Glass claddings for tall buildings

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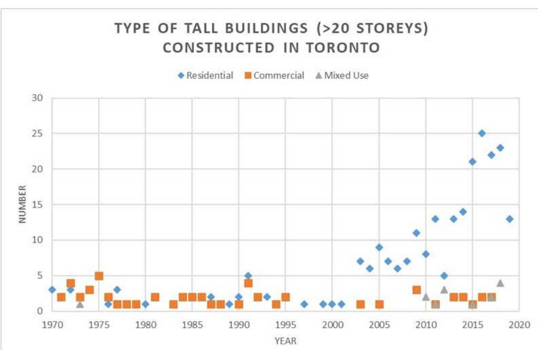
[1]*Photo © Dreamstime*

By Patrick Marquis, Brenda McCabe, PhD, P.Eng., FASCE, and Arash Shahi, PhD, P.Eng., PMP
A dramatic increase in the demand for and construction of tall buildings in Toronto has resulted in the city producing the highest per capita number of residential towers in North America. (This comes from Emporis' 2014 release, "High-rise Construction in North America: Toronto Continues to Lead Going into 2014." Visit www.emporis.com/press/press-release/1/high-rise-construction-in-north-america-toronto-continues-to-lead-going-into-2014[2].) Before 2000, 90 per cent of existing buildings taller than 150 m (492 ft) were commercial structures. In recent years, the paradigm has shifted—now 90 per cent of newly constructed towers over that height are used as residential property. (For more, see the Council on Tall Buildings and Urban Habitat [CTBUH]'s "Year Review for 2014," published in *International Journal on Tall Buildings and Urban Habitat* [1, 44-48].)

Using the University of Toronto's (U of T's) Building Tall Research Centre's database, Figure 1 shows a visual representation of the city's exponential growth of tall residential towers, including those scheduled for completion in 2018 and 2019. (The Building Tall Research Centre conducts and promotes research related to tall buildings from multidisciplinary technical perspectives. The group collaborates with designers, consultants, developers, builders, and policy-makers.) The increasing urbanization and high-density urban areas help provide affordable living, facilitate efficient supply of services, and further efforts to reduce greenhouse gas (GHG) emissions.



[3]**Figure 1**: Types of tall buildings in Toronto.
Images courtesy Building Tall Research Centre

High-rise residential buildings in Ontario follow the same codes and standards as commercial buildings, even though they have very different uses and contexts. As policy-makers continue to improve the standard for energy efficiency in buildings, it may be important to consider the context of an occupant in a high-rise residence separately from a commercial building workplace.

Window wall versus curtain wall
The enclosure designs for these modern tall buildings in Canada often incorporate highly glazed cladding systems such as the window wall and curtain wall (Figure 2). There have been varied concerns about these assemblies, such as energy performance, lifespan, reliability, and resilience. However, not all design/construction professionals truly understand the difference between the curtain wall and window wall.

When discussing curtain walls and window walls, much of the attention is on the performance of the window or insulated glazing unit (IGU). However, both systems can employ the same IGUs, whether poor-performing windows or high-performing triple-glazed units with low-emissivity (low-e) coatings. Where the systems differ is how they attach to the structure. Simply put, the main difference is the window wall structurally sits between the suspended reinforced concrete slabs while the curtain wall is hung off the slab edges by anchors.

However, there are many more intricacies differentiating the systems. The curtain wall is esthetically slick, modern, and desirable for many architects. It is used primarily for commercial buildings, and some unique residential projects. Curtain walls are structurally engineered and typically installed from the outside using a crane or a rig, which make them more expensive and more rigorous to install than window walls, which are put up from the building interior.

[4]**Figure 2**: A quick visual comparison of a curtain wall (left) and window wall (right).

In early versions of window walls, there was a break at every floor, detracting from their sleek continuity. Modern systems, though, make it possible to closely mimic the esthetic look of a curtain wall. Window walls are almost exclusively used in residential buildings since they provide a practical and cost-effective method to install highly glazed cladding, while still allowing balconies and operable windows—this feature is rarely offered with curtain wall designs.

The two cladding systems are used in different situations; a thorough and objective performance comparison has been made in a recent U of T report that recommends their best use and possible improvements. (The report in question, by this article's three authors and H. Ali, F. Mirahadi, R. Lyall, and P. De Berardis, was presented at the Canadian Society for Civil Engineering/Construction Research Congress [CSCE/CRC] International Construction Specialty Conference in Vancouver earlier this year. Entitled "Window Wall and Curtain Wall: An Objective Review," it is available at buildingtall.utoronto.ca/wp-content/uploads/2016/07/Marquis_P_et_al_CON125_Window_Wall_Curtain_Wall.pdf[5].) Three key findings from the report include:

1. The window wall is the more suitable application for residential construction.
For residential applications, window walls better accommodate features such as balconies, operable windows, and suite compartmentalization (*i.e.* containing odours, noise, and air movement within a single unit). These assemblies also offer significant advantages over curtain walls for constructability, cost, and maintenance.

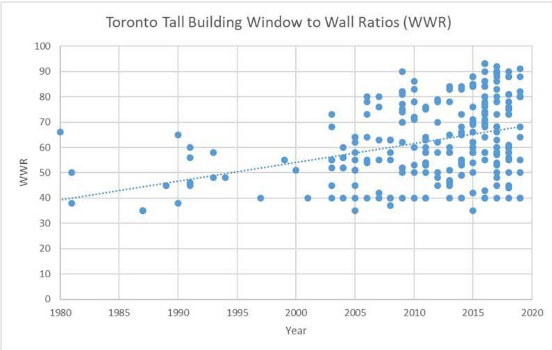
2. Curtain walls have certain advantages in the metrics of thermal performance, airtightness, and water penetration.
Intrinsic properties of curtain wall and the way it is attached to the structure give it advantages in the performance areas listed above. However, the review shows a well-designed and properly installed window wall system can perform equal to or better than a typical curtain wall based on these metrics, and at a lower cost.

3. Best practices for the design and installation of window wall cladding systems have advanced to achieve better performance.
This improved performance includes reduced thermal bridging to the concrete structure, less conductive window-wall frames, and use of a rainscreen design to collect and drain any penetrating water.

Construction mockups and field testing have become commonplace and further contribute to improving water penetration and air infiltration.

The window wall has substantially evolved since it first appeared. Many of the perceived faults are attributed to its older iterations, such as the lack of slab covers. With the new design features and technological advances, the window wall can be a good alternative to the more expensive curtain wall, even for commercial buildings. Considering its advantages for operable windows, balconies, odour and sound isolation, and cost, a well-designed and well-installed window wall is the most suitable choice for tall multi-unit residential buildings (MURBS).

While the differences between the systems have been well established and potential improvements suggested, a common concern for both the curtain wall and window wall still exists for many building scientists—the large window-to-wall ratios (WWR) that typically come with them.



[6]**Figure 3**: The window-to-wall ratios (WWR) of tall buildings in Toronto.

Window-to-wall ratios

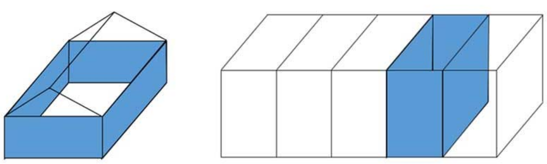
The WWR is typically expressed as a percentage and represents a building's total visible glazing area divided by its total exterior envelope area. This important variable directly affects energy performance in buildings given the window area impacts heating, cooling, and lighting needs. (This comes from John Straube's 2012 publication, "High-performance Enclosures" [Building Science Press].) Relatively large glazing areas can help reduce the electric lighting load of buildings with increased daylight. Solar gain through windows can also reduce the heating load in the winter, but that same heat gain in the summer is one of the main causes of increased cooling loads. Further, glazing assemblies generally have significantly worse thermal resistance compared to typical opaque wall assemblies, which makes them cold during the winter. Consequently, the objective of placing a limit on window areas is to reduce the heating load in winter and the cooling load in summer.

Despite WWR restrictions becoming stricter in the last 20 years (Ontario's prescriptive maximum WWR is now 40 per the 2012 *Ontario Building Code* [*OBC*]), the WWR of tall residential buildings in Toronto is trending higher (Figure 3). Large window areas are big selling points for condominium units, and developers are using the performance compliance path of the code to provide larger window areas than permitted by the prescriptive path. Performance-based compliance relies on whole-building energy modelling and typically uses efficient active systems such as HVAC and lighting to make up for poor building envelopes.

OBC introduced two supplementary standards to improve energy efficiency:

- SB-12 for low-rise (four or fewer storeys) residential buildings; and
- SB-10 for all other buildings, including high-rise commercial and residential.

One of the main challenges when it comes to the WWR of tall towers is the fact both residential and commercial buildings are controlled by the same code, while their use and, most importantly, their compartmentalization levels are vastly different. Commercial buildings often have large open spaces on each floor, allowing light from different directions to get into the space, while residential towers are highly compartmentalized and have much smaller units with only one or two walls (for corner units) to the outside. Further, the occupants in commercial buildings usually use the facilities between eight and 10 hours a day, while residential occupants obviously live in their units.


[7]**Figure 4**: A simplified low-rise house (left), and simplified low-rise attached townhome (right).

From a strict code perspective, SB-10 has a prescriptive maximum of 40 per cent WWR for both residential and commercial tall towers. SB-12 has a prescriptive maximum WWR of 17 per cent, but can go as high as 22 per cent if windows with better U-values are used. However, the rules for calculating the WWR in the two standards differ substantially. This inconsistency is explained in the following paragraphs, followed by an alternative and more consistent measure of WWR.

For low-rise detached single-family homes in SB-12, the 17 to 22 per cent WWR is calculated based on the building's entire vertical enclosure area as demonstrated by the shading in the left half of Figure 4. With windows located over four walls, light can enter the living space from all directions. The WWR is calculated as:

$$WWR_{SB-12(Single)} = \frac{Glazing\ area\ of\ building\ (1\ living\ unit)}{Area\ of\ vertical\ perimeter\ of\ building} * 100\%$$ [8]

When calculating the enclosure area for attached low-rise units such as townhomes, SB-12 A-2.1.1.1.(7) (8) and (10) explains:

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For attached homes, the above grade portions of the walls that are common to other conditioned units are also included in the wall area.
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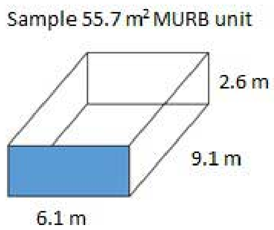
The equation to calculate the WWR in this case is:

$$WWR_{SB-12(Attached)} = \frac{Glazing\ area\ of\ living\ unit}{Area\ of\ vertical\ perimeter\ of\ living\ unit} * 100\%$$ [9]

As shown in the right-side portion of Figure 4, the interior common walls are included in the calculation for the WWR. Since interior common walls cannot have windows, the total window area can be placed in the two exterior walls, allowing significant light to enter the living space from two directions.



[10] **Figure 5**: Simplified multi-unit residential building (MURB) unit.

A simplified 55.7-m^2 (600-sf) high-rise MURB unit is shown in Figure 5. The three interior walls are windowless and natural light enters the suite solely from one direction. Each interior wall, floor, and ceiling is perfectly insulated since the temperature on both sides is approximately the same.

Under SB-10, the WWR is calculated on a whole-building versus living-unit basis, so the interior walls are not included in the WWR calculation. The equation is:

$$WWR_{SB-10} = \frac{Glazing\ area\ of\ whole\ building}{Area\ of\ vertical\ perimeter\ of\ whole\ building} * 100\%$$ [11]

This is inconsistent with the WWR calculation using SB-12, as it does not consider the number of units in the building and the individual living unit's access to light. If SB-12 (attached homes) is used, 100 per cent windows on the exterior wall would represent only a 20 per cent WWR for the unit in Figure 5. As previously mentioned, a 20 per cent WWR is allowable in the prescriptive code for a low-rise residential building (*i.e.* single living unit) as calculated under SB-12.

Effective window-to-wall ratio

To address this inconsistency in the codes, the effective window-to-wall ratio (EWWR) metric has been introduced by researchers at Building Tall Research Centre at the University of Toronto. It defines the window-to-wall ratio of a MURB unit within the confines of the living space from the perspective of the occupant. Like SB-12, the EWWR considers all perimeter walls of a living unit. The EWWR calculation is:

$$EWWR = WWR_{SB-12(Attached)} = \frac{Glazing\ area\ of\ living\ unit}{Area\ of\ vertical\ perimeter\ of\ living\ unit} * 100\%$$ [12]

WWR	100	90	80	70	60	50	40	30	20
Effective WWR	20	18	16	14	12	10	8	6	4

[13] **Figure 6**: Simplified side-unit WWR percentages.

The EWWR of the simplified unit with the corresponding whole-building WWRs is described in Figure 6.

If this simplified unit was designed to meet the SB-10 prescriptive 40 per cent WWR requirement, the unit would have an eight per cent EWWR for a side unit and a 20 per cent EWWR for a corner unit. This example shows, from the occupants' perspective, the WWR of their living unit is likely much smaller than the building's WWR and even much less than what they would have in a low-rise living unit if the current prescriptive code were to be followed.

While the scope of this paper only considers the differences in the local building codes, tall buildings around the world have traditionally been constructed for commercial use—therefore, the codes controlling their construction and operation are often more oriented toward nonresidential buildings. However, with the global intensification of cities and the need for high-rise residential towers, the codes around the world need to realize the unique needs and challenges of these tall communities.

Passive solutions for high-performing building envelopes

As governments attempt to achieve their GHG emission goals, building codes will continue to be major targets for reductions. There have already been attempts to reduce allowable WWR to 30 per cent and lower to have a more efficient prescriptive baseline. If these efforts were successful, side units might only have a four to six per cent EWWR. However, it is not justifiable to continue reducing the allowable fenestration area when there are alternative ways to achieve the energy goals with moderately sized windows.

There are passive methods of improving the overall U-value of building envelopes, as well as controllable shading and energy-positive solutions such as photovoltaic (PV) glazing. Improved IGUs such as low-e-coated triple- and quadruple-paned glass, evacuated windows, aerogel panels, and electrochromic (EC) windows can all be significant passive improvements to the building envelope while allowing reasonable window sizes.

Thermal bridging is an important factor that is often underestimated. Extruded balconies can be important thermal bridges without a thermal break, and framing materials such as aluminum are extremely conductive. Methods for reducing thermal bridging should also be taken more seriously, and be a requirement for code compliance.

Airtightness of the enclosure is another factor that has been taken more seriously in recent years. However, improvements can still be made. Relying on complicated active systems such as HVAC is not a resilient method for efficiency.

Whole-building energy models trade off these efficient active systems for poor envelopes, while their true performance is not well documented. Instead, the focus should shift to trading off the larger WWR with other passive and semi-passive enclosure improvements.

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Endnotes:

1. [Image]: https://www.constructioncanada.net/wp-content/uploads/2017/10/dreamstime_l_98403313.jpg
2. www.emporis.com/press/press-release/1/high-rise-construction-in-north-america-toronto-continues-to-lead-going-into-2014: http://www.emporis.com/press/press-release/1/high-rise-construction-in-north-america-toronto-continues-to-lead-going-into-2014
3. [Image]: https://www.constructioncanada.net/wp-content/uploads/2017/10/Figure-1.jpg
4. [Image]: https://www.constructioncanada.net/wp-content/uploads/2017/10/fig-2-1.jpg
5. buildingtall.utoronto.ca/wp-content/uploads/2016/07/Marquis_P_et_al_CON125_Window_Wall_Curtain_Wall.pdf: http://buildingtall.utoronto.ca/wp-content/uploads/2016/07/Marquis_P_et_al_CON125_Window_Wall_Curtain_Wall.pdf
6. [Image]: https://www.constructioncanada.net/wp-content/uploads/2017/10/Figure-3.jpg
7. [Image]: https://www.constructioncanada.net/wp-content/uploads/2017/10/Figure-4.jpg
8. [Image]: https://www.constructioncanada.net/wp-content/uploads/2017/10/TallGlass-EQ1.jpg
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