RESEARCH HIGHLIGHT

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Impact of Architectural Form on the Potential Energy Performance of Multi-Unit Residential Buildings

INTRODUCTION

The basic architectural form of multi-unit residential buildings (MURBs) is defined by floor plate (or plan) geometry and building height. The building envelope (windows, walls, roof and foundation) encloses the form and separates the interior environment from the exterior. Balconies and other features may also contribute to the architectural form of a building. Architectural form not only has an impact on space conditioning (heating and cooling) energy use but also determines the availability of roof and wall areas for solar energy collection.

Considered individually, the impact of the aforementioned elements of architectural form on space conditioning energy consumption is relatively well understood. However, when considered collectively, the impact is more difficult to anticipate. For instance, the interrelationship between building height and floor plate geometry and resultant energy use and solar energy potential is not always readily apparent. The thermal characteristics of wall and window areas of the building envelope, as well as the relative proportion of window area to wall area, can have a significant impact on the annual heating and cooling loads of buildings. While solar heat gains through window glazing can be beneficial in reducing heating loads during the heating season, they can also impose excessive cooling loads during the cooling season. The overall area ratio between opaque walls and the windows also has a significant effect on the “whole wall” thermal and solar heat gain performance and impacts the available facade area for solar energy collection. MURBs also frequently have balconies to provide outdoor living space. Depending on how balcony features are attached to the main building structure, the resultant thermal bridging effects can lower the effective thermal performance of the overall envelope. However, during the summer months, balconies can provide shading to fenestration areas beneath them, thereby reducing solar heat gains through the glazing and reducing the resultant building cooling loads.

How each of these individual parameters impacts the energy performance of a MURB is reasonably well understood; what is less understood, however, is how they all interact with one another and impact space conditioning energy use and solar energy generation. To better understand these interrelationships, CMHC initiated a research project to assess the relative impact of architectural form and envelope parameters on the energy performance and potential for solar energy collection of multi-unit residential buildings.

METHODOLOGY

This research study used computerized hourly building energy consumption modelling to assess the impact of the investigated parameters (table 1) on heating and cooling loads. Several thousand modelling simulations were conducted (using Toronto, Ontario, as the site location), investigating unique combinations of building architectural form (figure 1) and envelope parameters (figure 2). The results were then analyzed to identify trends in how the design and characteristics of architectural form and envelope parameters can impact annual heating and cooling loads. In addition, the impact of architectural form and envelope options on the potential for accommodating solar energy collection on either the roof areas and/or sun-facing opaque wall areas was assessed for both photovoltaic and solar thermal (for domestic water heating) systems.

The simulations modelled buildings of differing floor plate geometries and numbers of storeys, which resulted in differing gross floor areas. In order to compare the results, the heating and cooling loads were normalized by the floor area of the building, reporting values in energy use per unit of area of the building (that is, annual heating and cooling load intensities). This facilitates the comparison of buildings of differing total sizes and numbers of suites and occupants). The renewable energy potential results were calculated for their absolute output (for example, MWh) and also normalized against the building gross floor area—a factor that does not influence the performance of the renewable energy system. However, normalizing the renewable energy system output to the building floor area provides context when comparing the building heating/cooling loads against the renewable energy potential.

The annual heating and cooling loads are defined as heating or cooling energy (in watt-hours per square metre of conditioned building space) that is required to be supplied to the conditioned space by the heating or cooling system. It does not include the conversion efficiency (for example, boiler efficiency) or ancillary energy (for example, pumps and fans) required by the systems to deliver the heating and cooling to the conditioned space. It should not be confused with peak or design day loads, which are instantaneous values used to size space conditioning systems, or with annual energy consumption, which includes conversion efficiencies.

Table 1 Architectural Features Used in This Study

Architectural features to investigate	Details
3 MURB sizes	Low-rise, 3-storey Mid-Rise, 5-storey High-Rise, 10-storey (and up)
5 building floor plates	Bar-shaped (single, double-loaded corridor*) – 0 deg and 90 deg rotation Square (single-loaded corridor*) – no rotation required L-shaped (two double-loaded corridors,** that is, two bar-shaped buildings) – 0, 90, 180 and 270 rotation H-shaped (two double-loaded corridors** joined by a third that is, three bar-shaped building joined together) – 0 and 90 deg rotation U-shaped (similar to H-shaped) – 0, 90, 180 and 270 deg rotation
3 wall RSI-values (including effects of thermal bridging)	RSI 1.5, for example, brick facade with cavity wall, insulated steel stud cavity RSI 2.3, for example, brick facade with cavity wall, insulated stud cavity and exterior insulation between facade and exterior wall RSI 0.8, for example, window wall construction with insulated spandrel
6 window performance levels (U-value and SHGC combination)	Double-glazed, high solar gain, low-e, argon gas filled Double-glazed, low solar gain, low-e, argon gas filled Double-glazed, high solar gain, low-e in cavity and low-e on exposed interior surface, argon gas filled Double-glazed, low solar gain, low-e in cavity and low-e on exposed interior surface, argon gas filled Triple-glazed, high solar gain, low-e, argon gas filled Triple-glazed, low solar gain, low-e, argon gas filled
3 window-to-wall ratios	30% / 55% / 90%
3 balcony configurations	No balcony Cantilevered concrete balcony Thermally broken balcony

* A single, double-loaded corridor refers to a floor plate with a single corridor per floor with the residential suites located on either side of the corridor.

** Two double-loaded corridors refer to a floor plate with two corridors per floor with the residential suites located on either side of the corridors.

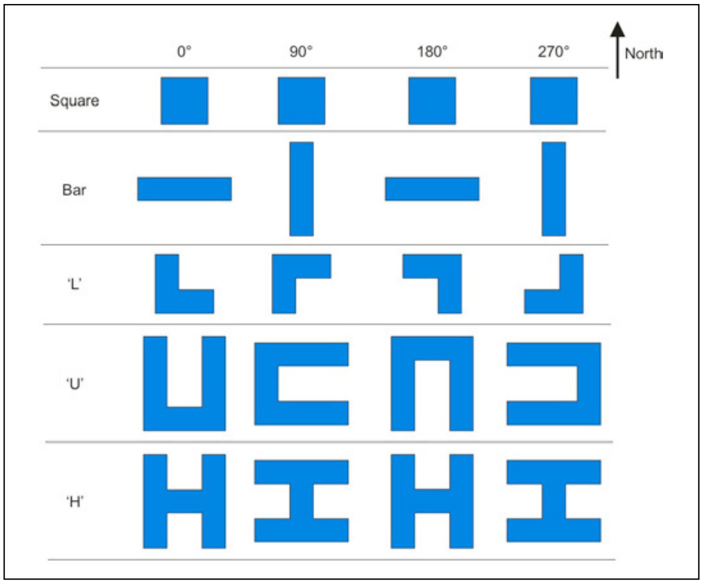

Figure 1 Building Floor Plates and Orientations Investigated

CONCLUSIONS

The study determined that several key architectural form parameters can result in significant reductions in annual heating and cooling load intensities. Floor plate geometry and building orientation were typically found to have very minor impacts on heating loads (that is, the results of the simulations of the impacts of different plate geometries and orientations on heating loads were always within close range of one another), and slightly bigger impacts on cooling loads. However, the overall combined building envelope factors, including wall insulation value, window U-value and window solar heat gain coefficient (SHGC) performance, and the window-to-wall ratio (WWR) have much greater impacts on heating and cooling loads than other factors (figures 3 and 4). So while the designer's initial decisions concerning the floor plate geometry and orientation can and will affect the potential energy performance of the building, the overall thermal performance of the envelope (including the WWR) remains the most important factor to consider when designing to minimize heating and cooling energy loads.

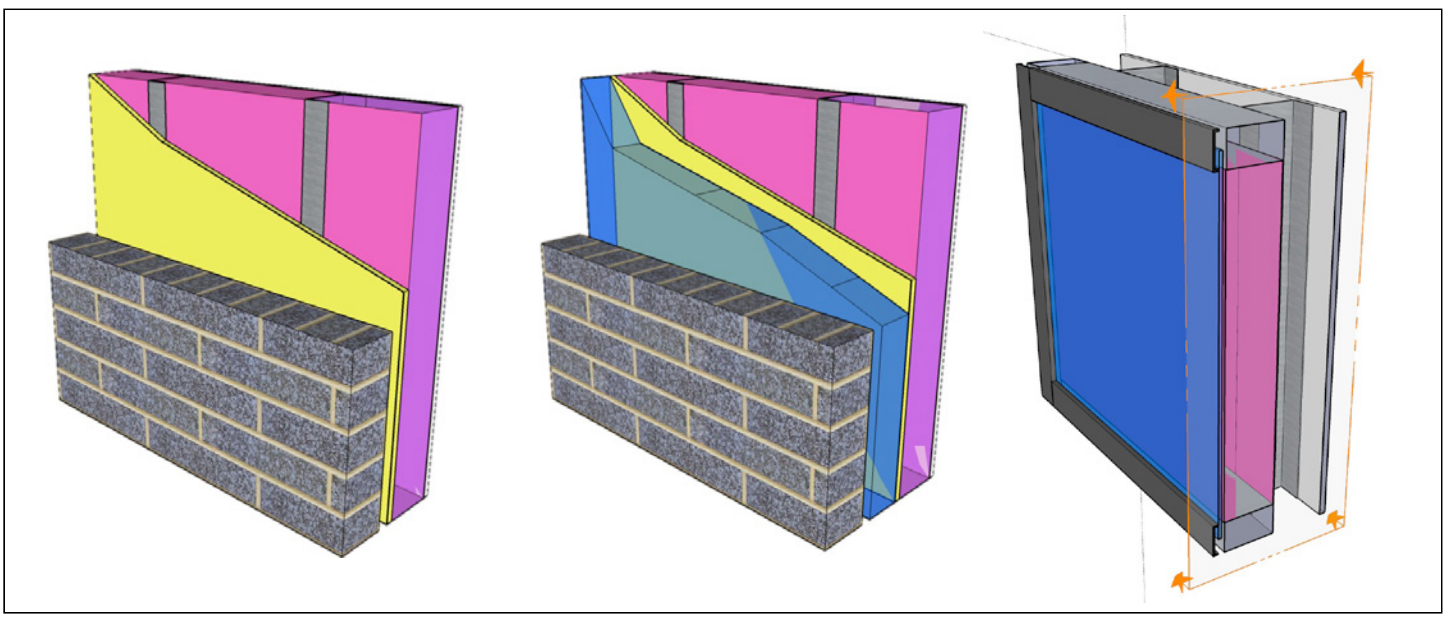

Figure 2 Wall Details Investigated

The study indicated that there were no preferred combinations of architectural form (floor plate, orientation and number of floors) for any of the envelope parameters. The impacts on the heating and cooling loads from the various envelope parameters—including wall construction (RSI-value), windows (U-value and SHGC), WWR (overall solar gains and overall wall/window thermal conductance) and balconies (wall RSI-value and solar gains into the building)—were found to be relatively independent of the building geometry.

Not surprisingly, the best-performing envelopes with respect to the heating load utilized a low WWR (30 per cent), well-insulated walls and triple-glazed windows with high solar gain, low-e glazing. To minimize the summer cooling loads, triple-glazed low-SHGC, low-e windows could be used; however, this would sacrifice a significant amount of passive solar heat gains, leading to higher heating loads.

Buildings having a "courtyard" floor plate (the 'U' and 'H' floor plates) experience slightly reduced heating loads and significantly reduced cooling loads compared to the more commonly employed 'Bar' and 'Square' geometries. In this study, 'L'-shaped floor plates were found to generally perform the poorest, as they tend to have the highest heating and cooling loads when normalized by floor area. While the orientation of each floor plate had little effect on the heating loads, a significant reduction in cooling loads was observed when orienting the 'U'- and 'H'-shaped buildings with the courtyards facing east or west.

The number of storeys in the buildings had a greater impact on the annual heating load intensity than either the floor plate or orientation of the building. Maximizing the number of storeys (that is, 10 storeys for the purpose of this study) showed a reduction in total load intensity approaching 20 per cent, with the large reduction of the heating load outweighing the increase in the cooling load. Reduced annual heating load intensity is due to the fact that, as the building increases in height, vertical envelope area (and thus heat loss) increases proportionally; however, the roof and floor slab areas (and heat loss) remain constant.

With respect to solar potential relative to building height, shorter buildings are optimal for both solar thermal domestic hot water (DHW) and photovoltaics (PV), in terms of energy production per unit of floor area, on account of the higher ratios of roof area to total conditioned floor area.

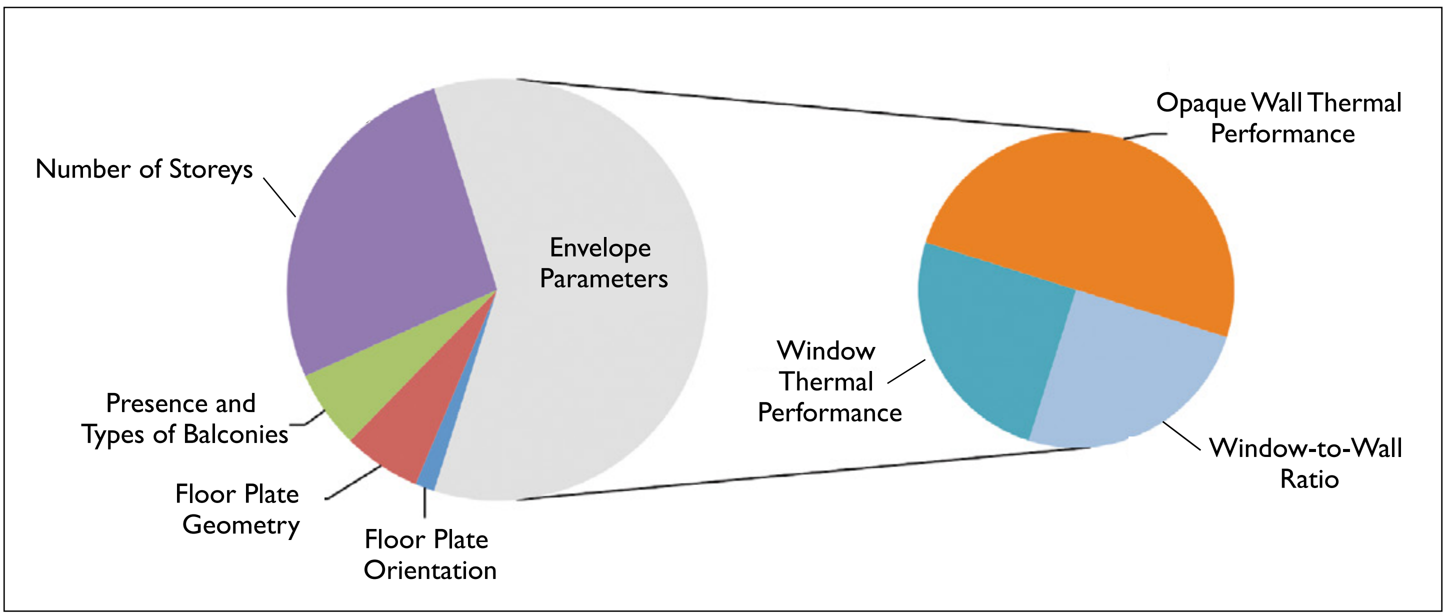

Figure 3 Relative Impact of Architectural Features on Heating Loads

This is in contrast to higher buildings having reduced annual heating load intensity, while at the same time increased annual cooling load intensity. Overall building designs targeting "net zero" site energy will need to seek a balance between building height and a larger floor plate (such as the 'H' and 'U' floor plates) to optimize the renewable energy potential. Further, the WWR has a significant impact on the available opaque wall area upon which to install vertical photovoltaic solar collectors—a higher WWR results in higher heating loads and lower solar energy potential because of an increase in window area over wall area.

Balconies can act as a shading device; however, depending on how the balcony slabs are attached to the main building structure, their (potential) thermal bridging can reduce the effective RSI-value of the surrounding wall system. The increase in heating loads due to the thermal bridge effect of the balconies is among the smaller effects investigated in this study (increases between 4 per cent and 8 per cent in heating load, depending on the WWR). However, when a balcony creates a thermal bridge, it will have a greater relative impact (that is, increase) on the heating load than the overall wall system (opaque walls and windows) RSI-value. This means that, with higher-performance envelopes, the thermal bridging due to the balconies matters and should be minimized by either using thermal breaks between the balcony slab and the building structure or limiting the length of the balconies. As balconies reduce annual cooling load intensity thanks to their shading effect, any measures that can reduce their adverse impact on heating loads would be beneficial.

The overall relative impacts of the architectural features on the heating loads and cooling loads are depicted in figures 3 and 4, respectively. The larger areas represent those elements that have a greater impact on heating and cooling loads and therefore warrant more attention at the design stage. For example, as can be seen in the figures, the envelope parameters (WWR, thermal performance) are the most important factors to consider with respect to controlling the annual heating and cooling load intensities of buildings. The number of storeys has more of an impact on heating load intensities than on cooling. The envelope parameters are relatively more important when considering the annual cooling load intensity impact (figure 4).

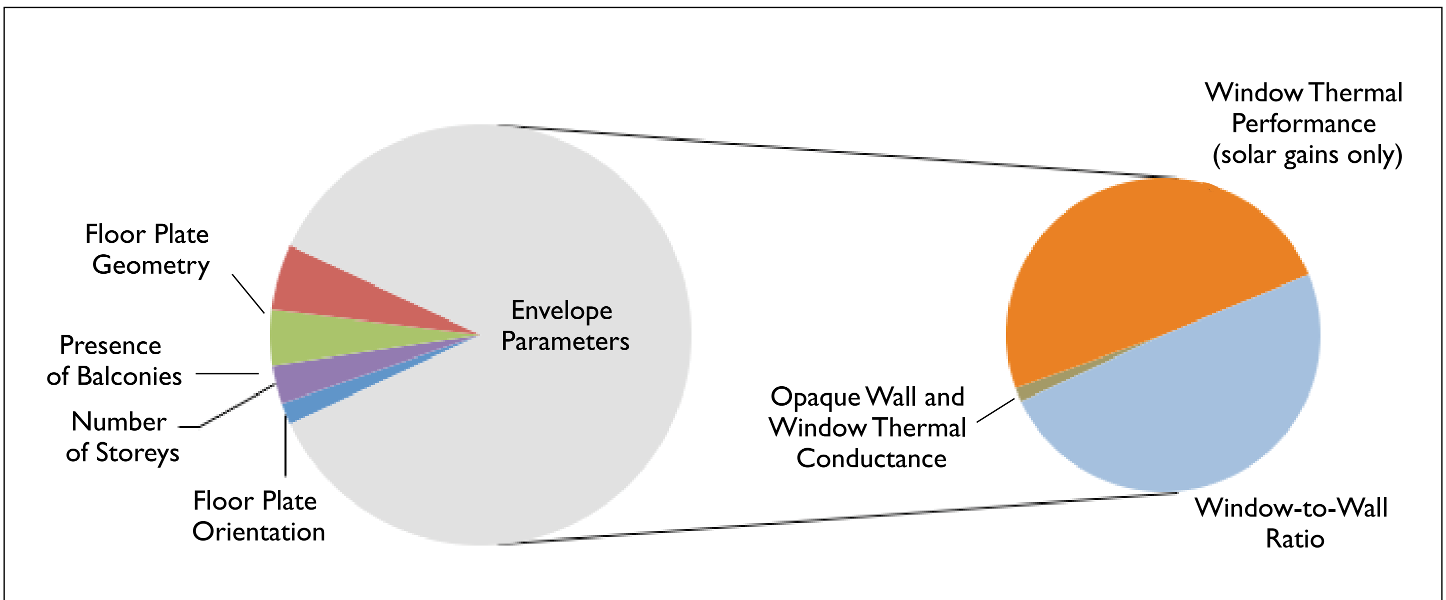

Figure 4 Relative Impact of Architectural Features on Cooling Loads

IMPLICATIONS FOR THE HOUSING INDUSTRY

The results of this modelling study indicate that designers seeking to reduce space conditioning loads in multi-unit residential buildings should focus first on building envelope performance parameters. Other parameters of architectural form such as floor plate geometry, building orientation and height tend to have less impact on the energy performance of MURBs and may be addressed once building envelope thermal performance has been optimized.

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