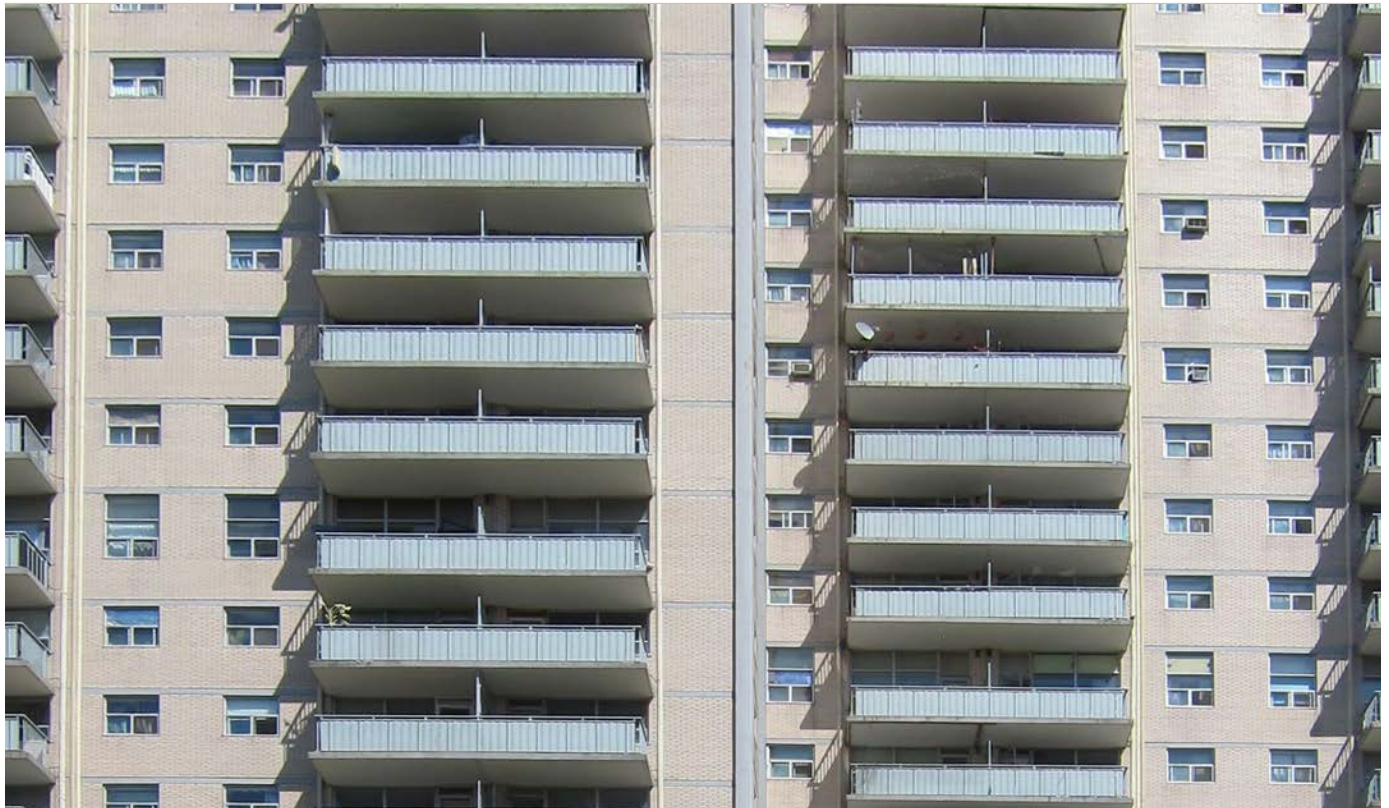


THERMAL COMFORT & COOLING IN APARTMENT TOWERS

RESEARCH BRIEF



THE TOWER RENEWAL PARTNERSHIP

Tower Renewal is a model to transform Canada's remarkable stock of mid-century apartment towers and their surrounding neighbourhoods into more complete communities, resilient and healthy places, fully integrated into their growing cities. The Tower Renewal Partnership is a collaborative initiative working to

preserve and enhance this key housing through research, advocacy and demonstration projects. The Tower Renewal Partnership's goal is to enable reinvestment into these dynamic neighbourhoods, working toward building lower-carbon, healthier and more complete communities.

Partners and Supporters

CENTRE FOR
URBAN GROWTH
AND RENEWAL
www.cugr.ca CUG+R

M Maytree
Poverty • Rights • Change

DKGi Inc.



nblc

Transsolar
KlimaEngineering

Cover image courtesy of Jesse Colin Jackson

APARTMENT TOWERS AND THERMAL COMFORT

Ontario's considerable stock of high-rise apartment towers, developed during the post-war period, provides much of the Province's purpose-built rental housing. Now in service for over half a century, these buildings are in need of upgrades to meet today's standards of thermal comfort. Most importantly, they require reconsideration in terms of mitigating negative impacts to public health.

Overheating, condensation, and the lack of temperature controls have significant negative impacts on the comfort and health for residents of this aging housing stock. Overheating, for example, has been shown to result in severe health impacts and premature death in Canada.¹

A greater understanding of the factors affecting thermal comfort is necessary for the development of comprehensive solutions. The following outlines some of the conditions, challenges, and strategies for achieving thermal comfort through deep energy retrofits, and considerations for the development of means of defining and measuring thermal comfort.



1 See "Reducing Health Risk from Extreme Heat in Apartment Buildings," Toronto Public Health Staff Report, 11 June 2015.

CHALLENGE: BUILDING ENVELOPE PERFORMANCE

The building envelope is the separation between the indoor and outdoor environments. Its performance determines the degree to which outdoor conditions impact occupant comfort inside a building, through the transfer of heat and air through the outer walls.

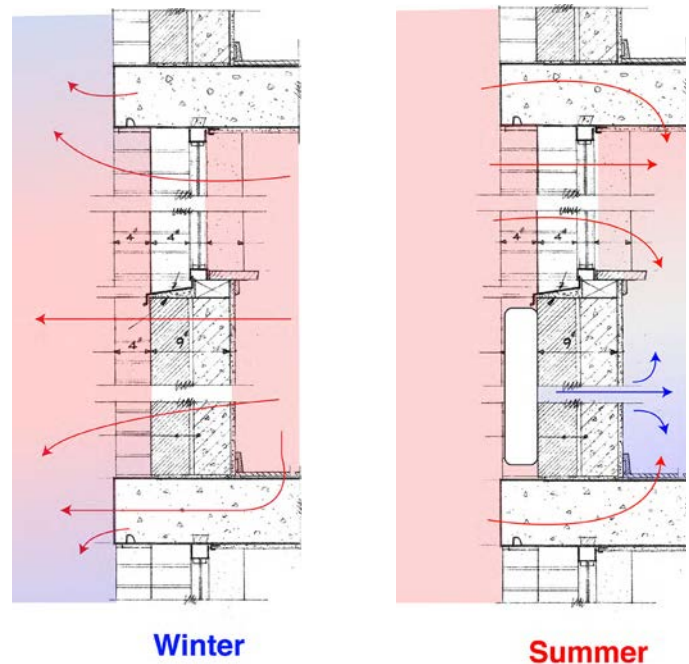
Contemporary building practice optimizes the envelope, by using effective insulation and controlled air leakage. This results in comfortable indoor environments, with minimal reliance on energy-intensive mechanical systems, such as heating and air conditioning.

However, optimized building envelopes were not common practice during the fuel-rich postwar years. The building envelopes found in Toronto's aging high-rise apartments were designed prior to mandated energy conservation measures in the Ontario Building Code (OBC). Today, these buildings are characterized by envelopes that are leaky and have minimal insulation (R-values).

Maintaining thermal comfort in buildings with poorly performing envelopes is extremely energy-intensive, consuming natural gas in winter and electricity in summer. On average, postwar towers are nearly twice as energy intensive as current building code requirements permit.¹

Poor building envelope performance can result in inconsistent indoor environments. For example, thermal bridges at cantilevered concrete balconies create cold indoor surfaces in winter, causing drafts and discomfort. Significant heat loads are required to offset the drafts created by these bridges. The risks associated with cold bridging are not limited to occupant discomfort; where indoor air temperatures are not increased to offset cold

Figure 1: Wall Constructions with Low R-Values



surfaces, condensation can occur, eventually leading to mould and its associated health risks. In summer, cooled air from air conditioning is rapidly dissipated, diminishing the efficacy of active cooling and requiring cooling systems to run continuously. In all seasons, thermal comfort is difficult to achieve and requires significant energy consumption to maintain.

¹ In Toronto, postwar apartment towers have an energy intensity of 300 kWh/m²a, with some as high as 450 kWh/m²a, according to City of Toronto Benchmarking Data, Tower Neighbourhood Revitalization Unit, 2016.

CHALLENGE: MEASURING OCCUPANT COMFORT

Thermal conditions are commonly measured by air temperature alone. However, thermal comfort is in fact a more complex result of the interaction between air temperature, radiant heat, and relative humidity. These factors, taken together, are termed ‘operative temperature.’ Operative temperature is a more comprehensive measurement, taking into account both radiative and convective heat exchange between the occupant and his or her surrounding environment. It more closely represents perceptions of comfort, as compared to measuring air temperature alone. The use of operative temperature as a measurement and design tool tends to result in solutions that increase occupant comfort while decreasing energy use.

Provisions for designing an adaptive range of thermal comfort are determined by operative temperature and adaptive comfort modelling. The adaptive model is based on the influence of outdoor climate on perceptions of indoor comfort. Since humans adapt to different temperatures during different times of the year. Rather than stipulating a fixed indoor temperature all year, adaptive comfort principles provide an operative temperature range related to time of year and outdoor temperature trends. For example, where 21°C may feel warm in winter, it may feel cool in summer. Using the adaptive comfort model allows for greater flexibility in the design range for indoor conditions, by assuming that occupants can regulate their thermal environments to a reasonable degree by opening windows, changing clothing, or controlling indoor air movement.¹

Several international standards use both operative temperature and adaptive comfort modelling to provide more contextual factors by which to measure comfort. Examples include ASHRAE 55-2013 and the German DIN 15251 Standard. Using the DIN Standard, for

Figure 2: DIN15251 Adaptive Comfort Ranges

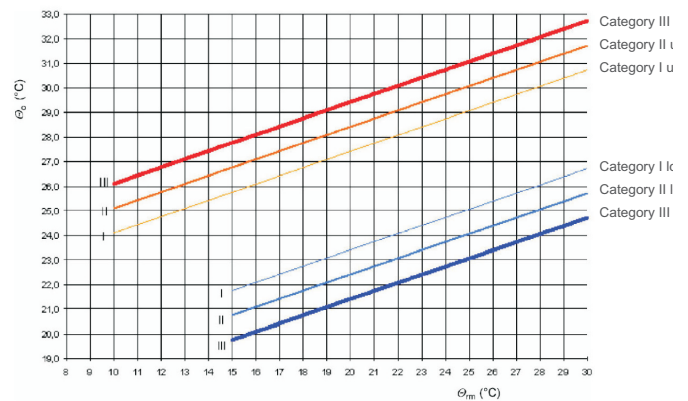


Figure 3: DIN4108 Acceptable Cooling Kelvin-Hours

Summer climate region	Comfort threshold for indoor operative temperature	Maximum allowed number of Kelvin-hours above the comfort threshold	
		residential	non-residential
A	25	1200	500
B	26		
C	27		

example, acceptable indoor operative temperatures vary according to outdoor air temperature. Moreover, those temperatures are permitted to exceed the acceptable comfort threshold for a small percentage of the time.

Rather than mandate maximum indoor operative temperatures, the standard allows for climactic variation. It also anticipates a range of user environmental controls, including changing clothing, operable windows, and increasing air movement.

¹ See Adaptive Comfort Standard in ASHRAE Standard 55-2013, Applicable for Naturally Ventilated Buildings.

MAXIMUM TEMPERATURES AND AIR CONDITIONING

Overheating in summer has been identified as one of the key health issues facing occupants of aging apartment towers. Public health agencies have long been pointing to the dangers of exposure to extreme heat in multi-unit residential buildings, particularly for vulnerable populations.¹

Ensuring indoor thermal comfort and mitigating extreme temperature exposure are critical issues driving envelope retrofits in many postwar apartment towers. Creating optimal conditions for indoor comfort requires a comprehensive retrofit approach, including envelope modernization tied to recalibrated mechanical systems. This approach significantly improves the effectiveness of active cooling, and in many conditions, may eliminate the need for active cooling entirely. For more on the role that envelope retrofit can play in regulating thermal environments, see page 11.

In buildings which have not been retrofitted, the installation of in-window air conditioning units is common practice as a means of providing in-suite cooling. There are some advantages to this solution, as units are installed and controlled by occupants, as needed. However, air conditioning units present critical challenges. When envelopes are leaky, air conditioning units are often ineffective and are run continuously with minimal impact. These units consume substantial electrical loads, resulting in significant pressure on the electrical grid at peak demand (See Figure 5). Individual units as a solution to overheating poses a risk if adopted as a long-term strategy.

Programs mandating mandatory minimum temperatures in apartments should consider the aggregate impact of in-window A/C units in their analysis. Assuming air conditioning units are currently installed in 30% of

apartment units, instituting mandatory minimum temperatures could result in the addition of nearly 350,000 air conditioning units within the Greater Golden Horseshoe alone. This would have significant impacts on the electrical grid capacity and production of GHGs.— While remaining relatively ineffective as a cooling strategy.

In determining the potential impact of the addition of these cooling units on the electrical grid, two scenarios were studied: a base scenario and an extreme weather scenario. The base scenario assumed one air conditioning unit per apartment, with an even mix of small (600 BTU) and medium (1,200 BTU) and large (1,800 BTU) units. Assuming 1,400 hours of cooling per season, this scenario resulted in a total seasonal load of 594,669 MW, with a peak load of 412 MW.

The extreme weather scenario assumed 30% of units would have two air conditioning units (one for living space and one for a single bedroom), and an even mix of small (600 BTU), medium (1200 BTU) and large (1800 BTU) sized units. Assuming 1,800 hours of cooling per season, this scenario resulted in a seasonal total load of 1,115,005 MW, with a peak load of 619.45 MW.

Given a typical Ontario summer peak load of 2,476 MW, the addition these two scenarios represent 11% (base scenario) or 17% (extreme scenario) increases to electrical loads. This net increase is comparable to the capacity of a medium-sized gas-fired plant (See Figure 6).

1 “Reducing Health Risk from Extreme Heat in Apartment Buildings,” Toronto Public Health Staff Report, June 2015.

Figure 4: The Cost of Active Cooling

The following outlines the impact of widespread adoption of in-window air conditioning units in postwar apartment towers, as related to electrical infrastructure, GHG emissions and cost to residents. This assessment assumes that 70% of suites within existing apartment towers install air conditioning units to achieve cooling targets. Two scenarios have been tested, average and high, taking into consideration both average and extreme weather conditions and characteristics of the energy supply mix. The results illustrate the potential impact of installing air conditioning units as a means of providing active cooling, adding a peak electrical load comparable to the capacity of a medium-sized gas-fired plant.



Scenarios	Toronto		Greater Golden Horseshoe		
	Average	Extreme	Average	Extreme	
	235 408	235 408	347 614	347 614	Apartments ¹
	235 408	392 343	347 614	579 350	New A/C Units ²
	1400	1800	1400	1800	Cooling ³ (Hours / Days)
	12.3%	27%	12.3%	27%	Energy Mix ⁴ (% Natural Gas)
Outcomes					
	40 588	129 673	59 935	191 482	GHG Emissions (tonnes/year)
	402 717	755 094	594 669	1 115 005	Usage (MW/year)
	279.66	419.50	412.67	619.45	Peak Load (MW)
	\$210.42	\$394.53	\$210.42	\$394.53	Cost per A/C Unit (Annual)
					Environment
					Infrastructure
					Tenant

1 This value represents 70% of buildings with 5+ units

2 Extreme conditions includes additional A/C units per apartment

3 1400 hours is equivalent to 60 days of cooling while 1800 is equivalent to 75 days

4 Natural gas power plants serve as demand peaking stations – brought online during peak demand periods. Natural gas has a higher CO₂e Intensity (g of CO₂ /KWh) than other forms of power generation resulting in higher GHG emissions in the extreme scenarios.

Figure 5: The Impact of Two Cooling Scenarios on the Electricity Demand Profile in the Greater Golden Horseshoe

The following illustrates the peak demand from Toronto's average and extreme scenarios to simulate a demand profile, using hourly electricity usage data from July 29, 2015. ^{5,6}

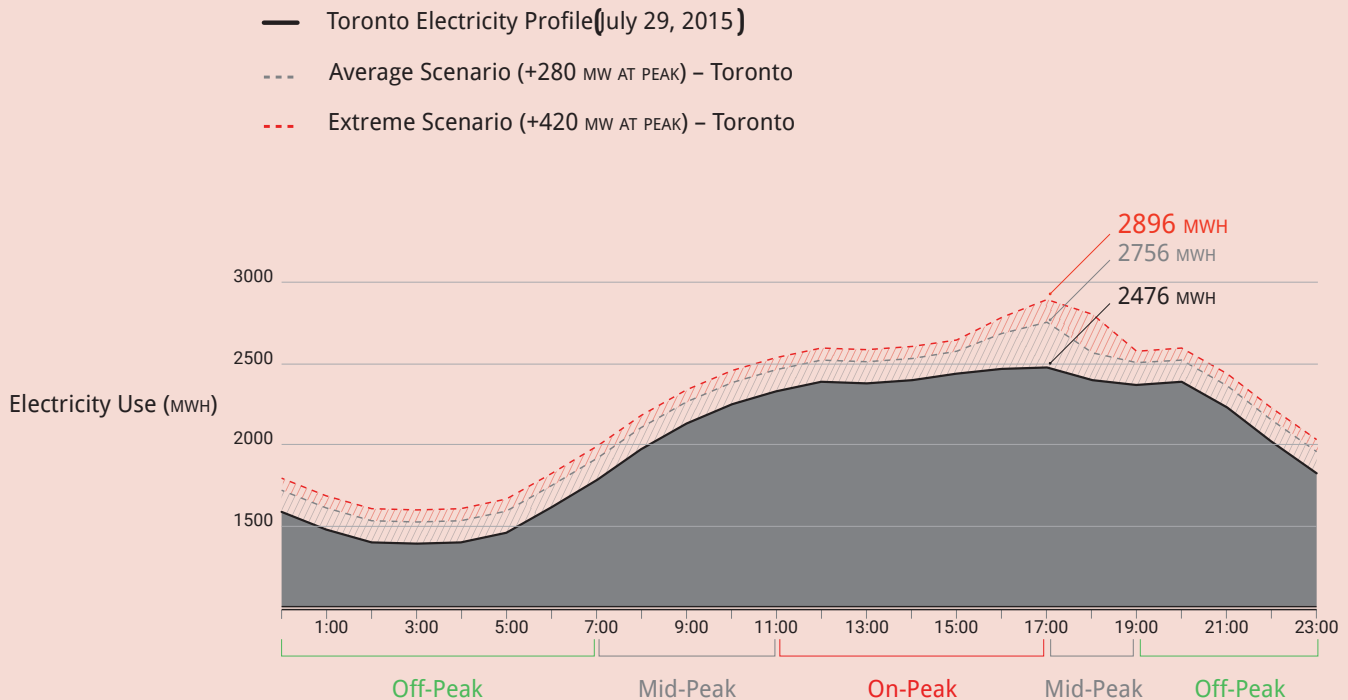
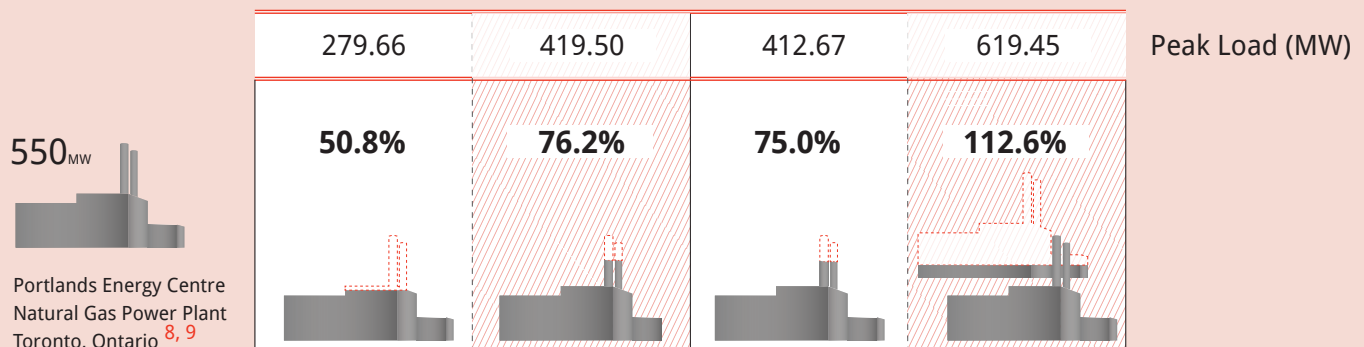


Figure 6: Peak Load from New Air Conditioning Units as a Percentage of Portlands Energy Centre's Capacity

The widespread adoption of air conditioning units in postwar apartment towers would require the construction of a new demand-peak power plant in the Greater Golden Horseshoe.



5. In 2009 74% of homes in Ontario used A/C. Stats Canada, Households and the Environment Survey, 2009.

6. Ontario's 2009 A/C integration rate applied to the number of dwellings in Toronto. Statistics Canada, Focus on Geography Series, 2011.

7. Ontario's 2009 A/C integration rate applied to the number of dwellings in the GGH. Statistics Canada, Focus on Geography Series, 2011.

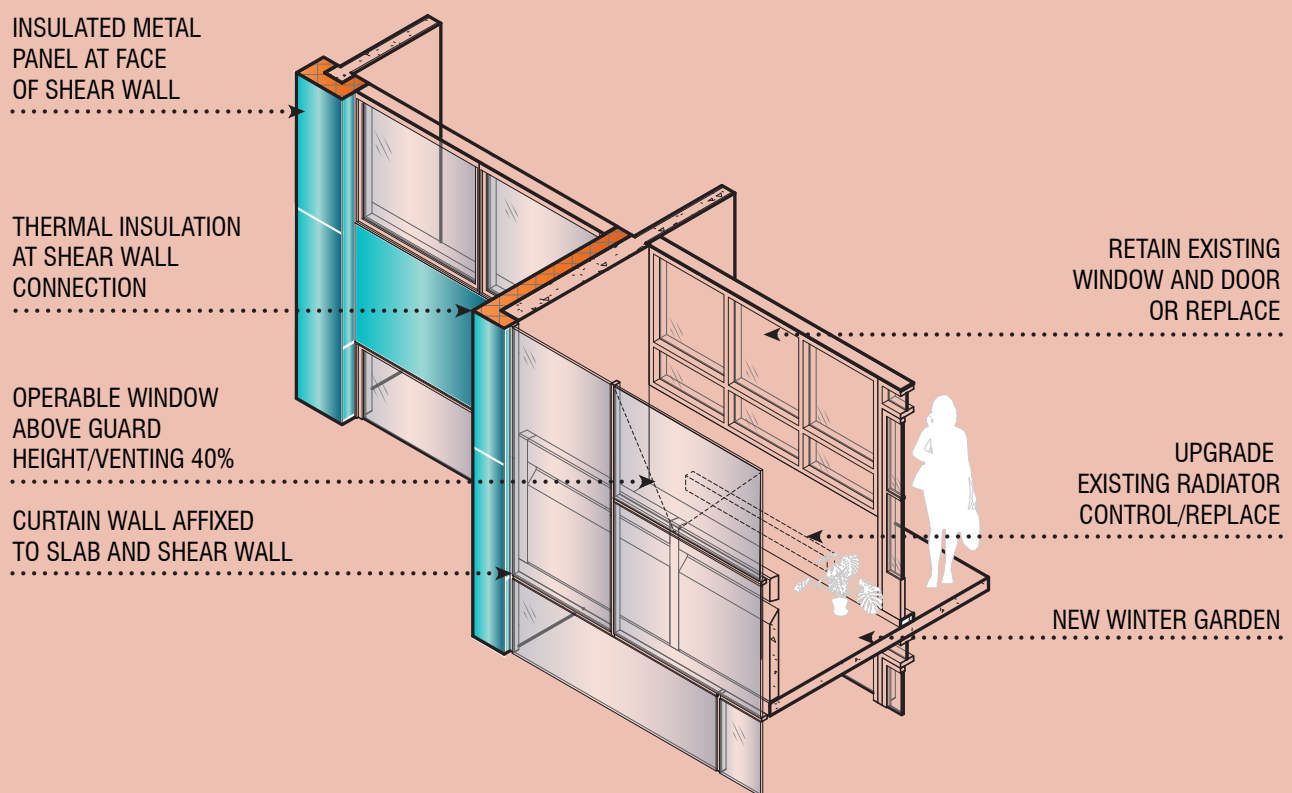
8. IESO, "Portlands Energy Centre". Accessed 04/08/2016. <<http://www.powerauthority.on.ca/sc-cc/portlands-energy-centre-5500-mw-toronto>>.

9. Portlands Energy Centre was built in 2006 at a cost of ~\$730 million

10. Toronto Hydro, "Net System Load Shape." Accessed 04/08/2016. <<http://www.torontohydro.com/sites/electricsystem/business/yourbilloverview/netsystemloadshape/Pages/default.aspx>>

11. 100 mw is equal to the electrical use of ~33 000 Home

Figure 7: Typical Envelope Retrofit Approach for Passive Thermal Conditioning



BUILDING TOWARD PASSIVE CONDITIONING: ENVELOPE RENEWAL

Postwar apartment towers are well-suited to high-performance envelope retrofits. These retrofits typically include high levels of thermal insulation, elimination of thermal bridging at exposed slabs or shear walls, airtightness, high-performance operable windows, and external solar shading systems.

Envelope retrofits can bring postwar apartment towers to best-in-class energy performance levels. Examples of such retrofits can be found throughout the world, particularly in the European Union. Some of these retrofits have achieved Passive House certification, with ultra-low energy demands and more than 90% reductions in GHG.

An improved envelope provides a key barrier between indoor and outdoor environments, significantly reducing the requirement for active heating and cooling. However, there are a number of considerations which must be taken into account when designing an envelope to achieve passive thermal conditioning.

Condensation Considerations: Increasing the thermal performance on exterior walls while leaving protruding slab edges and shears wall exposed (at balconies and elsewhere), creates thermal bridges. In winter these thermal bridges create a risk of mould due to condensation. Typically, existing buildings mitigate mould development through (1) air movement provided by a leaky envelope and (2) and the overheating of units. Once the building envelope is improved, lower suite air movement and lower indoor air temperatures can increase the potential for mould growth when thermal bridges remain. This is a particular concern when furniture is placed against exterior walls at thermal bridges, limiting air movement and access to warm indoor temperatures at covered surfaces. Fully isolating



Bugginger Strasse Passive House Tower Retrofit,
Fribourg Germany

the envelope removes this risk by ensuring all indoor wall surface temperatures are warm.

Mould poses serious health risks to its inhabitants and can be exacerbated by inadequate ventilation. Mould build-up became common in Germany in the 1990s, when overcladding first became popular. In Germany, these incidents led to new building code legislation. The current standard used in Germany and referenced around Europe is the DIN 4108-2: Thermal insulation and energy economy in buildings. This standard requires a minimum internal surface temperature of 12.6°C throughout the inside of the building. When this condition is met, the risk of mould due to thermal bridging is significantly reduced.

An advanced 3D dynamic thermal simulation was carried out on a sample tower in Toronto to evaluate the impact of thermal bridging on heat load and mould growth

potential on concrete balconies. The analysis determined that the existing building condition and non-insulated balconies pose serious mould risk potential, particularly if the air leakage through the façade is reduced.

The energy savings associated with eliminating thermal bridges is, on first inspection, small compared to the impact of insulating the majority of a building face. However, without addressing the thermal bridges to avoid mould growth, air temperatures in the units would need to be raised to approximately 25°C during the winter months. This represents a significant increase in heating demand compared to a 21°C typical indoor air temperature. Fans to provide evaporative air management are also recommended.

Fully mitigating the risk of mould requires the removal of thermal bridging through the complete isolation of building envelope through the wrapping of all exposed

Figure 9: Thermal Bridge Variants Evaluation: Thermal Simulation Results

<div> <div> <div></div> <div> <div></div> <div></div> </div> </div> <div> <div> <div></div> <div></div> </div> </div> </div>	<div> <div></div> <div>Condensation</div> </div>	<div> <div></div> <div>Thermal comfort</div> </div>	<div> <div></div> <div>Winter comfort & energy use</div> </div>	<div> <div></div> <div>Summer comfort</div> </div>	
<div> <div></div> <div>0</div> <div>external wall: no insulation balcony wall: no insulation balcony slab: no insulation</div> </div>	X	X	X		perform summer conditions studies as the reference base case
<div> <div></div> <div>1</div> <div>external wall: insulation balcony wall: insulation balcony slab: no insulation</div> </div>	X	X	✓		no summer studies because it does not pass the condensation requirements
<div> <div></div> <div>2</div> <div>external wall: insulation balcony wall: insulation balcony slab: insulation</div> </div>	✓	✓	✓		perform summer conditions studies
<div> <div></div> <div>3</div> <div>external wall: insulation balcony wall: no insulation balcony slab: winter garden</div> </div>	✓	✓	✓✓		perform summer conditions studies and optimize operation as the preferred variant
<div> <div></div> <div>4</div> <div>external wall: insulation balcony wall: insulation balcony slab: winter garden & insulation</div> </div>	✓	✓	✓✓		this option is not recommended no summer studies

exterior slab and shear walls. Eliminating thermal bridging in apartment balconies has positive impacts on long-term maintenance, energy savings, and occupant health and safety.

Ventilation Considerations: Providing adequate ventilation and air movement is also critical. The alteration of the envelope system will impact air movement within suites. A new airtight envelope will significantly reduce existing fresh air infiltration from the envelope, increasing reliance on corridor air to meet required air changes. Corridor supply air has been demonstrated to be, when improperly balanced, an inadequate way to bring ventilation air into apartment units.¹

Relying entirely on corridor supply air poses two risks:

- That incoming air is not fresh or is contaminated; and
- That incoming air moves directly from the suite door to the bathroom exhaust vent, bypassing living areas of the suite and not providing adequate air movement at the new envelope.

The envelope should be designed to provide controlled, conditioned exterior air to enter suites. Exterior air infiltration at the envelope can be achieved through passive means, such as trickle vents,¹ or through active means, such as energy recovery ventilators (ERVs). With ERVs, the intake air is conditioned through heat recovery to lower heating demand as it passes into the suite.

Solar Gain Considerations: An envelope with adequate insulation, airtightness, and external shading will provide significant passive cooling to units. This can be supplemented by ceiling fans to introduce additional air movement as required. In addition, a strategy of ‘night cooling’ in summer can allow occupants to fill units with cooler nighttime air, closing windows and lowering shades during warmer daylight hours. In shoulder seasons, operable windows allow for natural ventilation.

User Control Considerations: Postwar apartment towers were built with centralized mechanical systems, typically without end-user controls. Due to stack effect, heat distribution tends to be uneven, with many occupants overheating even during the coldest months.

Envelope retrofits provide the opportunity to introduce user control into the indoor environment. An improved envelope reduces indoor temperature fluctuations, while the ability to turn on and off heating systems on a suite-by-suite basis leads to building-wide energy savings and user comfort.

Additional environmental control can be provided by decentralizing mechanical systems through ERVs, allowing for more precise control of air changes, humidity and, in some cases, light active cooling during the summer months.

Comprehensive retrofit can allow for ‘smart’ building systems to enhance comfort, control, and optimize low-energy building performance. In-suite monitoring and control systems, such as those operated from a smart phone, provide the opportunity for occupants to monitor their energy use and indoors environments on the fly.

¹ “Ventilation Systems for Multi-Unit Residential Buildings: Performance Requirements and Alternative Approaches,” Canadian Mortgage and Housing Corporation Research Highlight: Technical Series, 2003

BEST PRACTICE: RETROFITTING FOR THERMAL COMFORT

Developing a greater understanding of the factors affecting thermal comfort is necessary for the development of a policy framework that can ensure residents have access to comfortable, healthy, safe and high-quality housing.

Key considerations for policy design include:

- The use of flexible standards that address adaptive seasonal temperature (such as the German DIN standard 15251) rather than fixed air temperatures.
- A focus on passive (shading, natural ventilation) or 'light' active (ceiling fans) solutions in contrast to traditional air conditioning.
- A focus on operative temperature rather than air temperature to more flexibly and accurately define comfort.
- Mitigate issues of mould in retrofit projects through eliminating thermal bridges and ensuring warm indoor wall surfaces (in line with German DIN standard 4108-20).
- The design of low cost, easy to install envelope and balcony enclosure systems to maximize opportunities and enable more owners to adopt approaches for passive heating and cooling.
- Develop interim solutions prior to retrofit programs such as shading and 'light' active cooling strategies, as well as the creation of building cooling rooms and outdoor shade structures.

Promoting retrofit as a comprehensive solution to support long-term comfort and cooling strategies, high-quality demonstrations and regulatory shifts paired with retrofit financing are the key steps towards catalyzing the widespread adoption of this approach.

