The Realities of High-Rise Multi Unit Residential Building Energy Performance in British Columbia, Canada

Curt Hepting[1], Graham Finch and Brittany Hanam[2]
[1] EnerSys Analytics Inc., Coquitlam, BC, Canada
[2] RDH Group, Vancouver, BC, Canada

Abstract

High-rise multi-unit residential Buildings (MURBs) have dominated the new construction market in the major metropolitan areas of British Columbia (BC). Unfortunately, their actual energy performance has not improved and even appears to be increasing. Annual energy intensities for new high-rise MURBs around the Vancouver and Victoria metro areas are significantly higher than expected, at an average of about 213 kWh_e/m^2/year.

This paper provides background and findings from a key study on energy consumption in high-rise MURBs for the BC market. This includes assessment of the enclosure heat transfer performance and results from calibrated energy modelling and bill analyses. Informed by many of these findings, we explore approaches and indicators from several representative new designs to demonstrate effective improvements that a few new designs are pursuing to improve energy performance. This includes exploration of the implications of installing hydronic heating versus the more common application of electric baseboards for space heating.

1 Introduction

In the largest metropolitan areas of British Columbia, Canada, around Vancouver and Vancouver Island (Southwestern BC), multi-unit residential buildings (MURBs) greater than 4 stories have dominated the new construction market in the last decade. There are many reasons, including the shortage of suitable land, the desire to live close to populated centers, views, etc. Also, policy makers and others cite the “eco-density” benefits that MURBs help to promote. This includes the purported lower average household energy use characteristics, compared to single family dwellings. At the same time, neighbourhood developments and planners are moving toward the promotion of high density housing to effectively support the promise that non-conventional, alternative energy district heating systems may provide. In many cases, this has lead to the promotion of hydronic space heating systems over the application of more typical electric baseboards for heating.

To address these interests, several prominent agencies sponsored a key study to more clearly understand the relative performance levels and contributors to overall energy and heating use in mid- and high-rise BC MURBs (greater than 4 storeys). The agencies were represented by local city planners, the major BC utility companies and both BC and national housing authorities. The key results relating to relative energy performance levels and characteristics of the high-rise MURB building stock is highlighted in this paper.

Based on the information and indicators from this and other related studies[1], we have been able to apply what we have learned to new designs in an effort to effectively lower energy use in the MURB market. This started with a clear understanding of how relatively new MURBs (built in 1980's to 1990s) are configured and operate in Southwestern BC.

Typical Characteristics and Market Conditions Affecting Heating

The majority of the new construction high-rise MURB market in Southwestern BC provide electric baseboards for suite heating. Some MURBs will provide distributed heat pumps fed by a central boiler, so as to provide cooling capability to a higher-end market. But the vast majority of the building stock do not have cooling and rely on opening of windows to help keep suites cool during warm periods (which is problematic in actual practice).

Electric baseboards are favoured over hydronic heating mainly due to their significantly lower capital cost and much lower risk of warranty/maintenance issues. However, they also better accommodate individual metering and billing since all suites are metered for electricity – something that most strata councils prefer since everyone individually pays for the heat they use. While many very recent developments with hot water heating have installed energy (Btu) sub-meters to facilitate suite billing of heat, it is much more common and less expensive for MURBs to have a single central meter for recording gas (or district heat) used for suite heating. Finally, typical MURBs with electric baseboards provide for individual thermostatic control of rooms. The relatively few new MURBs with hot water heating typically control the temperature of the entire suite based on a single suite thermostat. From our observations based on calibrated modelling to bills, the effective metering of heat and room zone control accounts for a reduction in heating energy use of about 20% or more.

Nearly all high-rise MURBs provide fresh air delivery via gas-fired rooftop make-up air units (MAUs) that dump 100% outside air into pressurized corridors. The air is intended to migrate into the suites under the entry doors and exhausted via kitchen and/or bathroom exhaust fans or effectively through enclosure leakage points (i.e., mainly windows). The reality is that most of the air never makes it into the suites. Ventilation effectiveness is not a topic of this paper, but is noted as it concerns potential efficiency measures for reducing energy associated with heating ventilation air.

Heating of outside air is one of the single biggest contributors to energy use in MURBs. The amount of fresh air, based on ventilation standards, is typically designed to be heated to about 18°C, but we have seen it actually provided at anywhere from about 13°C – 24°C (in fact, about 80% of the cases had the setpoint at a relatively toasty 21°C). With changes in ASHRAE 62.1 ventilation standards over the years combined with a trend toward smaller suites (outside air requirements are related to the number of suites), the amount of total fresh air has increased over time. Hence, outside air now typically accounts for about half of the space heating load for new high-rises, or more depending on the envelope characteristics.

As for the enclosure, windows represent the largest source of heat loss in new MURBs at about a third to half of the total heat loss for relatively new high-rises. MURBs in southwestern BC are plagued by high amounts of glazing – 50% of the gross wall area is a typical minimum amount, with many new high-rises pushing 80% glazing. Somewhat due to the new energy code, new designs are now typically installing low-e double pane units instead of units without low-e. But with the thermally broken aluminum framing and high glazing areas, the

[1] Several studies on specific new designs were for private clients and developers and hence, are not publically available. However, we have listed several available references concerning relevant past MURB assessments and studies at the end of this paper.

windows can rival the outside air as the largest contributor to energy use for particularly highly glazed buildings (and is the largest contributor to unwanted solar heat gains).

The exterior walls represent the next largest source of heat loss, ranging from about 12% – 33% of the total heating requirements for relatively new high rises. Typical new high-rises employ a concrete substructure, with uninsulated floor slabs and balconies. The relatively small remaining wall assemblies have a high degree of thermal bridging with the use of steel studs penetrating the insulation layer.

Infiltration rounds out the top three sources of heat loss associated with the enclosure. Pinpointing the contribution of infiltration is more problematic than with the windows and walls (and roof). However, somewhat through process of elimination from the calibrated models, it roughly accounted for about a tenth of the heat loss through the enclosure for a typical new MURB (or around 5% of the total heating requirements). Of course, this contribution can vary quite significantly depending on the amount and type of windows, wall construction and general leakiness of the building.

Yet another significant characteristic impacting gas use is the presence of gas fireplaces. As later discussed, MURBs with gas fireplaces tend to have relatively high energy use, mainly due to the response of suite owners to use the highly inefficient fireplaces to heat their suites instead of electric baseboards. This stems from the gas use for the fireplaces being paid for by the strata, versus the electric heat for which each individual suite owner is responsible. Luckily, new designs appear to be shying away from installing gas fireplaces.

2 Methodology

The founding study previously referenced involved an original sampling of 64 high-rise MURBs ranging from 5 to 33 storeys constructed between 1974 to 2002. The buildings were representative of typical MURB housing stock and representative of relatively recent construction practices, with typical building characteristics and configurations. Upon further investigation of the available billing data and gross building information, such as number of suites and floor area, the sampling was filtered down to 39 representative study buildings. This sampling was analyzed to assess the relative energy consumption indictors within the mid- to high-rise residential market. This included not only assessing the relative energy intensities, but also the contribution of gas and electricity to overall energy consumption. A focus also was on the contributions and usage patterns associated with space heating.

This sampling was further narrowed to 13 buildings for further detailed analysis involving site visits, detailed enclosure heat loss assessment and calibrated energy performance modelling. The 13 sites were selected not only because they were representative of typical MURBs, but also because building enclosure upgrades had been completed or were underway for nearly all of them. This provided an opportunity to more clearly define the performance (U-values/R-values and air-tightness) of the enclosure components for use within calibrated energy models. Further, relatively detailed information about the buildings was readily available.

The 13 buildings ranged from 9 to 26 storeys and contained 16 to 186 suites, providing an average of 18 storeys with 110 suites distributed over an area of 11,300 m^2 (122,000 ft^2). The gross wall area for the sample set averaged nearly 5800 m^2 (62,000 ft^2) with over 46% window area. All of the buildings except one were heated via electric baseboards (the remaining one was heated with hot water baseboards) with gas-fired make-up air units dumping heated fresh air into the corridors. The service water was heated by gas-fired heaters in all cases except one.

The overall building enclosure heat loss assessments for each building involved detailed thermal calculations that determined the effective pre- and post-rehabilitation wall, roof and window heat losses and thermal resistance values. Calculating the effective enclosure thermal performance involved detailed two-dimensional and three-dimensional modelling of each of the many assemblies, penetrations, interfaces and materials that make up the enclosure construction. This is in contrast to typical R-values (or U-values) provided by manufacturers and/or listed in reference tables often cited for Code compliance (e.g., ASHRAE 90.1).

Accurately accounting for the effective wall and roof R-values required calculating the area of each different assembly type for each building. Each assembly type was simulated using the two-dimensional (2D) heat transfer program THERM [LBNL 2003]. Also, we used three-dimensional (3D) details using 2D slices to determine effective material properties for thermally bridged elements that were out of plane (i.e., method of isothermal planes). R-values for certain 3D details (e.g., corners and slab edges) were also performed using the 3D heat transfer program HEAT3 [Blocon 2005]. The overall R-value of the opaque wall and roof was determined using area-weighted U-value calculations for the entire building enclosure. The overall effective window U-value was calculated by first simulating each different window component in THERM and WINDOW using National Fenestration Research Council (NFRC) procedures, but applied to actual window and framing configurations (i.e., not using standard sizes). We then applied an area-weighted calculation based on area take-offs to arrive at the overall heat transmission coefficient for the enclosure. Figure 1 illustrates the level of detail for the thermal heat transfer analysis and associated take-offs, and the referenced paper by Hanam, S. et. al. further describes the process.

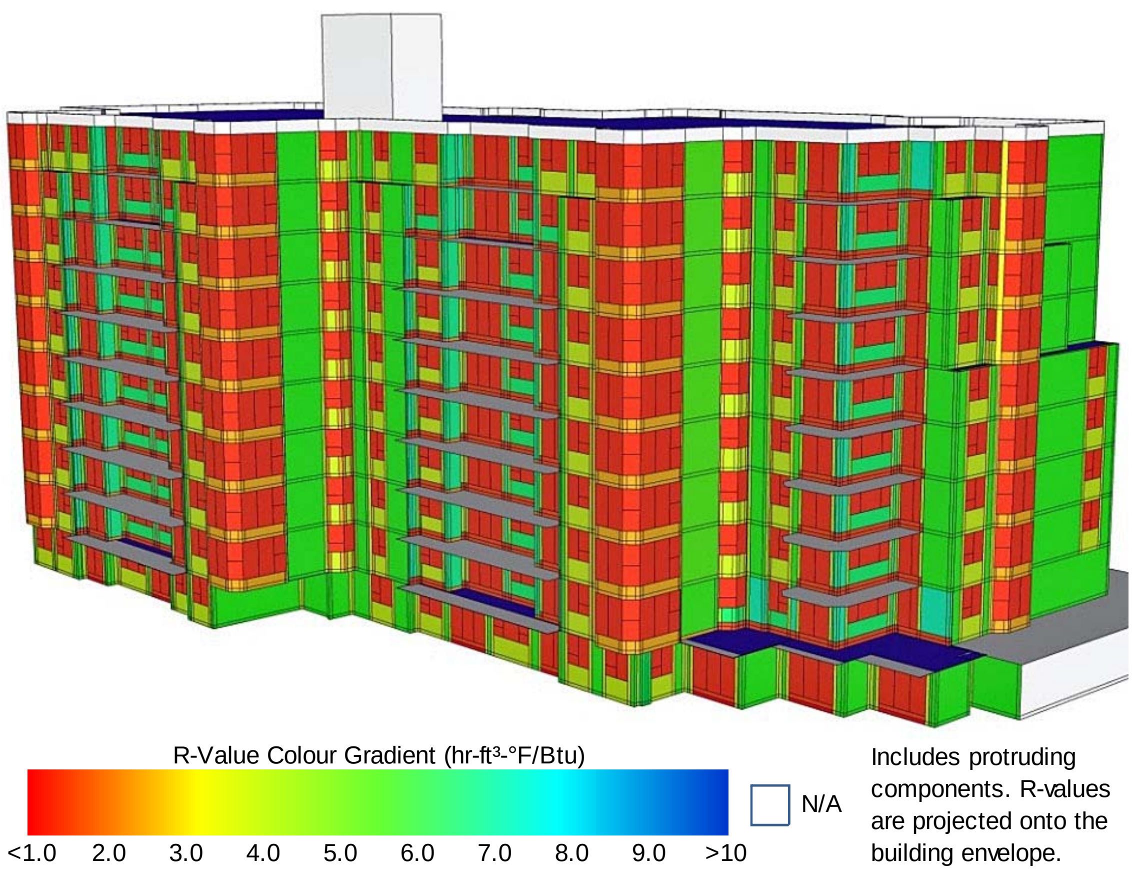

Figure 1. Sample Thermal Modelling of Existing Enclosure

Applying the overall wall, roof and window thermal performance values, we created energy performance models for each building. The models were created using an in-house Excel application (called FAST) developed by EnerSys Analytics for the local gas utility for the specific purpose of analyzing MURB energy performance. FAST facilitates the creation of DOE2.1e models using templates that account for all the major energy flows and sources in the building. The key simplification is with the enclosure by defining it using four major orientations and corresponding perimeter suite zones (set at any direction the user chooses), instead of defining every surface component for each suite. In tests on new designs with actual suite zoning and geometry applied versus this simplification, this compromise has resulted in less than a 1% difference in simulated energy use.

FAST was useful for this effort since it expedited the modelling and bill calibration process. Since it was developed specifically for MURBs, the results extracted from the DOE2.1e output are collated and presented for (1) the common meters and (2) the collection of suite meters. Hence, we could more accurately account for electricity use in particular since it was divided for the suites versus the rest of the facility (gas use was always recorded and billed from a central common meter).

Model calibration to electricity bills involved comparing the modelled monthly electricity use (kWh) for the suites to the normalized aggregate suite metered electricity use. Similarly, the common electrical energy use was calibrated using calendar and weather normalized billing data. Further, as electrical demand data was available for the common meter, it too was normalized and compared to the modelled demand for the corresponding common space. Calibration to gas bills only involved comparing the modelled monthly gas use to the corresponding normalized metered gas consumption.

Bill normalization first involved adjusting the billing data to align with calendar months. The calendar normalized billing data was then weather normalized to a typical heating degree day year to adjust for the effects of annual weather variances, applying linear and non-linear regression to determine a representative relationship between this energy and the heating degree day values. This was necessary to align the actual year of billing data with the typical meteorological year weather data (i.e., Canadian Weather for Energy Calculations, or CWEC weather files) used by the DOE2.1e simulation engine. The referenced paper by Hanam, S. et. al. and RDH Building Engineering Ltd. report further describe the calibration process.

Application of the information gained from the above exercise was utilized and applied to several new design projects. This provided guidance and an often eye-opening illustration of the relatively poor energy performance characteristics of typical MURBs in the market. Through the application of integrated design “Energy Performance Workshops” [Henderson], we helped optimize the energy performance of new MURB designs for three case studies. Applying life-cycle economic and energy analysis, these projects were useful to illustrate the improved performance levels MURBs can and should realistically attain.

3 Results

This section first presents key findings from the MURB Energy Consumption and Conservation report [RDH]. This provides a good backdrop for the ensuing results from the new construction case study modelling analysis, which characterizes the energy use patterns and indicators for several actual new designs.

Existing MURB Study: Utility Bill Analysis Findings

Starting with the utility bill analysis of the 39 MURBs, the average, weather adjusted metered energy utilization intensity (EUI) came out to 213 kWh_e/m^2 per year, with a range of

144 to 299 kWh_e/m^2. This corresponds to an average building configuration with 18 floors (ranging from 5 to 33 floors) and 11,023 m² of interior floor area (ranging from 2,412 to 19,593 floors). The number of suites equated to an averaged of 113 (ranging from 16 – 212), providing for an average of nearly 98 m² of gross floor area per suite. Based on a typical common area proportion of 10 – 20%, the direct suite area equates to about 83 m² per apartment (applying 15% for the common area allocation).

The metered energy use was almost evenly split between electricity (49%) and natural gas (51%). Based on regression analysis between weather data and monthly energy use from utility bills, an average of about 37% of the total metered energy was used for space heating. Of this, 69% of the space heating was met with gas-fired equipment (boilers, rooftop furnaces and fireplaces). Space heating from natural gas accounted for about half of the total natural gas use, with the rest dedicated mainly to domestic hot water (DHW)[2]. The remaining 31% of space heating energy use was allocated to electric baseboards, mainly located in the suites. At a site efficiency of 100% for the electric heating and a roughly 65% efficiency for gas-fired equipment[3], this infers that gas was used to satisfy about 20-25% of the total building heating load requirements.

It is interesting to note that seven of the eight worst performing buildings (i.e., with the highest EUIs), had gas fireplaces in most/all of the suites; this is out of a total of 11 buildings with gas fireplaces. The two buildings with hot water heating metered and supplied from central boilers were in the top third of worst performers. These findings support the relatively well known psychological influence of user pay pricing, where consumption is related to suite occupants directly paying for the energy they use. Gas use in the study buildings was centrally metered and billed to the strata. In contrast to electricity for which each suite tenant is charged, tenants were not directly billed for the gas they used for space heating. This presumably prompts them to conserve less and/or use gas fireplaces to offset electric baseboard usage.

From trend analysis of the study buildings, as well as new building analysis, space heating and overall energy consumption appears to be increasing. On average, newer MURBs used more energy than those constructed in the 1970s and 1980s. As the graph from the RDH report [RDH] presented in Figure 2 shows, gas used for space heating in particular shows an upward trend. Electricity for space heating has remained relatively constant, mainly because the overall thermal performance of the enclosure has not improved. Meanwhile gas use has increased with ventilation standards that have dictated providing increasing levels of mechanically introduce outside air. Finally, the use of gas fireplaces in newer buildings offset the electrical space heating.

---

[2] A small portion of the overall gas use may have gone to cooking, although recording this was not part of the study. This would have been relatively small given typical annual usage levels and assuming only about 25-30% of the buildings have gas for cooking (based on the portion of buildings with gas fireplaces, since the two typically are found together).

[3] Assumption for gas heating efficiency based on assuming a seasonal efficiency of 70% for boilers and rooftop furnaces, but reduced given 28% of the buildings had gas fireplaces that operate very inefficiently. Note that suite owners tend to operate gas fireplaces as much as possible since the cost for the gas is borne by the strata and not directly by the suite owner.

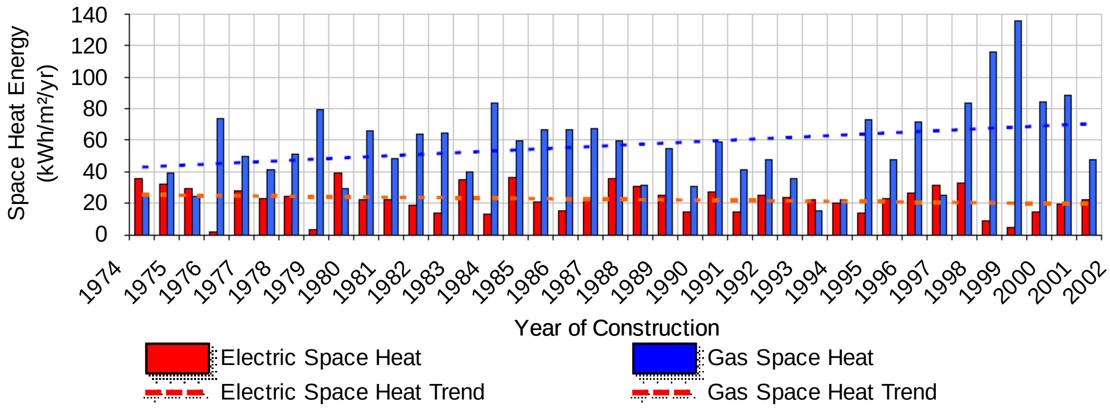

Figure 2. Space Heating Energy Trend by Construction Vintage [RDH]

Of the remaining electricity consumption not used for space or service water heating, an average of 35% of it was used in the suites for appliances, lighting, etc. The rest, representing about 40% of total electricity use on average, was allocated to common areas for ventilation fans, lighting, elevators, pumping, etc. As discovered for the subset of buildings that were further audited, modelled and calibrated to bills (see next section), the relative proportion of electricity allocated to the common meter varied dramatically between buildings, with a range of 23% to 67% of total building electricity use.

Existing MURB Study: Enclosure Performance Assessment

As previously described, a subset of buildings were identified for further detailed analysis. As these buildings required enclosure upgrades, it provided the opportunity to perform a combination of two- and three-dimensional heat transfer analyses on the overall gross wall (including windows) system.

The overall result from this analysis was that the opaque wall enclosure for the typical MURB had an effective R-value of only 0.69 m²-°K/W (3.9 hr-ft²-°F/Btu). For comparison, present Code in BC prescriptively dictates 1.95 m²-°K/W for "Mass" wall types to 2.75 m²-°K/W for "Steel-Framed" wall types (11.1 – 15.6 hr-ft²-°F/Btu). The main reasons for this deficiency stems from an abundance of thermal bridging from steel framing in walls to uninsulated floor, column and balcony penetrations.

The overall window performance for the subset equated to an average USI of 4.1 W/m²-°K (U_o-0.73 Btu/hr-ft²-°F). Present Code in BC prescriptively dictates a USIo of 2.6 – 2.7 W/m²-°K (U_o 0.46 – 0.47 Btu/hr-ft²-°F), but at a prescriptive limit of 40% – 50% vertical glazing. Note that for the metered sample, glazing only accounted for 34% of the gross wall area – a level few, if any, new high-rise MURBs get down to as most new high rises have at least 50% glazing or more.

For today's newly constructed MURBs, most designs will make use of better windows with at least low-e coatings, and walls next to conditioned spaces are often improved as well. However, the increased use of glazing and continued enclosure penetrations provide conditions where the gross wall system performs nearly the same or worse than the average indicators above. For instance, a very typical 60% glazed MURB with concrete and steel wall construction can commonly have wall/window systems with an effective USI_o of 2.0 W/m²-°K. This includes nominal R-20 batts between the steel studs – an insulation level that some practioners may feel is quite good and exceeds Code. In comparison, at the maximum 50% glazing the BC Code prescriptively references, the USI_o equates to about 1.6 W/m²-°K.

This example where the gross wall system provides for 30% higher thermal losses than prescriptively dictated by Code is very common in today's market. This highlights how there exists a large deficiency between the Code's prescriptive requirements and actual construction. However, some movement is being seen in the industry. The following section demonstrates how several new designs are taking steps to significantly reduce energy use in new MURBs.

Case Studies

The trends and indicators for how MURBs use energy, combined with past studies and experience, were applied to modelling total building energy use for three separate buildings representing new MURB designs. Additionally, a "typical design" is represented by one of the cases when it was in schematic design – prior to going through a significant redesign to reduce the glazing and improve the enclosure (Case Study 1). The following provides a general description of the cases:

- Typical Case: Conceptual design for Case 1, representing typical construction;
- Case Study 1: High-rise rental housing, concrete and steel construction;
- Case Study 2: High-rise student housing, concrete prefabricated construction;
- Case Study 3: Mid-rise low-income seniors housing, wood-frame construction.

Note that all cases employed electric baseboards for suite heating. In addition to this, Table 1 provides a listing of the key building characteristics.

Table 1. Key Characteristics Influencing Heating (all cases with electric baseboards for terminal heating)

	Case 1 Concept (Typical)	Case Study 1	Case Study 2	Case Study 3
Floor Area (m^2)	8,268	8,268	15,886	10,563
Number of Suites	110	110	431	140
Storeys	14	14	13	5
Common Space	11%	11%	17%	26%
Window Area	61%	46%	40%	29%
Overall Window USI	2.4	1.6	2.0	1.0
Overall Wall RSI	0.7	1.8	2.8	3.4
Infiltration (ACH)	0.37	0.37	0.18	0.30
MAU Source	Gas	Gas	Heat Pump / Gas	Heat Pump
Outside air ($l/s/m^2$)	0.63	0.63	1.04	0.63
Heat Recovery	N/A	N/A	60%	60%
DHW Source	Natural Gas	Natural Gas	Heat Pump / Gas	Natural Gas

Summary results from the DOE2.1e energy modelling are presented in Figure 3. As the figure shows, the EUI for the Typical Case is very close to the previously referenced study average at 210 kWh_e/m^2. Through simple enclosure improvements, the energy use may be reduced by about 26% to around 156 kWh_e/m^2, as exemplified with Case 1 where the reduction in glazing alone would have reduced the capital budget. Performance may be further improved with additional enclosure improvements and efficiency options applied to the make-up air units (MAUs) supplying fresh air to the building. Such measures were applied for Case 2 and Case 3, resulting in an EUI of 115 to 118 kWh_e/m^2.

The main source for these savings is in space heating, which was reduced by 40% for Case 1 and up to 76% for Case 3. Electricity use was reduced by as much as 27% (Case 1), but the majority of the savings were seen with gas use, which ranged from 25% for Case 1 to 83% for Case 3.

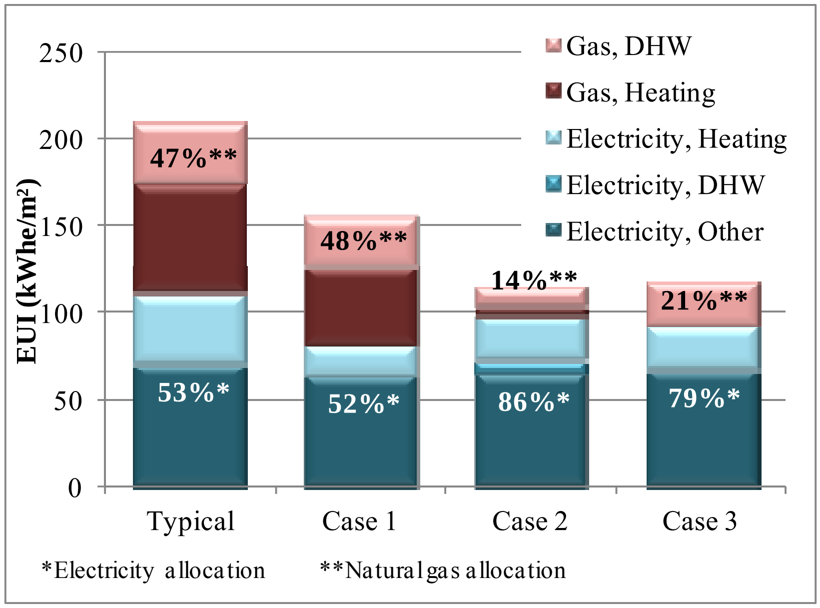

Figure 3. Case Study Energy Use Comparison

Case Study 1

As previously alluded to, *Case 1* began the design process as a typical highly glazed, concrete and steel stud building. But the developer's desire to improve the energy performance and the local development's green building standard influenced the design team to consider measures to improve the energy performance early in the design process. This was immediately manifested by reducing the glazing area by about a third and improving the wall system through reduced thermal bridging.

As the design progressed, life-cycle analysis further indicated that high performance triple pane glazing was cost-effective. It also proved cost-effective to narrow the steel stud thickness and pull them away from the exterior concrete wall, providing for a continuous two inch gap for spray foam insulation. Exposed concrete floor slabs and columns also were insulated (albeit, with some thermal bridging in the form of metal framing), leaving the relatively few balconies as the main area of thermal bridging that remained.

Further improvements to the interior and exterior lighting brought the overall energy use down by 26%, with heating energy being reduced by 40%. With the reduction in glazing, these savings were likely realized at a reduced capital cost, but we only completed life-cycle economic analysis for the triple pane glazing, wall system improvements and lighting measures. That is, the capital cost savings from reducing the glazing area was not included in the economic analysis. This design development bundle provided for a simple payback of 13.5 years with an internal rate of return of 11.5% over the 25 year analysis period.

Case Study 2

Case 2 was situated on a university campus that mandated high performance targets for all new designs. Hence, the design started with a high performance enclosure that included a relatively low amount of glazing and prefabricated structurally integrated concrete wall panels at a relatively high overall R-value (see Table 1). Being connected to another institutional facility, the MAU was served hydronically via a central heat pump system supplement via natural gas boilers. As is typical, MAUs delivered the fresh air to the corridors.

During the integrated design and modelling process, the design team evaluated dozens of strategies to cost-effectively improve the performance. The most significant energy saving measure included adding exhaust heat recovery. But this was also the most expensive measure since it involved ducting the fresh air from the MAUs directly to the suites and returning the exhaust back to the MAU. The measure was so expensive that it arguably was not cost-effective, in fact. However, the significant air quality and comfort improvements influenced the design team and owner to include the measure. This is a quite significant improvement, particularly since it is very rare for MURBs to have exhaust heat recovery.

Another significant and rarely implemented measure the design adopted was the use of sensors to shut off the electric baseboards when the windows are open. Evaluation of this measure was admittedly problematic, but even very conservative estimates on the reduction of infiltration proved the measure quite cost-effective (including an allowance for maintenance). While not recognized as a valid energy saving measure by programs such as LEED and the local electric utility, we feel this measure has a relatively high potential for savings. This is based on the observation on the number of windows left open for typical campus residences when in heating mode.

Other measures included improving the window performance, high efficiency elevators, corridor and suite lighting reductions, and use of waste heat coupled to the central heat pump system for DHW preheat. Roof insulation was actually *decreased* by two inches (R-10) as it was shown to be economically over-insulated. The net effect was a 41% reduction in energy use and 36% drop in the energy bills, resulting in a 13 year simple payback and a 12% internal rate of return over the 30 year analysis period. Compared to the Typical new design, energy use was 45% lower, with a 12% and 83% drop in electricity and natural gas use, respectively. Moreover, metered heating energy use ended up 69% lower than for the Typical case.

Case Study 3

Case 3 represents a retirement home for low-income seniors. As such, the suite heating requirements had an upward influence due to the need to maintain higher suite temperatures than is typical. With the original design employing wood frame construction (new to MURBs over 4 storeys in B.C.) and only 29% glazing, this helped reduce the suite heating load compared to the Typical Case. As with all Cases, the original design also provided for fresh air delivery directly to pressurized corridors via rooftop MAUs. The MAUs employed 80% efficient modulating gas-fired furnaces for tempering the fresh air.

During the energy and economic assessment of the schematic design, we explored at least 16 different efficiency measures. The most significant measure arguably involved providing for exhaust heat recovery added to the MAUs since the cost to return the exhaust back to the MAUs was significant (as with Case 2). The design team and owner, however, felt that the air quality and comfort improvements from directly ducting fresh air to the suites and reducing penetrations from individual suite exhaust was worthwhile, regardless of the cost-effectiveness based on only energy savings. Thus, only the cost associated with adding heat recovery to the central air system was applied for economic evaluation purposes.

Another significant measure that was proven cost-effective included the addition of high performance triple pane windows in low conductivity (non-metal) frames. Also, heat pumps were added to the MAUs (with gas backup), representing yet a third measure rarely seen in typical new MURBs but shown to be cost-effective. Combined with interior and exterior lighting measures, the optimization of the design identified further energy savings of 32% with energy cost savings of 21%. These saving were realized at a simple payback of 13 years and an internal rate of return of 11% over the 25 year analysis period.

Compared to the Typical new design, energy use was 44% lower, with electricity and natural gas use 17% and 74% lower, respectively. Metered heating energy use ended up 76% lower than for the Typical case.

Hydronic Heating Versus Electric Baseboards

Instead of electric baseboards, two of the Cases strongly considered using hot water to provide heating to the suites. For *Case 2,* the central MAUs were already hydronically served by a central heat pump and boiler plant. The design team considered expanding the boiler capacity to serve radiant heaters in lieu of the electric baseboards; the heat pump capacity was kept unchanged since no additional cooling capability was to be added. The hydronic heating configuration also included providing for zone control (e.g., thermostats separately controlling the bedrooms from the rest of the suite).

As expected, electricity use decreased significantly while gas use increased significantly, resulting in a slight net rise in metered energy. However, providing heat from the hot water source saved nearly $16,000 annually. This partly stemmed from the relative price of electricity at an average blended rate of 6.1 ¢/kWh versus natural gas at 3.4 ¢/kWh_e. Also, the savings was influence by (1) the partial heat pump system efficiently supplying heat at a relatively low unit cost (roughly 1.4 ¢/kWh_e) and (2) the supplemental boilers contributing heat from the relatively a inexpensive gas source (compared to electricity at the 100% efficiency of the resistance baseboards). The incremental capital cost for the hot water heating system was conservatively estimated at an additional $1.1 million (only about $2500 per suite – roughly half the typical cost we have seen and often referenced in the market). Also, an estimated annualized cost of $34,000/year was assigned for maintenance. This mainly was for repairing leaks as the developer's and builder's experience indicated that *at least* one significant, costly leak should be expected within the first few years of operation. Given these additional costs versus the savings, the suite hot water heating system would never pay back compared to the electric resistance heating.

Case 3 also investigated the electric baseboard heating being replaced by a hot water system that was comprised of central air-source heat pumps with gas-fired boiler backup. However, the heat pump capacity was sized for tempering of the MAUs supply air for cooling purposes, which resulted in it only serving about 20% of the peak hot water heating load. But even at this seemingly low contribution, the heat pumps were estimated to meet about half of the annual heating requirements. This included the heating requirements for the MAUs, as they also were converted from gas-fired furnaces (with DX cooling). Finally, the hydronic reconfiguration was to include Btu meters for facilitating the charging of heat to individual suite owners.

With the use of heat pumps offsetting electric baseboards in the suites and some of the natural gas use for the MAUs, net metered energy use was estimated to decrease by 17%. This resulted in an annual utility bill savings of nearly $25,000. However, at an estimated incremental capital cost of over $1.7 million, the internal rate of return over 25 years equated to -2.4%. And this did not include any provision for the risk of fixing possible leaks and related damage. Note the evaluation was applied to the baseline prior to any efficiency improvements that lowered the heating load, but in either case, the proposed hydronic conversion would be a net loser over its life.

Many planners and developments are mandating or considering the application of hot water heating for MURBs in B.C. – often in anticipation of the loads being served by district energy systems (DESs). In fact, there already exists several developments in which electric baseboards cannot be used for space heating. The hope is that DESs may deliver heat from waste, renewable and/or low carbon sources at a cost that would be more advantageous than providing heat from such sources directly at each building site. Hydronic heating provides for this possibility of utilizing such sustainable heat sources.

We fully support the utilization of such sustainable source as much as possible. However, the requirements on such DESs is significantly reduced if the building heating loads are lowered. As illustrated with the case studies, space heating loads can be effectively reduced very significantly, which potentially may make the business case for a new DES or DES extension more problematic. Within this effort, we have not attempted to analyze the economic implications and trade-offs on how reducing building heating loads impact the viability of DESs, but only wish to highlight how both the demand and supply sides need to be fully taken into account. It is not apparent that policy makers and planners are fully weighing the costs, risks and realities of setting policies centred on DES connections versus approaches that reduce loads at a comparably lower life-cycle cost.

4 Conclusion

In a recent study, energy performance levels in relatively new high- and mid-rise MURBs within the Vancouver and Victoria metropolitan regions were analyzed and found to use an average of 213 kWh_e/m^2 per year. This is higher than expected based on other studies and even in comparison to single family homes, which annually use 131 kWh_e/m^2 in the Lower Mainland region of BC [BC Hydro 2011]. The energy use per household is about 38% lower for single family homes than for high-rise MURBs, but we would expect an even larger disparity. Single family homes have over 60% more gross floor area and even more proportional exposure. Further, a national Canadian survey indicates that MURBs only use about 8 – 10% more energy than single family homes [NRCan 2006]. But existing high-rise MURBs in the relatively mild major population regions of British Columbia appear to be over 60% more energy intensive on a floor area basis than comparative single family homes in the same region.

Further, our energy analysis of some recent high-rise designs indicate that this is not improving much, if at all, particularly considering the adoption of new energy codes (in 2008) and increased focus on sustainability. In fact, in some aspects, energy consumption has increased. For instance, suite heating loads in many cases are higher now due to ever increasing amounts of glazing and the application of exposed concrete construction practices that result in wall systems that have relatively poor thermal characteristics. Further, new MURBs have significantly higher heating requirements associated with providing more outside air due to the application of new ventilation standards.

A few new designs, however, are making strides toward effectively reducing energy use. From the case studies highlighted in this paper, heating may be significantly reduced. This does come at an additional capital cost, but proves to be cost-effective, especially if a modest value is applied toward associated improvements in air quality and comfort. Ironically, heating loads might be reduced significantly enough to dampen the potential sustanability benefits of providing for more expensive suite hot water heating in comparison to more traditional electric baseboard heating.

5 Acknowledgements

Many findings presented in this paper are from a collaborative research study [RDH, 2011] sponsored by BC Hydro, Fortis BC (formerly Terasen Gas), the City of Vancouver, Canada Mortgage and Housing Corporation (CMHC) and the BC Homeowners Protection Office (HPO).

6 References

BC Hydro, 2011. *2011 Estimate for Post-1976 Gas and Electrically Heated Homes in Lower Mainland of BC.* Vancouver, BC, Canada. BC Hydro.

Blocon. 2005. HEAT3 Computer Software.

Compass Resource Management Ltd., November 2008. "Costs and Benefits of Energy Efficiency Measures for High Rise Multi-unit Residential Buildings and Rowhouse Units in Surrey, B.C." for The City of Surry, BC. Vancouver, BC, Canada. Compass.

EnerSys Analytics Inc., March 2004. *High-Rise MURB Sensitivities on ASHRAE 90.1-2001 Shell Compliance.* Internal review exclusively for City of Vancouver. Coquitlam, BC, Canada. EnerSys.

EnerSys Analytics Inc., March 2007. *User's Manual: Facility Analysis and Simulation Tool: A Building Energy and Economic Analysis Software.* Internal manual and archetype definition document exclusively for Terasen Gas, including Appendix on archetype energy management options. Coquitlam, BC, Canada. EnerSys.

Hanam, S., G. Finch & C. Hepting, May 2011. *Meter Calibrated Energy Simulation of High Rise Residential Buildings: Lessons Learned.* Canadian Conference on Building Science and Technology. Winnipeg, Manitoba, Canada.

Henderson, G., Hepting, C., Ehret, D., June 2001. "Real-World Integrated Design Practice and Tools: Effective Energy Performance Analysis Approaches," eSim 2001 conference proceedings. Ottawa, Canada.

Hepting, C., December 2011. "Summary Review Assessment of Energy Performance Codes: ASHRAE 90.1-2004, 90.1-2010 and NECB for British Columbia" study for BC Hydro. Coquitlam, BC, Canada. EnerSys.

Hepting, C., Yeoh, R., February 2004. "Life-Cycle Economic Assessment of ASHRAE 90.1 Applied to British Columbia" study for Province of British Columbia. Coquitlam, BC, Canada. EnerSys.

Lawrence Berkeley National Laboratories (LBNL), 2003. THERM 5.2 Computer Software.

Mattock, C., September 2008. "Final Report for a Design Charrette Held to Explore the Energy Efficiency Opportunities for the Essence of White Rock Multi Residential Building" for The Province of British Columbia. Vancouver, BC, Canada. Habitat Design + Consulting Ltd.

Mattock, C., December 2009. "Final Report for a Design Charrette Held to Explore the Energy Efficiency Opportunities for the Hudson Mews Multi Residential Building" for The Province of British Columbia. Vancouver, BC, Canada. Habitat Design + Consulting Ltd.

NRCan, 2006. Survey of Household Energy Use (SHEU), Detailed Statistical Report – 2003 Data. Ottawa, Canada. Natural Resources Canada (NRCan), Office of Energy Efficiency.

RDH Building Engineering Ltd., 2011. Energy Consumption and Conservation in Mid and High Rise Residential Buildings in British Columbia. Vancouver, BC, Canada. RDH.