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Technical Series

Energy Simulations of Strategies to Achieve Low-Energy, Multi-unit Residential Building Designs in Different Regions of Canada

INTRODUCTION

While single-family, detached residences have made significant gains in energy efficiency and environmental performance in Canada over the years, improvements in the multi-unit residential building (MURB) sector have not advanced as far.

In contrast, low-energy MURB projects are becoming more prevalent in Europe, mostly thanks to regulations and high costs of energy. Passive House, a voluntary energy efficiency certification and labelling system, is one program that helps designers, developers and property owners to construct buildings that consume very little energy. Its stringent energy targets limit the overall energy consumption of certified buildings to 120 kWh/m² per year, with space heating not exceeding 15 kWh/m².

While international examples of low-energy housing are useful, Canada Mortgage and Housing Corporation (CMHC) initiated a study that used building energy consumption simulations to examine how similar levels of energy performance could be achieved in Canada, given its significantly colder climate, existing design practices, building codes, and its readily available technologies.

METHODOLOGY

For this study, conceptual, or archetypal, energy models of MURBs were developed for six regions in Canada:

- British Columbia West Coast (Vancouver)
- British Columbia Interior (Kelowna)
- Alberta (Edmonton)
- Southern Ontario (Toronto)
- Southern Quebec (Montréal)
- Atlantic Canada (Halifax)

The initial “base” model had envelope; electrical; and heating, ventilation and air conditioning (HVAC) characteristics set to meet or exceed the 2011 National Energy Code for Buildings (NECB 2011) requirements for each region. Different energy efficiency technologies were then applied to reduce the annual space heating load to Passive House design levels (that is, heating requirements less than or equal to 15 kWh/m²). This led to the development of specifications that illustrate the extent to which the design of MURBs would have to change to achieve very low levels of energy consumption. The following subsections discuss these steps in greater detail.

Baseline model

The baseline model included features that met or exceeded the NECB 2011 minimum requirements.[1] The model had the following common characteristics:

- ten-storey, concrete-and-steel high-rise with a total floor area of 4,000 m² (excluding the below-grade, 1,600-m² parking levels);

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[1] While the Building Energy Performance Compliance Path (Part 8) of the NECB 2011 is the most lenient means of demonstrating compliance, the trade-off method for the envelope and prescriptive compliance for other components were used for simplicity.

- apartments representing 85% of the conditioned floor area, with 50 suites each averaging about 68 m^2 and all having a balcony;
- insulation levels set to comply with the NECB 2011 via the simple trade-off method, as direct prescriptive compliance typically would not be practical (for the floor and walls, in particular) given the targeted energy performance;
- windows at 30 to 35% of the gross wall area (while the MURBs built in many regions typically exceed this level, smaller, well-placed glass area allows ample access to views, daylight, and solar gains to offset space heating energy loads; further, such glazing levels already have acceptance in the low-rise MURB market);
- double-pane, low-e windows with argon fill and warm edge spacers in thermally broken metal frames (except for Edmonton, where frames were fiberglass in order to comply with the NECB 2011);
- infiltration at an average of 4 air changes per hour (ACH);
- fresh air delivered to suites via in-suite heat recovery ventilators (HRVs) at a rated effectiveness of 0.70, but with defrost/bypass limiting recovery during cold conditions (note that in-suite HRVs are not standard practice and go beyond the NECB 2011 requirements for climate zones 4 to 6);
- ventilation to common areas provided via a 100% outside air to corridor air units, without heat recovery;
- space heating provided via hot water served by a gas-fired boiler plant.

Analysis of low-energy strategies

After the baseline NECB-compliant archetype model was established, strategies to attain a targeted 15 kWh/m^2 of space heating load (as per Passive House guidelines) for each of the MURB archetypes in each of the regions were developed.

Because the purpose of this study was to determine viable ways of achieving low-energy consumption for MURBs in Canada, technologies and practices that are readily available to the market were applied to the baseline models. The exercise included the development of illustrative cost estimates and life-cycle economic analysis of applicable measures. The energy efficiency measures (EEMs) were first modelled individually, and then bundles of EEMs were created to meet the energy performance targets.

FINDINGS

Envelope strategies

In order to have a low heating load, the building envelope must minimize heating losses. One way to do that is to superinsulate buildings. Tactics to reduce heat losses were developed with consideration given to market availability, practicality and cost-effectiveness.

Exterior walls: Conductive heat losses occurs in insulated sections through thermal bridges such as structural elements, framing and fasteners that penetrate the insulation system, and “linear” heat losses occur at window, floor, and roof junctions. To maximize the efficiency of the wall, it was necessary to opt for a construction that could hold a significant amount of insulation, minimized both linear losses and thermal bridging, and was airtight. The low-energy wall assembly developed included 125–150 mm (5–6 inches) semi-rigid exterior insulation secured with non-conductive clips and interior spray foam insulation. The wall system had no spandrel panels and reduced the balcony connection-related thermal conductivity by half. Non-conductive window frames and connections reduced the linear losses even further. When fully accounting for thermal bridging and linear losses, the wall system had a thermal resistance of RSI-4.5 (R-26) to RSI-5.4 (R-31), with the RSI-5.4 applied to the walls of the buildings located in the colder climates. Note that this wall system, with the overall thermal resistance nearly the same as the nominal RSI-value of the insulation, is very high-performing compared to typical market practices.

Including interior spray foam insulation not only helped to improve the wall’s thermal resistance, it also permitted adjustments to the energy model to reflect improved the airtightness. Better airtightness both reduced the infiltration and improved the overall performance of the heat recovery systems.

Roof: The roof construction assumed for all regions was a typical concrete or metal deck roof with continuous rigid insulation and no significant thermal bridging. The low-energy roof system's thermal resistance generally was improved above that of the baseline, although for the mildest climates, it did not make sense to increase the RSI-values above levels required to meet the NECB. For the colder climates, however, the roof RSI-value was increased to as high as RSI-9.1 (R-52). The lowest roof thermal resistance was maintained at RSI-5.6 (R-32). As was the case for most measures, adding extra roof insulation did not prove to be cost-effective if the buildings were heated using natural gas, but was cost-effective if heated via electricity.

Floor: The baseline construction for the floors above the parkade consisted of spray foam insulation below the concrete slab, with no significant thermal bridging. Note that the parkade was modelled to be heated to just above freezing in all cases except the two British Columbia locations. The floor insulation was increased in most cases—but only slightly, since adding extra insulation saved very little energy. Moreover, the incremental capital costs began to accelerate as the thickness increased since the below-grade parkade height would need to be increased and, at some point, a different construction approach might be required (for example, a deeper soffit to house the thicker insulation).

Windows: Windows let in beneficial sunlight, which warms spaces, but they are a prime source of heat loss. In fact, the heat losses through the windows far exceeded the *combined* heat losses for the rest of the opaque envelope, even though they accounted for approximately one quarter of the overall building envelope exposure area. Hence, reducing the window area to save on the heating load was investigated. For the baseline, reducing the window area made a noticeable difference. However, the difference dampened significantly when applying higher-performing (lower USI-value) windows, especially if they still allowed in relatively high levels of beneficial solar energy offsetting space heating loads. Therefore, the window-wall ratio of 30 to 35%, was retained for the low-energy case, even though lowering the amount of glazing usually is an effective energy conservation strategy.

Because the window percentage was kept at the baseline level for the low-energy models, it was necessary to improve the window performance through changes to the framing and glass type to reduce heat losses. The windows modelled for the low-energy buildings included fibreglass frames. Fibreglass frames, which improve the window USI-value by roughly 30% or more over aluminum frames, are available from many manufacturers, and meet the necessary fire codes associated with high-rise construction.

The analysis also evaluated replacing the double-pane units by high-performance, triple-pane units with a relatively high solar heat gain coefficient. The impact of installing quadruple-pane windows with fibreglass frames was also examined. Quadruple-pane windows are much more costly but are available from several manufacturers in North America. Note that, while quad-pane windows were not cost-effective in comparison to triple pane units, they reduced the heating load noticeably in the colder locations. Therefore, quadruple-pane glazing was included in the final low-energy case for all regions except Vancouver, where triple-pane windows were adequate to reduce heat losses given the milder climate.

Ventilation strategies

The baseline building model included heat recovery ventilation via in-suite HRVs. While this approach to ventilation is not common in MURBs, it is needed to meet the NECB for at least climate zones 7 and 8. Therefore, the analysis maintained this approach for other locations for consistency, and because it represented good practice.

Heat recovery for the corridor air unit was the first consideration for saving energy associated with conditioning outside air. This would require the provision for a return or exhaust air duct to return air back to the corridor air HRV.

Space heating strategies

Heating with electricity is much more expensive than with natural gas—especially for Edmonton (Alberta), where the equivalent price of electricity was over six times that of natural gas. However, the capital cost to install, maintain and replace electrical resistance heating systems can be much lower than for fuel-fired systems. The Passive House approach is based on reducing space heating loads such that very little energy is necessary to provide heat. This makes it possible to consider the application of electric baseboard space heating, as it has much lower capital and life-cycle costs than fuel-fired systems. The capital savings can then be applied to significantly improving the performance of the building envelope and the energy efficiency of the mechanical system. This, in turn, helps to reduce the operating cost penalty associated with higher electricity costs in most regions of Canada, in comparison with natural gas. While this did not quite materialize economically for the low-energy design for Edmonton, it did prove to be the case for locations with lower heating requirements and electricity prices that were closer to that of natural gas.

Table 1 summarizes the building characteristics needed to achieve the targeted low-energy performance for each region.

RESULTS

As might be suspected, the archetypal MURBs located in milder climates had lower space heating loads than those in colder climates, both for the NECB 2011 baselines and for the designs that incorporated the low-energy strategies targeting Passive House energy performance. Figure 1 shows a comparison of the space heating loads calculated for each region for the base and low-energy designs.

All of the low-energy designs saved a significant amount of heating energy compared to the base NECB 2011 designs— with savings from 76% to 84%. However, only the buildings located in Vancouver and Kelowna were actually able to meet the targeted Passive House 15 kWh/m² threshold, which is shown as the green line in Figure 1.

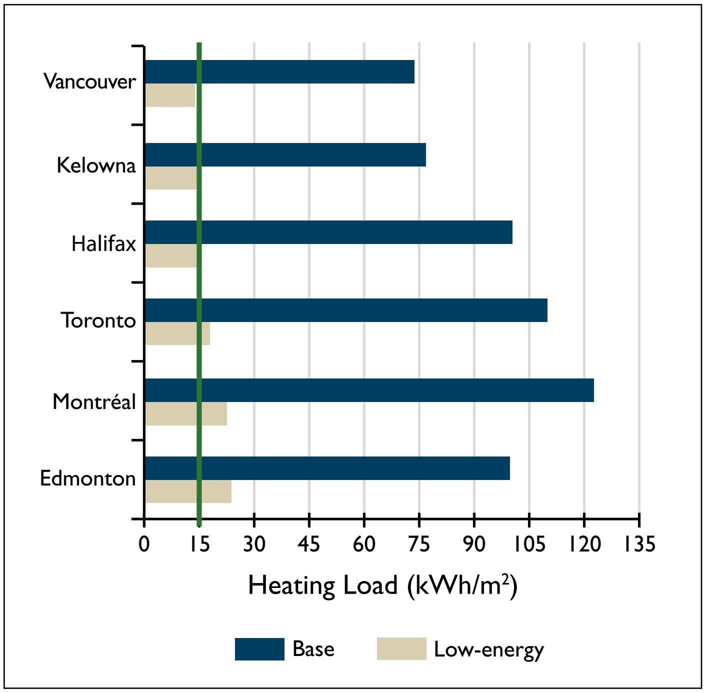

Figure 1 Space heating loads by region

Table 1 Regional characteristics for low-energy MURBs

Component	Vancouver	Kelowna	Edmonton	Toronto	Montréal	Halifax
Wall thermal resistance	RSI-4.5	RSI-4.6	RSI-5.4	RSI-5.4	RSI-5.4	RSI-5.4
Additional linear losses through walls	17%	15%	14%	14%	14%	14%
Roof thermal resistance	RSI-5.6	RSI-6.9	RSI-9.1	RSI-7.4	RSI-9.1	RSI-8.3
Floor thermal resistance	RSI-4.6	RSI-4.6	RSI-4.6	RSI-4.6	RSI-4.6	RSI-4.6
Window percent	35%	30%	30%	30%	30%	30%
Window conductance	USI-0.91	USI-0.91	USI-0.68	USI-0.68	USI-0.68	USI-0.68
Window SHGC	0.55	0.55	0.39	0.39	0.39	0.39
Natural infiltration (ACH)	0.1	0.1	0.1	0.1	0.1	0.1
Heat recovery effectiveness	0.70	0.80	0.80	0.80	0.80	0.80

Source: EnerSys Analytics Inc.

Table 2 expands upon the results shown in Figure 1 and provides the total metered kWh/m² for the buildings in each region, as well as the cost-effectiveness of the low-energy designs in terms of life-cycle cost payback period and internal rate of return. While the modelling showed that the low-energy designs had high life-cycle cost payback periods for Edmonton and Toronto, these designs proved more cost-effective for the other regions.

The reason the low-energy design was not estimated to be as cost-effective in Edmonton and marginal for Toronto was mainly due to their relative natural gas and electricity rates. The electricity rates used in the assessment for Edmonton and Toronto were 6.4 and 4.4 times higher than the equivalent gas rates; the next highest ratio was for the British Columbia locations at 3.5 to 1. Hence, switching to a cheaper electric resistance heating system and slashing the heating requirements largely appeared cost-effective depending on the relative utility rates (not just the absolute rates). From this assessment, it generally could be inferred that the low-energy cases became cost-effective when the marginal electricity prices fell below roughly four times the respective natural gas prices (in consistent units of measurement).

CONCLUSIONS

In Canada, targeting reductions in the space heating load is key to achieving low-energy use buildings. Based on the results of the building energy simulations and analysis, it appears possible to significantly reduce the space heating requirements of newly constructed MURBs through the application of available technologies and design practices.

The results also tend to support the financial viability of making higher capital investments in energy-saving features in order to reduce longer-term life-cycle costs.

IMPLICATIONS FOR THE HOUSING INDUSTRY

This research project helps to establish the characteristics of multi-unit residential buildings that would have to be delivered in order to achieve high levels of energy performance. The insulation and airtightness levels and mechanical system efficiencies are technically possible but nevertheless would represent a significant departure from current MURB design and construction practices.

Table 2 Regional energy and economic indicators for low-energy MURBs

Location	Heating load (kWh/m²)		Total energy (kWh/m²)		Economic results*	
	Base	Low-energy	Base	Low-energy	Payback Period	Internal rate of return
Edmonton	99.8	23.8	234.9	141.1	>30 yrs	N/A
Montréal	122.7	22.5	263.4	140.2	6.7 yrs	20.3%
Toronto	109.9	17.9	239.1	127.0	>30 yrs	5.5%
Halifax	100.4	15.7	223.0	120.4	8.2 yrs	17.1%
Kelowna	76.9	14.4	185.3	110.8	10.4 yrs	13.2%
Vancouver	73.7	13.9	176.7	106.4	11.7 yrs	8.1%

*30-year analysis based on 5% discount rate, 2% inflation and 3% energy cost escalation.
Source: EnerSys Analytics Inc.

CMHC Project Manager: Woytek Kujawski

Consultant: EnerSys Analytics Inc.

Housing Research at CMHC

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or contact:

Canada Mortgage and Housing Corporation
700 Montreal Road
Ottawa, Ontario
K1A 0P7

Phone: 1-800-668-2642
Fax: 1-800-245-9274

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