and corridors, and there is no mechanical cooling. Suites at the top five floors also have gas fireplaces (14 fireplaces in total). The building is ventilated using a corridor pressurization approach with a single gas-fired rooftop make-up air unit. Outdoor air is heated and delivered to the corridors of the building, with the intention that air enters suites via undercuts at the hallway entrance doors. Occupant controlled exhaust fans are located in the bathrooms and kitchens of the suites. The heating and ventilation systems were not modified as part of the retrofit work covered in this study, though Phase 2 of the project plans to focus on heating and ventilation improvements in the future.

When planning the retrofit project, whole building energy modeling was undertaken to assess several options for energy efficiency measures and perform a cost-payback analysis. Energy modeling was performed using the program DesignBuilder, an interface that uses the EnergyPlus engine. The model was calibrated to align with metered energy utility data provided by BC Hydro (electric) and FortisBC (natural gas), to ensure that the model reflects actual energy consumption at the building.

The energy efficiency measures that were implemented as part of the retrofit project included insulating the walls, replacing the windows and air sealing the building.

- The walls were overclad with semi-rigid mineral fiber insulation installed between fiberglass cladding support clips with low thermal conductivity. The effective wall R-value is approximately R-16 hr•ft^2•°F/Btu.
- The windows were replaced with fiberglass frame windows with low-e coated[4], argon filled, triple glazed IGUs that provide an effective window U-value of U-0.20 Btu/hr•ft^2•°F.
- Air sealing was completed, reducing the tested air leakage rate at the building to 0.32 cfm/ft^2 at 75 Pa, an improvement of 55%.

3. BENCHMARKING BUILDING ENERGY CONSUMPTION

Benchmarking a building's energy consumption is the process of comparing the energy consumption, typically the normalized Energy Use Intensity (EUI) in kWh/m^2 or kBtu/sf, to that of similar building types. Benchmarking building energy consumption is typically undertaken using a tool such as ENERGY STAR® Portfolio Manager, which compares energy consumption to data from the Commercial Building Energy Consumption Survey (CBECS) in the United States, or the Survey on Commercial and Institutional Energy Use (SCIEU) in Canada. This benchmarking tool contains data for a wide variety of building types and a 0-100 score for performance; however, the score is not currently available for residential buildings.

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4 Low-e coatings are Cardinal 366 on surface 2 and Cardinal 180 on surface 5.

Since it is not possible to benchmark multifamily buildings using Portfolio Manager, the case study building's energy consumption was compared to a study on energy in mid- and high-rise multifamily buildings in southwestern British Columbia (RDH 2012). This study found the average, weather-normalized energy use intensity for MURBs in southwest British Columbia to be 213 kWh/m^2 (68 kbtu/sf) per year.

The utility data in this study was weather normalized using regression to determine the typical annual energy use at each building. Monthly energy consumption was plotted versus the monthly heating degree day (HDD) value to determine a correlation. 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 same methodology for weather normalizing the utility metered energy consumption, the case study building started with a pre-retrofit EUI of 225 kWh/m^2 (71 kbtu/sf) per year. This pre-retrofit EUI is only slightly higher than the average from the study (RDH 2012), and is therefore very representative of typical high-rise multifamily buildings in southwestern British Columbia.

4. MEASUREMENT AND VERIFICATION OF ENERGY SAVINGS

4.1 Background and M&V Plan

An important part of this pilot project and the associated research study was to undertake M&V of energy savings to reliably determine the actual savings resulting from the retrofit. The International Performance Measurement and Verification Protocol (IPMVP Volume 1, 2012) was followed, as it is one of the most widely used M&V standards, frequently used by energy utilities and under the LEED rating system.

The IPMVP standard requires that an M&V plan be created prior to project implementation. An M&V plan was developed for the case study once the design and energy efficiency measures had been determined. The M&V plan defined the approach (Option D 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 M&V process. Measured energy consumption data was obtained from the gas and electricity utility meters.

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4.2 Measured Savings through Calibrated Energy Modeling

The calibrated simulation M&V approach requires the development of a whole building energy model, which is calibrated to align with metered consumption data. Two calibrated models were developed, pre-retrofit and post-retrofit, and the difference gives the measured energy savings. This method allows for the estimation of energy savings by end-use without sub-metering.

Energy model calibrations were performed by adjusting uncertain inputs in the model based on seasonal trends in the data. These included several inputs that vary due to occupant control, such as lighting and miscellaneous electrical (plug) loads, domestic hot water consumption, fireplace use, and temperature set points.

One interesting finding during calibration was that summer electricity consumption decreased following the retrofit, despite no air conditioning. It is hypothesized that this occurred because several occupants had thermostats set at high temperature set points (set points as high as 26°C were observed during initial site visits), resulting in summer electric baseboard heating energy, which was reduced or eliminated following the retrofit. The pre- and post-retrofit models were calibrated by raising the temperature set point to 23.5°C, reflective of an estimated average assuming that some owners have higher set points while others have lower set points.

Table 1 shows the overall building energy savings from the M&V calibrated pre- and post-retrofit energy models. The results show a measured 19% reduction in total energy consumption, a savings of 214,000 kWh per year. The pre- and post-retrofit electricity, gas and total energy consumption is illustrated in Figure 1, Figure 2 and Figure 3.

TABLE 1: Pre- and Post-Retrofit Energy Consumption from Calibrated Modeling.

	Pre-Retrofit	Post-Retrofit	Savings	
Electricity, kWh	618,200	417,000	201,100	33%
Gas, ekWh	517,300	504,400	12,900	2%
Total, ekWh	1,135,500	921,500	214,000	19%

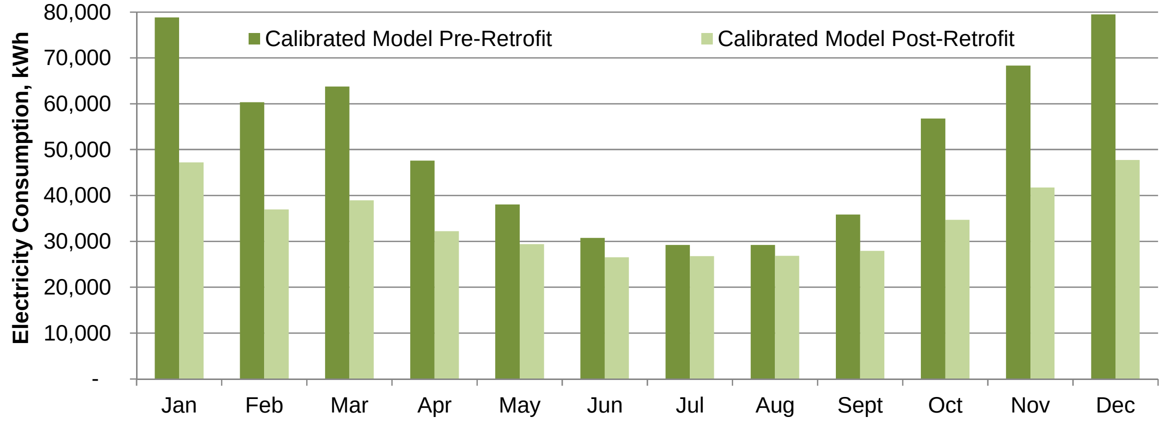

FIGURE 1: Calibrated model pre- and post-retrofit electricity consumption (suite and common areas), kWh.

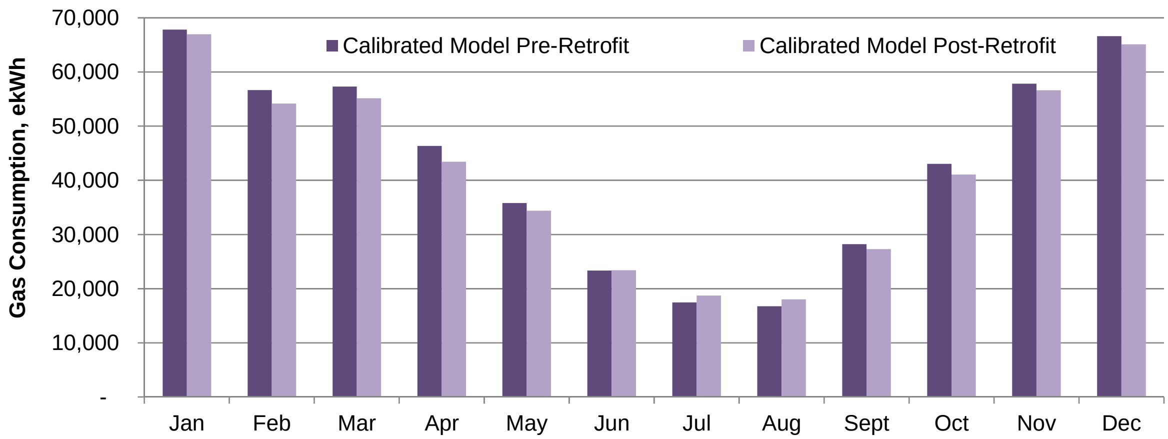

FIGURE 2: Calibrated model pre- and post-retrofit gas consumption, ekWh.

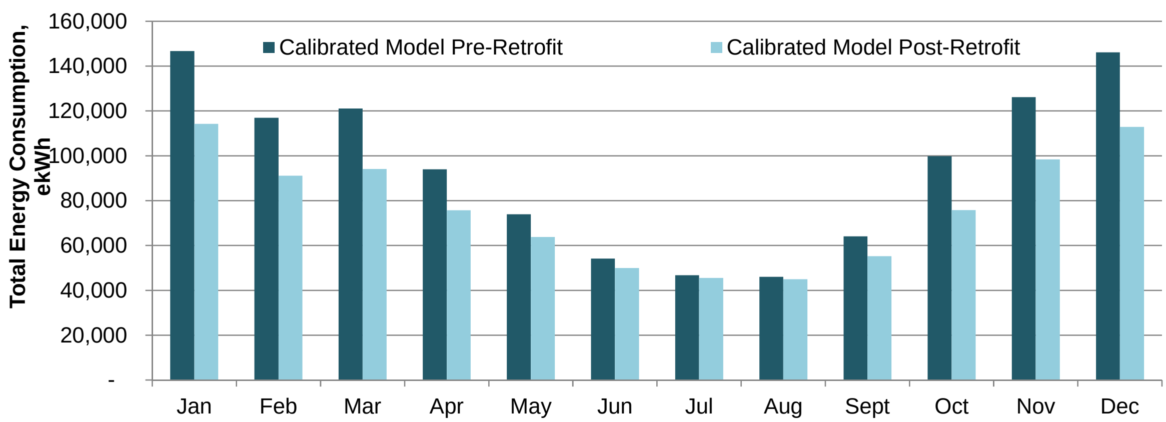

FIGURE 3: Calibrated model pre- and post-retrofit total energy consumption, ekWh.

4.2 Savings by End-Use through Calibrated Energy Model

The total energy savings was determined through building-level metering and is therefore reliably known. The variability in energy consumption or savings by end-use (i.e. electric baseboard energy savings) is estimated through modeling, since it is not feasible to sub-meter all electric baseboards. As a result, savings estimated for electric baseboard heating are an estimation, and are in reality influenced by several factors, in particular occupant behavior.

Table 2 shows the modeled energy savings by end-use, for the pre-design (predicted) model and the final post-retrofit calibrated M&V model. The two models yielded very close total energy savings, with slightly more predicted savings than measured savings; however, the savings by end-use vary. The final calibrated M&V model shows less electric baseboard heating savings than the design (predicted) model, offset by savings in gas fireplace energy. Gas fireplace savings were not modeled in the design stages as it was not known how occupants' fireplace use would change following the retrofit. The data shows reduced fireplace use following the retrofit.

The measured electric baseboard heating savings were lower than predicted (68% versus 63%), which may be due to owners opening their windows through the winter, resulting in additional air infiltration. This should be addressed through future work to improve ventilation to suites in an energy efficient manner, such as in-suite Heat Recovery Ventilators (HRVs).

Figure 4 shows the final calibrated M&V model energy consumption by end-use, compared to the original building calibrated energy model.

TABLE 2: Predicted design model and calibrated M&V model energy savings by end-use.

	Predicted Design Model		Calibrated M&V Model	
	Savings, ekWh	Percent Savings	Savings, ekWh	Percent Savings
Electric Baseboard Heating	215,500	68%	201,100	63%
Gas Fireplaces	0	0%	12,900	20%
Total Energy Savings	215,500	19%	214,900	19%

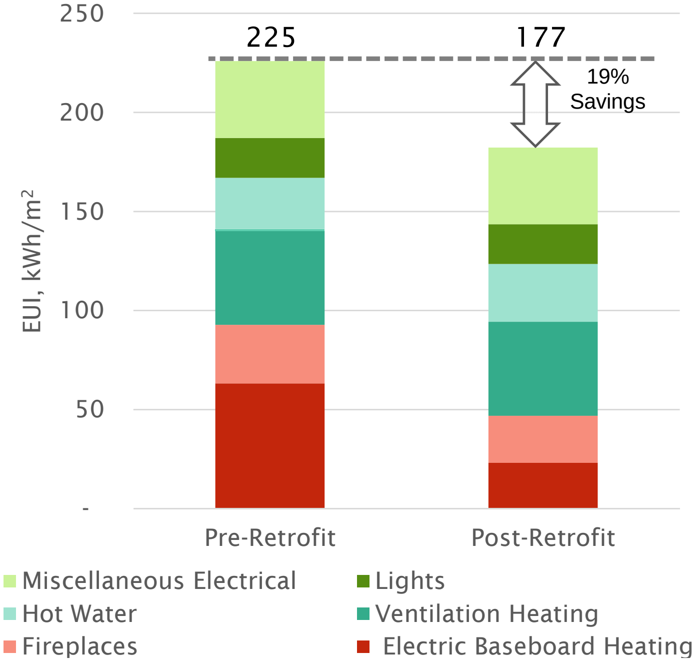

FIGURE 4: Calibrated model pre- and post-retrofit EUI by end-use, ekWh/m^2.

4.3 Cost Savings and Payback

Using gas and electricity prices and carbon tax for Vancouver, BC that are current as of January 2014, the retrofit resulted in an average annual savings of $21,000 for the building, an average of $570 per suite.

The airtightness and insulation retrofit measures were included in the project for durability and moisture control; as such, no incremental cost was assigned and their payback was immediate. The low-conductivity cladding attachment was an energy upgrade, but was cost-neutral compared to traditional metal girts.

The incremental cost of the windows compared to the minimum BC Energy Efficiency Act required windows was $88,000, or $60,000 net of the incentive received through BC Hydro's Commercial New Construction Program. To calculate payback period, the same utility rates used in the original pre-retrofit energy study were used, current as of April 2013. These are $8.66/GJ for gas[5], and for electricity a stepped rate of $0.069/kWh for the first 1,350 kWh in a two-month billing period (or 22.2 kWh per day)

[5] FortisBC Lower Mainland Rate 2, commercial with consumption less than 2000 GJ annually, April 2013, with carbon tax of $1.50/GJ

and $0.1034 above 1,350 kWh in a billing period[6]. These rates are exclusive of tax and fixed fee charges, but include the carbon tax. The current financial analysis does not account for increasing energy prices; if this was incorporated, payback periods would be lower (therefore the current analysis is conservative).

Based on this, total annual savings from the project compared to a code-minimum window baseline[7] are $20,600 (this was determined by re-running the pre-retrofit model with code-minimum windows in place of the existing windows to compare incremental costs to incremental savings). By modeling the ECM's individually it was determined that 49% ($10,100) of the total savings can be attributed to the window upgrade which yields a payback period of 9 years, or 6 years including the incentive funding.

The cost savings were also calculated using post-retrofit rates (May 2014) for comparison. This yields an annual savings of $25,700 due to the increase in both gas and electricity prices since the original study was completed. These prices yield a payback period for the windows of 7 years, or 5 years including the incentive funding.

5. OTHER MONITORING RESULTS

Since this case study building was part of a larger research project to understand the opportunities for energy savings through retrofits of multifamily 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 can be found in the paper "Corridor Pressurization System Performance in Multi-Unit Residential Buildings" (Ricketts and Finch, 2014) and "Airflow in High-Rise Multi-Unit Residential Buildings" (Ricketts, Finch, and Straube, 2015).

6. CONCLUSION

This paper details the retrofit work and M&V results for an energy efficient building enclosure renewals project undertaken as part of a larger research study and demonstration project on energy consumption and conservation in multifamily buildings. Overall, the M&V results yielded a measured, weather normalized energy savings of 214,000 ekWh, a reduction of 19%. The EUI was reduced by 43 ekWh/m^2 (from 226 kWh/m^2 to 183 kWh/m^2). This is comprised of 201,100 kWh electricity savings (electric baseboard heating) and 12,900 ekWh gas savings (fireplaces). The retrofit resulted in an average annual savings of $21,000 for the building, an average of $570 per suite.

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[6] BC Hydro residential rates, April 2013
[7] U-value of 0.45, per the BC Energy Efficiency Act

The calibrated energy modeling estimated a 63% savings in electric baseboard heating energy from the retrofit. Electrical sub-metering was not conducted, and thus savings are an estimate only.

An important component of this work was the M&V process to measure actual energy savings resulting from the project. An important finding was the comparison of modeled (predicted) to measured energy savings. This showed that overall savings were nearly identical to the predicted savings, though the overall gas and electricity savings were slightly different. Gas savings were measured that were not modeled (2% savings), likely due to the change in occupants' fireplace use. The measured electric baseboard heating savings were lower than predicted (68% versus 63%), which may be due to owners opening their windows through the winter, resulting in additional air infiltration.

Additional work at the building is needed to address ventilation, ensuring that suites receive outdoor air for health and comfort, delivered in an energy-efficient manner (currently planned as Phase 2 of this project). Further research should be performed following the implementation of ventilation improvements 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.

Overall, large-scale building enclosure renewals projects present an excellent opportunity to reduce building energy consumption at low incremental cost. This project provided numerous other benefits aside from energy cost savings, such as improved comfort and aesthetics, reduced maintenance costs, reduced outdoor noise transmission, and likely higher property values; any of these benefits can provide motivation for owners to pursue this type of project. This case study provides a model for energy efficient building enclosure renewals of existing buildings.

7. ACKNOWLEDGMENTS

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8. NOMENCLATURE

DHW = Domestic Hot Water
MAU = Make-up Air Unit
M&V = Measurement and Verification

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