THE EFFECT OF BALCONY ENCLOSURE RETROFITS ON THE PERFORMANCE OF MURBS

by

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Abstract

The City of Toronto has been undertaking retrofit projects to refurbish an aging building stock and increase performance in multi-unit residential buildings (MURBs). These retrofit considerations include solutions proposed for balconies, a common weak point in the building structure. A balcony enclosure retrofit was one such solution, using overcladding to insulate the exposed balcony slab and parapet, enclosing the open portion of the balcony with glazing.

The effect of the balcony enclosure differed depending on the balcony type, varying with characteristics such as balcony to façade ratio, orientation and the projection type of the balcony, whether inset or projecting. When models were retrofit with balcony enclosures, results showed an overall decrease in energy use as the enclosures raised internal air temperatures, lowering demand for heating. The balcony characteristics which showed the largest decrease in energy use when retrofit with balcony enclosures were inset balconies with high balcony to façade ratio.

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List of Abbreviated Terms

ACH – Air changes per hour

ASHP – Air Source heat pump

CMU – Concrete Masonry Unit

DHW – Domestic Hot Water

EIFS – Exterior Insulation and Finish System

EUI – Energy Use Intensity

GTA – Greater Toronto Area

HVAC – Heating, Ventilation, Air Conditioning

MURB – Multi-unit Residential Building

OBC – Ontario Building Code

PMV – Predicted Mean Vote

RCMs – Resource Conservation Measures

TBZ – Thermal Buffer Zone

WWR – Window-to-Wall Ratio

1. Introduction

1.1 Multi-unit Residential Buildings in Toronto

Multi-unit residential buildings were constructed in large numbers in the 1960s and '70s as an urban densification initiative that provided modern, 'European-style' housing to a post-war population (Kesik & Saleff, 2009). While in their earlier years, these buildings provided high-quality living to residents, this stock of buildings has degraded over time, exhibiting deterioration and overall inefficiency. It is estimated that 1,000,000 tonnes of greenhouse gases are released each year as a by-product of the Greater Toronto Area's inefficient multi-unit residential buildings (Kesik & Saleff, 2009).

The problem of this aging building stock was addressed by the City of Toronto as part of Mayor Miller's Tower Renewal Project. Through the Toronto Tower Renewal initiative, a surge of research was developed around methods of retrofitting multi-unit residential buildings (MURBs) in Toronto, touching on topics including replacement of glazing, overcladding of the envelope, and introduction of updated HVAC systems. Renewal strategies were proposed with the purpose of not only updating building elements, but also drastically improving building performance, as this building type is characteristically inefficient in terms of energy use.

1.2 Impact of Balconies on MURB Efficiency

Throughout the studies, balconies were pinpointed as key areas where improvements could be made, with many utilizing a cantilevered balcony slab that acts as a hotbed for thermal bridging and heat transfer (Kesik & Saleff, 2009). One solution proposed to mitigate this was an overclad retrofit of the balcony area. This retrofit would utilize insulated exterior cladding to cover the exposed balcony slab, mitigating a problematic source of thermal bridging. This retrofit could be achieved either by overcladding the exposed areas within the balcony, including the slab and the building façade within the balcony area, or by enclosing the balcony by overcladding outer surfaces of the parapet and adding in glazing to create an enclosed space (Kesik & Saleff, 2009).

While there is potential for energy savings by implementing balcony retrofit measures for MURBs, the practice has been slow to take off in the City of Toronto. This may, in part, be due to the complexities of MURB building designs and balconies which vary in size, with different configurations of balcony placement and geometry. This variability in balcony configuration may cause differences in the effect that the balcony enclosure would have on thermodynamics of the building envelope, and the energy use of the building.

1.3 Research Objective

With the addition of a balcony enclosure to a building in a cold climate, the expectation is an increase in building performance due to added solar gains and and reduction in thermal bridging. Therefore, the goal of this paper was to gauge the effect that a balcony enclosure retrofit would have on the energy use of a multi-unit residential building, when considered on its own, isolated from other retrofit strategies.

As this effect was assumed to be different depending on the configuration of the balcony, the main objective was to determine which types of balcony configurations would have the largest impact on energy usage if retrofit with an enclosure.

2. Literature Review

2.1 Existing MURB Balconies and Building Performance

Balconies are an observable feature that is characteristic of MURB aesthetics. Originally added to apartments to improve the marketability of rental units (Kesik & Saleff, 2009), balconies serve practical uses as well, providing shading for a portion of the building façade and fenestration against solar radiation. The City of Toronto's 'Tall Buildings Design Guidelines', 2013, encourages the use of balconies as the shade helps to reduce unwanted solar gains in the summer, while allowing for desirable solar gains in colder months due to the lower solar angle in winter (City of Toronto, 2013). An examination into the performance of apartments equipped with balconies by Chan and Chow, 2010, found that the presence of a balcony overhang reduced summer cooling loads by 7% to 19%, while heating demand was increased less significantly by approximately 1% to 3% (Chan & Chow, 2010). In a contrasting view, a study by William O'Brien, 2016, found that the presence of a balcony caused recurring periods of occupant discomfort from cold interior temperatures in winter months, due to imbalances in solar gains. However, the residential building examined in O'Brien's study had a high window-to-wall ratio (WWR) of 80% (O'Brien, 2016). This high WWR could explain why the balcony shading caused such a noticeable reduction in occupant comfort due to cold temperatures, as the heat loss through the highly-glazed envelope of the building exceeded the solar and internal gains. The WWR of the typical post-war MURB of focus is much lower than 80%, with the majority falling within the range of 25% to 30% (Kesik & Saleff, 2009).

While effective in providing shading, which can reduce solar gains and cooling loads, the balcony can also substantially detract from building performance. In 'Tower Renewal Guidelines,' Kesik and Saleff describe MURB balconies as the 'weakest link' in multi-unit residential structures of this era due to the exposed and uninsulated balcony slab, which is a major thermal bridging component (Kesik & Saleff, 2009). The issue lies within the cantilevered design of the balcony slab, which acts as an effective conductor of heat. In MURBs, the performance of the envelope can be significantly compromised by concrete balconies which are constructed as an extension of floor slabs (Cianfrone, Roppel, & Hardock, 2016) and in the heating season, this means that a significant amount of heat can be lost through the slab. According to Ge, McClung and Zhang, 2013, the impact of thermal bridging through a balcony slab has the potential to raise the U-value of a building façade for a typical floor by 8.9% to 18.5% compared to an assembly with a thermal break. Ge et al. also estimated that reducing thermal transfer through a MURB balcony slab by adding a thermal break could improve building performance by reducing annual heating load by 5% to 11% (Ge, McClung, & Zhang, 2013). As suggested by Ge et al., this thermal bridging is possible to address through the addition of a thermal break. For a balcony that is already constructed, this thermal break can be achieved by incorporating an overclad system which insulates the concrete slab, reducing the amount of energy transfer. Such retrofit measures will be discussed in the following section.

2.2 Balcony Retrofits as a Renewal Strategy

The paper, 'Tower Renewal Guidelines for the Comprehensive Retrofit of Multi-Unit Residential Buildings in Cold Climates ' by Ted Kesik and Ivan Saleff, 2009, outlines strategies which could be implemented to retrofit post-war era multi-unit residential buildings in order to revitalize and renew the buildings' effectiveness, while increasing energy efficiency. In 'Tower Renewal Guidelines', two main types of energy-saving balcony retrofits are identified: one in which an exterior insulating and finish system (EIFS) overcladding is applied to the exposed surfaces of the balcony slab and onto the surfaces of the building façade around balcony area, and another strategy which involves entirely enclosing the balcony structure using an EIFS overclad of just the outermost facing balcony elements, with an upper portion of double-glazed operable windows that complete the enclosure (Kesik & Saleff, 2009). While both the enclosure and non-enclosure methods of retrofit utilize overcladding which acts as an insulated and water-resistant 'skin' covering thermally conductive balcony slab edges, opinions on which is the better method to use vary. Kesik and Saleff outline the fully enclosed balcony as the preferred retrofit measure due to its cost and performance benefits over the unenclosed balcony retrofit. In addition, enclosure retrofits are said to have the advantage of being less disruptive to tenants, as implementation does not require the original façade to be disturbed (Kesik & Saleff, 2009).

Building on the work of Kesik and Saleff's 'Tower Renewal Guidelines,' Arup Canada conducted a study of energy and emissions savings, cost and overall feasibility of retrofits for Toronto MURBs. In this study, 7 of the 13 Resource Conservation Measures from 'Tower Renewal Guidelines' were explored and incorporated into 30 new RCMs presented by Arup (Arup Canada Incorporated, 2009). RCM 23, which involved a re-clad of exterior walls and glazing above the parapet, achieved an R-18 exterior wall for the enclosure. In Arup's analysis of potential RCMs, balcony enclosure retrofits were not believed to outperform non-enclosure overclad retrofits, showing "only incremental additional savings over non-enclosed balconies, in contrast to a large and expensive list of related issues" (Arup Canada Incorporated, 2009). These issues expected by Arup included moisture and condensation issues, relocation of tenants (as construction would require demolition and reconstruction of exterior walls), and upgrade in code requirements for HVAC, electrical and fire services, required structural enhancements to balconies, code compliance for window area restrictions, and the issue of tenant preferences and a right to fresh air (Arup Canada Incorporated, 2009). The areas of concern are examined below in more detail.

2.2.1 Balcony Enclosures and Moisture

An analysis of different enclosed balcony conditions was conducted by Kesik and Saleff to determine the best operating conditions for an enclosed balcony. As condensation and excess moisture were potential concerns with an unconditioned space that was receiving solar gains, a simulation of 9 different balcony conditions was conducted to analyze the most suitable scenarios in terms of space conditioning or non-conditioning, open air connection to the rest of the apartment suite, and use of interior shading devices (Kesik & Saleff, 2009). Moisture was expected to be an issue when the temperature of the enclosure glazing was 8^{o}C or below, indicating condensation potential. The simulation results showed that condensation was primarily expected to be present in an unconditioned enclosed balcony, where the enclosure glazing remained shut, except in the case of ideal outdoor temperature conditions. This scenario revealed numerous hours with condensation potential, especially for the North orientation (344 hours, compared to 47 hours for West, 56 hours for East and 0 for South). However, when this same scenario specified windows that were left closed during the heating season, but opened fully and provided with shade cover during the cooling season, this was consider a nearly-ideal condition with zero instances of glazing reaching temperatures at or below 8^{o}C, signifying little to no condensation potential (Kesik & Saleff, 2009).

In a paper examining balconies and sunspaces in Denmark by Olaf Jørgensen and Ole Hendriksen, the use of an enclosure design similar to the enclosure scenario outlined in 'Tower Renewal Guidelines', was examined. This design, which utilized highly insulated parapets and glazing, had operable glazing and was not conditioned, was determined to have comfortable temperatures during the heating season and the ability to avoid overheating in summer months by opening the glazing. When assessed for moisture potential, adding the balcony enclosure was expected to provide effective drying of the moisture-damaged balcony slab and façade within the enclosure (Jørgensen & Hendriksen, 2000). Similarly, a study by J.S. Mattila, which looked at the enclosing of balconies in Nordic climates, found that the enclosures not only reduced moisture due to lack of exposure to bulk water, but the conditions inside the enclosure created a micro-climate that promoted drying-out of materials (Mattila, 2007).

While the Arup study did not provide details of the moisture issues encountered in the study of balcony enclosures, it is possible that the concern may have been due to an examination of enclosures that were inoperable and closed all year-round. As Kesik and Saleff's study outlined, in order to avoid moisture issues, the windows should be open during the cooling season, and paired with blinds, as these conditions show the best performance in terms of energy performance and resistance to moisture, no matter the orientation of the balcony (Kesik & Saleff, 2009).

2.2.2 Code Compliance

When it comes to required upgrades to HVAC, electrical and fire services to an enclosed balcony space, the requirements prescribed by the building code are dependent upon the changes being made to the enclosure. According to the Ontario Building Code, exterior balconies in residential high-rises must be constructed in accordance with article 3.2.2.42 which specifies that constructions in Group C buildings (residential and exceeding 3 storeys) must be sprinklered, non-combustible assemblies, with 1 to 2-hour fire-rating depending on the assembly (Ontario Building Code, 2012). The authors of the Arup study may have been tentative about the addition of balcony enclosures as once the decision is made to retrofit the balconies, all assemblies which did not meet regulations must be brought up to code. This principle would apply to both balcony enclosure retrofit, and other balcony retrofit scenarios, such as overcladding.

When looking at upgrades required for HVAC systems in the event of a balcony enclosure retrofit, if adhering to the recommended enclosure scenario provided in 'Tower Renewal Guidelines', which specifies a non-conditioned enclosure, then no upgrades to HVAC would be required, as HVAC requirements would not change.

As a provision for fire safety, the OBC outlines restrictions for surface area of allowable openings according to the distance between the building's glazing and its surroundings. According the Ontario Building Code of Canada 2012, the limiting distance is defined as the distance from an exposing building face—or the part of the exterior wall of a building which faces one direction—to a property line, street centre, lane or thoroughfare, or an imaginary line between two buildings (Ontario Building Code, 2014). As specified by the Ontario Building code in table 3.2.3.1.B, as the limiting distance decreases, so does the allowable percentage of glazing (unprotected openings) for that wall (Ontario Building Code, 2014). Therefore, as the balcony enclosure would shift the position of the existing glazing forward, in certain cases, this may inhibit the ability of the building to meet the OBC requirements for unprotected openings, or may reduce the amount of allowable glazing.

2.2.3 Structure of Balcony and Durability

Whether a non-enclosed balcony overclad or full-enclosure as the selected method of retrofit, any deterioration to the structure or balcony slabs must be repaired prior to any overclad work, as it is costly and disruptive to perform repairs after the work has been completed (Kesik & Saleff, 2009).

A condition assessment survey found balconies to be a main location where deterioration was found, with exposed and corroded anchors and balcony guards, deteriorating concrete and surface finishes, and inadequate drip edges. (Kesik & Saleff, 2009). Balcony enclosures, which help to shield balcony spaces from the elements, were found to be effective in protecting the balcony slab from further deterioration.

Mattila found that by keeping water away from the balcony interior, the glazed enclosure could almost double service-life of the slab by reducing moisture loads and increasing temperatures in the space which encourages drying and enhances the durability of balcony components. Mattila also found that conditions for frost damage to the slab could almost completely be eliminated, as deterioration from freeze-thaw requires a considerable amount of moisture to be present to fill concrete voids enough to prevent the accommodation of expansion without damage (Mattila, 2007).

Compared to non-enclosure overclad retrofits, enclosures provide an advantage in terms of durability, as the probability of moisture penetrations and thermal bridging at fasteners and material interfaces is less likely, assuming water-shedding components and thermal breaks are properly detailed and constructed (Kesik & Saleff, 2009).

2.2.4 Tenant Preferences and Behaviour

If adhering to conditions of the balcony enclosure retrofit laid out in 'Tower Renewal Guidelines', which outlines a highly insulated enclosure with operable glazing, and an unconditioned enclosed space, the existing façade wall would remain in place and little or no demolition would be required, unless it was to alter the existing parapet or railing to receive the enclosure. With the original façade undisturbed, an enclosure retrofit can prove less disruptive to tenants than a non-enclosure retrofit, which would involve the overclad of the existing façade wall (Kesik & Saleff, 2009). In a study of balcony enclosures in Switzerland, Mark Zimmerman found the retrofit to have minor impact on tenants when the work occurring was on the exterior, as tenants could remain in their units, with construction causing minimal disruption that only lasted a few days (Zimmermann, 2011).

If enclosed, MURB balcony spaces could extend the amount of usable space for residents. In a GTA context, these balconies would still exist as unconditioned spaces, but the added insulation of the retrofit and the solar gains encouraged by the upper glazed area of the enclosure would help maintain a thermally moderated area, allowing for a space to be used for more days of the year. The addition of a balcony enclosure is not an uncommon retrofit performed in apartments outside of North America, throughout Europe and parts of Asia. In these papers, synonymous terms were present and were more common to find than the term 'balcony enclosure', including 'glazed balcony', 'sunspace', 'attached greenhouse' or 'glazed loggia', but most served the same function of passive space conditioning. With increased thermal comfort due to the capture of solar gains, these spaces could be used for more days of the year, and become an extension of usable space for tenants (Zimmermann, 2011). In Mattila's study of glazed balcony spaces in Finland, it was found that the original purpose of the enclosures was to increase the amount of living space before its benefits to the durability of the balcony structure were realized (Mattila, 2007). In other studies, tenants found balcony enclosures desirable even where solar gains did not provide a benefit to space conditioning. In Lebanon, a hot climate, Philip Saleh noted that tenants were retrofitting enclosures onto balconies in an attempt to create more indoor living space that was shielded from noise and air pollution (Saleh, 2015). In cases such as these, balcony enclosures can be seen to provide a customization to a building design so that it can better suit the needs of tenants. Similarly, the paper 'Enclosed Balconies: Complicity Between Builders and Users of Taipei Walk-ups', by J. Lin, 2015, discusses the addition of enclosure to balconies as a common retrofit that converted underused exposed balcony spaces to more versatile, semi-indoor spaces that were preferred by residents. Originally designed for a European market, the balcony-centric buildings constructed in the city of Taipei, Taiwan, were not aligned with the expectations and requirements of its residents, who preferred reducing the transparency of balcony spaces to increase privacy, encourage modesty, and reduce undesirable views of urban environments, while increasing the utility of these spaces (Lin, 2015).

Fresh air is an important function of balconies, as a feature that can increase tenant comfort and sense of wellbeing, as well as the marketability of apartment suites. In 'Tower Renewal Guidelines' Kesik and Saleff state that all enclosed balconies should be equipped with operable windows to provide natural ventilation (Kesik & Saleff, 2009). This means that when desired, the glazing could be opened or retracted by the tenant and the enclosure could function as it had pre-retrofit, providing ample airflow and ventilation. Of course, this assumes that the enclosed area is treated as unconditioned space, separated from the rest of the conditioned living spaces. Wilson, Jorgensen and Johannesen, 2000, comment on the variability of occupant behaviour, with doubts about the energy efficiency of these spaces, as tenants can end up heating enclosure spaces designed to be unconditioned, leading to significant heat losses (Wilson, Jorgensen, & Johannesen, 2000). The effect of this occupant misuse was found to diminish as thermal resistance of the balcony enclosure increased, specifically through the use of low-e double glazing and by insulating the parapet of the balcony (Jørgensen & Hendriksen, 2000).

When enclosures are added by tenants, without consideration of the way the retrofit is functioning, problems with durability, overheating and increased energy loads are common. In Belgrade, Yugoslavia, Aleksandra Krstic observed that balcony enclosures were being implemented without consultation of architects or coordination with other tenants, and lead to unfavourable building aesthetics that could be improved with organized, professional design (Krstic, 1998). In Lebanon, Saleh determined that the enclosure of balconies in Beirut, although common practice due to the practical appeal to tenants, was not recommended, as it caused significant inefficiencies due to overheating (Saleh, 2015). In a paper by K. Hilaho, 'Effects of Added Glazing on Balcony Indoor Temperatures – Field Measurements', Hilliaho et al. observed a lack of awareness in the way residents in Finland operated the glazing in balcony enclosures, sometimes keeping glazing open in winter, and closed in summer. This not only reduces the potential for energy savings through solar gains in the heating season, but also requires additional energy to make up for the increased cooling demand during warm months (Hilliaho, Köliö, Pakkala, Lahdensivu, & Vinha, 2016).

However, the building occupant can also play a positive role in contributing to building efficiency. O'Brien reported that examined façade designs all exhibited better performance when building occupants played an active role in improving their own comfort. This paper underlined the importance of the provision of operable glazing and shading devices that allow tenants to adjust levels of natural ventilation exposure to solar radiation (O'Brien, 2016).

If constructed with operable glazing, the balcony enclosure would not perform a function too different from the one it is currently serving. In certain retrofits that choose to incorporate the enclosure with the rest of an apartment suite by demolishing the existing façade wall, this could create larger livable space, allowing developers and landlords to charge more per unit. In Europe, this financial structure has been employed to produce profits which could help fund renovation initiatives (Zimmermann, 2011). Within a Toronto context, however, the enclosure space would be unconditioned, separated from conditioned space by the existing façade wall, and therefore should not count as additional rentable floor space. In terms of living expenses, balcony enclosures should reduce cost to tenants, if in fact, a decrease in energy demand is realized as a result of the retrofit. Often for lower-income rental housing in Toronto, tenants are not responsible for their own energy bill (Kesik & Saleff, 2009), meaning that any savings from energy reduction in many cases would go to the building owner, instead of the tenant. This method of billing has also been observed to increase energy usage by more than double the usage of tenants responsible for their own bill, as there is less incentive to conserve energy when the energy bill is not issued to the occupant (Natural Resources Canada, 2003).

2.3 Effect of Balcony Enclosures on Energy Efficiency

Addressing building performance is the primary reason for a balcony retrofit. Fully enclosed balconies are capable of outperforming balcony retrofits that are not enclosed, and in addition to thermal bridging mitigation, the enclosure can provide moderation of an unconditioned space, potentially contributing to a higher level of efficiency (Kesik & Saleff, 2009). Depending on the climatic conditions, the areas in which an enclosure retrofit would be employed would experience different rates of success in energy savings. For instance, while Saleh's study of enclosure in Lebanon saw overheating and adverse effects on building performance (Saleh, 2015), the study in Poland by Magdalena Grudzinska reported that in rooms adjacent to a glazed balcony energy use was reduced by 20% to 50% (Grudzinska, 2016).

Hilliaho's study of glazed balcony enclosures in Finland found that the space inside enclosed balconies was an average of 5^{o}C warmer than outdoor temperatures, compared to non-enclosed balconies which were an average of 2^{o}C warmer than outdoor temperatures. In an experiment using field measurements, performance of two adjacent apartment units were measured, one with an enclosed, glazed balcony, and the other with an non-enclosed balcony. Despite receiving the same amount of solar radiation, the apartments differed substantially in terms of temperature behaviour, with the glazed balcony performing better (Hilliaho, Köliö, Pakkala, Lahdensivu, & Vinha, 2016). Hilliaho determined that three main elements affect balcony enclosure efficiency: structural airtightness, absorption of radiation and heat loss from the building to the balcony (Hilliaho, Köliö, Pakkala, Lahdensivu, & Vinha, 2016).

2.3.1 Structural Airtightness

Different opinions are present when it comes to the ideal level of airtightness that a balcony enclosure should possess. Mattila states that glazing should not be too airtight as some natural ventilation is required to 'demist' glazing (Mattila, 2007). Similarly, Kesik and Saleff advised that operable windows should be utilized to provide natural ventilation, especially when paired with a non-conditioned enclosure space, to avoid risk of condensation (Kesik & Saleff, 2009). Hilliaho et al. found that the less airtight an enclosure was, the colder the temperature that was measured inside. In addition, it was found that the degree of airtightness was directly proportional to the amount of glazing that was used, and as a result, glazing on two sides of a balcony was preferred, as it encouraged more solar gains than one side of glazing, but displayed a higher level of airtightness than three sides of glazing, keeping temperatures in the enclosure higher (Hilliaho, Köliö, Pakkala, Lahdensivu, & Vinha, 2016). The study by Hilliaho et al. did not touch on the relationship between airtightness and moisture accumulation within the enclosure.

2.3.2 Absorption of Radiation

The amount of solar radiation that an enclosure receives is dependent upon location, climate and orientation of the balcony. According to Hilliaho et al., the more southern and the milder the climate, the higher the mean temperature of the inside the enclosure (Hilliaho, Köliö, Pakkala, Lahdensivu, & Vinha, 2016). While this can translate into energy savings for colder climates, too much solar radiation in more mild climates can lead to an increase in energy usage due to increased cooling loads. Similarly, when modelled year-round without shading and ventilation provisions for summer months, solar gains during the cooling season can cause the cooling loads to reduce the benefits from solar gains in the heating season. This was the case in Grudzinska's study of balcony enclosures in Poland, with cases of overheating from 8.6% to 38.7% of the time for five different sites (Grudzinska, 2016). Toronto MURBs are currently characterized by low cooling demands due to low window to wall ratio, shading of balconies and exposed concrete structural elements which transfers building heat. Due to solar radiation captured within the glazing, balcony enclosures have the potential to raise these cooling loads significantly unless the orientation, glazing properties and shading of the balconies are carefully considered (Kesik & Saleff, 2009). In Kesik and Saleff's simulation of an unconditioned balcony space that utilized open windows and blinds to reduce heat of the enclosure in the cooling season, it was found that the cooling load of the apartment unit was increased by 8.88 to 650.81 kWh annually depending on the orientation of the balcony, compared to a balcony with no retrofit (Kesik & Saleff, 2009).

North	Unconditioned Enclosure (shading and use of operable glazing in summer)	Existing balcony with no retrofit	Difference in Energy Usage	
Cooling Energy (kWh)	13.26	4.38	8.88	
Heating Energy (kWh)	921.77	6880.5	-5958.73	
Total Energy (kWh)	935.03	6884.88	-5949.85	-636%
South				
Cooling Energy (kWh)	655.86	5.05	650.81	
Heating Energy (kWh)	154.34	5853.5	-5699.16	
Total Energy (kWh)	810.20	5858.55	-5048.35	-623%
West				
Cooling Energy (kWh)	346.26	145.05	201.21	
Heating Energy (kWh)	430.56	5725.2	-5294.64	
Total Energy (kWh)	776.82	5870.25	-5093.43	-656%
East				
Cooling Energy (kWh)	283.45	103.57	179.88	
Heating Energy (kWh)	537.6	5764.6	-5227.00	
Total Energy (kWh)	821.05	5868.17	-5047.12	-615%

Figure 1: Annual energy usage for apartment suite - with balcony enclosure vs. without

As expected, south facing balconies showed the largest increase, and the north facing balconies seeing the lowest increase in cooling demand. The increase in cooling demand saw the second largest increase in cooling with the west-facing balcony, at 201.2 kWh, followed by the east-facing balconies that showed an increase in cooling demand of 179.9 kWh. However, an examination of these two scenarios shows a significant decrease in heating demand that surpasses the increased demand for cooling. This decrease in heating demand is seen to be largest for south-facing balconies (with an annual heating demand decrease of 943.96 kWh) as it receives the most exposure to solar radiation. Secondary to this is the east-facing balconies, followed by the north and west-facing balconies.

Overall, Kesik and Saleff's comparison between balconies left unchanged and balconies with an enclosure retrofit found that the overall energy annual energy saving per apartment unit was substantial: when retrofit with a balcony enclosure, for each orientation, energy savings of 615% or larger were observed when a small area of the building was examined. When the energy saved from the decrease in heating demand was combined with the increase in cooling demand, this resulted in different orientations seeing the highest overall energy benefit, with the west orientation seeing the largest energy decrease by 656%, followed by the north at 636%, south at 623%, and east at 615% (Kesik & Saleff, 2009).

When orientation and balcony glazing was measured in various climates in other studies, results of the ideal orientation of glazed balconies differed. In Saleh's study of balcony enclosures in Lebanon, it was found that west-facing balconies performed the worst due to prolonged solar exposure on the west side which increased cooling demand and negated any benefit from a decrease in heating demand, and for this reason west-facing balconies enclosures were not recommended (Saleh, 2015). In other climates, the ideal orientations were also seen to differ, such as with Krstic's study in Yugoslavia which recommended the enclosure of north-facing balconies to provide a thermal buffer, as well as protection against northern winter winds, while providing minimal risk of overheating (Krstic, 1998). Due to a small sample size, Hilliaho's study in Finland did not speculate as to which orientation provided the most beneficial energy savings for enclosures. It was noted however, that the highest energy savings from enclosed balconies was observed for south-east, south-west, south and west exposures (Hilliaho, Köliö, Pakkala, Lahdensivu, & Vinha, 2016). As the absorption of solar radiation into an enclosure can cause positive and negative effects from the reduction in heating demand or addition of cooling demand, differing results depending on climate zones can be expected as geographical differences can cause changes in solar exposure, outdoor temperatures and setpoints for indoor thermal comfort. Due to the flux in heating and cooling demand that can be caused by exposure to different orientations, it has been observed that in studies of enclosed balconies, orientation is not always considered a major determining factor of energy savings (Esteves et al, 2003).

The simulations performed by Kesik and Saleff also revealed the energy saving effects of an enclosure retrofit compared to a non-enclosed overclad retrofit. The results showed a significant difference in energy savings between the two retrofit measures.

As with the comparison between the enclosure retrofit and the existing balconies, the enclosure displayed an increase in energy usage when it came to cooling demand, and a significant decrease in heating demand. When combined to find total energy savings, the east exposure saw the largest energy savings between the two retrofit options, at 98% less energy usage for the enclosed balcony retrofit.

North	Unconditioned Enclosure (shading and use of operable glazing in summer)	Insulated Non-Enclosed Balcony Overclad	Difference in Energy Usage	
Cooling Energy (kWh)	13.26	0.60	12.66	
Heating Energy (kWh)	921.77	1796.1	-874.33	
Total Energy (kWh)	935.03	1796.70	-861.67	-92%
South				
Cooling Energy (kWh)	655.86	1.85	654.01	
Heating Energy (kWh)	154.34	1098.3	-943.96	
Total Energy (kWh)	810.20	1100.15	-289.95	-36%
West				
Cooling Energy (kWh)	346.26	225.88	120.38	
Heating Energy (kWh)	430.56	1290.8	-860.24	
Total Energy (kWh)	776.82	1516.68	-739.86	-95%
East				
Cooling Energy (kWh)	283.45	154.07	129.38	
Heating Energy (kWh)	537.6	1467.7	-930.10	
Total Energy (kWh)	821.05	1621.77	-800.72	-98%

Figure 2: Annual energy usage for apartment suite - with balcony enclosure vs. non-enclosed retrofit

Similarly, the west orientation saw a decrease of 95% energy with the enclosure option, and the north with a 92% decrease. Lastly, the south orientation saw the smallest decrease in energy usage, with only a 36% decrease in energy usage when the enclosure retrofit was selected, primarily due to the increase in cooling demand that was incurred by the south exposure (Kesik & Saleff, 2009).

2.3.3 Heat Transfer from Building to Balcony

In Hilaho's study on the effects of glazed balcony enclosures, field measurements were taken for apartment suites with and without balcony enclosures. Using data loggers, temperatures were recorded at three data collection points: inside the apartment unit, within the balcony area (whether enclosed or not enclosed), and on the exterior, outside the balcony. Using these temperatures, 2-dimensional heat loss for that section of the façade was determined using the following equation:

$$\text{Heat Loss Reduction} = 1 - \left((T_{Apartment} - T_{Balcony}) / (T_{Apartment} - T_{Outdoor})\right)$$

The results showed that a micro-climate was formed within the balcony area, as temperatures were consistently higher within balcony spaces than the outdoor air (Hilliaho, Köliö, Pakkala, Lahdensivu, & Vinha, 2016). For the non-enclosed balconies, the temperature between the balcony and the outside ranged from 1.8°C to 2.4 °C, depending on the balcony. For the enclosed balconies, this temperature difference between the balconies and outdoor air was observed to be higher, ranging from 3.5°C to 6.6°C. In addition to increased temperatures due to solar gains, Hilliaho attributed these higher temperatures to the ability of the enclosure to store heat loss from the building in the balcony (Hilliaho, Köliö, Pakkala, Lahdensivu, & Vinha, 2016). Similarly, Jørgensen and Nielsen, 2000, found that facades with a glazed balconies in Denmark provided lower energy loss due to a higher ambient temperature within the enclosure, and therefore reduced infiltration through the envelope (Jørgensen & Nielsen, 2000). As a result of this relationship between the ambient enclosure and the rest of the building, Maria Wall found that glazed enclosures can act as a climatic shield (Wall, 1996). The shielding effect of the enclosure allowed the parts of the envelope that were enclosed within the balcony to have a lower technical standard of construction, as the enclosure acts as a secondary façade.

These ambient climatic conditions can also be referred to as a 'thermal buffer zone' (TBZ). In the paper, 'Improving the Energy Performance of Multi-Unit Residential Buildings Using Air-Source Heat Pumps and Enclosed Balconies', 2014, Marianne Touchie describes the ability of the insulated and glazed balcony enclosure to act as a thermal buffer zone, as enclosing the unconditioned space partially with glazing allows the volume of enclosed air to be heated by solar gains (Touchie M. , 2014). The TBZ decreases the temperature differential across the envelope profile of an enclosed balcony section, which can decrease the overall energy transfer through a façade. Touchie's paper specifically addresses the usefulness of this thermal buffer zone when paired with an air source heat pump, which allows the heat pump to utilize free heat from the buffer zone, allowing it to operate more efficiently (Touchie M. , 2014).

2.4 The Effect of Balcony Characteristics

In a study by Hilliaho, Kovalainen, Huuhka and Lahdensivu, 2016, a simplified method was created to determine the effectiveness of an enclosure's performance based on design characteristics. Simple graphs depicted estimates of energy savings depending on characteristics such as balcony width, orientation of façade, and the type of balcony which ranged from recessed to protruding and variations in between (Hilliaho, Kovalainen, Huuhka, & Lahdensivu, 2016). Although simulated for Finnish apartment blocks, the simplified method revealed substantial amounts of data, represented graphically to depict performance of different balcony characteristics. Among the findings, the graphs showed an increase in energy savings as balcony width increased, and as the balcony type changed from protruding to recessed. Additionally, southern orientation was seen as the most effective orientation for energy savings, and as the number of glazed sides of the balcony increased, energy savings were seen to decrease (Hilliaho, Kovalainen, Huuhka, & Lahdensivu, 2016). In the work by Hilliaho, Köliö, Pakkala, et. al, field measurements for multiple existing enclosed balcony structures in Finland revealed different degrees of performance for 'integrated' and 'protruding' balconies. The integrated balconies were inset into the building, with all or parts of the side walls made up by 'warm' sides of the building structure, whereas the protruding balconies stuck out from the building. The findings revealed that the integrated balconies performed better than the protruding balconies, as heat transfer from the building affected three sides instead of just the one for protruding balconies, and also contributed to a higher airtightness of the enclosure (Hilliaho, Köliö, Pakkala, Lahdensivu, & Vinha, 2016).

Marianne Touchie also comments on the efficiency of balcony enclosures depending on whether the enclosures are inset or projecting. The author explains that the efficiency of enclosed balconies change, whether inset or projecting, due to the changes in surface area of walls that are shared between the building and balcony, which affects heat exchange between the thermal buffer zone and an apartment unit (Touchie M. , 2014). While Touchie's simulation only explores the use of inset balconies, an algebraic relationship was used to estimate the effect that projecting balconies may have had on the results, and concluded that the projecting balconies would likely reduce energy use even further compared to inset balconies. (Touchie M. , 2014).

Kesik and Saleff also make mention of different typology groups, briefly touching on different geometries of the buildings, as well as some examples of different balcony configurations that could arise (Kesik & Saleff, 2009). Kesik and Saleff note that cost of the balcony enclosure retrofits differ as the characteristics change, notably decreasing in cost as more adjacent balconies are paired together without a space in between. This reduces the required overcladding by 22.7% to 40.9%, cutting costs up to 22.1% compared to separated balconies, depending on the configuration (Kesik & Saleff, 2009).

2.5 Research Methods in Literature

Throughout the gathered literature, research methods have ranged from data collection from existing enclosures to energy modelling simulations. Hilliaho touches on the concept of different balcony characteristics and the effects this has on performance by using data loggers to take field measurements of 22 different balconies, some enclosed and some open. (Hilliaho, Köliö, Pakkala, Lahdensivu, & Vinha, 2016). Generally, balconies enclosed with glazing were warmer than those without, and a 'recessed' balcony type was observed to have better thermal performance than non-recessed balconies. Although producing practical information about glazed enclosures and thermal behaviour, in some cases, the sample size of the balconies was not large enough to draw conclusions about which balcony characteristics performed best (Hilliaho, Köliö, Pakkala, Lahdensivu, & Vinha, 2016).

In literature that has come out of Toronto, the research methods have been primarily simulation-based, presumably because balcony enclosures are not a widespread occurrence in Toronto, creating a limited sample for field measurements. Energy modelling simulation was used in several MURB-focused studies that have explored the use of balcony enclosures. In 'Tower Renewal Guidelines,' Kesik and Saleff's simulation of balconies in different conditions showed differences in energy usage in an apartment unit based on whether the balcony was enclosed or left open, the amount of space conditioning, natural ventilation, and shading of solar radiation. Simulating 8 variations of balcony retrofits on the same base model allowed for performance of each scenario to be compared to one another. The scenario that arose as the best performer in terms of annual energy consumption and condensation potential, was an enclosure with operable glazing that received natural ventilation and shading in the summer (Kesik & Saleff, 2009).

Marianne Touchie also utilized simulation when exploring the potential of an enclosed balcony to act as a thermal buffer zone, increasing building performance when paired with an air-source heat pump.

Touchie used eQUEST software to model the performance of an enclosed balcony, paired with an ASHP, but kept the scope of the simulation limited to just an inset balcony. While the effect of projecting balconies were commented on, and presumed to reduce energy-use even further when paired with an ASHP, enclosed, projecting balconies were not included in the simulation (Touchie M. , 2014).

3. Research Question

The explored literature examined the benefits of balcony retrofits in terms of preventing thermal bridging, improving durability and capturing solar radiation to decrease heating demand. The glazed enclosure-style balcony retrofit seemed to be favoured within literature, due to its ability to capture and hold radiation in a thermal buffer zone, limit thermal transfer through the façade, and protect the balcony structure from moisture better than an overclad balcony retrofit. However, balcony enclosures are not without concerns, with potential for overheating and condensation if not properly designed, and with code compliance implications which may complicate retrofits, or prevent them. Arup's 'Community Energy Plan for Three Pilot Sites,' and Kesik and Saleff 's 'Tower Renewal Guidelines,' both demonstrate conflicting viewpoints regarding whether balcony enclosures represent a viable retrofit measure for MURBs. While many of the more successful examples of balcony enclosures appear in literature from Asia and Europe, with many European studies in Nordic regions, it is apparent that balcony enclosures have potential to increase building performance in a cold climate, but require further research in a North American context, and specifically in relation to use on Toronto MURBs.

Several European papers commented on the effect that different balcony characteristics have on the performance of enclosures, including the orientation, dimensions, and type of balcony (whether balconies are inset or projecting outward). While different MURB building and balcony types were mentioned in papers by Kesik and Saleff, and Touchie, the effect that different balcony characteristics have on building performance when paired with an enclosure remains a subject that has not seen much attention when paired with enclosures in a Toronto context. Additionally, in studies of retrofits for MURBs, the performance of enclosures, when examining different balcony enclosure characteristics has yet to be examined on its own, uncoupled from other retrofit strategies.

This paper seeks to determine the benefit that a balcony enclosure retrofit has on the energy use of a multi-unit residential building, and specifically, which characteristics of balconies may result in larger energy savings if retrofit with an enclosure. While this study examines the effects of different balcony retrofit enclosures apart from other retrofit measures, this is not to say that it is expected balcony enclosures should be used as a solitary retrofit measure. Rather, it is a study designed to better understand what affect a balcony enclosure has on the energy performance of a building, and specifically, how this performance changes as balcony characteristics change.

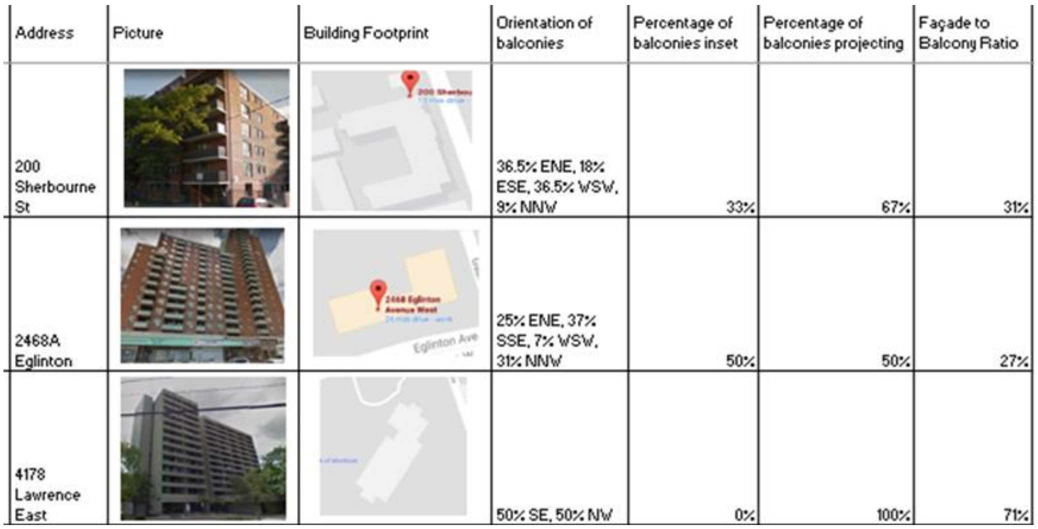
It was expected that certain buildings, when retrofit with a balcony enclosure, would show better results than others due to characteristics like balcony to façade ratio and whether the balcony is projecting from the building or inset. Buildings with a higher balcony to façade ratio were expected to see more beneficial results in terms of energy saving potential, as a higher percentage of the building façade would be affected by the overclad, applying more thermal resistance to a larger area. The effect that balcony projection has on the results was more uncertain, as the literature review revealed diverging opinions of whether the inset or projecting balcony was the better performer. In the end, the prediction was in favour of the inset balcony, as the increase in wall area adjoining an apartment site could increase the amount of heat transfer from the thermal buffer into an apartment, reducing heating demand.

4. Methodology

Multi-unit residential buildings in Toronto see varying architectural characteristics in terms of the geometries of buildings and configurations of attached balconies. This study assumes that the way in which the balconies are configured on a building will have an effect on EUI when the building is retrofit with balcony enclosures. In order to determine how characteristics of balconies impact the effectiveness of a balcony enclosure, a dataset was acquired containing a variety of different types of post-war multi-unit residential buildings with balconies. In a 2012 study by Yirong Huang, entitled *Energy Benchmarking and Energy Saving Assessment in High-Rise Multi-Unit Residential Buildings*, MURBs were examined to gather energy-use information. This dataset was made available for the study and provides energy-use data for over 50 MURBs in the city of Toronto (Huang Y. , 2012). Using this data as a starting point, two main methods were undertaken. The first phase required a collection of physical attributes of the buildings and balconies to be collected through observation of building visuals. These attributes were then used to help sort the data and narrow down buildings for the study. The second phase involved energy modelling as the main method of data collection. The balconies of the selected buildings were modelled onto a base model using DesignBuilder software to simulate buildings with and without balcony enclosures. The relative effects of a selection of balcony characteristics were determined by comparing the change in energy-usage data for models with different balcony configurations, with and without balcony enclosures. Because EUI and energy data was measured as energy usage per area, it was possible to compare energy usage even in buildings of varied sizes.

4.1 Phase 1: Categorizing Buildings based on Balcony Characteristics

The data for each of the buildings in Huang's dataset was assigned an identification number, which allowed each building to be identified through a provided address. By identifying the building location, additional information could be obtained through observation of the building exterior. Online satellite imagery was used to denote characteristics of balconies through observation and translate it into quantifiable data. These observations for different balcony characteristics were recorded in terms of percentages which could be compared numerically against other building characteristics. The following figure shows a snapshot of the method used to track observations of building attributes. The full chart of observations can be found in *Appendix C*.



Address	Picture	Building Footprint	Orientation of balconies	Percentage of balconies inset	Percentage of balconies projecting	Façade to Balcony Ratio
200 Sherbourne St			36.5% ENE, 18% ESE, 36.5% WSW, 9% NNW	33%	67%	31%
2468A Eglinton			25% ENE, 37% SSE, 7% WSW, 31% NNW	50%	50%	27%
4178 Lawrence East			50% SE, 50% NW	0%	100%	71%

Figure 3: Tracking of building observations related to balcony characteristics

Categorizing buildings based on balcony characteristics was not always straightforward, with many buildings with complex footprints, and various balcony configurations within one building. The following sections explain the methods used for defining characteristic categories including orientation of balconies, balcony projection, prevalence of shear wall, prevalence of overhang and façade to balcony ratio.

4.1.1 Orientation of Balconies

The direction of exposure that a balcony receives ultimately determines how much solar gain a balcony will receive. As a result, properly documenting the orientation of all balconies during the observation phase was considered to be a crucial step, providing information that would be used for later analysis.

Most often a building will have balconies on more than just one side, so it was decided that the directions of balconies facing in each direction would be documented as a percentage of the total amount of balconies on the building. To do this, the approximate area of balconies, and the area of balconies that directly faced each direction were estimated through observation of each side of a building's exterior, and used to determine the percentage of balconies that had exposure to each direction. This quantification of balcony exposure varied with complexity depending on the building geometry and the amount of sides the geometry had. For instance, a building that had a rectangular footprint might have an equal number of balconies on two opposite sides, half facing East North-East, and half facing West South-West, and would therefore be assigned an orientation of '50% ENE, 50% WSW'. If a building of a similar footprint contained balconies on all 4 sides, without an equal amount of balconies on each side, the orientation assigned might increase in complexity and be denoted as, '32% ENE, 9% SSE, 41% WSW, 18% NNW'. As buildings increased in complexity to include buildings with 'L' and 'Y' shaped footprints and other configurations, this denotation of orientations increased in complexity as well.

Due to the varied geometries of buildings, the estimation of orientations utilized a more detailed set of compass coordinates that could capture tertiary orientations. This allowed for a higher degree of accuracy in which more balcony directions could be distinguished from one another. In addition, when examining common building footprints, it could be observed that buildings often followed the grid of Toronto roads, which seemed to be oriented several degrees off of a North, South, East, West axis, running North North-West to South South-East and East North-East to South-East.

4.1.2 Balcony Projection

Similar to orientation, a percentage was used to evaluate how much a balcony projected out from the building façade or was inset into the façade. Based on observation of the building exterior, a percentage would be assigned to two categories: 'percentage of balconies projecting' and 'percentage of balconies inset'. This percentage would take into account what percentage of the balcony depth protruded out from the façade, or was inset into the façade. This percentage also factored in designs where some balconies were protruding from the façade and some were inset. The assigned percentages in both of these categories would to add up to 100%, as a balcony could not be more than 100% projecting, or 100% inset, but could be a combination of both.

4.1.3 Shear Wall Depth and Depth Occupied by Building

Originally, the above categories looking at projected and inset of balconies was replaced with two categories that examined the percentage of depth of the balcony that was occupied by a shear wall (if the balcony was projecting) and the percentage of the balcony depth occupied by the building (if inset).

The prevalence of the shear wall was considered important to the study as these are often concrete thermal-bridging elements that impact the rate of thermal transmittance from the interior to the exterior of the building during the cold season. While some shear walls protruded for the entire width of the balcony, others protruded only partially, or were not present at all. Based on the evaluation, the percentage rating given for a shear wall protruding the entire width of the balcony was 100%, while a partial protrusion was estimated based on the percentage of the balcony width it extended. A balcony which did not interact with a shear wall was given a rating of 0%.

The complication with this rating system was that a shear wall could sometimes be difficult to define, and could appear to be present even when balconies were inset into the building façade. In addition, a balcony that was projecting, but did not have a shear wall, did not fit into a category at all, and therefore would be lost information that could not be quantified. As a result, this method of defining the percentage of balcony depth occupied by the shear wall percentage or the building was replaced with the more straightforward evaluation of percentage of balconies inset or projecting.

4.1.4 Prevalence of Overhang

For MURB buildings of the post-war era, the balcony slab is almost always a cantilevered concrete slab (Kesik & Saleff, 2009) and can be assumed for this study. In most MURB designs, this concrete slab also acts as a balcony roof, or overhang for the balcony below. The presence of an overhang represents a ‘stacked’ style configuration common to balconies, while no overhang would mean that the balconies would be staggered. A ‘staggered’-style balcony with no immediate overhang, would require a roof to be constructed when retrofit with a balcony enclosure, and depending on the construction of this roof, this type of enclosure may receive more solar gains if subject to less shading.

Originally when evaluating these criteria, and how it would be quantified using a percentage value, it was thought that the category would see only two options for percentage rating, 100% if stacked, or 0% if staggered. However, not all balconies on a building are designed to be the same, and a while most of the buildings did fall into the category of ‘100% overhang’ a recurring design feature saw the uppermost balcony in a stack of balconies to have no overhang. In this case, if about 1 in 20 balconies did not have an overhang, the percentage of balcony overhang for that building would be 95%.

4.1.5 Balcony to Façade Ratio

The ratio of balcony area to façade area was estimated based on how much of the façade was occupied by balcony space. This ratio was important to determine, as it would affect the amount of the area influenced by a balcony enclosure, which was expected to influence the overall performance of the building. When determining the ratio, the area of each side of the building was estimated as a percentage of the overall surface area of the exterior walls. Then on each side, the amount of the façade area occupied by balconies was estimated in terms of a percentage of the façade surface area for that side. Each of the percentages of balconies per side were multiplied by the percentage of total facade area that was represented by that side. These values were then added to get the total balcony to façade ratio of the building. The breakdown of this estimation process can be seen in the following figure.

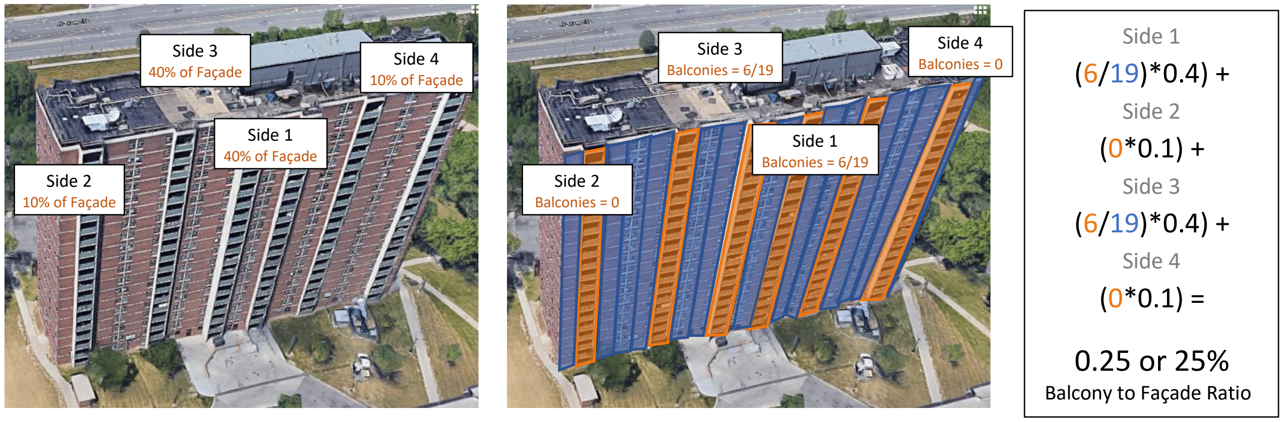


Figure 4: Estimating Balcony to facade ratio

4.1.6 Selecting Buildings for Study

Once the above characteristics were noted for each of the buildings in the dataset, these buildings were sorted based on the characteristic categories previously mentioned, with a particular focus on balcony to façade ratio and whether the buildings had inset or projecting balconies. High, mid-range and low building to façade ratio buildings were placed in separate groups, and from there, the High and low ratio buildings were each categorized further based on whether the balconies were projecting or inset.

The goal of this categorization process was to ensure that the buildings selected for the simulation were diverse enough to represent different types of buildings which are common to Toronto. Therefore, the buildings that ranked as having a mid-scale building to façade ratio were eliminated, as the high and low ratios were expected to show a more diverse result when compared.

Once the high and low ratio buildings were further categorized into groups with inset and projecting balconies, the goal was to make a selection of buildings that would be effective in conducting simulations comparing the two main characteristic groups in question: balcony to façade ratio, and inset or projected.

Two Buildings Selected for Balcony to Façade Ratio Simulation

Balcony Ratio	High Ratio	Low Ratio
Balcony Type	Both have either projecting or inset balconies	

Two Buildings Selected for Balcony Type Simulation

Balcony Type	Projecting	Inset
Balcony Ratio	Both have either high or low ratio	

Figure 5: Comparison between balcony to façade ratio, and inset or projected balcony type

Two buildings were selected for each simulation. Where the effect of building to façade ratio was being examined, a building with a high and low ratio were selected for comparison purposes, but the two buildings selected needed to both have either projecting or inset balconies to maintain balcony to façade ratio as the variable in question. Similarly, when selecting the two buildings to be used to compare balcony type, a building with primarily projecting balconies and a building with primarily inset balconies needed to be selected, but both with either a high or low ratio balcony to façade ratio.

In addition, the buildings selected to be compared in both simulations had similar building footprints, with the same orientations of balconies in order to make for a more accurate comparison. When it came to the orientation of the building, the direction that the enclosures face would be expected to have a significant impact on the solar gains, and therefore an impact on heating demands and EUI. For this reason, it was considered important to keep the orientations consistent for all of the buildings being modelled to maintain an accurate comparison.

4.2 Phase 2: Simulating Enclosures through Energy Modelling

Currently in Toronto, balcony enclosures are not common practice, nor is a standard method of implementing a balcony enclosure. While some enclosures exist as an initiative of the tenant or unit owner, most of the constructions of these enclosures vary widely, meaning that monitoring the energy use of these building with enclosures through field testing would not make for an accurate comparison across different buildings. Therefore, simulation through building modelling was considered the most effective method to analyze how the effects of added balcony enclosures differ between buildings with different balcony characteristics.

4.2.1 Setting up the Base Models

According to the selections of buildings made in phase 1, base models were set up to simulate buildings with balcony conditions that represented that of each of the selected buildings. These initial building models represented the base case for the simulation, and the 'pre-retrofit' scenario which would later be compared with a 'post-retrofit' model which has balcony enclosures added on. In order to ensure that the base models presented an accurate depiction of the energy use of these buildings in reality, the base case models were checked against actual energy usage data available from Huang's dataset. Ensuring that the output of the model matched actual energy usage data to an accurate degree was a crucial step in ensuring that the highest degree of accuracy and reliability was achieved from the modelled outputs.

Buildings were constructed in DesignBuilder using digital measurements of satellite images of the buildings, as well as data from Huang's Energy Benchmarking study dataset, which specified the number of floors, and units within each building. Zones and activity schedules were defined, as well as well as occupant profiles and usage criteria for the spaces. Floor designs were the same from the second floor and up so parameters inputs and floor designs were duplicate from the second floor and used for upper levels.

Selection of the envelope assembly, HVAC system, domestic hot water system, and lighting were input into the model based on detailed MURB information from ARUP's report for the City of Toronto Mayor's Tower Renewal project, 'Community Energy Plan for 3 Pilot Sites', 2009 (Arup Canada Incorporated, 2009). These inputs remained consistent across each of the modelled buildings. In order to match the EUI in the model to the one measured in actuality, plug load schedules, heating and cooling schedules were adjusted in order to meet the energy usage breakdown in each of these areas as defined by Huang's energy usage data for each building.

4.2.2 Modelling Building Enclosures

Once the energy usage of the base models were matched approximately to actual data on energy usage for each building, the balcony enclosure retrofits could be simulated. When it came to the actual construction of a balcony enclosure, the description of a balcony enclosure, as outlined in Kesik and Saleff's 'Tower Renewal Guidelines', was used as the basis for the construction. The envelope construction of enclosures was the same across each of the models. However, due to different sizes and configurations of balconies, each enclosure was modelled differently to fit around the geometry of the existing balcony, as it would in reality.

While the sizes of enclosures differ, the construction principles and materials for each of the model enclosures remained the same, as defined by the *Appendix A – Overcladding Design and Detailing* from the paper 'Tower Renewal Guidelines' (Kesik & Saleff, 2009).

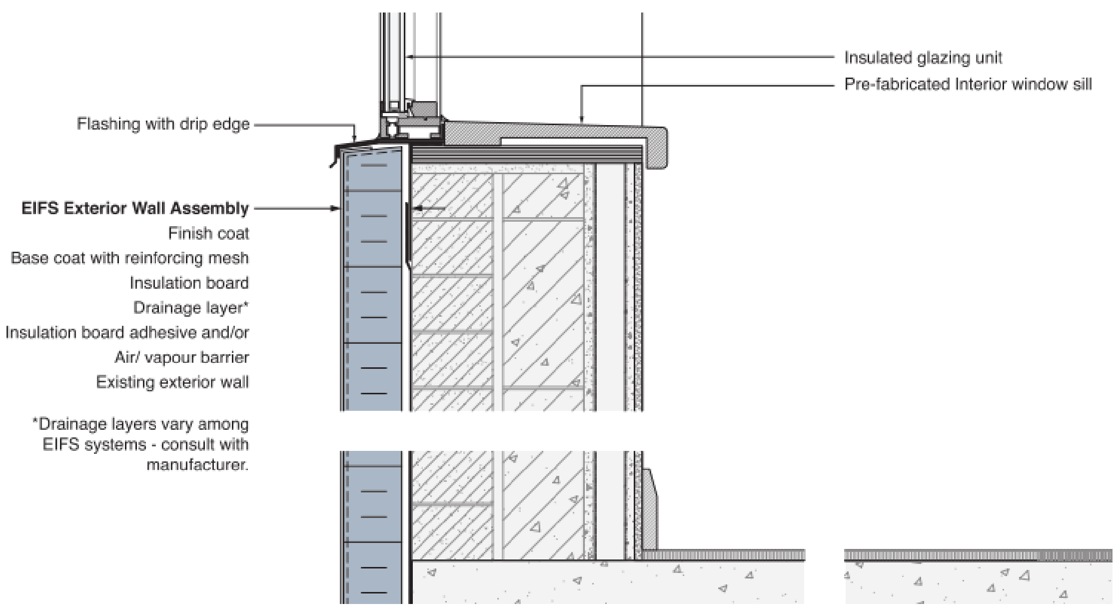


Figure 6: Enclosure assembly (Kesik & Saleff, 2009)

While this resource offers several variations on different balcony retrofit and overcladding systems, the one that was selected for the simulations in this study was an EIFS, or exterior insulation and finish system, which was used to cover the exposed balcony slab and the protruding shear wall, where applicable. This selection of overcladding also had the benefit of added insulation, which would be used to cover exposed concrete and thermal bridging elements. The system also incorporated double-glazed, operable windows used above the balcony parapet to finish the enclosure. The enclosure glazing was operable to allow for seasonal transition. By allowing the glazing to be opened to allow for natural ventilation, this was expected to reduce unwanted solar gains during the cooling season.

Several key outputs can be derived from the modelling software DesignBuilder and analyzed for each of the building models. The EUI and energy usage was examined in each model with and without balcony enclosure, and these changes in outputs due to the addition of enclosures were compared against all models to determine how results changed with differences in balcony characteristics. Other outputs such as solar gains and amount of energy used for heating and cooling were also examined and compared between models.

4.2.3 Simplifying the Building Model

For the purpose of simplification of the model, buildings were modelled without underground parking areas, or mechanical penthouses, as it was assumed that the addition of these spaces would not have a significant effect on the model results.

As mentioned earlier in section 2.2.2, the OBC's requirement for allowable openings meant that the introduction of exterior glazing in the balcony enclosure could change the position of the building's outermost openings. As the new glazing shifts outward, in certain cases, this may cause the building to exceed the limiting distance requirements of allowable openings, meaning that enclosure retrofit would not be permissible. While limiting distance is certainly something to consider before implementing a retrofit project, for this study, the decision was made not to examine the buildings' situation in relation to neighbouring buildings. By keeping the focus on just the buildings themselves, simplifying the comparison between the buildings and leaving balcony enclosure characteristics as the focus. By not modelling the effect of the neighbourhood, however, this meant that neighbouring buildings and trees would not have an influence on the models, whereas in actuality, the amount of solar gains could be affected by shading of surrounding objects. This may cause model results to indicate slightly higher solar gains than experienced in reality, which may in turn influence heating and cooling demand outputs from the models.

5. Analysis of Building Data

5.1 Phase 1: Defining Balcony Characteristics

The 2012 study by Yirong Huang on Energy Benchmarking was based on a set of raw data that was made available for this study. While this raw data contained over 120 accounts with corresponding building ID numbers, only entries that had corresponding addresses could be used for the study. Additionally, some of the buildings did not have balconies, and therefore had to be eliminated from the sample. This left 55 remaining entries that were suitable to examine for this study. Using online satellite imagery, observations of building and balcony characteristics were gathered for each of these 55 buildings. The following figure shows a map of the locations of the studied buildings, which were fairly evenly distributed throughout Downtown Toronto, Scarborough, North York and Etobicoke. Year of construction of these buildings ranged from 1962 to 1989, with 67% of the buildings constructed between 1969 and 1974. A complete breakdown of the building information and characteristic observations can be found in *Appendix C*.

Figure 7: Locations of building analyzed for balcony characteristics

5.2 Observations of Building Sample

Characteristics of each of the 55 Toronto buildings were visually observed and analyzed according to the Phase 1 methodology. The majority of buildings were of a simplistic design, often with a rectangular footprint, with balconies split evenly between each of the long sides. After the rectangular footprint, the L-shaped building was most common, followed by an irregularly-shaped footprint. The irregular shaped buildings were most difficult to quantify in terms of balcony to facade ratio and percentage of balconies facing each orientation, as these buildings often had complex geometries with numerous surfaces, often varying heights, and uneven arrangements of balconies.

Building Footprint	
Rectangle	60.0%
L-Shaped	16.4%
Irregular	12.7%
Y-Shaped	7.3%
U-Shaped	1.8%
Circle	1.8%

Figure 8: Occurrence of building footprint type within building sample

The most common type of balcony observed was a balcony projecting from the façade, accounting for 45% of the total balconies observed. Of the buildings determined to have balconies that were mostly projecting, 72% could be considered to be fully projecting, or 100% projecting, with no portion of balconies inset into the façade. Buildings were considered to fit into the 'mixed' category if less than 75% of the balcony area on the building could be consider projecting or inset.

Balcony Type	
Mostly Projecting (75% or More)	45.5%
Mostly Inset (75% or More)	29.0%
Mixed	25.5%

Figure 9: Occurrence of balcony type within building sample

The prevalence of overhang on balconies in the dataset was 97%, with few buildings deviating far from a full overhang. While 20% of buildings observed had less than 100% overhang, this was mostly due to a lack of overhang on only the uppermost row of balconies. Buildings with this design feature still maintained a high percentage of balcony overhang, ranging from 93% to 96%, and in another building's case, 75%, resulting values which did not affect the overall average percentage of balcony overhang too drastically. Only one building in 55 cases was observed to have staggered balconies, and these were only partially staggered, resulting in an overhang rating of 35%. As this was the only outlier, it was determined that the buildings in the sample did not possess a large enough range of differences when it came to balcony overhang as a defining characteristic, as a stacked balcony design was observed to be much more prevalent. Therefore, it was decided that overhang would not be included as a balcony characteristic that would be studied further, and instead would be assumed to be 100% for the modelling process.

In order to determine whether balcony to façade ratio was low or high, the ratio percentages acquired for each building had to be sorted into high, low, and mid-scale categories. With the lowest balcony to façade ratio at 12%, and the highest at 78%, it was determined that the range of data could be separated into three categories of 20% of the range, with a low range representing a ratio of 10% to 29%, a mid range representing 30% to 49% and a high scale representing 50% to 79%. These categories placed 40% of buildings in the low range, with an average balcony to façade ratio of 22%. 40% of buildings also fit into a mid-scale category of balcony to façade ratio, with an average ratio of 40%, and the buildings with a high range balcony to façade ratio only amounted to 20%, with an average ratio of 58%.

An assessment of each of the buildings' balconies revealed that the most common orientations for balconies were East North-East and West South-West. The least common orientations for balconies to be facing were directly East, North, South or West, with directly South as the least common orientation for balconies, at only 0.5%.

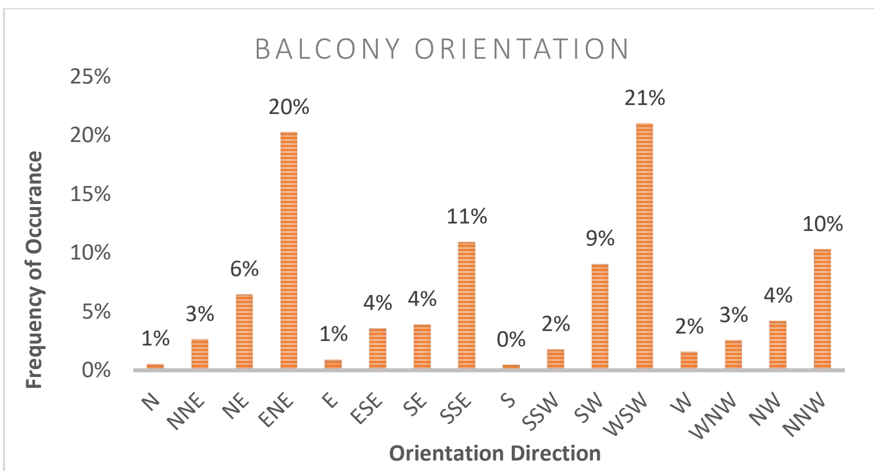


Figure 10: Occurrence of balcony orientation within building sample

5.3 Selection of Buildings to Model

With the decision to eliminate percentage of overhang from the variables being modelled, the focus was left on the type of balcony (projecting or inset) and the balcony to façade ratio as the main variables to be looked at further through building simulation. In order to allow these variables stand out, the buildings selected needed to be of similar design in order to make sense for comparison. After some analysis, the buildings selected for the Building to Façade Ratio study were 325 Bleecker Street and 20 Falstaff Avenue.

Façade Ratio Simulation

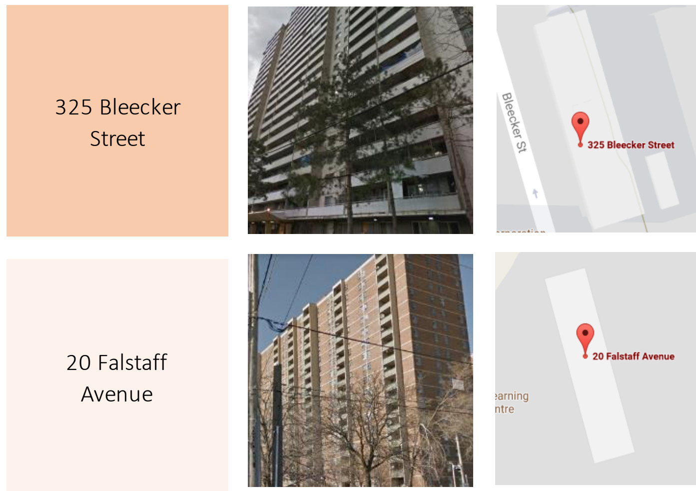


Figure 11: Buildings selected for comparison between high and low balcony to façade ratio

These buildings, built in 1969 and 1970, respectively, are buildings of similar vintage, and both possess a similar rectangular footprint and projecting balconies, with 325 Bleecker possessing a high balcony to façade ratio of 53% and 20 Falstaff with a low balcony to façade ratio of 25%. Both buildings have a 100% percentage of overhang, with stacked balconies which are fully projecting and supported by a surrounding shear wall which extends the full depth of the balcony on both buildings. When it comes to the orientation of the balconies, both buildings have balconies on only the East North-East and West South-West sides, which are split equally with 50% of the building's balconies on opposite sides.

Two Buildings Selected for Balcony to Façade Ratio

Balcony Ratio	High Ratio	Low Ratio
	325 Bleecker Street	20 Falstaff Avenue
Balcony Type	Both have projecting balconies	

Two Buildings Selected for Balcony Type Simulation

Balcony Type	Projecting	Inset
	20 Falstaff Avenue	6 Glamorgan Avenue
Balcony Ratio	Both have low ratio	

Figure 12: Buildings selected for comparison studies based on balcony characteristics

For the simulation that examines the difference between inset or projecting balconies, the two buildings selected for the simulation were 20 Falstaff Avenue and 6 Glamorgan Avenue. The decision was made to include 20 Falstaff Avenue in both the balcony type and façade to ratio comparison studies as this would allow one model to be used for two different comparisons, saving time in the modelling phase.

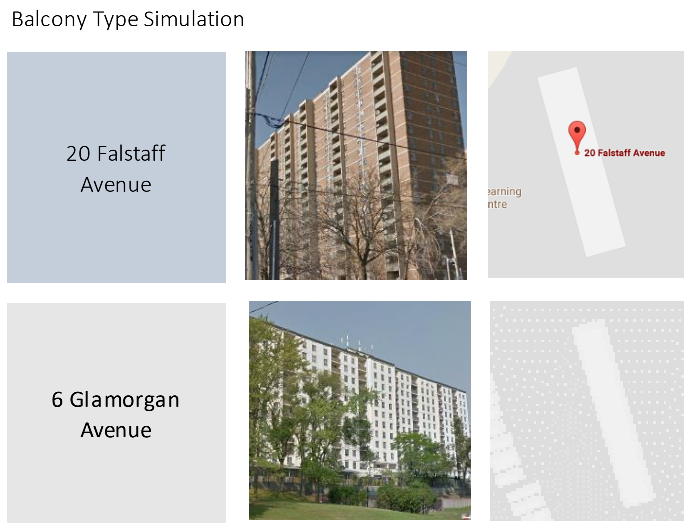


Figure 13: Buildings selected for comparison between inset and projecting balconies

Like the two buildings selected for the balcony to façade ratio comparison, these two buildings share a similar rectangular building footprint, with 50% East North-East facing balconies and 50% West South-West facing balconies. Both buildings are of a similar vintage (1970 and 1971) and have a 100% overhang. While 20 Falstaff Avenue has fully projecting balconies, and 6 Glamorgan Avenue has fully inset balconies, both buildings have a low building to façade ratio of 25% balcony coverage.

6. Building Simulations

6.1 Base Models

The model of 6 Glamorgan Avenue was used as the initial model on which the three base models were created. Following the same building orientation, with similar building dimensions, the geometry of 6 Glamorgan was quite close to that of 20 Falstaff and 325 Bleecker. Therefore, the decision was made to use 6 Glamorgan as the initial model that was used to create three subsequent base models which were designed according to the façades of 6 Glamorgan Avenue, 20 Falstaff Avenue, and 325 Bleecker Street. While similar, the dimensions of the buildings in actuality were not the same, with the lengths of the later two buildings measuring approximately 10 metres less than the length of 6 Glamorgan. Despite this difference, it was decided that one calibrated model could act as a suitable model on which to construct the three base models, as long as the balcony areas were left true to its original measurements. Therefore, the dimensions of balconies originally belonging to Falstaff and Bleecker were left unchanged when added on to the Glamorgan base model. This meant that the inconsistent dimension for these two models was the area of façade between balconies, primarily on the long sides of the buildings, resulting in a slightly larger area that was not covered by balconies than existed in the original base models for these buildings.

6 Glamorgan Avenue 20 Falstaff Avenue 325 Bleecker Street

Figure 14: Balconies and fenestration from three buildings were modelled onto the base model

Along with the balcony configuration, fenestration was the only other element borrowed from the Falstaff and Bleecker buildings. As the configuration of the balconies determined the available space for windows, it made sense to also adopt the corresponding window configuration, and model the façade as if it were 20 Falstaff Avenue or 325 Bleecker Street.

Due to balconies being inset or projecting, the overall floor area changed slightly between the three base models. Both the Falstaff and Bleecker buildings possessed projecting balconies, which meant that the floor area of these buildings were slightly higher than the original Glamorgan model. Like 6 Glamorgan Avenue, 20 Falstaff Avenue was modelled to have a similar 1 meter bump-out in the centre of the long side of the building, giving Falstaff a slightly larger floor area than Bleecker. These differences in building area were taken into account when generating outputs that were measured per m^2.

Images of the three base models with different balcony and façade elements belonging to 6 Glamorgan Avenue, 20 Falstaff Avenue, and 325 Bleecker Street can be seen below.

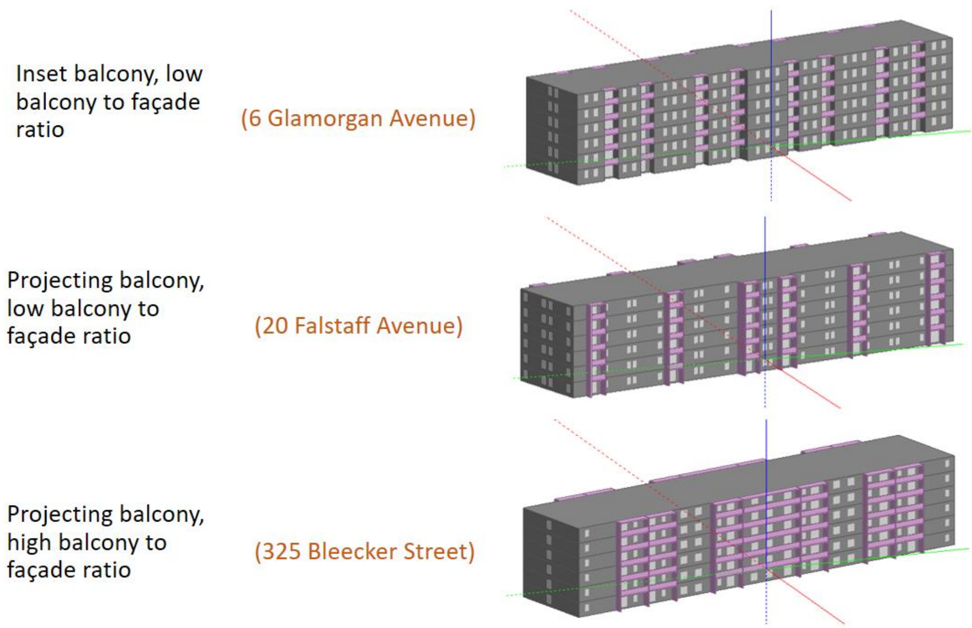


Figure 15: Three base models with different balconies and fenestration

6.1.1 Zones

The second floor is representative of all floors above, while first floors contain lobby, laundry as well as some residential units. Below is a breakdown of the space usage for the base model, which was based on information for 6 Glamorgan Avenue.

Building Area (m2)	Number of Floors	Number of units	Zones - Floor 1	Zones - Floors 2 and above
17,801	12	184	Lobby, Utility, Laundry, 8 Residential Suites (Each contains 2 Bedrooms, 1 Bathroom, Living and Kitchen Areas)	16 Residential Units per floor (Each contains 2 Bedrooms, 1 Bathroom, Living and Kitchen Areas)

Figure 16: Zoning for the base model

It was assumed that each residential apartment suite contained an average of two bedrooms, one bathroom and one open concept kitchen/living/dining space. With 16 units per floor, plus a corridor, this meant that there could have been up to 64 zones per floor, which would have caused the simulation to be very data heavy. To streamline the model and speed up simulation processing times, zones were strategically located and combined with similar adjacent zones, for instance, combining two bedrooms into one zone. In addition, similar zones in adjacent units were also combined, allowing the amount of modelled zones to be cut in half. While in actuality, suites are separated by firewalls and would not normally be counted as one zone if separated into different suites, the simplification of zones in this manner allowed for a model that ran more smoothly with faster simulation times.

6.1.2 Envelope Assemblies

A common exterior wall system for MURBs was used to model the envelope assembly, as outlined by the Arup study, 'Community Energy Plan for Pilot Sites', and Kesik and Saleff's 'Tower Renewal Guidelines'. The exterior was modelled to be brick clad with the interior of these walls constructed from concrete masonry units (CMUs), and a plaster interior finish. While it was unknown whether the walls contained insulation, the Arup study assumed the presence of a 1" insulation board within the assembly (Arup Canada Incorporated, 2009). The structure of the building was comprised of 200mm vertical shear walls made up of steel-reinforced poured concrete spaced 6 to 9 meters apart. 200mm thick steel-reinforced poured concrete slabs are also used horizontally every 2.4m and often spanned beyond the envelope to create cantilevered balcony slabs (Kesik & Saleff, 2009). The roof assembly consisted of four-ply felt and gravel, with a thin layer of rigid insulation on the concrete slab (Touchie, Pressnail, & Binkley, 2012). The envelope assembly was modelled according to these specifications and summarized in Figure 17.

Wall Assembly (as defined by Arup Canada Incorporated, 2009)	Modelled materials	Thickness (m)
Exterior Face Brick	Brickwork Outer	0.100
Air Gap	Wall air space Resistance	0.079
Water Proofing Membrane	Bitumen felt/sheet	0.001
Insulation Board	Glass fiber board	0.025
CMU	Concrete Block	0.215
Wood strapping	Wooden Battens	0.010
Gypsum board lath	Plasterboard	0.013
Plaster finish	Plaster (Lightweight)	0.013
Interior Walls		
Plaster	Plaster (Lightweight)	0.013
CMU	Concrete Block	0.100
Plaster	Plaster (Lightweight)	0.013
Ground and floor slabs		
Concrete Slab	Concrete Slab	0.200
Roof		
Gravel/ Ballast	Gravel	0.050
4-Ply felt paper and asphalt	Bitumen/ felt layers	0.075
Rigid Insulation	Board Insulation	0.038
Concrete Slab	Concrete Slab	0.200

U-Value:	0.64 W/m2-K

Figure 17: Assembly of building model envelope

As presented in the Arup report, windows in the modelled MURBs were original to the building, single-pane, with aluminum frames and operable, so that the glazing could be opened to allow for natural ventilation (Arup Canada Incorporated, 2009). Balconies were modelled through the addition of 0.2 metre concrete slabs, with parapets 1 metre in height.

According to literature by Ge et al., the impact of thermal bridging through a balcony slab without a thermal break can raise the U-value of a building façade for a typical floor by 8.9% to 18.5% (Ge, McClung, & Zhang, 2013). Using this information to guide the simulated degree of thermal bridging, the exterior facade was assumed to receive an increase of 8.9% to 18.5% in U-value, per floor, due to the effects of the thermal bridging balcony slab. For this study, it was assumed that 8.9% was representative of thermal bridging effects in a building with low balcony to façade ratio, while 18.5% would be representative of these effects in a building with high balcony to façade ratio. Without the effect of thermal bridging, the opaque façade assembly had a U-value of 0.562 W/m^2-K. An 8.9% increase in U-value, or a U-value of 0.61 W/m^2-K was achieved by simulating a steel thermal bridging element in the concrete block of the exterior façade wall, which accounted for 2.0% thermal bridging of this component, raising U-value for the exterior walls to 0.61 W/m^2-K. The same was repeated for the increase in U-value of 18.5%, which increased U-value for the exterior walls to 0.67 W/m^2-K through 34.0% thermal bridging. The assembly with the lower U-value of 0.61 W/m^2-K was assigned to the construction of the base models with low balcony to façade ratio, the 6 Glamorgan and 20 Falstaff balcony models, while the U-value of 0.67 W/m^2-K was assigned to the model with the high balcony to façade ratio, the model with balconies from 325 Bleecker Street.

Airtightness was an important variable in the setup of the base models. In a study of the airtightness of Canadian MURBs, Gulay, Stewart and Foley, 1993, determined that measured over the entire floor of a building, air leakage ranged from 0.68 to 10.9 $L/s{\cdot}m^2$ at 50 Pa (Gulay, Stewart, & Foley, 1993). Another study by RDH Building Engineering found that MURBs being tested and compiled in a database had an average airtightness of approximately 3.76 $L/s{\cdot}m^2$ (RDH Building Engineering Ltd., 2013). This airtightness rate was used as a starting point for the base model, before calibration took place. Airtightness represents an unknown variable which can also significantly alter the performance of the building. Therefore, the adjustment of airtightness was one of the main methods of calibration used to adjust the model outputs to correspond to the billing information available for heating and cooling energy and EUI. This method of model calibration through the adjustment of airtightness was also used by Sara Damyar in the paper 'The Impact of Building Envelope Retrofit Measures on Postwar MURBs in Toronto' (Damyar, 2014).

6.1.3 Heating, Cooling, Ventilation

The HVAC system for each of the three buildings was detailed according to Arup's Tower Renewal report, which outlined details of the HVAC systems found in the examined MURB pilot sites. The report specified the use of boiler systems which supplied heating to radiators located in each unit, to a minimum temperature requirement of 21^{o}C in the heating season, from September 15th, to June 1st. The boiler system was also used to supply domestic hot water to the building, utilizing a heat pump with an efficiency of 86.5% to 89.5% to deliver hot water to the apartments at 48^{o}C to 50^{o}C (Arup Canada Incorporated, 2009). This heating system was modelled in Design builder using a radiator heating boiler system fueled by natural gas. The system was assigned a CoP of 88%, the average of Arup's estimate for system efficiency. The setpoint for heating was set to 21^{o}C and the supply temperature for domestic hot water was set to 49 ^{o}C to correspond to Arup's pilot sites. The schedule for heating was set up as to have heating turn off completely in summer months.

According to the Arup report, the infrastructure of the MURBs examined did not include installed air conditioning systems, however it was estimated that 11% of the units contained an air-conditioning window unit (Arup Canada Incorporated, 2009). To simulate this, two templates were made for the HVAC system, one with cooling and one without. The HVAC system with cooling was assigned to 11% of units in the building. For the model of 6 Glamorgan, which ended up being the building used for all base models, 11% of units was the equivalent of 1.7 units per floor that had air conditioning, so cooling was assigned to 2 units per floor as a starting point, and later adjusted to meet the benchmark cooling load for the building.

In a study of ventilation in Canadian MURBs by Phillips and Hill, 2002, ventilation in 5 buildings were examined. In these buildings, ventilation from the corridor fan ranged from 223 to 376 l/s/floor. While building exhaust ranged from 221 to 533 l/s/floor (Phillips & Hill, 2002). The third examined building in the study, a 21-storey natural gas-powered building, was seen to represent the base model in this study most accurately, so a ventilation rate of 305 l/s per floor was used in the model, with a combined kitchen and bathroom exhaust of 533 l/s/floor. These ventilation rates were applied to the base model by incorporating ventilation supply of 305 l/s to the HVAC system for the corridor on each floor, and the addition of an extraction fan to each bathroom and kitchen unit, which amounted to the exhaust of 533l/s per floor. In order to input these ventilation rates, the values needed to first be converted into air changes per hour (ACH), factoring in the volume of one floor of the building. For corridor supply air at 6 Glamorgan, this amounted to 0.33 ACH. For exhaust air, this amounted to 0.57 ACH, which was divided by 16 units per floor, and further divided by two to account for separate extraction units in each bathroom and kitchen space on each floor, each assuming an extraction rate of 0.018 ACH. On the first floor, the laundry facilities were assigned extraction equivalent to 8 apartment units, to make exhaust ventilation on each floor equal to 0.57 ACH.

6.1.4 Plug Loads and Electricity Use

In order to build a model that corresponded to actual usage data, the annual electricity output of the base model needed to fall within a close range of actual values for billed electricity usage. As electricity use was one of the more variable elements of the model, the plug loads and lighting could be adjusted incrementally until electricity fell within a reasonable range of the actual electricity usage data. This strategy for model calibration using plug loads was outlined in Marianne Touchie's report, 'Improving the Energy Performance of Multi-Unit Residential Buildings Using Air-Source Heat Pumps and Enclosed Balconies' (Touchie M. , 2014).

6.1.5 Water Consumption

Water consumption for the base model was determined by billing data available in Yirong Huang's MURB dataset for energy benchmarking. This dataset specified an annual water consumption of 4.3 m^3/m^2 for 6 Glamorgan Avenue, or 11.7 l/m^2/day (Huang Y. , 2012).

6.1.6 Building Model Height Sensitivity Analysis

To determine whether changes could be made to the base model to speed up simulation times, a sensitivity analysis was completed to gauge the impact that the height of the building had on the results, and the ability to correspond outputs in the model to the actual billing data for the buildings. With the base model building for 6 Glamorgan Avenue originally modelled as 12 storeys high, the simulation was slow and inhibited the modelling process and ability to run models multiple times with different variables. To determine the impact the height had on the modelled results, the model for 6 Glamorgan Avenue was run once with its actual height, 12 storeys, and again, with the same parameters, for 10, 8 and 6 storeys to see if the same results could be reached by modelling fewer storeys. As the balconies being used in the model came from 20 Falstaff Avenue and 325 Bleecker street, buildings which were over 12 storeys high, the sensitivity analysis using the 6 Glamorgan model was also modelled using 14 and 16 storeys to see how the results from the model with the most level of floors differed from the model with the least number of floors. Results for the analysis can be seen in Figure 18. It should be noted that the sensitivity analysis was conducted before the calibration was complete, so the outputs are not reflective of that of the final calibrated base model.

Number of storeys	EUI (kWh/m^2)	Electricity usage (kWh/m^2)	Heating (kWh/m^2)	Cooling (kWh/m^2)	DHW (m^3/m^2)	Simulation run time (minutes)	EUI deviation from 12-storey model (%)
6	298.8	86.4	207.7	4.8	4.2	21	-0.2%
8	297.4	84.0	208.6	4.8	4.2	35	0.2%
10	296.6	82.7	209.0	4.9	4.2	50	0.5%
12	**298.1**	**81.7**	**211.7**	**4.7**	**4.2**	86	0.0%
14	297.7	81.1	211.9	4.7	4.2	110	0.1%
16	297.5	80.6	212.2	4.7	4.3	150	0.2%

Figure 18: Sensitivity Analysis for Modelled Building Height

The results of the analysis showed that decreasing the number of storeys resulted in minimal changes to the model results. Even the results from the 6 and 16 storey models showed an EUI deviation of only 0.4% from one another. The decision was made to simulate each model using 6 storeys, as this would speed up the simulation times, but also leave enough height to the buildings to maintain realistic boundary conditions.

6.1.7 Calibration

To ensure accuracy of the base model, model outputs were compared against energy usage information available in Huang's dataset for 6 Glamorgan Avenue. The outputs compared included EUI (kWh/m^2) of the building, total electricity usage (kWh/m^2), heating (kWh/m^2) and cooling (kWh/m^2). Once the base model inputs were complete, the model was simulated and energy outputs were compared against the actual billed data that Huang recorded for the study. The goal for calibration followed the standards in the Arup report, in which the model could be considered within an accurate range if the error fell within a range of 10% (+ or - 5%) (Arup Canada Incorporated, 2009).

The first step in the calibration of the base model involved adjusting plug loads to bring the electricity usage up to a level closer to that of the actual billed electricity use in the building. This was done by adjusting the usage schedule of electricity in the building, increasing times of residential electricity use.

By adjusting the airtightness level, lowering infiltration from 3.76 to 3.0 $l/s/m^2$ at 50 Pa, this lowered the error for heating as the increase in airtightness reduced heating demand to -4.7% error. Finally, adjustments were made to the amount of air conditioning units in the building, raising the percentage of apartment units with air conditioning to 34%, opposed to the 11% originally estimated. This raised the cooling levels enough to reach an appropriate level of cooling demand, and raised EUI, decreasing the degree of error to 4.0%.

	EUI (kWh/m^2)	Total electricity usage (kWh/m^2)	Heating (kWh/m^2)	Cooling (kWh/m^2)
Model Output	303.3	86.3	212.9	4.1
Billed Data	316.1	82.2	203.3	4.0
Error %	4.0%	-5.0%	-4.7%	-1.9%

Figure 19: Simulation outputs from the calibration of 6 Glamorgan Avenue building model

These adjustments brought the model within an error range of plus or minus 5% of the actual energy usage data from Huang's dataset. It should be noted that certain inputs may have been over-calibrated, as 10% error for EUI is different from 10% error for the elements that comprise EUI. The level of error for electricity usage, heating and cooling can potentially be larger without compromising the 10% level of error required for EUI, and as a result, these categories may be calibrated within an unnecessary level of precision. Nonetheless, the low level of error of the end results indicated that the model could proceed to the next stage of the simulation: the addition of the balcony enclosures.

6.2 Modelling Enclosures

The enclosure was modelled using EIFS exterior cladding, which was added to the exterior of the existing concrete balcony parapet. Depending on whether the balcony was inset or projecting, the EIFS overclad covered one to three exposed sides of the parapet. Above the parapet, or 1m up from balcony slab, the double-paned glazing was added. Again, depending on the geometry of the balcony, the glazing would be added just to the outermost side if the balcony was inset, or all three exposed sides if the balcony was projecting. The selected glazing was double glazed, low-e, with an argon fill and aluminum frames with a thermal break. The glazing was specified as operable, meaning that in summer months, when solar gains are much less desirable, windows can be opened. Following the optimal design for a balcony enclosure, as outlined in 'Tower Renewal Guidelines', an unconditioned balcony enclosure, that utilized shading and natural ventilation in the summer was used for this model (Kesik & Saleff, 2009). This was simulated by implementing a schedule in which the enclosure glazing was open 50% of the time in summer (June 21 to September 22). The use of shading was also modelled for the balcony enclosure as interior blinds, which would be implementing shading of the glazing 50% of the time, following the same schedule. 50% of summer hours was selected as the schedule for shading and ventilation, as this was estimated to be a realistic operation schedule that could be attained by apartment residents. A test was run to evaluate the effect of this summer ventilation and shading, and the results showed an overall decrease in EUI for the for the balcony enclosures that made use of the shading and ventilation, compared to the enclosures that did not. This decrease in EUI was due to a decrease in the demand for cooling. These results can be found in *Appendix A*.

For the 325 Bleecker Street balconies, in which the balcony to façade ratio was higher, adjoining adjacent balconies were modelled as one long enclosure over the balcony, with dividing shear walls encased within the enclosure. Where there was a shear wall present adjacent to the balcony, the overclad was assumed to wrap around the shear wall to insulate it. Attached to the existing concrete parapet or concrete shear wall, the EIFS overclad consisted of an insulated board adhesive and/or air/vapour barrier, a drainage layer, insulation board, a stucco base coat with reinforcing mesh, and the stucco finish coat (Kesik & Saleff, 2009). The below chart indicates the materials that were selected in the model to represent the layers of this assembly.

EIFS Wall Assembly (as defined by Kesik & Saleff, 2009)	Modelled materials	Thickness (m)
Finish coat	Stucco	0.019
Base coat with reinforcing mesh	External rendering	0.010
Insulation board	Extruded Polystyrene	0.130
Drainage layer	Air gap	0.025
Air/vapour barrier	Polyethylene sheet	0.003
Existing exterior wall	Cast concrete	0.200

U-Value:	0.24 W/m2-K

Figure 20: EIFS Assembly

The balcony enclosures were modelled without the use of additional lighting or HVAC systems, as the enclosure was meant to function as an unconditioned space. The airtightness in the enclosure was modelled according to Hilliaho's estimate of an adequate level of airtightness for a balcony enclosure, 1.5 ACH, or 2.78 $l/s/m^2$ (Hilliaho, Kovalainen, Huuhka, & Lahdensivu, 2016). The three base models before and after enclosures were added can be seen in Figure 21.

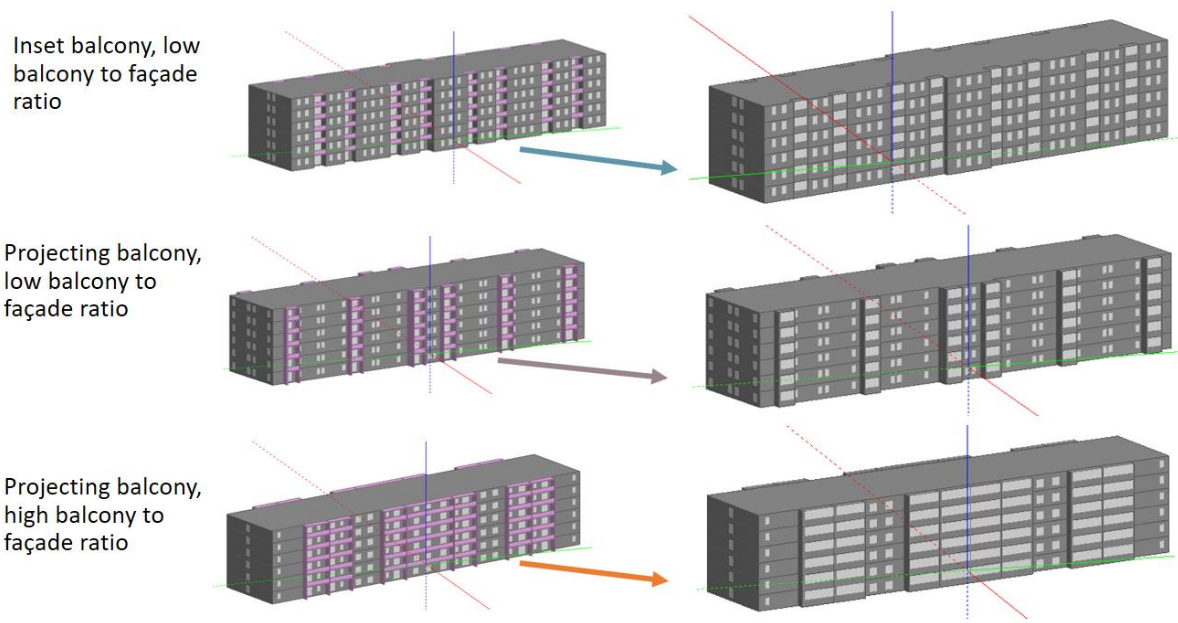


Figure 21: Three base models before and after balcony enclosures

6.2.1 Thermal Bridging Improvements

The 8.9% to 18.5% increase in U-value that was modelled for the façade (8.9% for low balcony to façade ratio, and 18.5% for high balcony to façade ratio) was included in each of the base models to simulate an exposed balcony slab that was causing thermal bridging. With balconies enclosed, it could be assumed that the retrofit models would not be subject to this thermal bridging, as the balcony slabs were modelled using the insulating overclad provided by the balcony enclosure. Therefore, models with the enclosures were run without thermal bridging, under the assumption that the enclosure would remove the instances of thermal bridging through the balcony slab. *Appendix B* shows a test of the results of the enclosure models run with and without thermal bridging. These results showed that this removal of thermal bridging did have an affect on the overall performance as it lowered EUI in each of the models displaying larger energy saving potential in the enclosures models without thermal bridging.

6.2.2 Running Simulations

After attaching the enclosures and running initial simulations for each of the three balcony cases, the results with the enclosures were compared with the three original base cases. From there, simulations were run for different timespans and different areas within the building, as well as for a perpendicular orientation, to determine the role that balcony characteristics played in the energy use of a building, and how this was affected when balcony enclosures were incorporated.

7. Results and Analysis of Building Models

7.1 Performance of Buildings with and without enclosures

After running models with and without balcony enclosures, the simulation results were compared to determine the annual difference in energy use between buildings before and after a hypothetical balcony enclosure retrofit. In each of the three models, EUI was lowered when modelled using enclosed balconies compared to open balconies.

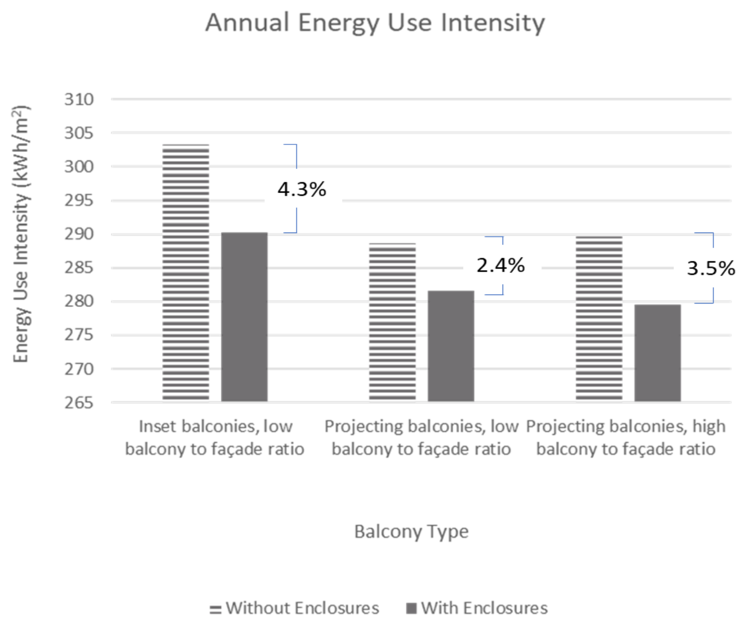


Figure 22: Results from initial simulations of three models with and without balcony enclosures

The largest decrease in annual energy use intensity was seen in the model with inset balconies in a building with low balcony to façade ratio. This model, with the balcony arrangement from 6 Glamorgan Avenue, saw an annual EUI decrease by 4.3% when a balcony enclosure was added. Therefore, in the initial comparison between two balconies of different projection types, inset or projecting, the inset balcony, represented by the balconies of 6 Glamorgan Avenue, were seen to achieve the highest energy savings when retrofit with enclosed balconies. When comparing two balconies of the same balcony projection type, high balcony to façade ratio showed better performance than low balcony to façade ratio, as indicated by the model with balconies from 325 Bleecker street, which saw EUI decrease by 3.5% when balconies were enclosed.

This decrease in EUI can be explained by a decrease in heating demand. The following figure shows that space heating in each of the three models decreased in the models which incorporated balcony enclosures, with the largest decreases in space heating evident in the model with inset balconies with low balcony to façade ratio, and the model with projecting balconies and high balcony to façade ratio.

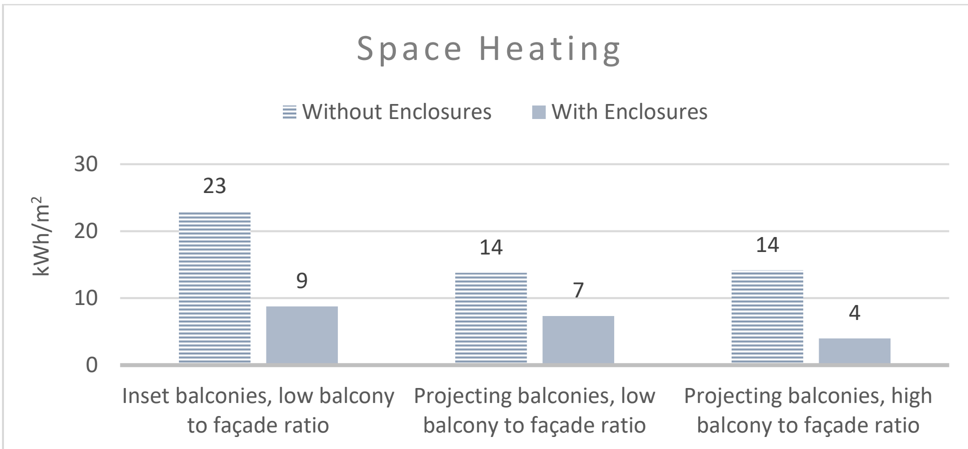


Figure 23: Space heating in models with and without balcony enclosures

When examining solar gains present in the models before and after balcony enclosures were added, it can be observed that in each of the models, the addition of the balcony enclosures lowered the amount of solar gains. This is to be expected, as the enclosure structure provides additional shading of the existing fenestration when the balcony enclosures were added, with the enclosure glazing filtering the solar radiation entering the building. As part of the balcony enclosure design, partial interior shading was incorporated in summer months, also acting to decrease the solar gains received by the building.

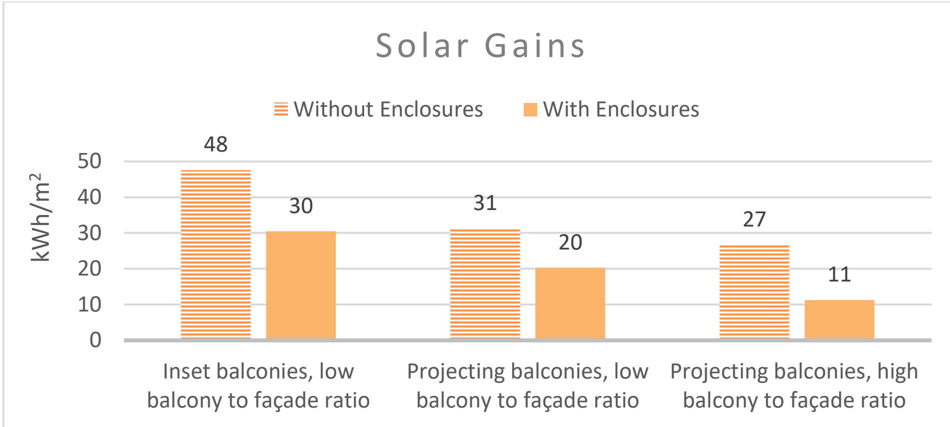


Figure 24: Solar gains in models with and without balcony enclosures

As solar gains decrease in parallel with space heating, it can be determined that while not actually receiving additional solar radiation, the balcony enclosures are working to hold in heat and reduce heat transfer through the building envelope, reducing heating demand.

A monthly breakdown of average temperatures shows outdoor dry bulb temperature versus indoor air temperature for each model, with and without balcony enclosures. The monthly temperature profiles show that in each model, average indoor temperature with solar gains increased when balcony enclosures were added, especially during winter months and shoulder seasons. During the winter season, depending on the model, average indoor air temperatures were seen to increase from 2°C to 5°C. This increase in temperature is to be expected as the addition of enclosures affect thermal transfer through the façade, adding additional layers of thermal resistance that reduces heat transfer through the envelope. The added resistance decreases the U-value of the façade, leading to higher indoor temperature when balcony enclosures are present, especially in colder seasons when the rate of heat transfer through the envelope is highest.

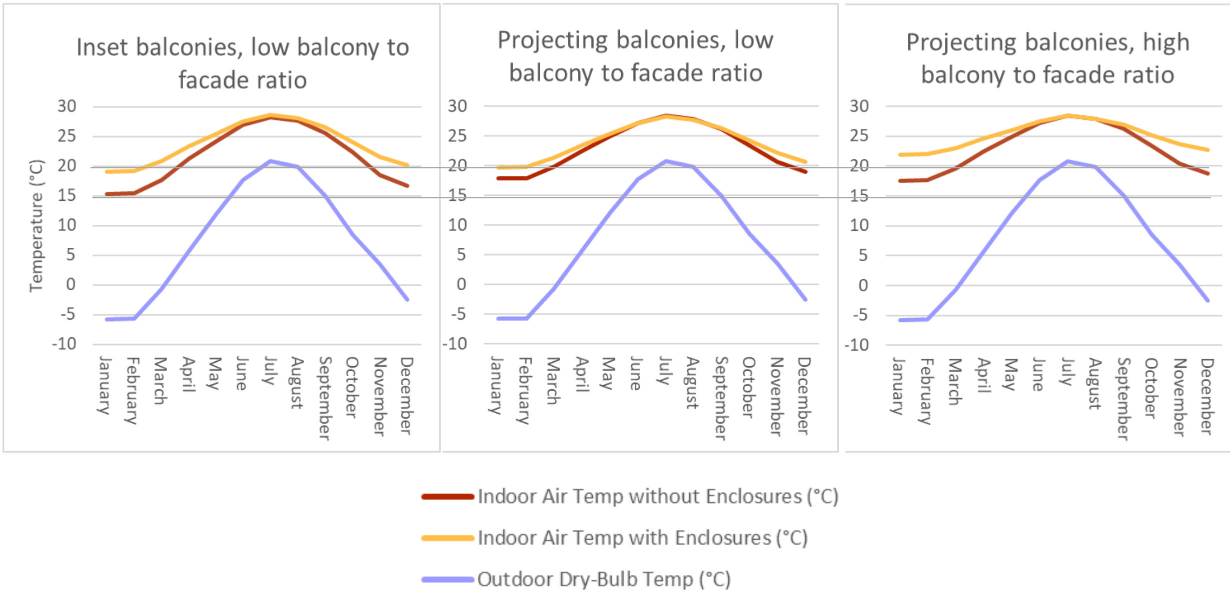


Figure 25: Average temperature fluctuation per month

In summer months, temperature increase in all three models was minimal, due to the design of the enclosure. As natural ventilation and shading was employed in the modelled enclosures for summer months, the effect on the temperature for summer months was negligible.

The largest increase in indoor air temperature when balcony enclosures were added could be seen in the same two models which experienced the highest decrease in EUI and heating demand: the model with the inset balconies and low balcony to façade ratio, and the model with the projecting balconies and the high balcony to façade ratio. In the inset balcony, this lower initial air temperature might be explained by the fact that three walls of the balcony area were shared with exterior walls, causing more heat loss in winter and a higher benefit when balcony enclosures were added. This may explain the lower initial indoor temperature without the enclosures, as the inset balcony had a larger surface area of walls that were shared between the building and balcony, causing a higher amount of heat exchange through the envelope compared to a projecting balcony of the same ratio. Similarly, the projecting balcony with high balcony to façade ratio has a larger surface area of exterior wall that was shared with the balcony area, compared to that of a projecting balcony with a low balcony to façade ratio. This may explain the lower initial indoor air temperature compared to the model with the low ratio projecting balconies, and the larger increase in indoor temperatures in the winter when balcony enclosures were added.

To examine the temperature profile in more detail, as well as the effect of the added balcony enclosures on occupant comfort, one room on each side of the building was compared across all three models, with and without enclosures. The room selected was a living room/kitchen space, as this is the space which connected to the balcony. The same room on the fourth floor, towards the centre of the building, oriented towards the east was selected for all three models and compared for three days out of each season. The 28th, 29th, and 30th were used as the dates selected for the months of January, April, July and October, as dates towards the end of the month in January and July were observed to show the highest extremes in temperature when the modelled weather data was plotted. The following figure shows a plot of the yearly outdoor temperature from the Toronto weather file used in the simulation, which shows coldest seasonal temperatures towards the end of January and hottest seasonal temperatures at the end of July and beginning of August.

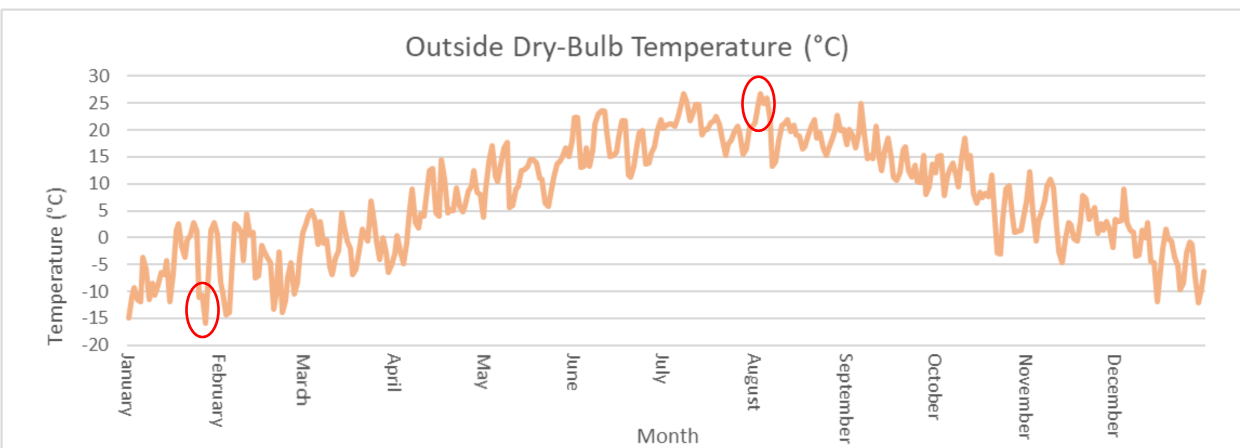


Figure 26: Plotted annual outdoor temperature for the timeline of the simulation

When modelling these time periods in each season, three consecutive days were used as it provided an extended snapshot of temperature performance in an interior space adjacent to the balcony. Like the monthly temperature averages, these daily results showed an increase in temperature with the addition of the balcony enclosures, especially for the model with inset, low balcony to façade ratio, and the model with projecting, high balcony to façade ratio.

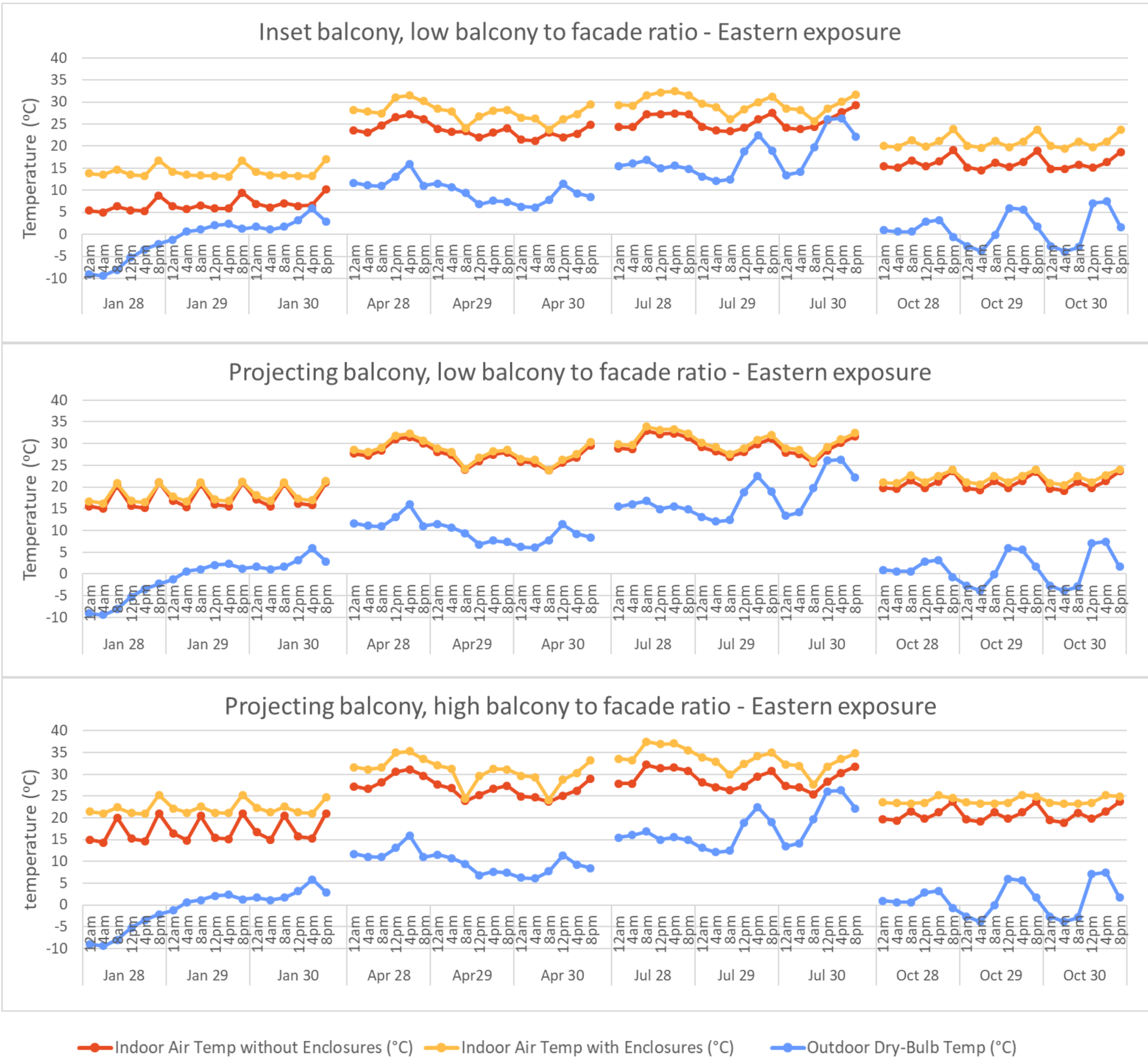


Figure 27: Seasonal air temperature fluctuations for indoor living space

The model with the projecting and low balcony to façade ratio saw some change in indoor air temperature when balcony enclosures were added, but very little. The temperature of indoor air with and without balcony enclosures was seen to follow a similar trajectory in the plotted results, with indoor air temperatures with balcony enclosures appearing up to 9°C warmer than indoor air temperatures without enclosures. In many instances, lowest temperatures were present in the early morning, and higher temperatures in late afternoon. In several cases, in early morning hours, the effect of the balcony enclosure on temperature can be seen to be very minimal compared to that of midday or late afternoon. This drop in early morning temperature for several of the models with balcony enclosures indicates that heat is being dissipated during the night and gained during the daytime. While indoor air temperatures for models without balcony enclosures show a similar trend of losing heat at night and early morning, several of the models with balcony enclosures show a more sudden morning temperature decrease. This phenomenon can likely be attributed to the enclosures acting as a thermal buffer zone, receiving and storing solar gains throughout the day and transferring this heat to surrounding indoor spaces and raising the temperature several degrees higher than would be possible without enclosures. During the night, the absence of solar gains causes the enclosure to lose its stored heat, reverting to a temperature similar to that without balcony enclosures in early morning.

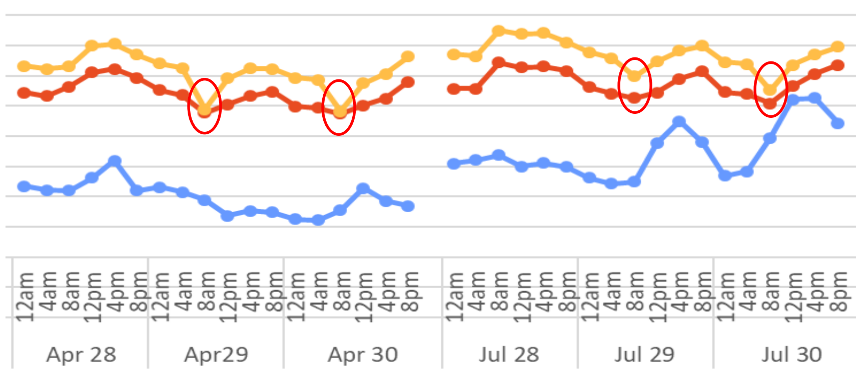
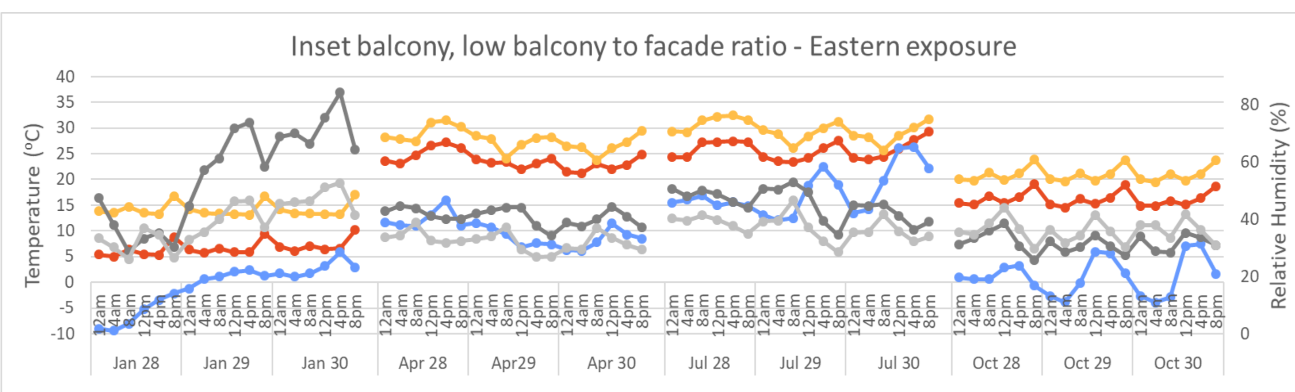


Figure 28: Observed drop in temperature for models with enclosures, early morning

The ASHRAE comfort standard outlines that temperature should remain within about 19.5 °C to 28°C, and less than 55% relative humidity in order to stay within +/- 5% of the PMV limit for occupant comfort (AREN 3050 Environmental Systems for Buildings, 2005). The addition of the enclosures, especially for the days observed in the months of January and October, help to raise indoor air temperature to meet the occupant comfort level, particularly for the models with low ratio inset balconies, and high ratio projecting balconies, helping to raise indoor air temperatures around the range of 15 °C and 25 °C. However, on the days examined in April and July, the addition of the balcony enclosures can be seen to raise indoor air temperatures above 28 °C, and therefore above the PMV limit for occupant comfort. While this temperature increase may mean a decrease in heating demand in winter and certain days of the shoulder season, as seen for January and October, it may also mean an increase in cooling demand, or a reduction in occupant comfort for some summer and shoulder season days, as seen for the days examined in July and April.

Relative humidity was also examined for these dates for models with and without balcony enclosures. It can be expected that as temperature increases, relative humidity will decrease if water vapour content in the air remains constant. This could be seen in most cases, with the relative humidity of the living space showing a decrease for the models with the balcony enclosures, as air temperature increased. For the first model with inset balconies and low balcony to façade ratio, January showed the largest temperature increase when enclosures were added out of all of the other dates and models examined. As a result of this large temperature increase when balcony enclosures were added, the relative humidity when enclosures were added dropped significantly. This drop brought indoor relative humidity down to around 50%, within the limit for occupant comfort.



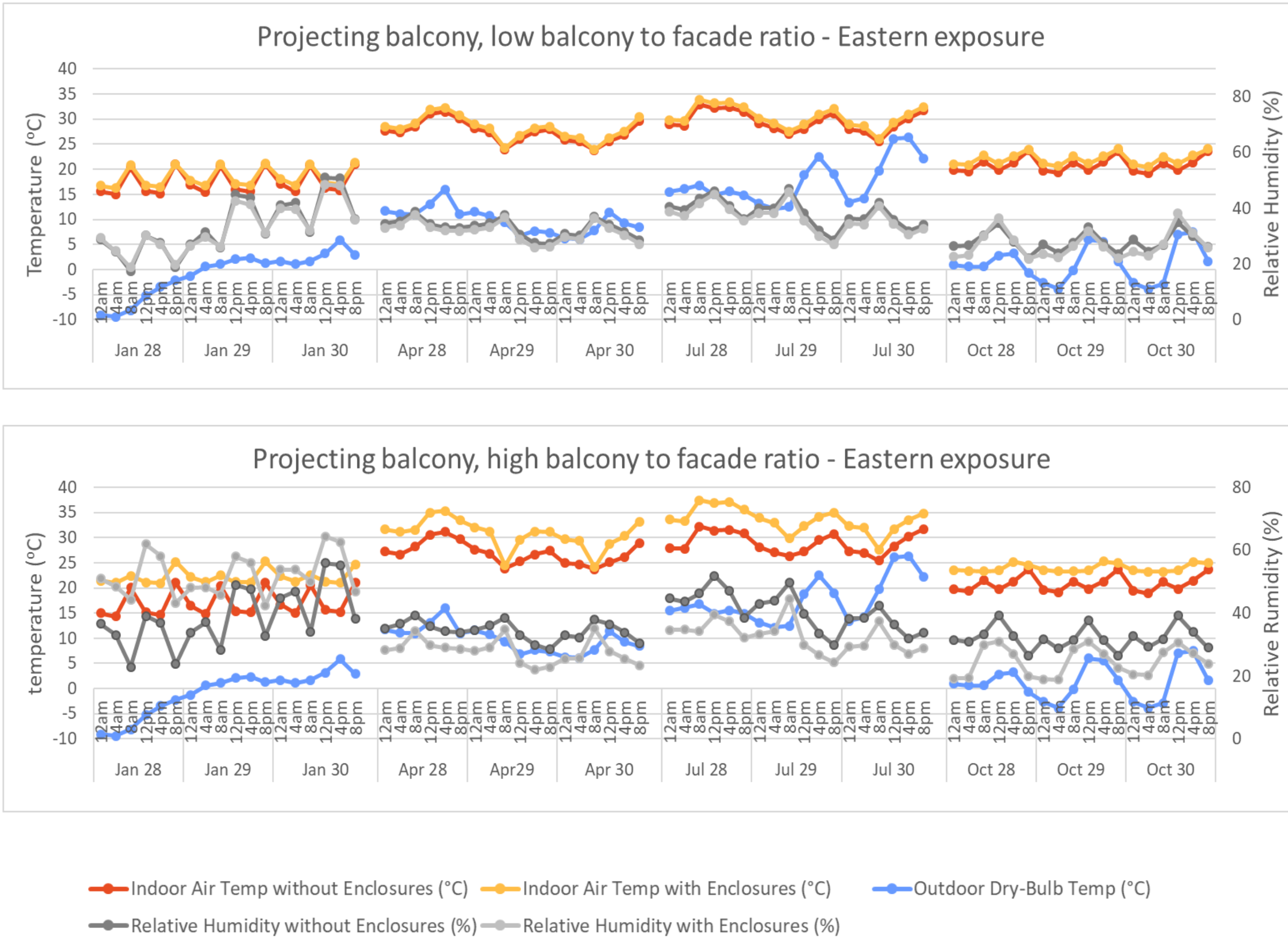


Figure 28: Seasonal air temperature fluctuations for indoor living space

However, in several cases, the relative humidity did not decrease as temperature increased. In the model with high balcony to façade ratio and projecting balconies, when balcony enclosure was added, indoor air temperature increased as relative humidity increased for the three days modelled in January. The same could be seen for the three days modelled in October for the model with the inset and low ratio balconies, except to a lesser extent. This increase in relative humidity when temperature increased indicates that the water vapour content of the indoor air also increased when balcony enclosures were introduced. For the three days in January in the model with the high ratio, projecting balconies, this increase in vapour could be explained by the formation of condensation. As the indoor air temperature in this model increased to 20 °C to 25 °C, with an outdoor temperature between -10 °C and 5 °C, only a low relative humidity would need to occur in order for dewpoint to be reached, forming condensation. For instance, at 20°C indoor temperature with balcony enclosures, dewpoint at 25% relative humidity can form at a temperature around -1 °C. Therefore, it may be a prolonged risk of condensation that is increasing the vapour content of air, acting to raise the relative humidity. This may also be the case for the relative humidity increase for the inset, low ratio model during the October timeframe.

7.2 Effect of changing orientation

Each of the three models were simulated for a second time, with and without enclosures, oriented perpendicular to the original orientations. Originally modelled on a North North-West axis, with half of balconies oriented East North-East, and half oriented West South-West, the building was rotated 90°, so that balconies were facing North North-West and South South-East.

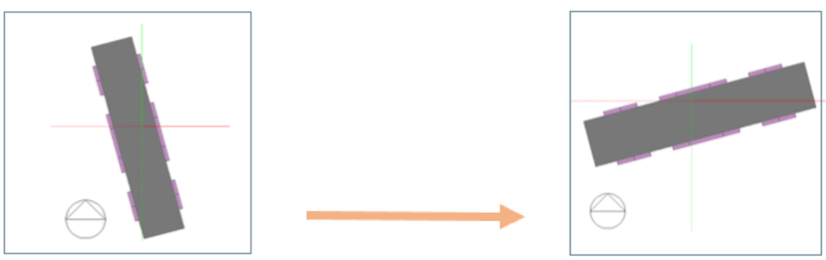


Figure 29: Plan view of a model with 90° orientation change

This change in orientation had a significant impact on the overall EUI for all three models. For each of the models, changing the orientation so that balconies faced North North-West and South South-East lowered overall energy usage for each building, for model without balcony enclosures and with balcony enclosures alike.

Balconies oriented ENE, WSW	EUI (kWh/m^2)	
	Without Enclosures	With Enclosures
Inset balconies, low balcony to façade ratio	303.3	290.2
Projecting balconies, low balcony to façade ratio	288.6	281.6
Projecting balconies, high balcony to façade ratio	289.6	279.6

Balconies oriented NNW, SSE	EUI (kWh/m^2)	
	Without Enclosures	With Enclosures
Inset balconies, low balcony to façade ratio	300.9	289.0
Projecting balconies, low balcony to façade ratio	286.9	281.0
Projecting balconies, high balcony to façade ratio	287.6	279.2

Figure 30: EUI comparison between models after 90º orientation change

This reduction in EUI can be attributed to a reduction in heating due to an increased exposure to radiation, with half of balconies facing the south side, receiving solar radiation all day. This can be especially efficient in winter months when the sun is at a lower angle and the building can utilize free solar energy for heating. Cooling also decreased in all models, as the half of balconies were exposed to the north, receiving very little solar radiation and creating a condition where half of the building requires very little cooling in summer.

The results also showed that the effect that the orientation change had on performance was more extreme for the buildings which did not have balcony enclosures. This indicated that implemented balcony enclosures could potentially lessen the effect of orientation change, allowing buildings to show a consistent level of performance, despite the orientation.

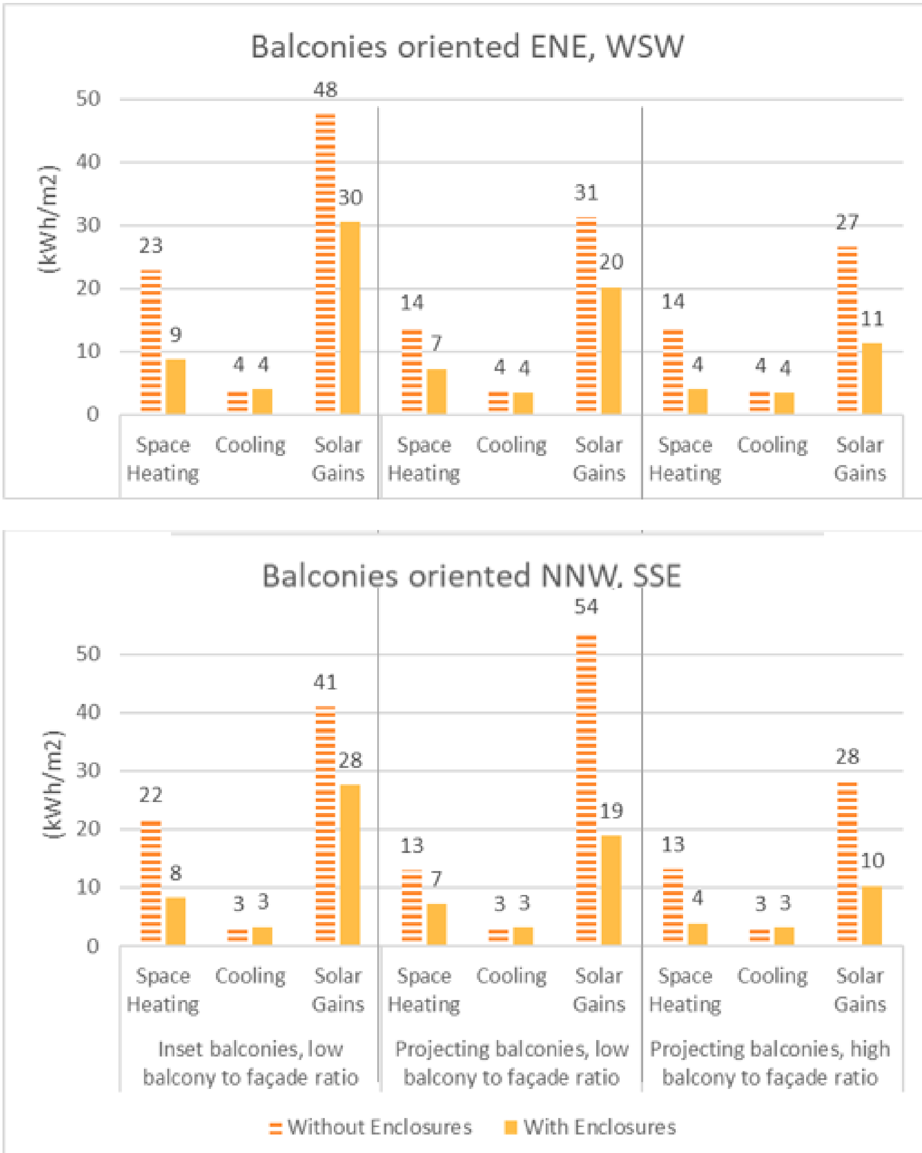


Figure 31: Effect of changing orientation on EUI, space heating, cooling, solar gains

8. Conclusion

It can be concluded that balcony characteristics have a significant impact on building performance when balcony enclosures are being used. While each model saw an improvement in energy use when enclosures were added, some showed better results than others. The initial simulations run for the three models with and without balcony enclosures resulted in the inset balcony performing better than the projecting balcony when compared with the same balcony to façade ratio, and the high balcony to façade ratio performing better than the low balcony to façade ratio when compared with the same balcony type. This suggests that a building with a combination of an inset, high balcony to façade ratio may experience the highest decrease in EUI, compared to buildings with other balcony types, when retrofit with a balcony enclosure.

Balcony Type	Projecting	Inset
Balconies modelled from	20 Falstaff Avenue	6 Glamorgan Avenue
Inprovement in Energy Use Intensity	2.4%	4.3%
Balcony Ratio	Both have low balcony to façade ratio	

Figure 32: Comparison of results from balcony type simulations

Balcony Ratio	High Ratio	Low Ratio
Balconies modelled from	325 Bleecker Street	20 Falstaff Avenue
Inprovement in Energy Use Intensity	3.5%	2.4%
Balcony Type	Both have projecting balconies	

Figure 33: Comparison of results from balcony to façade ratio simulations

This decrease in EUI for these models was primarily due to a decrease in heating demand when balcony enclosures were added. While annual heating demand decreased in each of the models, so too did the annual solar gains received by the building. This indicated that the addition of the enclosures can help to hold in more heat within the building by limiting heat transfer through the building envelope. A breakdown of average monthly temperatures showed a distinct temperature increase in indoor air temperature of the building when balcony enclosures were added, especially for the models with inset, low ratio balconies and projecting, high ratio balconies, the same models which showed the largest decrease in overall energy use intensity, especially during winter months and the shoulder seasons.

A detailed examination of the indoor air temperature for three consecutive days from each season indicated that the additions of enclosures helped to raise temperature in winter, bringing indoor air temperature up to a more comfortable temperature in winter and certain days of the shoulder season, but could potentially lead to days of overheating in summer and days in the shoulder season as well. In addition, when relative humidity was factored into the detailed seasonal analysis, instances of increasing relative humidity in winter and fall were observed for two of the models, indicating there may be a potential for condensation when balcony enclosures raise indoor temperature during times of the year when outdoor temperature is very low. However, with this seasonal analysis, the days selected provided just a snapshot of possible performance over short periods of time, so more days would need to be examined in order to determine if overheating and condensation would be a concern over extended periods of time.

When the effect of orientation was examined for each of the models, the overall energy use intensity of each of the models decreased, due to a decrease in heating and cooling demand in the modelled buildings when the balconies faced towards the North and South. This indicates that both buildings without balconies and buildings with balcony enclosures may experience decreased energy usage when buildings are oriented so that balconies are north and south facing. It is interesting to note that the models with the balcony enclosures were less affected by the orientation change than the models without the balcony enclosures, indicating that orientation may have less of an effect on building performance when balcony enclosures are utilized.

Appendix

Appendix A: Effect of Shading and Ventilation

A simulation of each of the three models was performed to gauge the effects that natural ventilation and shading had on the performance results. In this simulation, the models were simulated with and without the schedules for partial shading and natural ventilation of the enclosures in summer, simulating the results with and without interior blinds and natural air movement through the enclosure glazing.

Inset balconies, low balcony to façade ratio

	EUI (kWh/m^2)	Heating (kWh/m^2)	Cooling (kWh/m^2)
Without summer ventilation/ shading	290.32	199.00	3.96
With summer ventilation/ shading	290.20	199.56	3.72
Difference in performance with and without summer ventilation/ shading %	0.04%	-0.28%	6.08%

Projecting balconies, low balcony to façade ratio

	EUI (kWh/m^2)	Heating (kWh/m^2)	Cooling (kWh/m^2)
Without summer ventilation/ shading	283.22	189.66	3.51
With summer ventilation/ shading	281.65	188.04	3.49
Difference in performance with and without summer ventilation/ shading %	0.55%	0.85%	0.49%

Projecting balconies, high balcony to façade ratio

	EUI (kWh/m^2)	Heating (kWh/m^2)	Cooling (kWh/m^2)
Without summer ventilation/ shading	282.03	186.21	4.59
With summer ventilation/ shading	279.59	186.30	3.58
Difference in performance with and without summer ventilation/ shading %	0.87%	-0.05%	22.04%

Figure 34: Comparison of models with and without summer ventilation and shading

Appendix B: Models with and without Thermal Bridging

In order to gauge the effect that the modelled thermal bridging had on the simulations, two versions of the enclosure models were simulated: with and without thermal bridging. The results from these models were compared against the model without the balcony enclosures to observe the effect that thermal bridging had on EUI, space heating and cooling.

Inset balconies, low balcony to façade ratio

	EUI (kWh/m^2)	Difference from performance without enclosures %	Space Heating (kWh/m^2)	Difference from performance without enclosures %	Cooling (kWh/m^2)	Difference from performance without enclosures %
Without Enclosures	303.30		22.90		4.10	
With Enclosures - Thermal bridging	290.34	4.27%	8.73	61.86%	4.07	0.72%
With Enclosures - No thermal bridging	290.20	4.32%	8.70	62.01%	4.00	2.44%

Projecting balconies, low balcony to façade ratio

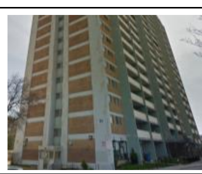
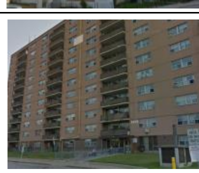
	EUI (kWh/m^2)	Difference from performance without enclosures %	Space Heating (kWh/m^2)	Difference from performance without enclosures %	Cooling (kWh/m^2)	Difference from performance without enclosures %
Without Enclosures	288.57		13.8		3.71	
With Enclosures - Thermal bridging	281.65	2.40%	7.33	46.88%	3.54	4.77%
With Enclosures - No thermal bridging	281.62	2.41%	7.30	47.10%	3.53	4.98%

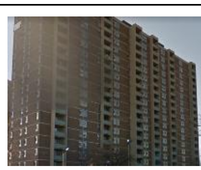
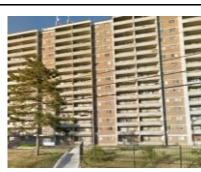
Projecting balconies, high balcony to façade ratio

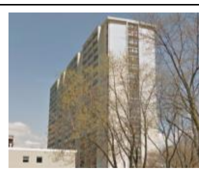
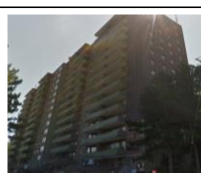
	EUI (kWh/m^2)	Difference from performance without enclosures %	Space Heating (kWh/m^2)	Difference from performance without enclosures %	Cooling (kWh/m^2)	Difference from performance without enclosures %
Without Enclosures	289.58		14.10		3.83	
With Enclosures - Thermal bridging	279.59	3.45%	4.00	71.61%	3.52	8.07%
With Enclosures - No thermal bridging	279.53	3.47%	4.00	71.63%	3.51	8.35%

Figure 35: Models with and without thermal bridging due to enclosure retrofit

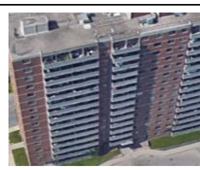
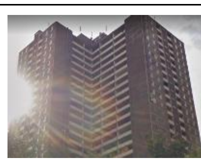
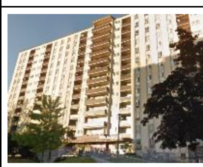
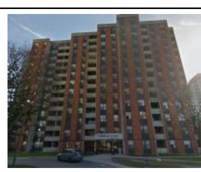
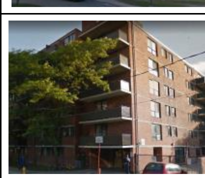
Appendix C: Observations of MURB Attributes

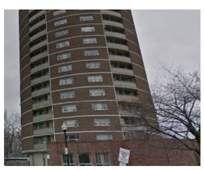
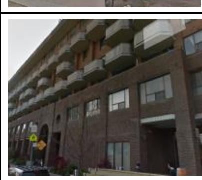
Building Id	Address	Picture	Year Built	Building Area (m2)	Building Area (ft2)	Energy Use Intenstity kWh/m2	# of Floors	# of units	Building Footprint	Notes
3145	30 Teesdale Place		1971	22,633	243,624	374	24	278	Rectangle	
3146	40 Teesdale Place		1971	22,633	243,624	378	24	278	Rectangle	
3200	675 Kennedy Rd		1969	17,028	183,293	265	11	192	L-shaped	No balconies on SSE side
3242	3847 Lawrence Avenue E		1969	21,645	232,990	339	13	213	L-shaped	Shear wall present 100% on only 6 of 18 balconies
3243	275 Shuter St		1964	25,826	277,984	355	16	299	L-shaped	
3244	285 Shuter Street		1964	25,826	277,984	346	16	300	L-shaped	
3245	295 Shuter St		1964	25,826	277,984	347	16	300	L-shaped	
3477	31 Gilder Drive		1970	14,264	153,540	357	18	190	Rectangle	
3496	2821 Birchmount Rd		1969	19,220	206,880	341	12	237	Rectangle	

Building Id	Address	Picture	Year Built	Building Area (m2)	Building Area (ft2)	Energy Use Intenstity kWh/m2	# of Floors	# of units	Building Footprint	Notes
3497	155 Sherbourne St		1973	16,846	181,328	309	16	301	Irregular	
3527	6 Glamorgan Avenue		1971	17,801	191,604	316	12	184	Rectangle	
3624	15 Tobermory Drive		1972	34,850	375,118	316	24	374	Rectangle	
3637	2743 Victoria Pk Ave		1971	18,016	193,920	349	14	201	Rectangle	Top balconies no overhang (7%)
3638	2739 Victoria Pk Ave		1971	17,971	193,440	329	15	203	Rectangle	Top balconies no overhang (7%)
3641	30 Falstaff Ave		1970	19,742	212,496	343	19	221	Rectangle	8% of balconies depth adjacent to building
3642	20 Falstaff Ave		1970	19,742	212,496	353	19	224	Rectangle	8% of balconies depth adjacent to building
3643	40 Falstaff Ave		1970	26,785	288,312	372	24	327	Rectangle	8% of balconies depth adjacent to building
3798	2999 Jane Street		1971	16,551	178,155	331	15	188	Rectangle	one side of 2 out of 14 balcony depths occupied by building

Building Id	Address	Picture	Year Built	Building Area (m2)	Building Area (ft2)	Energy Use Intenstity kWh/m2	# of Floors	# of units	Building Footprint	Notes
3815	5 Needle Firway		1971	15,300	164,688	312	12	137	Rectangle	4 out of 16 balconies have 25% shear wall
3898	5005 Dundas Street W.		1962	18,621	200,431	355	19	255	Rectangle	
3899	57 Mabelle Avenue		1962	18,621	200,431	351	19	255	Rectangle	
3900	710 Tretheway Dr		1974	13,795	148,485	302	19	165	Rectangle	
3901	720 Trethewey Dr		1974	19,224	206,928	301	18	204	Rectangle	
3903	325 Bleecker St		1969	26,785	288,312	335	24	327	Rectangle	
3976	44 Willowridge Rd		1972	19,243	207,130	401	14	238	Y-Shaped	
3983	190 Woolner Ave		1968	26,448	284,688	332	16	304	Y-Shaped	
3991	121 Humber Blvd		1968	19,657	211,582	337	14	215	Rectangle	

Building Id	Address	Picture	Year Built	Building Area (m2)	Building Area (ft2)	Energy Use Intenstity kWh/m2	# of Floors	# of units	Building Footprint	Notes
3999	61 Pelham Park Gardens		1968	19,448	209,338	340	17	352	Irregular	
4015	245 Dunn Avenue		1971	26,319	283,298	286	20	384	Rectangle	
4018	5 Bellevue Cres		1971	24,941	268,460	340	21	326	Rectangle	
4053	100 High Park Ave		1969	29,162	313,896	302	24	439	Irregular	missing overhang on top balcony (5% of balconies)
4077	10 Gordonridge Place		1972	16,658	179,303	329	16	217	Rectangle	missing overhang on top balcony (6% of balconies)
4078	30 Gordonridge Place		1972	17,699	190,509	334	17	231	Rectangle	missing overhang on top balcony (6% of balconies)
4079	40 Gordonridge Place		1972	32,420	348,968	286	18	421	Irregular	missing overhang on top balcony (6% of balconies)
4086	4301 Kingston Rd		1972	36,002	387,520	287	20	419	Irregular	
4115	4100 Lawrence Ave. E.		1972	17,853	192,170	294	11	185	Y-shaped	

Building Id	Address	Picture	Year Built	Building Area (m2)	Building Area (ft2)	Energy Use Intenstity kWh/m2	# of Floors	# of units	Building Footprint	Notes
4116	4110 Lawrence Ave East		1972	17,853	192,170	307	11	185	Y-shaped	
4117	2190 Ellesmere Rd		1969	14,883	160,200	438	16	180	Rectangle	
4118	2180 Ellesmere Rd		1969	19,742	212,496	441	19	224	Rectangle	
4140	110 Mornelle Crt		1971	8,829	95,032	556	15	145	Rectangle	1/15 balconies do not have overhang
4147	7 Glamorgan Avenue		1971	18,712	201,409	299	12	196	Rectangle	
4310	220 Oak St		1972	25,047	269,600	379	27	469	L-shaped	
4358	2 Brahms Avenue		1971	14,964	161,076	357	12	164	Rectangle	
4359	5 Brahms Avenue		1971	14,964	161,076	372	12	178	Rectangle	
4741	49 Mabelle Avenue		1979	14,746	158,726	323	13	128	L-Shaped	
4790	200 Sherbourne St		1978	10,262	110,460	331	7	174	U-shaped	

Building Id	Address	Picture	Year Built	Building Area (m2)	Building Area (ft2)	Energy Use Intenstity kWh/m2	# of Floors	# of units	Building Footprint	Notes
5440	2468A Eglinton		1989	20,656	222,341	290	21	210	L-Shaped	
5529	4178 Lawrence East		1974	17,673	190,232	279	13	375	Irregular	balconies technically projecting but all adjacent, giving the look of inset
5549	41 Mabelle Avenue		1979	22,603	243,299	295	19	350	Rectangle	Balconies staggered on SE side
5551	71 Merton		1980	12,242	131,773	264	10	167	Irregular	
5634	40 Firvalley Crt		1964	9,240	99,459	264	15	168	Circle	
5643	30 Denared St		1983	20,239	217,853	271	15	255	Rectangle	
5674	2765 Islington		1984	24,010	258,441	255	14	237	Rectangle	
5759	575 Adelaide St W		1983	11,405	122,763	141	11	150	Rectangle	
5964	176 The Esplanade		1982	16,193	174,300	242	8	219	L-shaped	35% of balconies are shaded by other balconies

Building Id	Address	Notes	Orientation of balconies	Percentage of balconies inset	Percentage of balconies projecting	Prevalence of overhang	Façade to Balcony Ratio
3145	30 Teesdale Place		10% NNE, 40% ESE, 10% SSW, 40% WNW	80%	20%	100%	28%
3146	40 Teesdale Place		40% NNE, 10% ESE, 40% SSW, 10% WNW	80%	20%	100%	28%
3200	675 Kennedy Rd	No balconies on SSE side	33.3% ENE, 33.3% WSW, 33.3% NNW	100%	0%	100%	19%
3242	3847 Lawrence Avenue E	Shear wall present 100% on only 6 of 18 balconies	22.2% ENE, 22.2% SSE, 22.2% WSW, 3.33 % NNW	0%	100%	100%	45%
3243	275 Shuter St		7% NE, 21.5% ENE, 21.5% SE, 7% SSE, 21.5% WSW, 21.5% NNW	50%	50%	100%	16%
3244	285 Shuter Street		21.5% NNE, 7% NE, 21.5% ESE, 21.5% SSW, 7% WNW, 21.5% NW	50%	50%	100%	16%
3245	295 Shuter St		21.5% ENE, 7% SE, 21.5% SSE, 28.5% WSW, 21.5% NNW	50%	50%	100%	16%
3477	31 Gilder Drive		50% ENE, 50% WSW	0%	100%	100%	48%
3496	2821 Birchmount Rd		50% ENE, 50% WSW	75%	25%	100%	30%

Building Id	Address	Notes	Orientation of balconies	Percentage of balconies inset	Percentage of balconies projecting	Prevalence of overhang	Façade to Balcony Ratio
3497	155 Sherbourne St		40% ENE, 10% SSE, 40% WSW, 10% NNE	5%	95%	100%	78%
3527	6 Glamorgan Avenue		50% ENE, 50% WSW	100%	0%	100%	25%
3624	15 Tobermory Drive		50% NE, 50% SW	50%	50%	100%	20%
3637	2743 Victoria Pk Ave	Top balconies no overhang (7%)	60% ENE, 40% WSW	0%	100%	93%	14%
3638	2739 Victoria Pk Ave	Top balconies no overhang (7%)	60% SSE, 40% NNW	0%	100%	93%	13%
3641	30 Falstaff Ave	8% of balconies depth adjacent to building	50% ENE, 50% WSW	8%	92%	100%	25%
3642	20 Falstaff Ave	8% of balconies depth adjacent to building	50% ENE, 50% WSW	8%	92%	100%	25%
3643	40 Falstaff Ave	8% of balconies depth adjacent to building	50% ENE, 50% WSW	8%	92%	100%	25%
3798	2999 Jane Street	one side of 2 out of 14 balcony depths occupied by building	43% ENE, 57% WSW	7%	93%	100%	47%

Building Id	Address	Notes	Orientation of balconies	Percentage of balconies inset	Percentage of balconies projecting	Prevalence of overhang	Façade to Balcony Ratio
3815	5 Needle Firway	4 out of 16 balconies have 25% shear wall	50% ENE, 50% WSW	94%	6%	100%	27%
3898	5005 Dundas Street W.		50% SE, 50% NW	0%	100%	100%	35%
3899	57 Mabelle Avenue		50% NE, 50% SW	0%	100%	100%	35%
3900	710 Tretheway Dr		32% E, 9% S, 41% W, 18% N	60%	40%	100%	38%
3901	720 Trethewey Dr		47%ENE, 53% WSW	0%	100%	100%	57%
3903	325 Bleecker St		50% ENE, 50% WSW	0%	100%	100%	53%
3976	44 Willowridge Rd		18% NE, 18% E, 14% SE, 18% SW, 18% W, 14% NW	40%	60%	100%	36%
3983	190 Woolner Ave		14% NNE, 18% ESE, 18% SSE, 14% SSW, 18% WNW, 18%NW	50%	50%	100%	48%
3991	121 Humber Blvd		50% SSE, 50% NNW	15%	85%	100%	54%

Building Id	Address	Notes	Orientation of balconies	Percentage of balconies inset	Percentage of balconies projecting	Prevalence of overhang	Façade to Balcony Ratio
3999	61 Pelham Park Gardens		50% SSE, 50% NNW	50%	50%	100%	28%
4015	245 Dunn Avenue		50% ENE, 50% WSW	50%	50%	100%	20%
4018	5 Bellevue Cres		50% ESE, 50% WNW	50%	50%	100%	55%
4053	100 High Park Ave	missing overhang on top balcony (5% of balconies)	50% ENE, 50% WSW	10%	90%	95%	28%
4077	10 Gordonridge Place	missing overhang on top balcony (6% of balconies)	50% NE, 50% SW	0%	100%	94%	51%
4078	30 Gordonridge Place	missing overhang on top balcony (6% of balconies)	50% NE, 50% SW	0%	100%	94%	51%
4079	40 Gordonridge Place	missing overhang on top balcony (6% of balconies)	45% NE, 5% SE, 45% SW, 5% NW	0%	100%	94%	49%
4086	4301 Kingston Rd		50% SSE, 50% NNW	0%	100%	100%	34%
4115	4100 Lawrence Ave. E.		11.1%N, 11.1% NE, 11.1% ESE, 11.1% SE, 11.1% SSE, 11.1% SW, 11.1% W, 11.1% WNW, 11.1% NNW	100%	0%	100%	48%

Building Id	Address	Notes	Orientation of balconies	Percentage of balconies inset	Percentage of balconies projecting	Prevalence of overhang	Façade to Balcony Ratio
4116	4110 Lawrence Ave East		11.1% NE, 11.1% ENE, 11.1% ESE, 11.1% SSE, 11.1% SSW, 11.1% SW, 11.1% WNW, 11.1%NW, 11.1% NNW	100%	0%	100%	48%
4117	2190 Ellesmere Rd		40% ENE, 60% WSW	0%	100%	100%	33%
4118	2180 Ellesmere Rd		60% SSE, 40% NNW	0%	100%	100%	35%
4140	110 Mornelle Crt	1/15 balconies do not have overhang	53% SSE, 47% NNW	0%	100%	93%	42%
4147	7 Glamorgan Avenue		45% ENE, 55% WSW	0%	100%	100%	60%
4310	220 Oak St		19% NE, 25% SE, 25%SW, 31% NW	100%	0%	100%	53%
4358	2 Brahms Avenue		56% ENE, 44% WSW	82%	18%	100%	25%
4359	5 Brahms Avenue		56% ENE, 44% WSW	82%	18%	100%	25%
4741	49 Mabelle Avenue		50% NE, 50% SW	100%	0%	100%	27%
4790	200 Sherbourne St		36.5% ENE, 18% ESE, 36.5% WSW, 9% NNW	33%	67%	75%	31%

Address	Notes	Orientation of balconies	Percentage of balconies inset	Percentage of balconies projecting	Prevalence of overhang	Façade to Balcony Ratio
2468A Eglinton		25% ENE, 37% SSE, 7% WSW, 31% NNW	50%	50%	96%	27%
4178 Lawrence East	balconies technically projecting but all adjacent, giving the look of inset	50% SE, 50% NW	0%	100%	100%	71%
41 Mabelle Avenue	Balconies staggered on SE side	20% NE, 30% SE, 20% SW, 30% NW	75%	25%	75%	55%
71 Merton		50% SSE, 50% NNW	75%	25%	100%	45%
40 Firvalley Crt		16.6% NE, 16.6% ESE, 16.6% S, 16.6%SW, 16.6% W,16.6% NNW,	100%	0%	100%	35%
30 Denared St		100% SW	100%	0%	100%	12%
2765 Islington		45% ENE, 5% SSE, 45%WSW, 5%NNW	50%	50%	100%	40%
575 Adelaide St W		10% ENE, 40% SSE, 10% WSW, 40% NNW	60%	40%	100%	39%
176 The Esplanade	35% of balconies are shaded by other balconies	45% SSE, 50%WSW, 5% NNW	0%	100%	35%	36%

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