Insights from Energy Modeling into the Design of High-Performance Residential High-Rise Condominiums

Christopher Hadlock, P.Eng. and Michael Pelton, P.Eng.
Fluent Group Consulting Engineers Inc., Orangeville, Ontario, Canada

Abstract

In recent years, green building standards have had a strong influence on the energy performance of new building projects. Whether voluntary (such as the LEED® Green Building Rating System) or mandatory (such as local Green Development Standards) – new standards have pushed energy performance targets to higher and higher levels and, at the same time, they have created an increased reliance on energy modeling to assess and document energy savings. As a result, new and important information about the energy performance of specific building types is emerging.

A prime example of this effect can be seen in the residential high-rise condominium market in Toronto, Ontario. In 2006, the City of Toronto adopted the Toronto Green Standard (TGS), which set elevated targets for the minimum acceptable energy performance of new buildings within the City's jurisdiction. While this affected many building types, it had a particularly dramatic effect on the high-rise residential condominium market. Developers of these buildings, that previously showed little interest in energy savings, were suddenly forced to make significant improvements in overall energy performance.

Using the City of Toronto and the TGS as a case study, the authors provide an examination of condominium design, past and present. Data obtained from actual energy simulation results from more than a dozen current projects will highlight the impact of the TGS and the successes of practical "real-world" measures that enhance energy performance (through incremental improvements in the design of lighting, HVAC, and plumbing systems). More importantly, key limitations that are stifling further progress, but which are firmly entrenched in the current design ethos (such as floor-to-ceiling glass, uninsulated spandrel, and balconies), will be revealed and their impact explained.

Finally, the authors will explore the future of condominium design and assess what will be required to meet increasingly stringent energy performance standards. Using predictive modeling, we will show how evolutionary design improvements (similar to the ones that have occurred over the past 30 years) will be insufficient to meet future energy performance requirements - this challenge will only be possible through a fundamental change in the design ethos.

1 Introduction

Over the last 10 years, residential high-rise construction has been booming in cities around the world like Dubai, Mexico City, and Toronto (Sarner, 2001 and Arafat, 2004). Many of these buildings are characterized by predominantly glass (or all glass) facades – regardless of the climate of the region in which they are built. The Toronto climate, however, is not like that of Dubai or Mexico City. Experts have warned that glass condominiums in Toronto may become the "pariah" buildings of the future – due to poor energy performance (not to mention the potential for premature building envelope failures) (CBC, 2012). At the same time, developers say they are focused on floor-to-ceiling glass to satisfy the market demand for this style of building. These conflicting viewpoints beg the following questions: *Exactly how energy efficient are new Toronto condominiums?* and *What can be done to improve the energy performance of these buildings in the future?*

The purpose of this paper is to help answer these questions by offering new insights into the design of high-performance residential high-rise condominiums. We have developed these insights as a result of extensive experience working with actual design teams and preparing real-world energy models using eQUEST simulation software.

Our experiences over a period of 3+ years documenting the compliance of buildings to the Toronto Green Standard (TGS) are used as the principal data source. Drawing directly from high-rise designs in the City of Toronto and the associated eQUEST modeling files, we present data that have been collected in three ways:

- Firstly, for the purposes of this paper, we have selected a typical condominium form (i.e. building size, layout, massing, etc.) to develop two prototypical models in order to compare similar condominiums built in two very different time eras: the Past (circa 1980s) and the Present (circa 2010). The purpose of this is to demonstrate the evolution of condominium design over the past 30 years using a representative example.
- Secondly, we present a survey of energy modeling results from over a dozen actual high-rise condominiums that have been recently modeled to provide further evidence of the current state of energy performance for this building type. These results strengthen our understanding of the Present (circa 2010) situation in Toronto relative to TGS requirements and also provide insights into the influence this green standard has had on design decision-making.
- Thirdly, we present results from a third prototypical model (based on the same typical condominium form as the Past and Present models) to investigate the future of condominium design. Using this Future model, we are able to look beyond the limitations of the current design ethos to reveal what could potentially be done to optimize the energy performance of high-rise condominiums.

Although the conclusions from this paper are based on high-rise condominiums in Toronto, we believe the results presented herein can be extrapolated to many other geographical areas with similar climates and that these results provide evidence of the positive effect green standards can have on building owners, developers, and the design community.

2 Energy Performance Standards in Toronto

The Toronto skyline (Figure 1) is changing at a remarkable pace. According to a recent article in the Toronto Star (Kennedy, 2011), "there are currently 132 high-rise[1] buildings under construction in Toronto", more than any other city in North America. The article goes on to

[1] High-rise includes residential apartments, office development and condominiums.

say that of the 39,000 condo units under construction in the region, "88% per cent of those are already sold" – an indication that there is no sign of a slowing trend in the foreseeable future.

In 2006, the City of Toronto launched the voluntary Toronto Green Development Standard (TGDS). The Standard was created to provide "targets, principles and practices to guide the development of City-owned facilities and to encourage sustainable development amongst the private sector" (Toronto Green Development Standard, 2006). To help create the TGDS, existing rating systems (including LEED, Green Globes, Energy Star for Homes, and R-2000) and existing guidelines and targets were assessed. From the research emerged a custom "home-grown" standard applicable to all new development in the City of Toronto.

Figure 1: Toronto skyline in 2011 (David Cooper/Toronto Star 2011)

In early 2010, TGDS became a by-law within the City of Toronto – this meant that every new building would be held to the same standard. The TGDS, now simply called the Toronto Green Standard (TGS), has two levels of compliance: Tier 1 and Tier 2. The less stringent Tier 1 compliance requirements are mandatory for all new buildings while Tier 2 requirements are, at this time, voluntary. To incent developers, the City provides a development charge refund for projects pursuing the more stringent Tier 2 requirements.

Similar to LEED, TGS is organized into the following categories:

- Air Quality
- Greenhouse Gas Emissions/Energy Efficiency
- Water Quality, Quantity and Efficiency
- Ecology
- Solid Waste

Within the Greenhouse Gas Emissions/Energy Efficiency category, the Standard mandates energy performance requirements (modeled) for all new high-rise buildings, as follows:

- Tier 1: Achieve at least 25% savings over the Model National Energy Code for Buildings (MNECB 1997) [13% savings over the 2006 Ontario Building Code (OBC)]
- Tier 2: Achieve at least 35% savings over the MNECB [23% savings over the OBC]

In order to demonstrate Tier 1 compliance, all new mid or high-rise buildings exceeding 2,000 m^2 of gross floor area (GFA) must submit a Final Design-Stage Energy Modeling Report which identifies the modeled energy savings (an As-Constructed Energy Modeling Report is required for Tier 2). The savings from the energy simulations must be completed using either EE4, DOE 2, or eQuest and the report must be sealed by a Professional Engineer.

3 The Evolution of High-Rise Condominium Design

3.1 The Story of the Evolution: Historical Design Trends

The requirements set out by TGS have forced Toronto-area developers and designers to consider energy performance as an important design objective. With TGS compliance now at the forefront of many decision-making processes, new light has been shed on the way condominiums are designed – and we can begin to trace the important design measures that have been employed to improve energy performance.

This section will tell the story of the evolution of condominium design (from an energy perspective) by contrasting high-rise residential designs of the past (circa 1980s) to those of the present (circa 2010). We describe the extent of the changes for each of the major building systems that affect energy performance (i.e. the building envelope, lighting, HVAC, and plumbing systems).

Building Envelope

One of the most noticeable differences between current Toronto condominiums and designs from the past is the prolific use of glass. Gone are the days of "punched" windows – floor-to-ceiling glass facades (either window-walls or curtain-walls) have almost completely replaced mass walls. It is not that the mass walls in the pre-glass era where necessarily "good design" from a thermal perspective (since, in many cases, a lack of insulation and thermal bridging resulted in low insulating values). But, by comparison, the old mass walls performed much better than the newer walls based primarily on insulated glazing units (IGUs).

There is no doubt that IGUs have improved over the past 30 years with the introduction of advanced coatings, fills, and spacers – but expansive vision glass sections (even those with state-of-the-art IGUs) do not provide best-practice insulation levels. Furthermore, whatever insulation is added to the spandrel sections of window-walls and curtain-walls is typically located between metal mullions and within metal backpans, where the net insulation value can easily be cut in half by thermal bridging.

Making matters worse, a large portion of high-rise residential buildings now design with significant balcony area, in some cases 360 degrees of cantilevered balcony – an excellent design for maximum heat dissipation. To our knowledge, there are currently no new high-rise condominiums in the City of Toronto[2] that plan to use thermally broken balconies – at least not yet.

For reference, two typical high-rise condominium wall sections are shown in Figure 2.

[2] The Absolute Condominium located in Mississauga (just outside of Toronto) has thermally broken balconies.

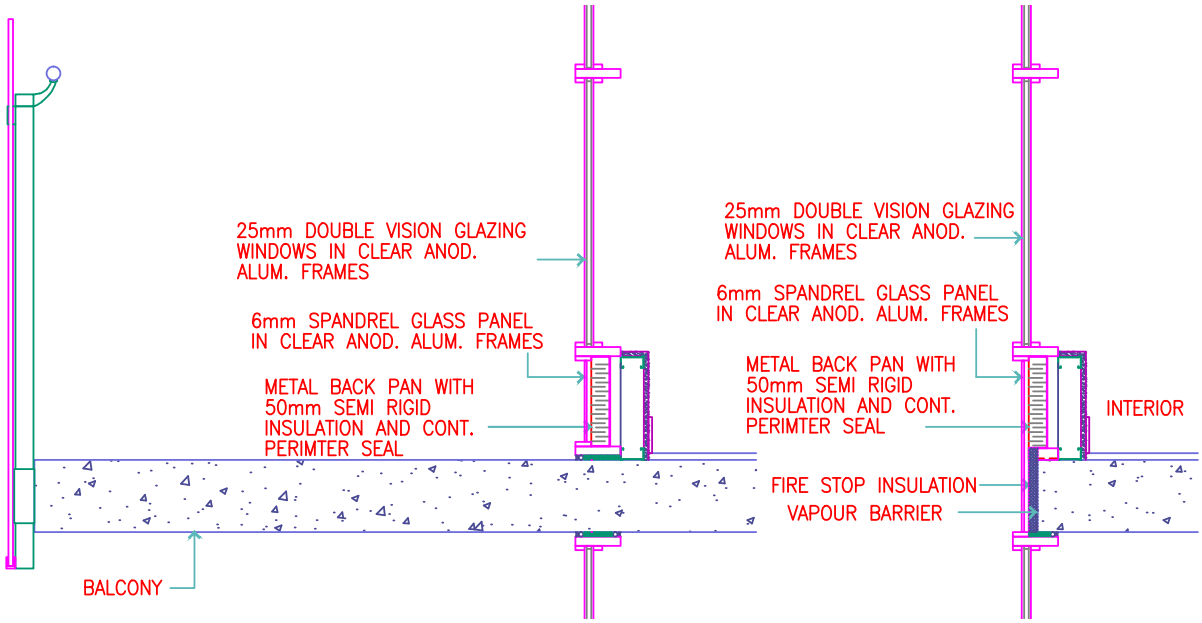

Figure 2 – Typical condominium wall section at balcony (left) and bypass (right)

Building Envelope – Technical Analysis

So what are the impacts of window-to-wall ratio (WTWR), wall type (glass wall versus mass wall) and cantilevered balconies and how does one affect the other? As it turns out, a wall is only as good as its weakest component.

In order to determine the thermal performance of a wall assembly, each of the different components that make up the wall must be considered. A study of the impact of different wall assembly components was performed whereby three different wall constructions were analyzed. The independent variables in the analysis were WTWR, wall construction, and window characteristics. Table 1 provides a description of each of the three assemblies. Wall assembly Type 1 is reflective of Present-day Toronto condominium walls, similar to the sections shown in Figure 2.

Table 1: Wall Assembly Types

Wall Assembly	Wall Construction Details	Window Characteristics
Type 1 (Figure 2) Wall: Spandrel WTWR: 80% Window: Curtain-wall	Spandrel with 2” of mineral wool insulation between mullions, framed cavity behind	Curtain-wall: 25 mm double glazed, low-e (e=0.035), argon-fill, warm-edge spacer, thermally broken (3 mm) aluminum frame
Type 2 Wall: Spandrel WTWR: 40% Window: Curtain-wall	Spandrel with 2” of mineral wool insulation between mullions, framed cavity behind	Curtain-wall: 25 mm double glazed, low-e (e=0.035), argon-fill, warm-edge spacer, thermally broken (3 mm) aluminum frame
Type 3 Wall: Mass WTWR: 40% Window: Punched	Brick wall with 1” air gap, 2” polystyrene on 3/8” plywood, 3.5” fiberglass insulation between 2” x 4” metal studs	Punched window: 25 mm double glazed, low-e (e=0.035), argon-fill, warm-edge spacer, fibreglass frame

Wall R-values (for both opaque and vision sections) for each assembly type in Table 1 were calculated using three different (cantilevered) balcony arrangements: balcony with no thermal

break, balcony with thermal break, and no balcony. The total wall assembly R-values are plotted in Figure 3.

The Present-day condominium wall (Type 1) has an R-value of 2 $ft^2 \cdot °F \cdot h/Btu$ and is only minimally affected by the different balcony configurations. A slight improvement in R-value can be seen from the Type 2 constructions, having an R-value closer to 3 $ft^2 \cdot °F \cdot h/Btu$. Interestingly, reducing the WTWR without improving the window and wall constructions (regardless of balcony scenario) does little to improve the wall R-value – at most an increase of R-1 $ft^2 \cdot °F \cdot h/Btu$ is obtained. A much wider range of R-values can be seen from the Type 3 construction, for which the window and walls have been optimized (punched windows and insulated mass walls) and the window-to-wall ratio has been reduced to 40%. In this case, the balcony configuration is pivotal in determining the wall R-value. With a cantilevered balcony, the total R-value is less than 3 $ft^2 \cdot °F \cdot h/Btu$. With no balcony, the wall improves to almost R-7 $ft^2 \cdot °F \cdot h/Btu$, more than doubling the R-value. These results demonstrate that a significant improvement to the thermal performance of the wall is limited by the weakest component. This explains why improvements to one aspect of the wall (example: adding additional insulation to the backpan) will not necessarily result in a significant improvement to the overall wall R-value.

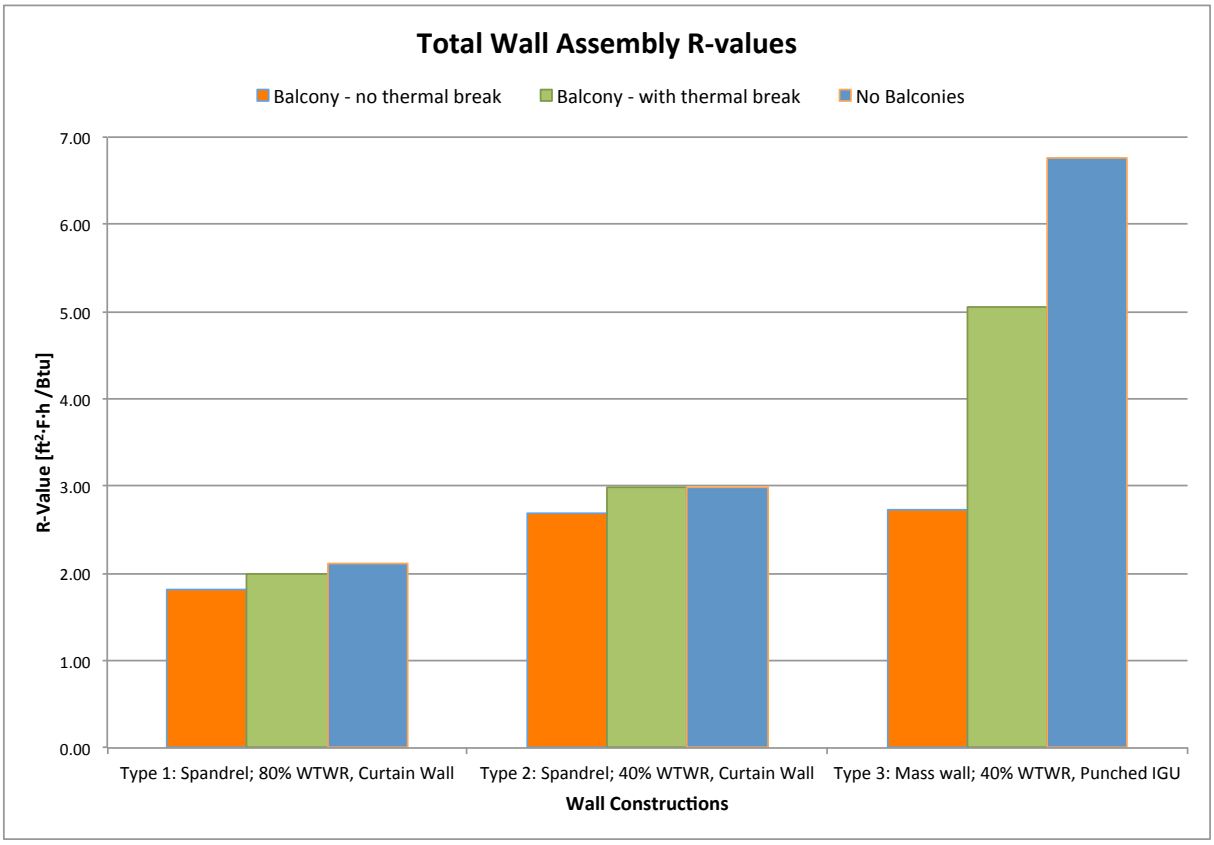

Figure 3: Impact of Window-to-Wall Ratios, Wall and Window Types and Balconies

Lighting

Unlike modern day walls, lighting in condominiums has changed for the better. Almost gone are the days of inefficient incandescent lamps (now replaced with CFLs and LEDs) – and an encouraging trend is that developers are often supplying integrated energy efficient lighting to condominium suites – instead of leaving the selection of lighting fixtures up to the purchaser. Typically, lighting is supplied in the kitchen, entranceways and washrooms, and less frequent-

ly for the bedrooms, dining rooms, and living rooms. Energy efficient lighting has had significant uptake, being readily adopted by most developers and interior and electrical designers. In addition to designing to lower lighting power densities (LPDs), many designers are now using occupancy sensors in common areas and suite-level corridors. In corridors, it is common to use the occupancy sensors to control roughly half the lights, helping reduce the corridor cooling load, thereby allowing for lower airflow requirements during the hours when the lights are off.

HVAC

Most Toronto high-rise condominiums are now being designed with four-pipe fan coils (4P-FC) or water-loop heat pumps (WLHP) in each suite. Hot water provided to the fan coil or heat pump is often provided by high-efficiency condensing boilers. In order to ensure a low return water temperature with fan coil units, over-sized heating coils are specified and an outdoor air reset strategy is used. In the pre-glass era, 2 pipe fan coils (2P-FC) would have been common with electric heating during the changeover season; hot water would have been supplied by an 80% boiler with a higher supply temperature. For the chilled water loops, it would have been common to use air-cooled electric chillers. Today, water-cooled, variable speed, electric chillers with higher part-load and full-load efficiencies are specified. In larger buildings, heat recovery chillers are used to preheat the hot water loop or the domestic water loop. Unlike the pre-glass era, variable speed pumps are specified on all major circulation loops and provide significant savings.

Ventilation systems have improved dramatically, with many buildings opting for in-suite HRVs (or ERVs). This "compartmentalized" approach treats each suite as a separate "sealed" unit (with balanced ventilation to and from) and avoids many of the air distribution problems associated with the old "pressurized corridor" approach that relied on ventilation air to be transferred to the suites, via undercut suite doors, from the main corridor.

The evolution of mechanical equipment from past to present has also resulted in very significant improvements. Adding variable speed control to major mechanical systems has improved part-load efficiencies while reducing wasted energy. Moreover, equipment efficiencies seem to be topping out as boilers reach efficiencies over 90% and chillers with COPs exceeding 6 (at design conditions) are now common. From a mechanical equipment perspective, it is difficult to foresee another significant jump in efficiency like the ones that have already occurred.

Plumbing

After space heating, domestic water heating is typically the second largest residential load. There are therefore significant savings opportunities to be had by specifying low-flow plumbing fixtures. The current OBC mandates 2.2 gpm for both kitchen and washroom lavatories and 2.5 gpm for showers. Many condominium developers now install low-flow fixtures with the following flow rates: 1.5 gpm for the kitchen, 0.5 gpm for the washroom lavatory and 1.75 gpm for the showers. In addition to low-flow fixtures, high efficiency condensing heaters are also employed, replacing 80% boilers. It should be noted that low-flow toilets, although not contributing to hot water savings, are also becoming widely used and can have a significant impact on water-use reduction.

3.2 The Results of the Evolution: An Energy Simulation Case Study

A typical condominium form (i.e. building size, layout, massing, etc.) was selected to develop two prototypical models to compare similar condominiums built in two very different time eras: the Past (circa 1980s) and the Present (circa 2010). The purpose of the simulations is to

demonstrate the effect the evolution of condominium design has had on energy performance. The design features presented in Section 3.1 and additional model parameters summarized in Table 2 form the basis for the Past and Present simulations.

Table 2: Simulation Data for Case Study

General Parameters	**Simulation Data**	
Software	eQuest, version 3.64	
Weather File	Toronto, CWEC	
Utility Rates	Gas = $0.21/m3; Electricity Commercial = $0.052/kWh + $7.67/kW; Electricity Residential = $0.11/kWh	
Schedules	MNECB PCB Schedules	
Modeled Area	45 Storeys; 424,778 ft^2	
Receptacle Loads	Default PCB; Suites = 0.46 W/ft^2	
Infiltration	Perimeter = 0.038 cfm/ft^2; Core = 0.001 cfm/ft^2	
Number of Occupants	1102 (2 for the first bedroom + 1 for each additional bedroom)	
Design Parameters	**Past**	**Present**
Building Envelope		
Construction Type	Type 3 (Table 1)	Type 1 (Table 1)
Balcony	360°, no thermal break	360°, no thermal break
Total Wall Assembly	R = 2.73 $ft^2 \cdot F \cdot h/Btu$	R = 1.82 $ft^2 \cdot F \cdot h/Btu$
Lighting		
Suite LPDs	2.5 W/ft^2	1.0 W/ft^2
Lighting Controls	None	Occupancy sensors on half of corridor and most of amenity space lighting
HVAC		
Mechanical Systems	2 pipe fan coil, changeover temperature = 60°F	4 pipe fan coil
Heating (Boiler)	Efficiency = 80%	Efficiency = 92%
Cooling (Chiller)	Air-cooled COP = 2.8	Water-cooled, variable speed COP = 6.1
Ventilation	Pressurized corridor, 140 cfm per suite	In-suite ERV, 75 cfm per suite, 200 cfm per corridor
Fan Power	Fan Coil: TSP = 1.0 in w.g.	Fan Coil: TSP = 1.0 in w.g. ERV: TSP = 3.0 in w.g.
Plumbing		
Kitchen Flow Rate	2.2 gpm	1.5 gpm
Bathroom Flow Rate	2.2 gpm	0.5 gpm
Shower Flow Rate	2.5 gpm	1.75 gpm
Hot Water Heater	efficiency = 80%	efficiency = 94%
Water Use[3]	Lavatory = 3 min/person/day; Kitchen = 5 min/person/day; Shower = 8.2 min/person/day and 0.67 uses/person/day	

[3] Water use assumptions are per LEED Canada NC version 1.0, credit WEc3.

In addition to the Past and Present simulations, another energy model was also developed to benchmark a building built to the current (2006) Ontario Building Code (following ASHRAE 90.1-2004 and supplement SB-10). This additional model was generated out of interest to see how the Past and Present simulations "stack up" to the current building code. The results from the Past, Present and OBC models are shown in Figures 4 and 5. The total energy and cost consumption has been shown, broken out by load type, namely: plug loads, domestic hot water, pumps, fans, lights, cooling and heating.

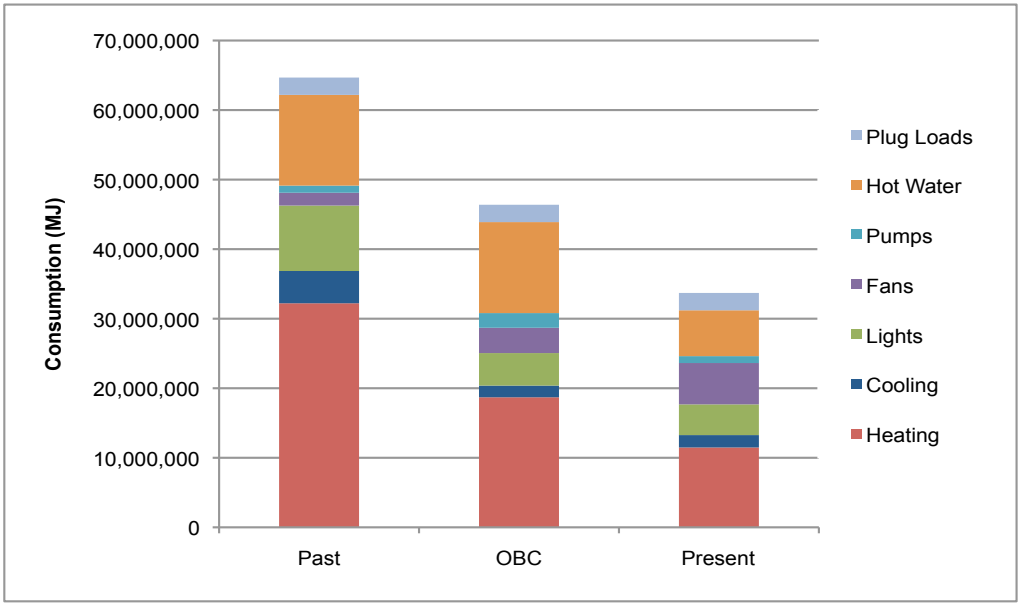

Figure 4: Energy Consumption of the Past, Present and OBC Simulations

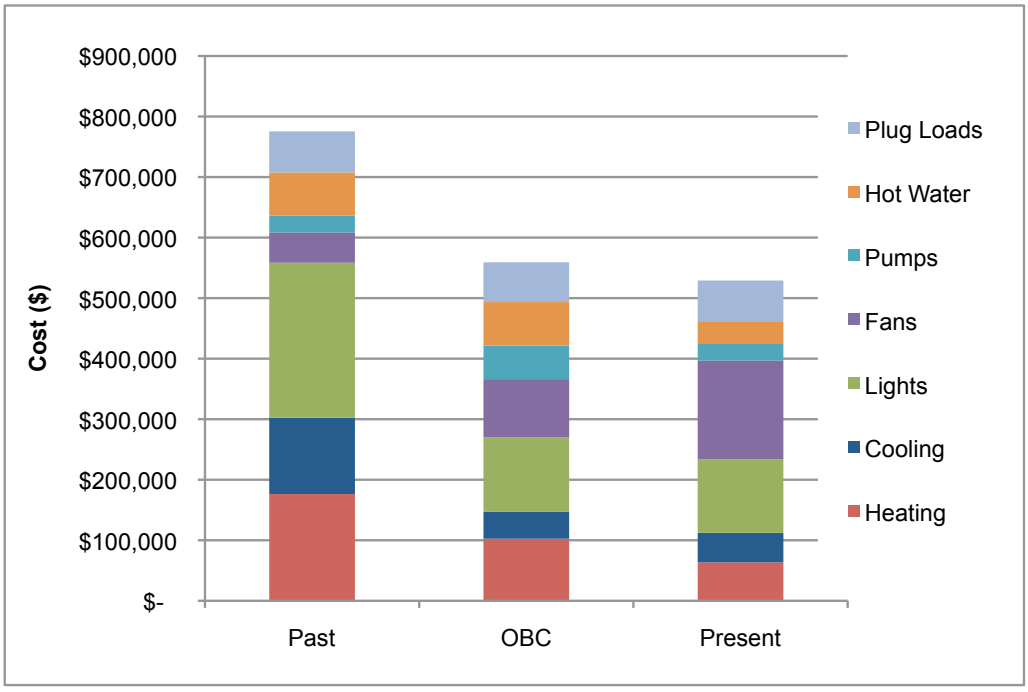

Figure 5: Energy Cost of the Past, Present and OBC Simulations

As can be seen from Figures 4 and 5, both the Present and OBC models demonstrate considerable energy and cost savings over the Past model. Savings from heating, domestic hot water and lighting provide the majority of the savings. Interestingly, not all loads have been reduced; an increase in fan energy can be seen due to the additional fan power required for the in-suite ERVs. Although the energy recovery in the suites provides significant heating savings by reducing the ventilation load, a cost is incurred for the additional fan energy.

The prototypical models were used to calculate the estimated annual utility cost for a 700 ft^2 suite (Table 3).

Table 3: Case Study Results – Utility Costs for Past, Present and OBC

	Past	OBC	Present
Cost Density [$/$m^2$]	$14.80	$11.04	$10.09
Annual Utility Cost for Typical 700 ft^2 suite	$962	$718	$656

Another very interesting result is the difference in savings between Figure 4 and Figure 5. The gas consumption savings (as shown in Figure 4) is significant – but when the same savings is viewed by cost (as shown in Figure 5), it is drastically reduced. The opposite is true for electrical savings. Currently, there is a large discrepancy between the price of gas and electricity in the City of Toronto (this is generally true for most of Ontario). To help put this into perspective, an analysis of the current utility rates is shown in Table 4.

Table 4: Utility Rate Analysis

Utility Type	Current Cost	Equivalent Cost[4]
Gas	$0.21/$m^3$	$5.48/GJ
Electricity	$0.11/kWh	$30.56/GJ

The current discrepancy between gas and electricity rates helps explain why the gas cost savings are proportionately lower than the electricity cost savings. Since the largest energy savings for the Present simulation is due to gas savings, and since there is also an increase in fan energy, the overall energy cost savings is significantly less than the overall energy consumption savings.

At the current rate structure, gas savings are much less "valuable" than electrical savings – not all savings are created equal when it comes to cost. This case study helps illustrate a very important result; while energy savings are not influenced by time or market fluctuations, cost savings are highly sensitive to both. Conceivably, the same project could be showing significantly different cost savings at two different snap-shots in time. This is a very important result for green building standards that use cost savings as the measuring stick. The construction period for many condominiums can be 5 years or longer from concept design to building occupancy. Over this duration, it is very conceivable that utility rates may double (or be cut in half). Case in point, the effective price (commodity price with cost adjustment) of natural gas in Ontario [Ontario Energy Board] is shown in Table 5 over a 5-year period.

Table 5: Natural Gas Rates Since 2006

	Jan 2006	Jan 2007	Jan 2008	Jan 2009	Jan 2010	Jan 2011
Effective Price [¢/m^3]	41.19	30.61	24.49	29.15	12.91	12.24

[4] Equivalent gas cost calculated using an HHV of 38.3 MJ/m^3.

The simulated cost savings (relative to OBC) for a building built in 2006 compared to 2011 (using current electrical rates in both simulations) would vary by a net 13% margin (based on the difference in natural gas rates) as shown in Table 6.

Table 6: Impact of Utility Rate on Cost Savings

	Jan 2006	Jan 2011
Effective Price [¢/m^3]	41.19	12.24
Cost Savings over OBC	16.3%	3.3%

Building owners make multi-million dollar decisions during design to determine which cost-savings measures will be incorporated into the building, often times based on achieving a particular savings threshold set by a green building standard. Once construction has started, decisions made during design can be very difficult and costly to change. Most green building standards (including OBC, LEED version 1.0, TGS) do not specify how fluctuating utility rates are to be handled; this decision is typically at the discretion of the energy simulator.

4 A Survey of Energy Modeling Results for the Present Era

The results presented in Section 3 were based on a theoretical study. However, the design improvements studied can and have been applied to real-world buildings with great success.

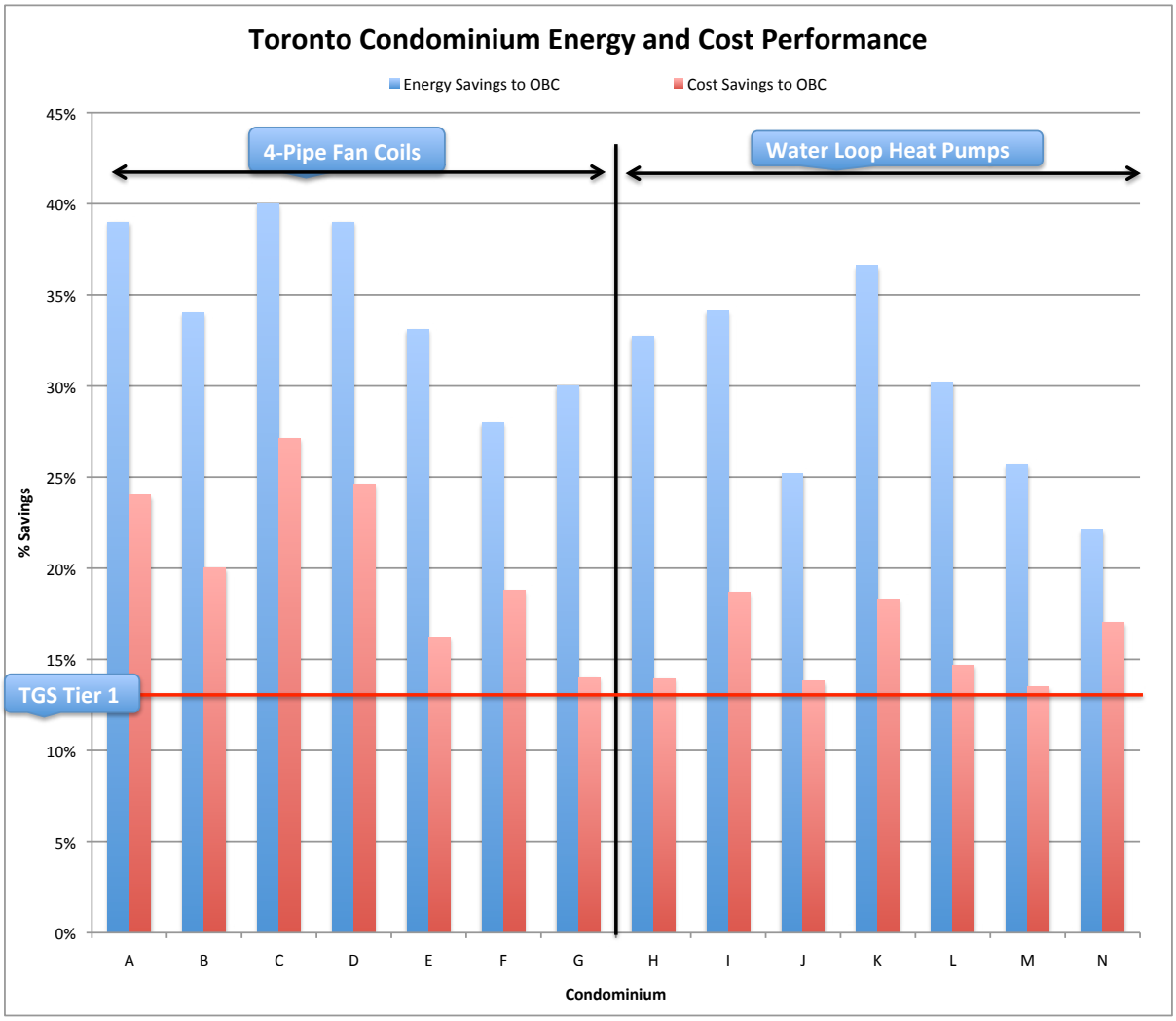

Figure 6: Energy Results from 14 Toronto Condominium Simulations

Over the past 3 years, the authors have been documenting the compliance of buildings pursuing TGS within the City of Toronto. Figure 6 shows simulation results from actual high-rise condominium buildings currently under construction in the City of Toronto - all of them pursuing Tier 1 of the TGS. It should be noted that these results are based on design-stage energy simulations, as per the current TGS Tier 1 requirements.

Consistent with the results of Section 3, there is an evident discrepancy between energy and cost savings in Figure 6. The 14 buildings surveyed have an average energy savings of 32%, while the average cost savings is only 18%. Furthermore, the difference between energy and cost savings for a particular building can vary significantly, from a 5% difference for building N to a 19% difference for building H. These discrepancies reflect the notion that the impact of gas and electricity rates will be different for each building as each building pursues different energy conservation measures (ECMs).

The type of ECMs is not, however, the only factor contributing to the difference in energy and cost savings. Figure 6 also illustrates the impact of the suite-level HVAC equipment type. The data for the seven buildings on the left side of the graph are for 4P-FC HVAC systems while the data for the seven buildings on the right side of the graph are for WLHP HVAC systems. As seen from the graph and further illustrated in Table 7, on average the buildings with 4P-FC systems outperform buildings with WLHPs in both energy and cost savings.

Table 7: Impact of HVAC System on Cost Savings Compared to OBC

	Average Energy Savings to OBC	Average Cost Savings to OBC
4P-FC	35%	21%
WLHP	30%	16%

This difference in energy and cost savings (relative to OBC) between a WLHP and 4P-FC can be attributed to two factors. The first can be explained by examining the plant-level equipment that is required to support the different system types. Cooling for fan coils units is typically supplied by a chiller, which may consume a higher magnitude of electricity, but allows for greater savings potential compared to the minimum ASHRAE chiller efficiency used for the OBC simulation. Conversely, cooling for a WLHP system is typically supplied by a cooling tower (or fluid cooler), which may consume less energy compared to a chiller, but provides marginal savings compared to the corresponding OBC building cooling equipment. The second factor is the energy source for the heating load. Although WLHP systems have a higher efficiency and can "share" energy, they are less cost effective than a 4P-FC simply due to the difference between electricity and gas costs. In general, our observations have indicated that high-rise condominiums with WLHP systems will have a more difficult time meeting the Tier 1 thresholds of the TGS than 4P-FC systems.

5 The Future of High-Performance High-Rise Condominium Design

5.1 Forecasting Potential Design Trends

High-rise condominiums built in Toronto have come a long way in terms of energy efficiency, thanks in part to mandated bylaws like the TGS as well as other green building standards. Some of the most notable improvements are: in-suite heat recovery, condensing boilers, high efficiency variable speed chillers, energy-efficient lighting, low flow fixtures and condensing hot water heaters. Lighting, mechanical, and plumbing systems are now extremely efficient, with only minor increases in efficiency still available. As shown in Figure 6, some of the highest performing condominiums in Toronto are approaching 40% energy savings.

It is likely that OBC and TGS, like other standards (ASHRAE and LEED for example), will increase the stringency of the energy efficiency requirements over time. Projecting several years ahead, questions arise: *How will high-rise condominiums get to the next level of energy performance?* and *Would it be possible to exceed 50% savings and if so, what improvements would have to be made?* (excluding for the moment the application of renewable energy generation). If we continue with the current evolutionary trends (i.e. improving mechanical and electrical efficiencies), it seems clear that overall energy performance is very close to an asymptotic limit. If evolutionary changes are not the answer, perhaps revolutionary ones are.

Looking back at Figure 3, it is evident that our building envelope evolutionary path to date (i.e. the one that has resulted in floor-to-ceiling glass and cantilevered balconies) is failing in comparison to the performance of today's mechanical and electrical systems. Present day building envelopes do not provide much insulating value when compared to mass walls with continuous insulation and punched windows. The next big step in high-performance condominium design is therefore likely going to come by way of an envelope facelift: less glass, better (or no) balconies, and more appropriate insulation levels. But how much of an improvement would fundamental changes to the building envelope provide? First, we must define the proposed changes, as per Table 8.

Table 8: Condo Design – From Present to Future

Building Envelope Component	Present	Future
Window-to-wall Ratio	80%	40%
Balcony	360°, cantilevered	None
Above Grade Wall Construction	Spandrel panel with 2" batt behind backpan	Brick wall with 1" air gap, 2" polystyrene on 3/8" plywood, 3.5" fiberglass insulation between 2" x 4" studs R-16.7 ft^2-ºF/(Btu/h)
Window Characteristics	Double-glazed, argon fill, warm-edge spacer, aluminum frame with 6 mm thermal break	Punched windows: 25 mm double glazed, low-e (e=0.035), argon-fill, warm-edge spacer, fibreglass frame
Total Wall Assembly R-value	R = 1.82 ft^2-ºF/(Btu/h)	R = 6.76 ft^2-ºF/(Btu/h)

5.2 Forecasting Potential Results

The prototypical condominium case study was extended to a Future model to quantify the potential improvements in energy performance of the Future design scenario. A significant improvement to the case-study simulations can be seen from the results (Table 9 & Figure 7).

Table 9: Case Study Results for Past, Present and Future

	Present	Future
% Savings to OBC (Figure 7)	28.6%	46.6%
Annual Utility Cost for Typical 700 ft^2 suite	$656	$531

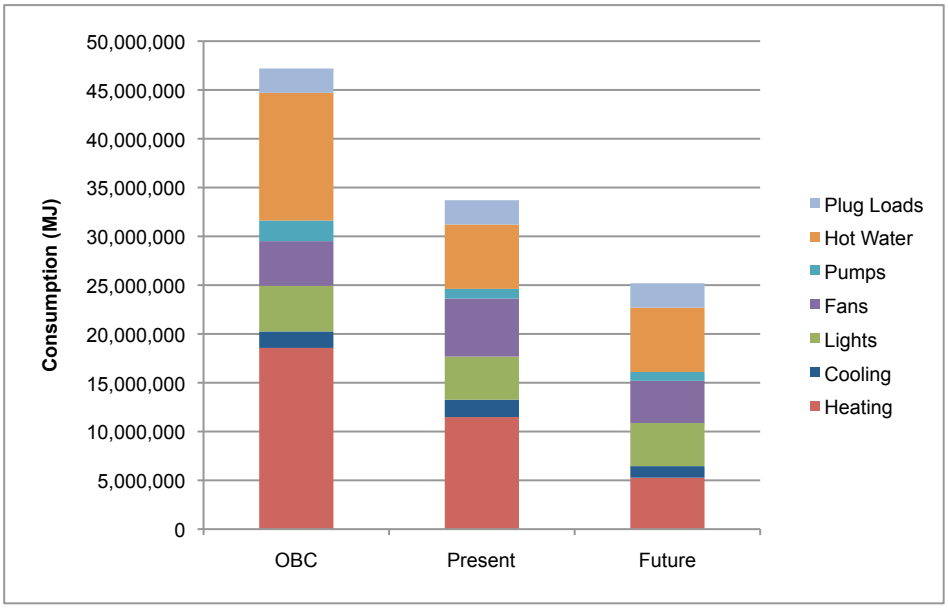

Figure 7: Energy Consumption of the OBC, Present and Future Simulations

A net energy savings of 46.6% compared to OBC is achieved, equivalent to an 18% incremental improvement over the Present simulation energy savings. The improvements to the building envelope have made a notable impact on heating and cooling energy, as well as fan power. The reduction in fan power is attributed to the reduction in airflow required to meet the heating and cooling loads that were previously driven by the large solar heat gains (due to the floor-to-ceiling glass). Based on these results, it seems that achieving 50% energy savings over the OBC reference building is plausible, but only with the proposed fundamental changes to the building envelope.

6 Conclusions

The Toronto Green Standard (TGS) has had a strong influence on the energy performance of residential, high-rise condominiums in the City of Toronto. Present day designs show a marked improvement in modeled energy savings since the TGS bylaw was adopted.

Extensive energy modeling results show that present day high-rise condominium projects are able to meet the current TGS thresholds. The documented savings have been achieved primarily through incremental energy conservation measures – mostly relating to evolutionary improvements in the design of mechanical and electrical systems.

However, the best examples of present day condominiums are close to exhausting the energy savings opportunities associated with mechanical and electrical systems. Barring unforeseen and dramatic technological advancements, energy savings from lighting, HVAC, and plumbing systems are approaching asymptotic limits.

To achieve significant additional savings in the future, developers, designers, and condominium owners will need to reject the current architectural design ethos epitomised by glass walls and concrete cantilevered balconies and embrace moderately-glazed, well-insulated building envelopes. If this is done, key limitations that are currently stifling the energy performance of residential high-rise condominiums will be overcome, and savings of 50% or more over the OBC reference building would be possible.

7 References

Sarner, J., 2011. *Toronto Leads In New Highrise Buildings Constructions*. Available at: http://jamiesarner.com/toronto-real-estate/2011/10/toronto-leads-highrise-constructions/ [Posted October 13, 2011]

Arafat, H., 2004. *High Rise Buildings in the Middle East.* Available at: http://www.wobo-un.org/Archives/Arafat%20High%20Rise%20ME.pdf [Accessed March 8, 2012]

CBC, 2012. *Throw-away buildings: The slow-motion failure of Toronto's glass condos.* Available at: http://www.cbc.ca/toronto/features/condos/ [Accessed March 8, 2012]

Kennedy, B., 2011. *Highrises? We're tops on the continent*. Article from the Toronto Star. Available at: http://www.thestar.com/news/article/1064773--highrises-we-re-tops-on-the-continent [Published October 5th, 2011].

Toronto Green Development Standard, 2006. *Making a Sustainable City Happen*. Available at: http://www.toronto.ca/planning/environment/pdf/gds_discussionpaper_1.pdf [Published July 27th, 2006].

Ontario Energy Board, 2011. *Natural Gas Rates – Historical*. Available at: http://www.ontarioenergyboard.ca/OEB/Consumers/Natural+Gas/Natural+Gas+Rates/Natural+Gas+Rates+-+Historical [Accessed December 29, 2011].

8 Acknowledgements

The authors would like to thank Bronwyn Roberts for her assistance in preparing much of the data used for this paper.