

METER CALIBRATED ENERGY SIMULATION OF HIGH RISE RESIDENTIAL BUILDINGS: LESSONS LEARNED

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ABSTRACT

A study was undertaken to understand the total energy and space-heating energy consumption of mid- and high-rise multi-unit residential buildings (MURBs) in the Lower Mainland of British Columbia. To perform this study, detailed monthly energy consumption data was provided by the local gas and electric utility providers for over sixty MURBs constructed during the past 40 years. Detailed information including drawings, mechanical system specifications, and building history were collected for each building to understand the influence of different characteristics of a building on its overall energy performance.

This initial selection of buildings was then narrowed to buildings that had previously undergone building enclosure rehabilitations to address moisture damage. These buildings provided the opportunity to directly compare pre- and post- building enclosure rehabilitation energy consumption and analyze potential energy savings from more thermally efficient and air-tight building enclosures.

Whole building energy models of these buildings were created using detailed as-built enclosure R-values, air-tightness values from research and some field testing, mechanical information, and building operating conditions. Metered energy was then compared to simulated predictions and calibrations were performed to improve the accuracy of the models to better predict the actual energy consumption. Because information was available for both pre- and post-rehabilitation cases, it was possible to assess the ability of a pre-rehabilitation building model to predict the energy consumption of a corresponding post-rehabilitation model. Additionally, common assumptions regarding high-rise residential building energy use were tested including the level of detail required to accurately simulate the thermal performance of a building enclosure.

Using the knowledge gained through this energy simulation process, recommendations can be made to improve the accuracy of representative energy use patterns for retrofits and new construction of high-rise multi-unit residential buildings.

INTRODUCTION

A study was undertaken to analyse energy consumption in mid- and high-rise multi-unit residential buildings (MURBs) in the Lower Mainland of British Columbia. Gas and electricity consumption were obtained for more than sixty buildings. This group was narrowed to 13 buildings with complete gas and electricity data: eleven buildings that underwent full building enclosure rehabilitations plus two newer buildings representative of current construction practice. Building enclosure rehabilitations were performed primarily to address moisture related damage (i.e. leaky condos) while minimizing the financial impact to the owners; hence, they were not considered energy upgrades per se. However, the enclosure repairs made significant improvements to the overall thermal performance and air-tightness of the MURBs which in turn, has reduced the space heating energy (RDH 2011).

Energy simulations were performed for each of these thirteen buildings in order to better understand end-use energy consumption in MURBs and the impacts of enclosure and mechanical parameters. This paper presents the findings of the energy simulation and techniques used to calibrate energy simulations to actual energy use.

WHOLE BUILDING ENERGY SIMULATION OF MURBS

The following procedure was used to build energy models of each of the thirteen study buildings and simulate the annual energy consumption.

Metered Energy & Weather Normalization

Gas and electricity billing data were obtained for each of the thirteen buildings identified. A total of ten years of data was obtained for each building with at least three years pre- and post-enclosure rehabilitation. For each of the study buildings, electricity was metered by suite for each unit and common area, and gas was on a single meter for the main common areas of the building.

Metered energy consumption was calendarized and weather normalized. Since meter reading dates vary month to month, the metered readings were converted to monthly consumption data proportionately (calendarization). For example, the meter may have been read January 3rd and February 2nd, whereas energy data is required for January 1st to 31st for consistent comparison to the energy simulation results. The calendarized data was then weather-normalized to a common heating degree day year to remove the effects of annual weather variances (since the energy simulation program uses a typical meteorological year, i.e. Canadian Weather for Energy Calculations, CWEC). Weather normalization involved plotting the monthly energy consumption versus the actual monthly heating degree day value (from Environmental Canada weather data) for each month pre- and post-rehabilitation. Regression analysis was then performed to determine a representative relationship between this energy and the heating degree day values. The resulting formula is used to calculate the typical month energy consumption based on the set CWEC heating degree day values. This relationship is often assumed to be linear based on a heating degree day set-point, however data from this study shows improvements on this assumption can be made to refine meter calibrations.

Weather normalization was performed for the gas, suite electricity and common electricity separately for the pre- and post-rehabilitation periods for each of the buildings. During the course of weather normalization distinct relationships became apparent for the common gas and electricity and suite electricity, which improved the selection of a weather normal year data set. This was very important when meter calibrating the data, particularly in the spring and fall months. For all cases a standard heating degree day baseline value of 18°C (64°F) was used and best correlated with the data. The use of several alternate heating degree day baselines (i.e. from 12 to 21°C or 54°F to 70°F) was explored for each building; however, this did not improve the correlations (RDH 2011).

Common area gas consumption (used for make-up air heating and domestic hot water) had a linear relationship with heating degree days as demonstrated for one of the study buildings in Figure 1. The baseline monthly use consisted of domestic hot water with the make-up air being the seasonally variable load. This is expected since the make-up air unit thermostat is set based only on the exterior air temperature; it is typically fixed over the year, and heats the incoming air-stream for all hours that the air temperature is below the set-point. This set-point was typically observed to be 21°C, having been set by the service contractor or the strata.

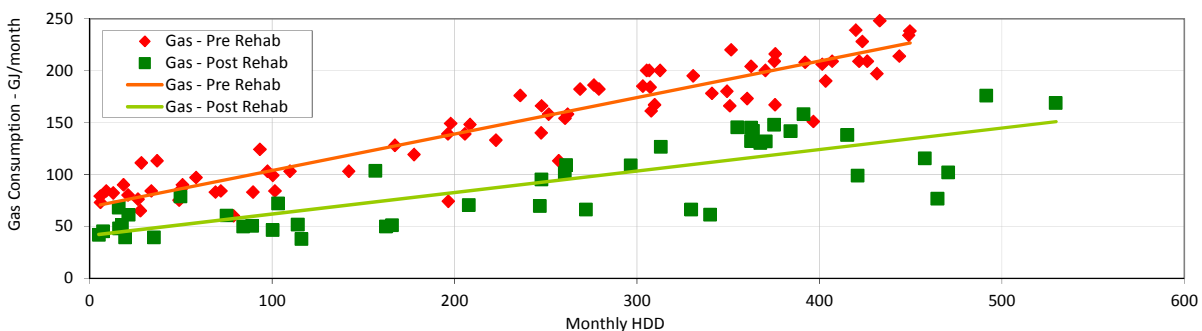


Figure 1: Gas consumption weather normalization – pre- and post-rehabilitation relationship, Building 33.

The exceptions to this linear gas-HDD relationship were for MURBs with a high proportion of gas fireplaces or where hydronic heating was used (gas fired boilers). In these cases, the gas consumption heating degree day relationship tended to be non-linear (exponential or polynomial) and similar to the suite electrical consumption relationship discussed below.

For suite electricity it was found that the relationship to heating degree days was non-linear as demonstrated in Figure 2 for a typical MURB. The shape can be described simply as a “hockey stick” or mathematically by a 2nd or 3rd order polynomial. This accounts for the lower amount of space heat used in the summer and swing months (May-June and September-October); i.e. when the heat is shut off (thermostats turned down) or infrequently used by all occupants. This was an occupant behaviour factor attributed to thermostat set-point and use. For example, it is often observed that thermostats are shut off from spring through fall, and only turned on when conditions become too cold during the first cold period of fall and turned off during the first warm period in spring. A linear relationship tends to average these months out and shave off the wintertime peak and summertime baseline and hence, is inaccurate when trying to calibrate energy bills to all months.

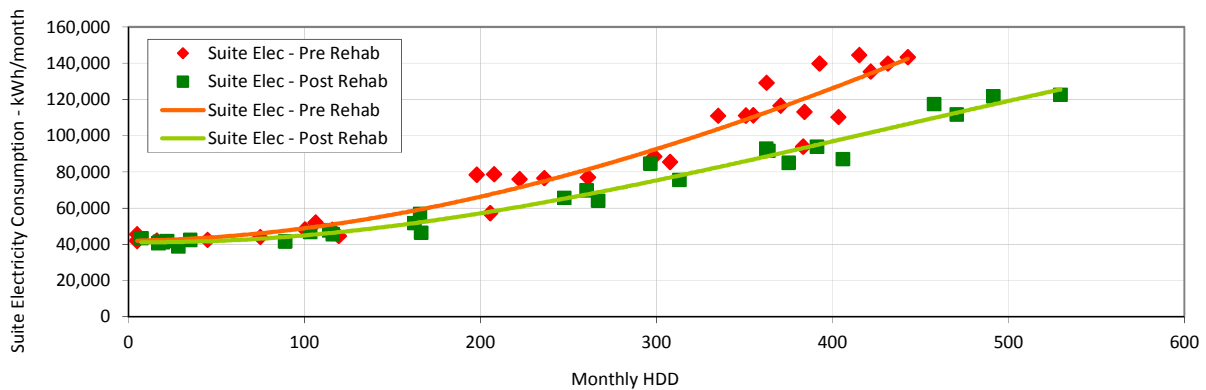


Figure 2: Suite electricity consumption weather normalization, pre- and post-rehabilitation, Building 33.

Common area electricity, because of the relatively low proportion of space-heating controlled by occupants (except for lobby and amenity areas) tends to have a linear relationship to heating degree days. In buildings without common area electric heat, an average monthly value can often be determined.

Using the weather normalized data, pre- and post-rehabilitation monthly energy consumption is compared to the results of the energy simulation in order to calibrate the simulation.

Overall Building Enclosure R-values

Detailed thermal calculations were performed to determine the effective pre- and post-rehabilitation building enclosure R-value, and the overall effective window U-value (R-value). Calculating the effective enclosure R-value is a complicated task of thermal modeling and quantity accounting due to the numerous assemblies, arrangements, interfaces, materials and thermal bridges that need to be accounted for. It has been common practice to use nominal “insulation only” center of wall R-values for walls, roofs, floors and standard sizes of fenestration for energy calculations, or at least for energy code compliance purposes. However, center-of-wall R-values are not indicative of overall performance due to the effects of thermal bridging, and R-values for standard window sizes tend to be more conservative than the actual window R-values.

To accurately account for the effective wall and roof R-values, the area of each different assembly type that occurs on the enclosure was calculated. Each assembly was simulated using the two-dimensional heat transfer program THERM [LBNL 2003]. Three-dimensional details were simulated by using 2D cuts to determine effective material properties for thermally bridged elements out of plane (method of isothermal planes). R-values for certain three-dimensional details (ie slab edges, corners and intermittently supported claddings) were also performed using the three-dimensional heat transfer program HEAT3 [Blocon 2005]. The overall R-value was calculated using area-weighting using U-value

calculations for both the pre- and post-rehabilitation building enclosure. The overall effective window R-value was calculated by simulating each different window component in THERM and WINDOW, and area-weighting based on take-offs. Figure 3 demonstrates the level of detail for the thermal take-offs.

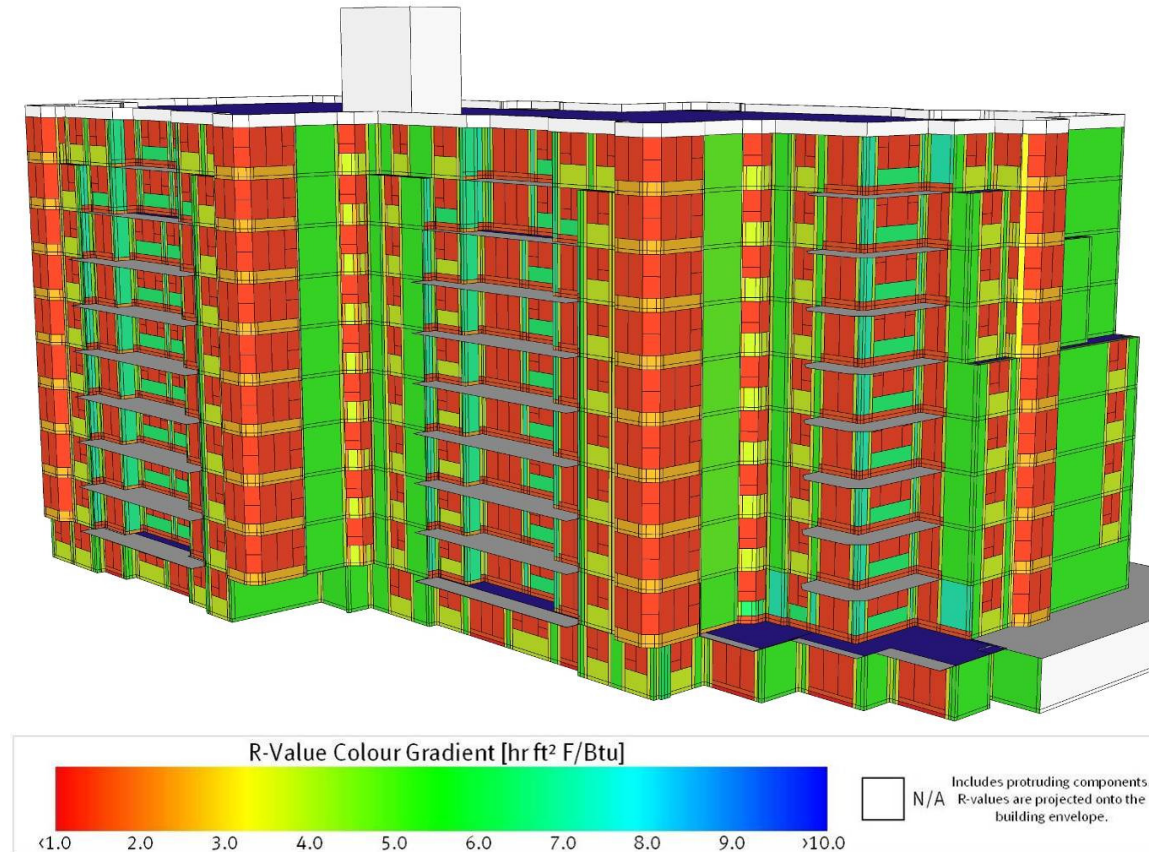


Figure 3: Pre-rehabilitation thermal modeling results for Building 19, Overall R-value = 2.92 hr ft² F/Btu (0.51 m²-K/W).

Air Leakage

Air leakage represents a significant source of heat loss to existing buildings (and heat gain). However it is difficult to measure or estimate for an in-service MURB with operable windows. Air leakage testing of whole or part of high-rise buildings has been performed primarily on a research basis since the 1970's but is not performed on a widespread basis primarily due to the high cost, time and equipment involved, and logistics of such disruptive tests to tenants. A literature review of published data was performed as part of this study, and combined with high-rise air leakage testing performed by the authors on recently rehabilitated buildings (RDH 2011).

The wall and window assemblies in the buildings tested are typical of the rehabilitated buildings in the study and the air leakage rates are similar to other buildings across the country, which is useful for predicting air leakage rates and the effect on energy consumption in this study. The literature review and previous air leakage testing experience provided typical air leakage rates for MURBs (Table 1). The energy simulations all used the same air leakage rate, a value that was assigned as a “Tight – High Average” value of 0.15 cfm/ft² @ 5 Pa. This consistent assigned level was assigned since the actual air leakage rate of the buildings (even pre- and post-rehabilitation) is highly uncertain and it could not be reasonably justified to use different levels for different buildings. Further work is being performed as part of this study to refine this estimate by measuring in-situ air-exchanges in MURBs in service.

Table 1: Typical air leakage rates for MURBs

Enclosure Air-Tightness	Representative of
0.02 cfm/ft ² @ 5 Pa	Very Tight
0.05 cfm/ft ² @ 5 Pa	Tight - Low Average
0.10 cfm/ft ² @ 5 Pa	Tight - Average
0.15 cfm/ft ² @ 5 Pa	Tight - High Average
0.20 cfm/ft ² @ 5 Pa	Leaky
0.40 cfm/ft ² @ 5 Pa	Very Leaky (4x the average) with some windows open

Mechanical Audits

Mechanical audits were performed at each of the study buildings to obtain information on the mechanical systems and equipment of the building. The audits provided important inputs for the energy simulations, including:

- Make-up air flow rate and temperature set-point
- Type of heating system (electric baseboards or hydronic radiators)
- Equipment efficiencies for make-up air heating, in-suite heating (for hydronic systems) and DHW heating
- When mechanical upgrades or improvements were made
- Lighting types and densities.

Energy Simulations

An energy model was created for each of the thirteen study buildings selected for energy simulation. The buildings were simulated using a program called FAST (Facility Analysis and Simulation Tool). This program is a customized Excel application that uses the DOE2.1e energy performance modelling engine to calculate annual energy consumption on an hourly basis. The program takes weather data for a typical year as well as generalized inputs that describe the key building characteristics that account for energy use, such as enclosure exposure components, enclosure parameters, mechanical systems and electrical systems. The program uses these inputs to calculate energy consumption for a typical year. FAST was developed by EnerSys Analytics and customized to simulate MURBs.

Architectural, mechanical and electrical inputs were determined through the information collection process described above. However, some of the mechanical and electrical inputs were not accurately known. In cases where the required input parameters were not as well defined, typical standard inputs were selected and used for each building simulation based on past studies and experience. This group of simulations was referred to as the un-calibrated simulations, and would be representative of a new building simulation where there was no existing metered data.

The initial (un-calibrated) output of each simulation was compared to metered data for each building. The unknown mechanical and electrical input parameters were varied until the simulation output matched the metered data. Mechanical parameters that were varied to calibrate the simulations included make-up air supply temperature, nominal equipment efficiencies, domestic hot water flow rate, fireplace load, heating temperature setpoint and baseboard heat output capacity. Electrical parameters that were varied to calibrate the simulations included lighting density, plug load density, elevator energy and miscellaneous common area electrical loads. This process resulted in a reliable, meter-calibrated energy simulation for each building that reflected actual energy consumption.

The meter-calibrated simulations were then used to determine the impact of various enclosure and ventilation parameters. The following sections discuss lessons learned in energy simulation of MURBs.

THE IMPORTANCE OF METER CALIBRATIONS

The uncalibrated energy simulations are representative of a typical new building energy simulation where calibrations cannot be done since there is no history of actual energy consumption. Figure 4, Figure 5 and Figure 6 show the metered energy consumption compared to the un-calibrated and calibrated simulated energy consumption for gas, suite electricity and common electricity, respectively. Buildings are given numeric names for confidentiality purposes. Only the eleven buildings that underwent enclosure rehabilitation are shown in these plots.

Comparing the uncalibrated simulations to the metered data shows the value of the calibration process. The calibrated results are much closer to the actual metered data than the uncalibrated results. Comparing the un-calibrated simulation consumption to the calibrated and metered consumption, the gas results (Figure 4) were inconsistent. In the gas plot, six of the buildings have higher consumption in the uncalibrated simulation than the metered data while five of the simulations have lower gas consumption. Two buildings (21 and 28) have significantly different gas consumption in the uncalibrated simulations. Building 20 gas was underpredicted because the metered data included swimming pool gas consumption. The gas calibrations required adjusting fireplace consumption and DHW, both of which are highly dependent on occupant behaviour.

Figure 5 shows that suite electrical consumption was over-predicted in the un-calibrated simulations for all buildings except Building 19, which is gas heated. These simulations required limiting the average baseboard capacity as a means to reduce the suite electric space heat consumption for a better winter calibration to the metered data. Baseboard capacities were generally in the range of 2 – 4 Btu/ft² for the Vancouver MURBS that were simulated. Further research is required to study this parameter for other climates and other types of buildings. This is a significant finding of the calibration process; without a baseboard capacity the program significantly over-predicts space heating energy consumption. This may be because of occupant behaviour, thermostatic control and variation in swing seasons.

Figure 6 shows that common electrical consumption was under-predicted for nine of the buildings and over-predicted for two of the buildings (20 and 28). There was a lot of variation between the common electrical consumption of the different buildings; some had very high energy consumption while others consumed very little common energy. This could be due to the types of amenity spaces present in the building (for example some buildings have work out rooms with energy intensive equipment).

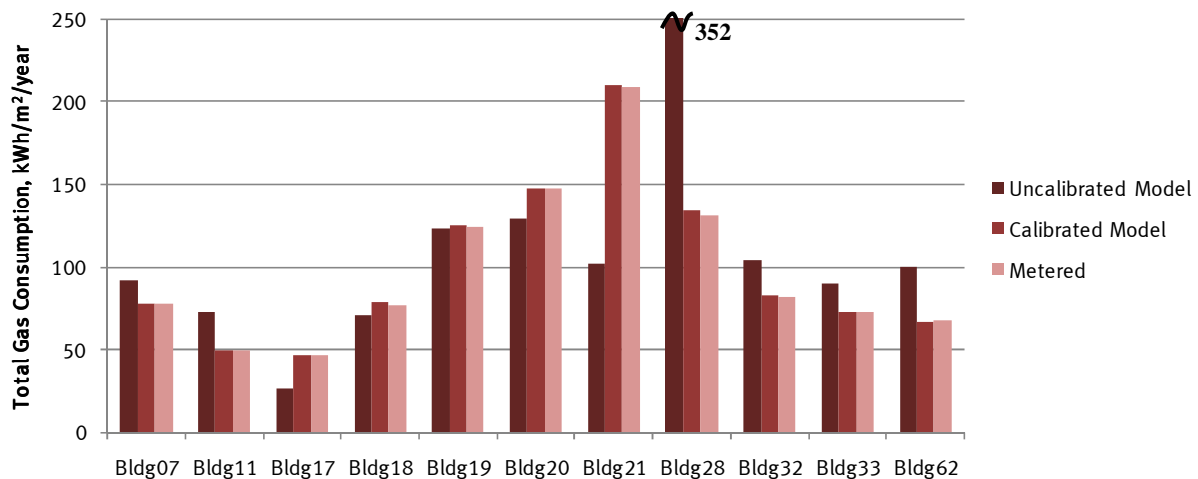


Figure 4: Metered and simulated gas consumption.

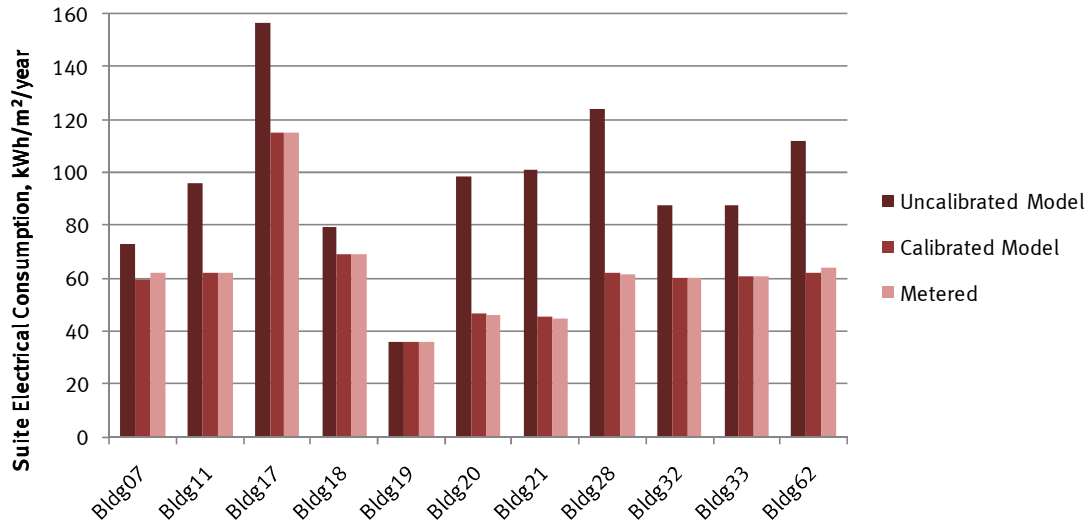


Figure 5: Metered and simulated suite electrical consumption.

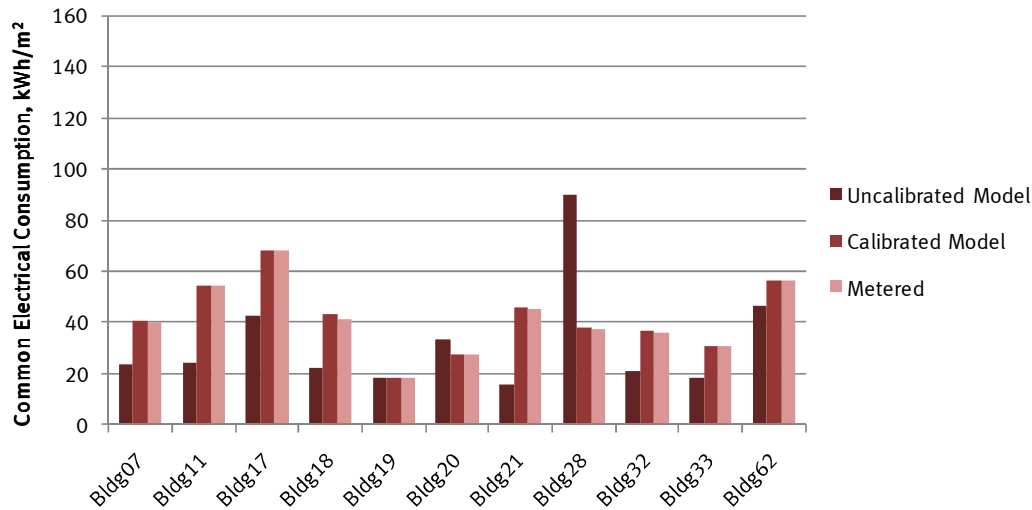


Figure 6: Metered and simulated common electrical consumption.

Once the pre-rehabilitation calibrations were complete, the simulation was run with the post-rehabilitation enclosure changes to determine whether the simulation would predict the change in the post-rehabilitation energy consumption. Figure 7 and Figure 8 show the metered and simulated gas and electrical consumption, respectively, for the pre- and post-rehabilitation scenarios. The pre-rehabilitation metered and simulated energy consumption is very close for all buildings, reflecting the good calibrations that were achieved by varying certain input parameters. The majority of the post-rehabilitation metered and simulated consumption values have a much higher difference in energy consumption.

As shown in the electrical plot, for two buildings (Building 19 and 21) the simulated space heat savings was the same as the metered savings (for Building 19 seen in the gas plot since this building has gas-powered hydronic space heating). In two other buildings (Buildings 11, 18 on the electrical plot) metered electrical consumption increased post-rehabilitation. The reason for the metered increase in space heat consumption is not known.

However, the large majority of the buildings demonstrated that the buildings had a greater pre- to post-rehabilitation savings in the metered data than in the energy simulation (Buildings 7, 17, 20, 28, 32, 33,

62). This could be due to an improvement in air tightness with the enclosure rehabilitation that was not simulated. Additionally, psychological and/or social factors may have had an influence. For instance, the process of the retrofit may have indirectly influenced the consciousness of occupants to make personal changes to save energy. Also, direct and indirect influences of local utility programs, increased local focus on sustainability, and even change-out of old appliances may have influenced the apparent metered savings. (For instance, new refrigerators use significantly less energy than the ~15-20 year old ones in the pre-retrofit sampling, and some may have been replaced between the pre- and post-periods.)

The gas plot shows that nine of the buildings had a greater pre- to post reduction in the metered data than in the energy simulation (Buildings 7, 11, 17, 20, 21, 28, 32, 33, 62). The metered reduction in gas consumption could be due to a change in occupant behaviour; occupants may have used their fireplaces less after the rehabilitation due to an improvement in thermal comfort. Also, direct and indirect influences to save energy appeared to have played a role in at least a few cases where excessive fireplace use was addressed by the governing strata councils.

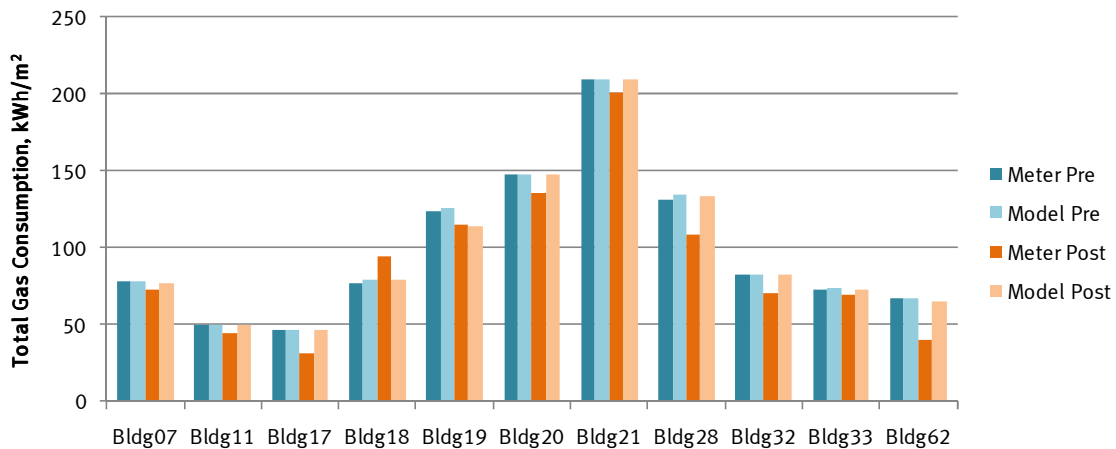


Figure 7: Metered and simulated total gas consumption, pre- and post-rehabilitation.

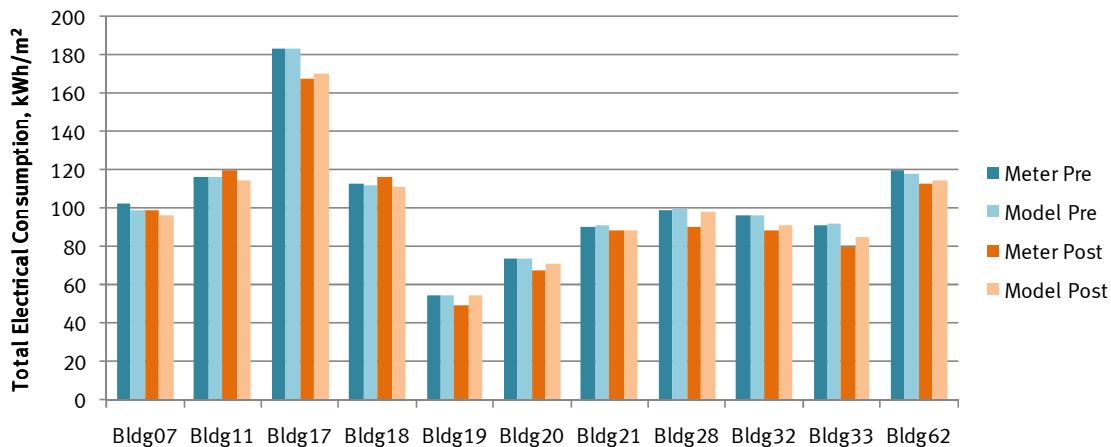


Figure 8: Metered and simulated total electrical consumption, pre- and post-rehabilitation.

IMPACT OF ENCLOSURE AND VENTILATION ON ENERGY CONSUMPTION

The thirteen study buildings were used to develop an average or typical building that is representative of high-rise MURBs in the lower mainland of Vancouver, British Columbia. The typical building was then

simulated to determine the impact of various enclosure and ventilation parameters on energy consumption.

Distribution of Energy Consumption

Ventilation (make-up air) and space heating accounted for 49% of energy consumption in the typical building simulation (see Figure 9). The remaining energy consumption was attributed to 16% DHW and 35% electricity for lights, appliances and other equipment. Of the space heating energy, 12% is for electric baseboards, 18% fireplaces and 19% ventilation make-up air heating.

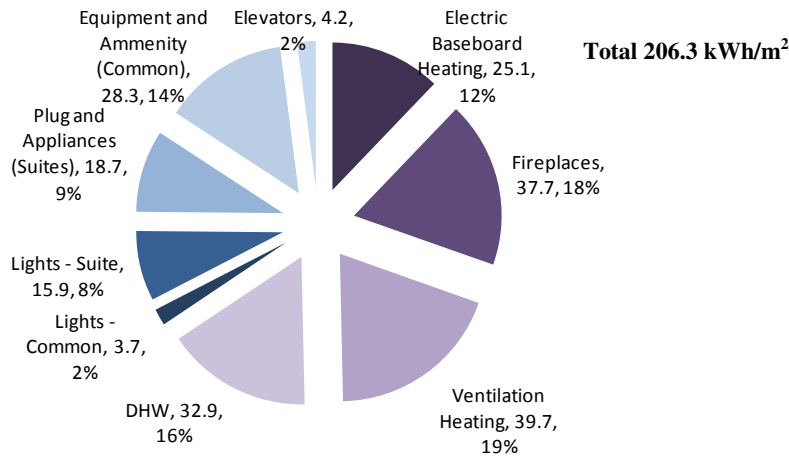


Figure 9: Distribution of total building energy consumption for typical MURB simulation, kWh/m² and % of total.

Impact of Nominal R-Values

Simulations were run to determine the change in energy consumption when nominal center of wall assembly R-values and center of glass window U-values are used in the simulation. This resulted in an average space heat energy reduction of 18% for the thirteen study buildings, with a high of 29% and a low of 7%. In other words, using nominal insulation R-values or center of glass U-values in energy simulations significantly under-predicts the space heat energy consumption. This shows the importance of overall enclosure R-value calculations that account for thermal bridging.

Fireplaces

Fireplaces accounted for 18% of total energy consumption in the typical building simulation, or 36% of space heating (37 kWh/m²). On average, fireplace use per suite within a MURB was determined to be 18 GJ per suite per year. Fireplaces contribute to space heating so removing fireplaces should increase electric space heating energy consumption. Removing fireplaces from the simulation reduces annual gas consumption by 38 kWh/m² and increases electrical consumption by 4 kWh/m². Electrical heating consumption goes up due to the elimination of space heat provided by the gas fireplaces. However, the total space heating reduction from removing fireplaces is therefore 34 kWh/m², a reduction of 33%. This confirms that gas fireplaces are not an efficient space heating system and minimizing their use can have significant energy savings where this is a goal.

Impact of Walls, Windows, Air Leakage

Simulations were run to determine the impact on space heating energy consumption of individual enclosure upgrades including the wall R-value, window U-value and SHGC and the air leakage rate. All resulted in significant reductions in space heat energy consumption.

The enclosure in the typical building simulation had an effective R-value of 3.6 hr-ft²-F/Btu (0.63 m²-K/W). Improving to an effective R-10 reduced space heat energy by 7%, improving to R-15.6 (RSI-2.7)

(ASHRAE 90.1-2007 standard for steel frame construction) reduced space heat energy by 8%, and improving to R-18.2 (RSI-3.2) (ASHRAE 189.1-2009 standard) reduced space heat energy by 9%.

The window U-value in the pre-rehabilitation typical building was 0.7 Btu/hr-ft²-F (4.0 W/m²-K), representative of clear non low-e double glazing within a typical non-thermally broken aluminum window frame. Improving the windows to U-0.45 (2.6 W/m²-K) (BC Energy Efficiency Act for metal frames) reduced space heat consumption by 5%. Improving to U-0.27 (1.5 W/m²-K) (double glazed with low conductivity frame) reduced space heat consumption by 14%, and improving to U-0.17 (triple glazed with low conductivity frame) reduced space heat consumption by 17%.

As previously mentioned, the air leakage rate simulated in the baseline building was consistently maintained at 0.15 cfm/ft² @ 5 Pa, defined as “Tight – High Average” in the air leakage study. Improving to a “Tight – Low Average” value of 0.05 cfm/ft² @ 5 Pa reduced space heat energy by 4%, and improving to a “Very Tight” value of 0.02 cfm/ft² @ 5 Pa reduced space heat energy by 5%. This does not consider occupant behaviour and operable windows left open during the heating season.

Impact of Make-Up Air

Make-up air heating accounts for 39% of heating energy consumption in the typical building simulation (Figure 10). Simulations were run to determine the impact of certain make-up air parameters on space heating energy consumption. The parameters investigated were setpoint temperature, airflow rate and heat recovery.

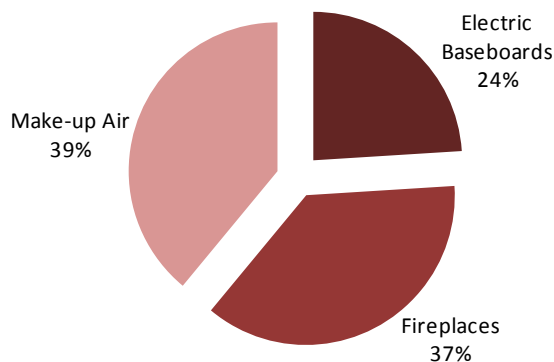


Figure 10: Distribution of space heating energy consumption for typical MURB simulation.

The baseline simulations used a make-up air unit (MAU) temperature setpoint of 20°C (68°F). Increasing the setpoint to 23°C (74°F) increased total heating consumption by 13%, while reducing the setpoint to 16°C (60°F) reduced total heating consumption by 12%. Reducing the setpoint to 13°C (55°F) reduced total heating consumption by 17%. Lowering the MAU temperature setpoint decreases gas heating consumption but increases in-suite electric baseboard heating consumption. However the change in energy consumption provides for a net reduction, resulting in a significant energy savings from simply turning down the MAU temperature setpoint.

The baseline simulation used a MAU flow rate of 50 cfm/suite (24 l/s per suite) to the corridors. Reducing the flow rate by 10 cfm/suite (5 l/s per suite) (20%) reduced heating energy by 7% but is not recommended in practice unless it could be ensured this actual ventilation rate was reaching the suites. Increasing to a flow rate as seen in many new construction projects of 110 cfm/suite (52 l/s per suite) to compensate for inadequacies in the delivery of fresh air with a pressurized corridor approach, increased heating energy by 46%.

The baseline simulation did not have ventilation heat recovery. Two heat recovery scenarios were simulated: central MAU heat recovery (assuming fully ducted return exhaust air) and individual in-suite HRV units. A 70% efficient central HRV system reduced heating energy by 21%, and a 70% in-suite HRV system reduced heating energy by 20% compared to the typical building with a MAU flow rate of 50 cfm/suite (24 l/s per suite). If the typical building had a higher MAU flow rate representative of

modern buildings (and with comparable ventilation to in-suite HRVs) the in-suite HRVs consume less energy than a central HRV system.

Impact of Combining Energy Efficiency Measures

Two simulations were run to determine the impact of combining the energy efficiency measures discussed previously. A “Good” building was defined as having effective R-10 (RSI-1.8) walls, U-0.27 (1.5 W/m²-K) windows (double glazed with a low conductivity frame), 0.05 cfm/ft² @ 5 Pa air leakage, MAU temperature of 18°C (64°F) and no heat recovery. A “Best” building was defined as having effective R-18.2 (RSI-3.2) walls, U-0.17 (1.0 W/m²-K) windows (triple glazed with a low conductivity frame), 0.02 cfm/ft² @ 5 Pa air leakage, MAU temperature of 16°C (60°F) and 80% heat recovery (see Table 2). These simulations were run with and without fireplaces.

Table 2: Typical air leakage rates for MURBs

	Good	Best
Wall R-Value, hr-ft ² -F/Btu (m ² -K/W)	10 (1.8)	18.2 (3.2)
Window U-Value, Btu/hr-ft ² -F (W/m ² -K)	0.27 (1.5)	0.17 (1.0)
Air Leakage, cfm/ft ² @ 5 Pa	0.05	0.02
MAU temperature, °C (°F)	18 (64))	16 (60)
Heat Recovery	None	80%

Figure 11 shows the simulation results of combining energy efficiency measures. Space heat energy consumption is 34% lower than the baseline in the “Good” scenario and 56% lower in the “Best” scenario. Removing fireplaces, space heat energy is 63% lower in the “Good” scenario and 91% lower in the “Best” scenario. These simulations show that significant energy savings are possible through enclosure and ventilation changes.

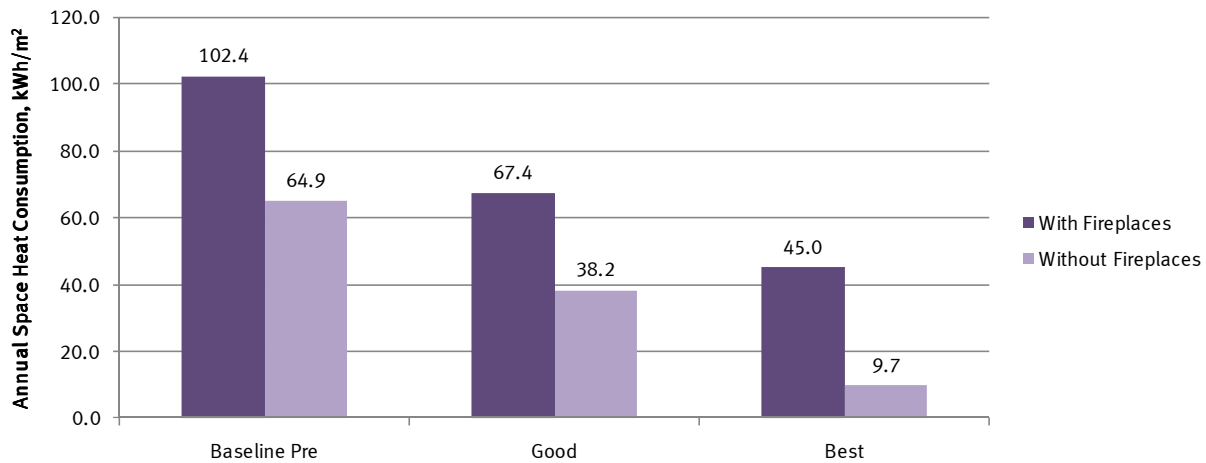


Figure 11: Impact of combining energy efficiency measures.

Impact of Geographic Location

The typical building simulation was run for cities across Canada to determine the energy impact of geographic location (see Figure 12) for this MURB archetype. In addition to Vancouver, the simulation was run for Calgary, Edmonton, Winnipeg, Toronto, Ottawa, Montreal, Halifax, St. John’s and Whitehorse. It is understood that MURBs are constructed differently in different cities across Canada. Different mechanical systems are used and different enclosures are typical for various geographic regions, therefore the energy results shown here are likely not typical of the corresponding city. However, this analysis is presented in order to show the relative impact of climate on heating consumption.

Being the most temperate climate, Vancouver has the lowest space heat energy consumption of the cities simulated. The next highest space heat consumption from Vancouver is Toronto, which has 18% higher space heat consumption than Vancouver. The city with the highest heating energy consumption, Whitehorse, has 56% higher space heat consumption than Vancouver.

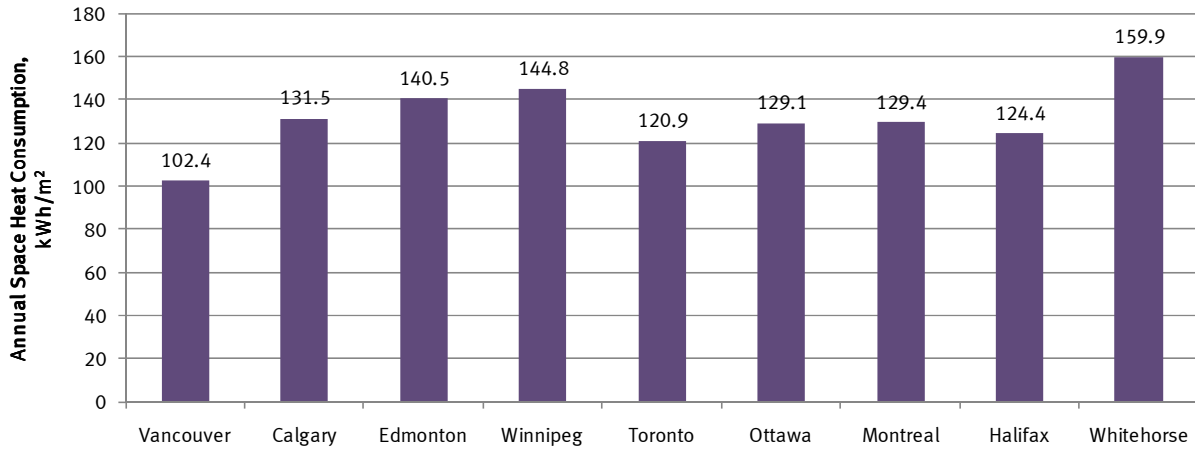


Figure 12: Space heat energy consumption for locations across Canada.

CONCLUSIONS AND RECOMMENDATIONS

The simulation process performed as part of this study resulted in important findings regarding computer simulation of MURBs as well as energy consumption in MURBs. The calibration process showed the importance of calibrating simulated energy consumption to metered consumption data. The gas calibrations required adjusting the fireplace load and DHW since these are highly dependent on occupant behaviour. Nearly all of the suite electrical calibrations required a baseboard capacity to be applied in the simulation in order to limit simulated heating energy. The common area electrical consumption also varied significantly between buildings, with some buildings having a large unknown common electrical load.

Parametric analysis of the study buildings and the typical building simulation showed that significant space heat energy savings are possible through enclosure and ventilation upgrades. The following is a summary of significant findings.

- Heating accounted for about 50% of energy consumption in a typical high-rise MURB. Of heating energy, 24% was for in-suite electric baseboards, 37% was for gas-fired in-suite fireplaces and 39% was for gas-fired ventilation make-up air heating.
- It is very important to simulate using effective R-values rather than nominal R-values; nominal R-values resulted in under-predicting space heat energy by 18% in the typical building simulation.
- Individual enclosure upgrades such as improving the wall R-value or window U-value or air leakage rate resulted in space heat savings in the range of 5% to 20%.
- Changing the MAU temperature setpoint and airflow rate have significant effects on energy consumption. Heat recovery ventilation (MAU or in-suite HRVs) reduced energy consumption by 20% in the typical building simulation.

The study showed through representative energy performance simulations of high rise MURBs, significant energy savings are easily attainable. As demonstrated with the assessment of the typical high rise MURB model, combining energy efficiency measures can result in up to 90% space heat energy reduction.

ACKNOWLEDGMENTS

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