

ONE COLUMBIA STUDENT RESIDENCE

ZBA Energy Study Report

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Prepared for Studio Limina Inc.

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ECOVERT

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1. Project Description

Ecovert is undertaking an Energy Study in support of One Columbia Student Residence Zoning By-Law Amendment application located at 355 King St N, Waterloo, ON. The proposed residential development is comprised of a 7-storey (3,873 m^2) high-rise multi-unit residential building, with a retail space (98 m^2) located at the ground level. The total gross floor area of the new development is 3,971 m^2 excluding mechanical penthouse areas and underground parking. The building



Figure 1 *– One Columbia Student Residence Development Context Plan (Courtesy of Studio Limina Inc.)*

2. Energy and Emissions Analysis

2.1 Methodology

The One Columbia Student Residence project consists of two predominant building types including high-rise residential, and commercial retail. Performance targets of this mixed-use building type are derived using an area weighted average of performance targets from the two predominant building types. Ecovert uses archetypes to show a set of building characteristics which fulfills the project requirement to meet the different scenarios.

Scenario 1 is the minimum performance to meet the Ontario Building Code for all new developments. Ecovert shows feasible paths on how to achieve Scenario 2 (High Performance) and Scenario 3 (Net-Zero Ready Performance), to contribute to the Region of Waterloo's objectives to be resilient and near zero emissions by 2050.

Ecovert categorizes the energy conservation measures proposed to meet the requirements of each Scenario based on the type of measure (passive or active) per archetype. Developers and designers are encouraged to incorporate these energy conservation measures in their design. As the project evolves based on the actual design a more representative energy model should be developed for the site plan approval and building permit. CO2 emission factors are assumed to be 0.05 kgCo2e/kWh of electricity and 1.899 kgCo2e/m^3 of natural as per Table 1.1.2.2. of MMA supplementary Standard SB-10 [1]. Energy cost analysis are based on the assumed virtual rates of $0.16/kWh of electricity and $0.045/kWh of natural gas.

The Energy Strategy will identify how the development can achieve net zero energy and zero carbon emissions. Net zero energy refers to a building that produces as much energy as it consumes on an annual basis. Zero carbon builds on net zero with the additional requirement of producing the amount of energy equivalent to the amount of carbon that is consumed. In order to achieve this, the carbon emissions of the building must first be minimized, then offset with renewable energy sources such as solar PV. Given the significantly lower carbon density of electrical energy compared to natural gas, a fully electric building is typically required to achieve a zero-carbon design. In order to achieve a zero-carbon design under cost and environmental constraints (local electric carbon density, site area, solar access, etc.), the load on the building is first minimized, followed by providing passive solutions to meet the building energy demand, then addressing the remaining demand with active solutions. Any outstanding energy consumption is then matched by renewable energy. The amount of energy required to be produced varies by location due to the variation in electrical carbon density by location. If sufficient energy cannot be produced by the building, energy can be produced off site or purchased from a renewable energy provider [2].

4.1.1 BUILDING CODE BASELINE

Ecovert uses the high rise MURB, and commercial retail archetypes incorporating commonly adopted mechanical and building envelope systems to fulfill the minimum requirements of the Ontario Buidling Code SB-10 Standard. Detailed building charactristics are shown in Appendix A.

Passive Design:

- Double pane glazing unit, hybrid U-PVC, argon filled and thermally broken spacer with multiple low e coatings. Overall performance of USI-2.17;
- Exterior wall performance effective R-10 in residential; effective R-20 in retail;
- Infiltration to target NECB 2017 0.25L/s.m2 of façade @ 75 Pascal.

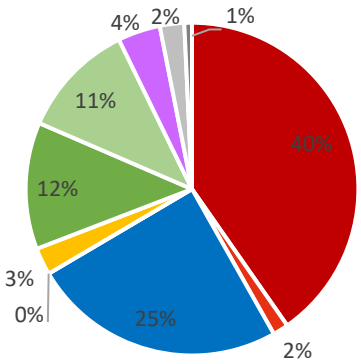
Active Design:

The following active design solutions are incorporated over the baseline:

- HVAC system in commercial areas to be a dedicated outdoor system with an ERV of 50% effectiveness, fan-coil units coupled with Electronically Commutated EC motors fans and;
- Energy recovery ventilators with 65% efficiency in residential units;
- Time of Day corridor pressurization during periods of food preparation and reduce pressurization in residential corridors at other hours; (average 30 cfm/doors)
- Low-flow plumbing fixtures – reduces 10% potable water consumption and energy requirements for domestic hot water heating.

Figure below shows the performance of the Building Code Baseline model.

Building Code Baseline	
EUI (kWh/m²/year)	
Heating (Gas)	80
Heating (Elec)	3
Cooling	49
Heat Rejection	0
Lights	5
DHW (Gas)	24
DHW (Elec)	22
Receptacle	8
Fans	5
Pumps	1
EUI (kWh/m²/year)	198
TEDI (kWh/m²/year)	42
GHGi (kgCO2/m²/year)	23



4.1.2 HIGH PERFORMANCE

Passive Design:

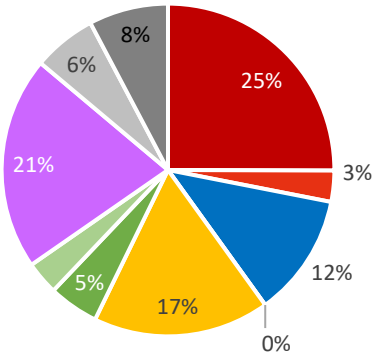
- Windows Improved to triple pane windows with hybrid U-PVC, argon filled and non-metal spacer with multiple low e coatings. Overall performance of USI-0.90;
- Exterior wall performance improved to effective R-20 in residential and office spaces; effective R-30 in retail;
- Roof performance improved to effective R-30;
- Infiltration reduced to the US Army Corps Engineers Standard 0.22L/s.m2 of façade @5 Pascal.

Active Design:

The following active design solutions are incorporated over the baseline:

- HVAC system in commercial areas improved to a dedicated outdoor system with an ERV of 80% effectiveness, fan-coil units coupled with Electronically Commutated EC motors fans, Potential demand controlled ventillation for selective spaces and;
- High efficiency energy recovery ventilators with 80% efficiency in residential units, as well as 80% efficiency in ammenities;
- Time of Day corridor pressurization during periods of food preparation and reduce pressurization in residential corridors at other hours; (average 20 cfm/doors)
- Energy star equipment in residential units (10% receptacle energy reduction);
- Low-flow plumbing fixtures – reduces 10% potable water consumption and energy requirements for domestic hot water heating.

Tier 2	
EUI (kWh/m²/year)	
Heating (Gas)	25
Heating (Elec)	3
Cooling	12
Heat Rejection	0
Lights	17
DHW (Gas)	5
DHW (Elec)	3
Receptacle	21
Fans	6
Pumps	8
EUI (kWh/m²/year)	99
TEDI (kWh/m²/year)	29
GHGi (kgCO2/m²/year)	9



Meets the High-Performance Scenario Requirements

Reduction against SB-10 model
50%
32%
62%

2.1.3 NEAR ZERO EMISSIONS

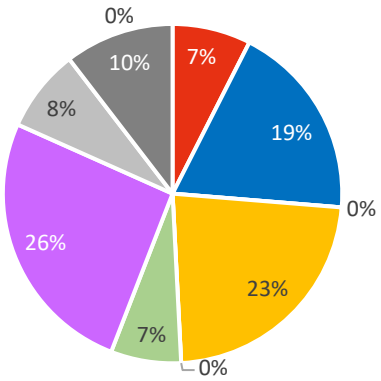
Passive Design:

- Windows Improved to punched windows with hybrid U-PVC, triple pane, argon filled and non-metal spacer with multiple low e coatings. Overall performance of USI-0.8;
- Exterior wall performance improved to effective R-20 in residential and office spaces; effective R-30 in retail;
- Roof performance improved to effective R-35;
- Infitration reduced to the Passivehouse level of performance - 0.6 ACH @ 50 Pascal

Active Design:

- High efficiency Air Source Variable Refrigerant Flow (VRF) with electric radiant heating backup leveraging fuel source switching from natural gas to electricity and high part-load COP operation;
- Best in class in-suite energy recovery ventilators with 85% efficiency in residential units and best in class semi-centralized ERV with 90% efficiency in commercial areas;
- Improved ventilation effectiveness using dedicated outdoor air systems ducted directly to all non-residential areas and coupled with CO2 sensors for demand control ventilation;
- High-efficacy lighting fixture such as LED with advanced controls in non-residential areas (25% lighting reduction in the remaining non-residential areas);
- Energy star equipment in residential units (25% reduction);
- Centralized drain water heat recovery (60% efficiency) to recover heat from showers in residential area coupled with air source heat-pump for service water heating.
- 18kW Solar rooftop PV array generating approximately 22,800 kWh annually to offset building emissions, or annual purchase of Renewable Energy Credits for an equal amount.

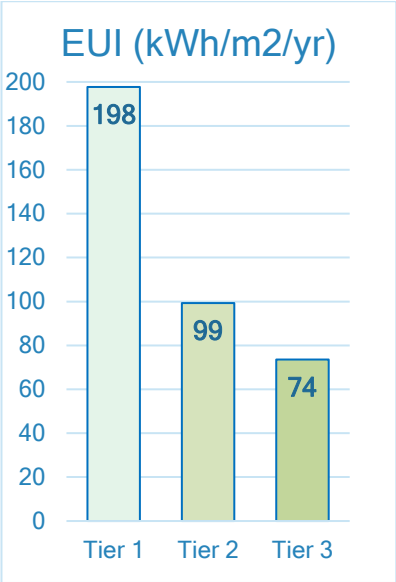
Tier 3	
EUI (kWh/m²/year)	
Heating (Gas)	0
Heating (Elec)	6
Cooling	14
Heat Rejection	0
Lights	17
DHW (Gas)	0
DHW (Elec)	5
Receptacle	19
Fans	6
Pumps	8
EUI (kWh/m²/year)	74
TEDI (kWh/m²/year)	9
GHGi (kgCO2/m²/year)	2.3

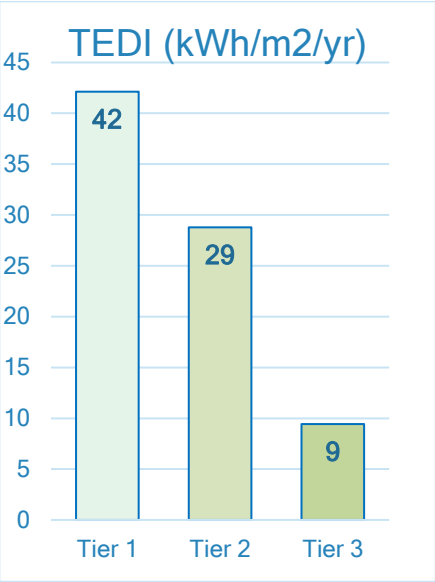


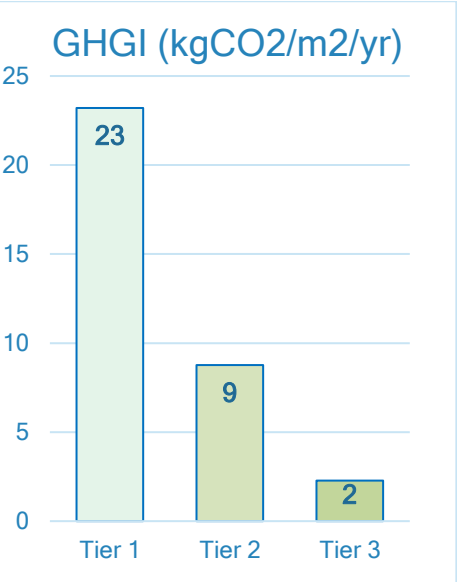
Meets the Near Zero Emissions Scenario Requirements

Reduction against SB-10 model
63%
78%
90%

2.1.4 DEVELOPMENT RESULTS SUMMARY







	Baseline	High Performance	Near Zero Emissions
Proposed Development Overall Analysis			
Total Electricity (MWh/year)	372	276	181
Total Gas (MWh/year)	413	118	0
Total Energy (MWh/year)	785	394	292
Total Energy Cost ($/year)	78,093	49,507	28,947
Winter peak Electricity (kW)	55	62	85
Summer peak Electricity (kW)	69	84	81
Proposed Development Intensities			
EUI (kWh/m^2/year)	198	99	74
TEDI (kWh/m^2/year)	42	29	9
GHGi (kgCO2/m^2/year)	23	9	2
		Meets the High-Performance Scenario Requirements	Meets the Near Zero Emissions Scenario Requirements

3. Envelope Analysis

3.1 Opportunities to minimize TEUI and TEDI

3.1.1 Massing and form options

While the massing and form of the project are greatly constrained by property line limitations, in many cases there are opportunities to consider alternative massing options. The following table summarizes the results of a case study for a mock building in which the residential tower massing has been optimized:

	Residential Tower- Regular Design	Residential Tower- Reduced External Surface Area to Volume ratio
GFA (m^2)	31,375	31,805
Ext Wall Area (m^2)	15,361	14,308
Ext Opening Area (m^2)	6,144	5,723
Total Volume (m^3)	92,558	93,825
S/V ratio	0.17	0.15
WWR	0.40	0.40
Infiltration (l/s)	3,840	3,577
TEUI	128	125
TEDI	40	38

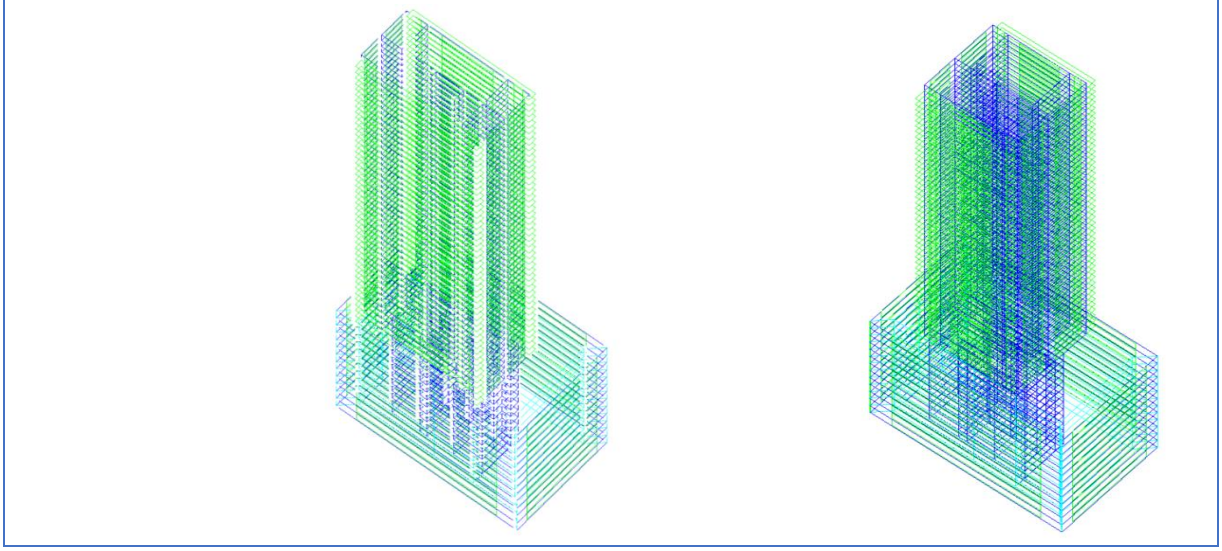


Table 2. *Optimized Residential Tower Results*

The results indicate that there is an opportunity to reduce exterior thermal conduction as well as infiltration by lowering the Exterior wall Surface to Volume ratio of the building and therefore decrease TEDI and TEUI. It should be noted that these strategies can have tradeoffs. In this case the resulting form would lead to a deeper floorplan, and therefore reduce daylight penetration.

3.1.2 Enclosure design and construction

Infiltration can contribute to approximately 20% of the building's Thermal Energy Demand. Therefore, it is crucial for the design team to implement strategies that effectively reduce building infiltration and conduct thorough testing to ensure that the desired target for the building envelope is achieved. Reduced infiltration can be achieved by implementing strategies such as reducing building penetrations, selecting an adequate air barrier, and enlisting a skilled construction team to ensure effective implementation.

Fenestration plays a key role in building design, offering occupants views, and welcoming natural light. However, it can also contribute significantly to heat losses within a building. It is essential to strike a balance and explore methods to minimize its adverse effects. The following are strategies meant to achieve said balance.

Window-to-Wall Ratio - Maintain a window-to-wall ratio that meets the occupants' needs while considering the energy requirements of the building. For this study, a ratio between 35% to 40% should be targeted, as this balance allows for adequate natural light and views without compromising energy efficiency.

Solar Heat Gain Coefficient (SHGC)- In the past, it was recommended to use high SHGC glazing due to colder weather. However, with increasing temperatures, it's important to future proof the building design. It is advised to use high SHGC glazing, between 0.4 and 0.5, on the north façade where it is less exposed to direct sunlight. Using glazing with lower SHGC values on the remaining orientations, between 0.25 and 0.35, can help reduce the building's cooling load and provide an appropriate amount of heat during winter.

Number of panes and framing system – The number of panes and framing system are key factors that significantly impact window thermal performance. To enhance efficiency, it is recommended to prioritize thermally broken framing systems and triple-pane windows. Additionally, when financially feasible, opting for unitized systems or punch windows can offer improved performance.

Thermal bridging has a significant impact on the thermal efficiency of a building's envelope. Thermal bridges refer to specific areas within walls, roofs, and other insulated components of the building envelope where there is localized high heat transfer. They occur due to the presence of highly conductive elements that penetrate the thermal insulation or when the layers of insulation are not properly aligned. These pathways enable heat to bypass the insulating layer, leading to a decrease in the insulation's effectiveness.

The Building Thermal Bridging Guide [3] provides information regarding the correct procedure to perform thermal bridging calculation. Additionally, the guide developed the website thermalenvelope.ca, where a database of assemblies and their thermal performance is published. The following are strategies to reduce the thermal bridges at specific envelope components. Appendix B presents a series of envelope details that will allow the design team to achieve the energy and emissions targets.

Balconies and terraces – Balconies and terraces contribute significantly to the heat flow through thermal bridges. To minimize this, it is recommended to avoid inset balconies as they increase the perimeter of the balcony in contact with the opaque wall. Additionally, reducing the quantity and length of balconies in the building and incorporating thermally broken balcony designs may be necessary to meet the energy performance targets.

Glazing and opaque wall linear transmittance– The interface between the opaque wall and glazing pertains to the window perimeter that contacts the wall. To minimize this interface, it is recommended to opt for a smaller number of larger windows instead of numerous smaller ones.

Slab bypass linear transmittance – The linear transmittance of slab bypass becomes more significant in facade designs that feature a considerable spandrel area. In such cases, it is recommended to prioritize curtain wall systems over window wall systems. This is because curtain walls incorporate insulation in front of the slab, effectively reducing thermal bridging.

The design team is encouraged to conduct an assessment with the assistance of an envelope consultant or energy modeling specialist to determine the optimal characteristics and find the right balance for their façade design. Ecovert has developed TEST (Thermal Envelope Solver Tool) which allows the design team to quickly analyze design alternatives and construction alternatives. When TEST is coupled with a box model, the selection of thermal details, Window-to-wall ratio, and length of balconies, among others, can be done efficiently.

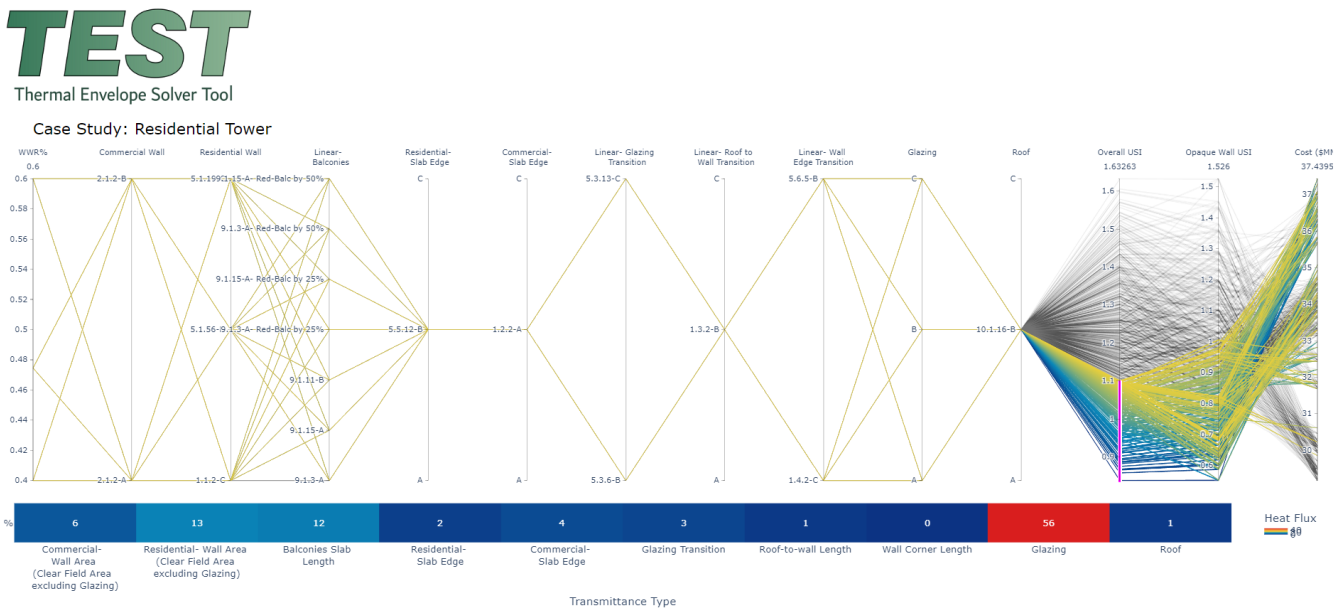


***Figure 2** – Thermal Envelope Solver Tool visualization of tested thermal detail combination.*

4. Renewables & Low-Carbon Solutions

6.1 Solar Energy

Solar photovoltaic (PV) panels generate electricity by capturing energy from solar radiation. They are becoming increasingly economically viable for generating energy on-site due to reduced costs over the last several years, and as such are an important design consideration for low carbon and net zero buildings. Many developments, including residential, institutional and commercial, utilize solar PV in their designs to take advantage of the long-term economic benefits they provide.

To optimize the feasibility of solar energy on site, a suitable location for a solar array must be available. Such a location needs to have a clear, shade free view due east to west through south in order to take advantage of the highest amount of available direct sunlight throughout the year. Therefore, it is important for a development to have a sizeable flat roof area or south-facing sloped roof in order to take full advantage of the solar energy resource.

The non-amenity rooftop area at the tower of One Columbia Student Residence project was evaluated and considering an inclination angle of 20° facing due south and 60% available roof area with an output of 0.15 kW/m2 it is estimated that the development can harness over 22,800 kWh of electricity annually. The results are summarized in Table 3. Figure 4 shows the location of the proposed PV Panels.

Roof Area	m^2	201
January	*kWh*	1,065
February	*kWh*	1,365
March	*kWh*	2,103
April	*kWh*	2,286
May	*kWh*	2,576
June	*kWh*	2,718
July	*kWh*	2,723
August	*kWh*	2,566
September	*kWh*	2,106
October	*kWh*	1,500
November	*kWh*	962
December	*kWh*	858
TOTAL	*kWh*	**22,828**

Table 3 - Monthly and Annual Solar PV Energy Output (kWh) per building

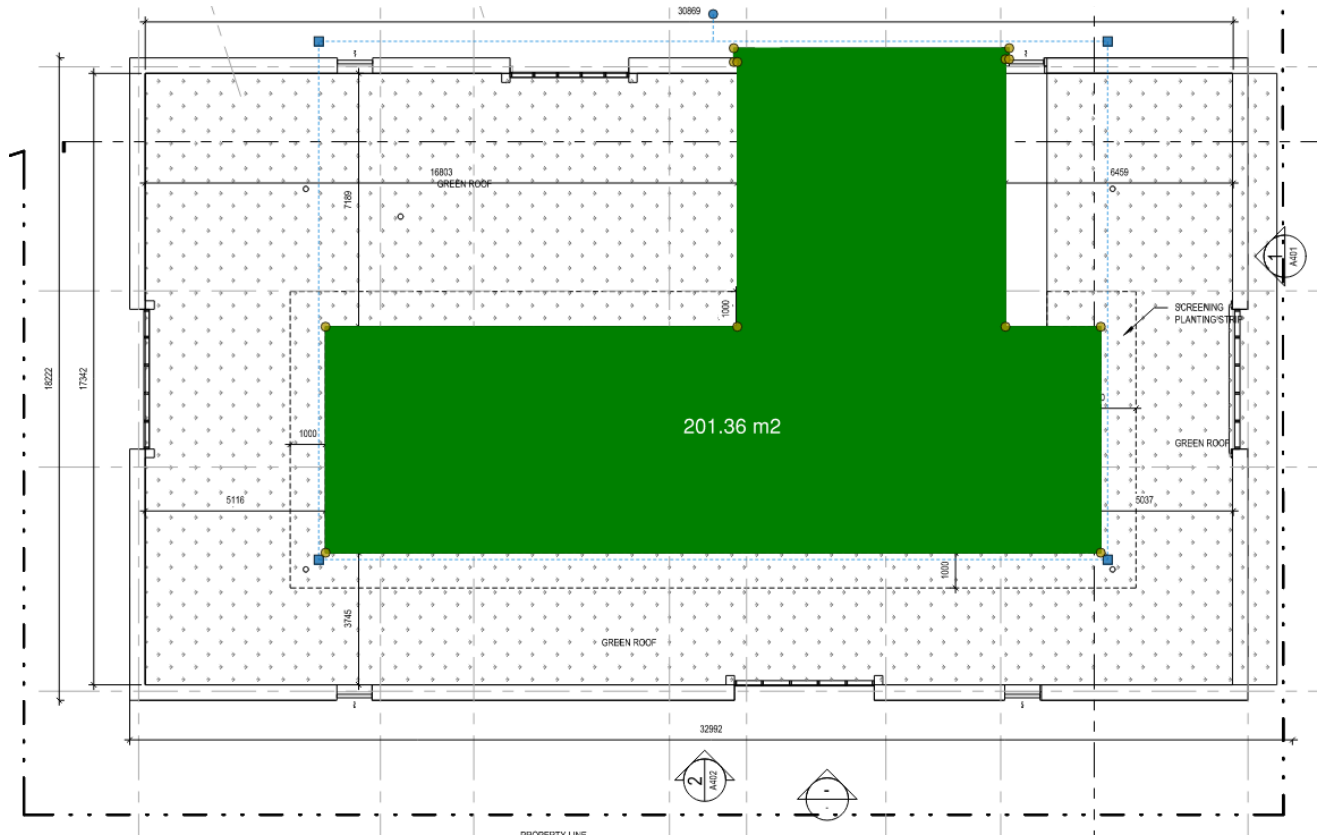


Figure 4 *- Recommended location for solar PV Panels on mechanical penthouse*

6.1 DISTRICT ENERGY SYSTEMS

Low carbon thermal energy networks/district energy systems are identified as an important strategy in reducing emissions. These networks may include options such as deep lake water cooling, biofuels, solar heating, data centre waste heat, or waste heat recovery. If connecting to an existing network is not currently a design option, opportunities for designing the building to be district energy ready should be explored. In preparation for a future district energy connection, Ecovert suggests the following key items be incorporated into building design:

- Ability to supply thermal energy from the ground level
- Adequate space at or below ground level for a future energy transfer station
- An easement between the mechanical room and the property line to allow for thermal piping
- Two-way pipes placed in the building to carry thermal energy from the district energy network to the section in the building where the future energy transfer station will be located
- A low temperature hydronic heating system that is compatible with a district energy system in order to reduce the pipe sized and associated valves, fitting, etc.
- Appropriate thermal energy metering

Although the proposed development is not currently connected to a district thermal energy network, it is highly recommended that it considers a connection to future available district energy systems. In doing so, this will add resiliency to the development and have the potential to reduce its future carbon footprint.

6.3 OTHER LOW AND ZERO CARBON TECHNOLOGIES:

Ground Source Heat Pumps - A piping network uses the mass of the earth to improve the performance of a vapor compression refrigeration cycle which can heat in winter and cool in summer. It's important to note that the efficiency of GSHPs is heavily influenced by the heating and cooling loads of the building. If these loads are unbalanced, the overall efficiency of the system will be significantly reduced.

Solar Thermal - Rooftop mounted solar energy collectors capture the sun's thermal energy. These are usually used to offset the heating of domestic hot water loads in buildings.

Solar Wall – This passive solution reduces thermal energy demand though preheating outdoor air. A solar collector is heated by solar radiation and outdoor air is drawn through or across the collectors in the heating season. Increased fan power is required to overcome the resistance of the collector, however, a significant reduction in heating load can be achieved.

Cogeneration / Trigeneration - A gas fired engine is used to locally generate electricity, allowing waste heat to be used to offset space and water heating. Biomass fueled CHP is a renewable source alternative to natural gas. In addition, an absorption chiller can be added to provide cooling (tri-generation). A properly designed CHP plant can be twice as efficient as a typical fossil fuel power plant, converting up to 80% of the energy from input fuel into electricity and useful heat.

TABS (Thermally Active Building Systems) – TABS leverages the diurnal exterior environmental conditions and thermal inertia inherent to the building to preheat/precool building thermal mass in order to reduce conditioning load. Cool nighttime air can be used to precool building thermal mass in the summer to reduce the cooling load during the day, and daytime solar radiation can be collected through glazing to preheat building thermal mass in the winter to reduce the heating load at night.

Wind - Wind turbines are a large-scale renewable energy technology – generally requiring open, unobstructed topography to best capture the wind's energy resources. Wind turbines can be situated in an urban setting to generate renewable electricity locally, but this is usually less cost effective as efficiencies are reduced. The proposed development is in a predominantly commercial neighborhood which wouldn't be appropriate for a large wind turbine. Smaller rooftop wind turbines are not a cost-effective option due to their lower efficiency.

Off-site Renewable Energy Procurement – Aside from on-site renewable technologies, any development may procure off-site renewable energy generation credits to offset their carbon footprint. It is advisable to choose projects located within Ontario and hold certifications such as Green-e Energy.

Drain-water or trunk sewer heat recovery – This heat exchanger preheats the supply water using the energy contained on the drain water from appliances such as showers, bathtubs, sinks, dishwashers, and clothes washers. SHARC Energy offers two systems, namely Piranha and Sharc, which employ specialized water-to-water heat pumps to extract energy directly from wastewater and generate hot water. Additionally, their HC Series model offers enhanced cooling capabilities. Both systems include a wastewater holding tank designed to accommodate the hot water usage profile of the building.

5. Low Embodied Carbon

CaGBC defines embodied carbon as the emissions associated with material and construction processes through a building's life [2]. As shown in the image below, embodied carbon is quantified by stages. It is estimated that the upfront carbon accounts for 55% of the whole life carbon emissions. Therefore, it is of great importance to select low embodied carbon construction material at the design stage of the project.

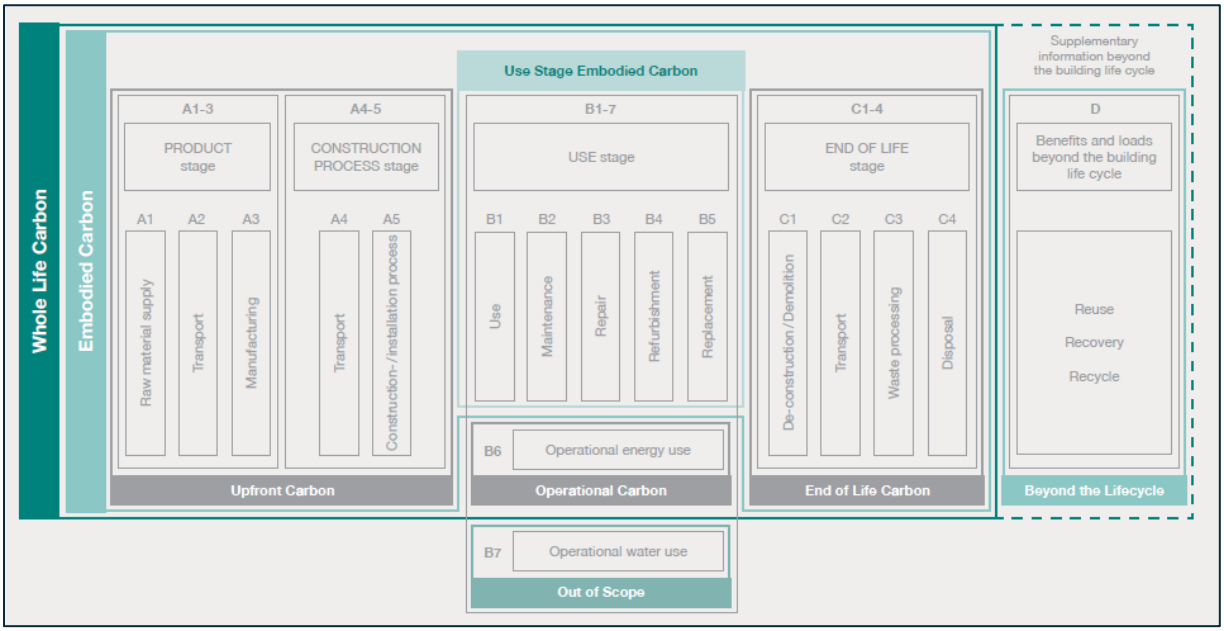
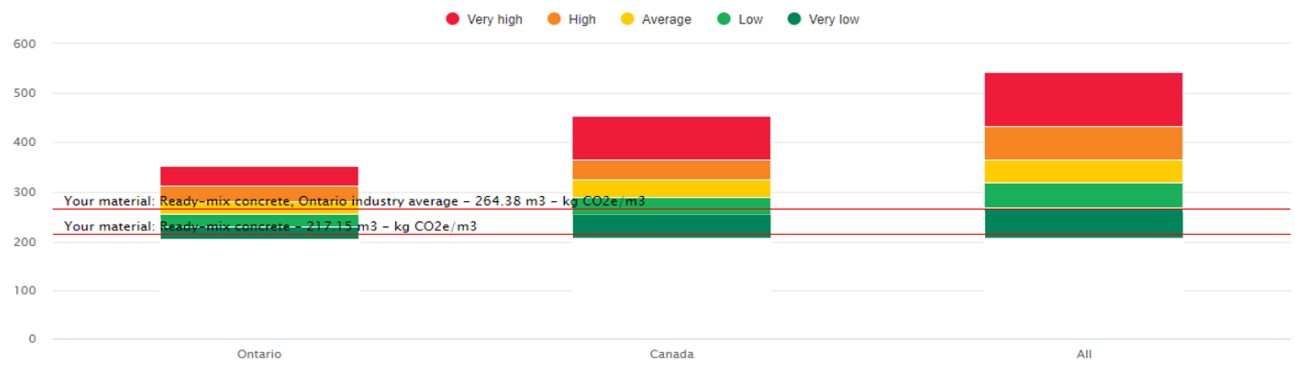


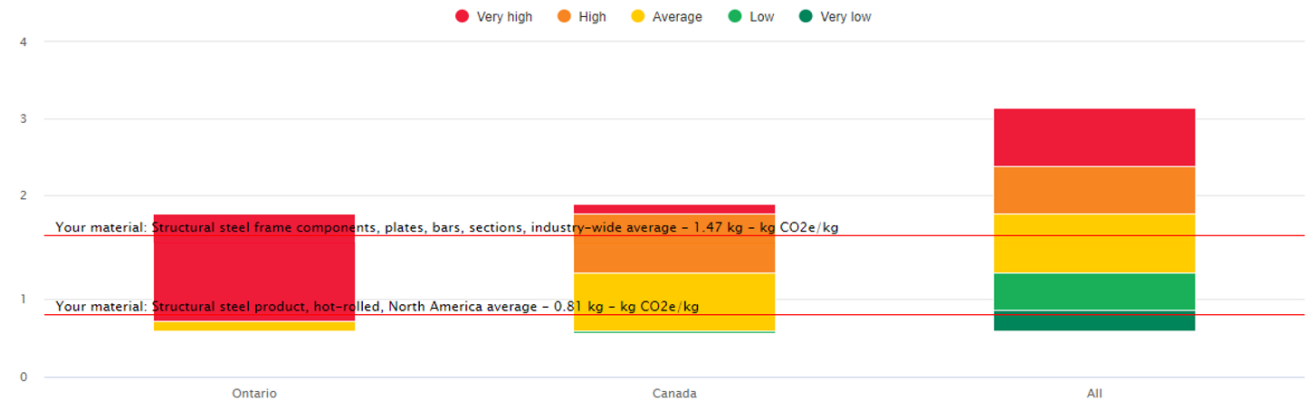
Figure 5 *- Embodied carbon lifecycle stages and modules*

The materials in these resource categories will be the focus of embodied carbon reduction opportunities as they will provide the largest impact. It is important to mention that a holistic analysis must be done, as some of this material with a lower embodied carbon may a reduced thermal performance

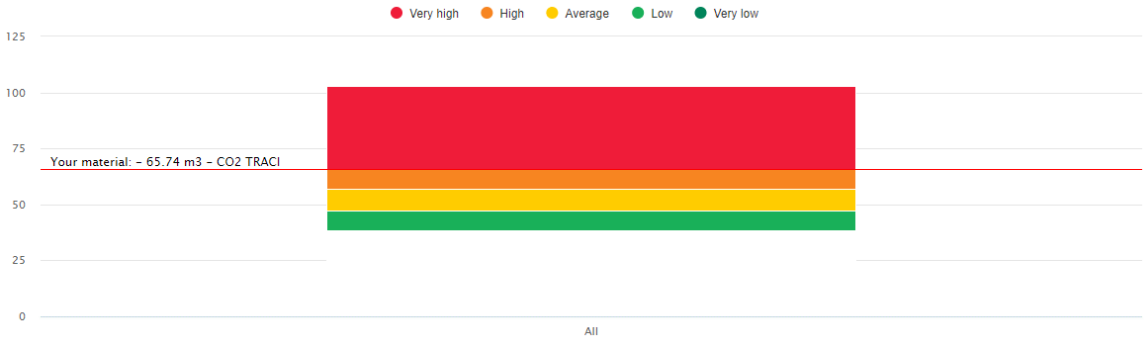
The graph below shows the industry average concrete with an emissions intensity of 264 kgCO2e/m3, and the Lafarge ECOPact concrete product that is implemented with a lower emissions intensity of 217 kgCO2e/m3. The Lafarge ECOPact concrete product uses recycled construction and demolition materials in the cement mixes to reduce emissions.



The below graph shows the industry average structural steel assumed for the baseline design and has an emissions intensity of 1.47 kgCO2e/kg. The bottom line represents the Gerdau North American standard structural steel product that is implemented with a lower emissions intensity of 0.81 kgCO2e/kg. Gerdau's steel mills operate with electric arc furnaces which optimize the manufacturing process and are able to use a lot of recycled steel to build new products.



The Polyisocyanurate (PIR) roof insulation board is a typical material used for foundation and roof insulation and it has an emissions intensity of 84.28kg CO2e/m3. A better alternative design with lower emission intensity is switching out the Polyisocyanurate insulation with expanded polystyrene (EPS) roof insulation boards that have an emissions intensity of 65.74 kg CO2e/m3 (as seen in the visual below). The expanded polystyrene roof system is better from an emissions perspective. Additionally, foundation insulation can be replaced from Extruded Polystyrene Insulation (XPS) to Graphite Polystyrene Insulation (GPS), reducing the emissions intensity from 3.48 kg CO2e/m3 to 1.76 kg CO2e/m3.



6. Energy Resilience

It is important to identify opportunities for backup power systems that will improve the resilience of buildings to area-wide power outages. This includes meeting all emergency power (life safety) requirements, as well as providing for 72 hours (at a minimum):

- Domestic water (hot and cold)
- Elevator service
- Space heating, lighting and receptacle power to the central common area/amenity space/lobby, where applicable

We recommend that the applicant review the City of Toronto's "Minimum Backup Power Guidelines for MURBs" (December 2021) for more detail and case studies [4], as it is applicable to this development.

The current design intent for the proposed development is to include back-up power via generators that will supply all emergency life safety requirements. Passive design measures such as a low window-wall ratio, high thermal mass elements within the building, and high R-values for the building insulation will assist in maintaining building temperature in the event of mechanical system failure and reducing the backup system sizing.

Diesel generators are more common than natural gas generators as they are significantly cheaper and smaller in size. Additionally, natural gas generators over 350kW have difficulty meeting the 15 second maximum time allowance for life safety equipment to come back on. This issue could be addressed with multiple or twin generators. The benefits of natural gas generators are lower NOX emissions, as well as a constantly available fuel supply that does not have to be manually delivered. The distribution and sizing of the backup systems will need to consider Ministry of Environment and Climate Change requirements for NOX emissions. Typically, the generators must be located at higher levels, such as a penthouse, to satisfy the emissions requirements.

Critical equipment, such as backup generators, and heating and cooling equipment should be located on above grade floors to ensure that it remains accessible in the event of flooding. In addition, as the city experiences higher temperatures, and more frequent heat events, implementing better insulation for the mechanical penthouse and integrating passive design elements like shading devices and green roofs can effectively address increasing temperatures. These measures minimize damage risks from extreme weather events.

7. Discussion and Recommendations

7.1 Capital cost premium

To achieve the performance targets, the project should implement a range of envelop and HVAC upgrades. The subsections below illustrate the estimated capital cost premiums associated with these upgrades. It is important to note that these prices are only meant for reference purposes and conducting a feasibility study prior to implementation is highly recommended to obtain accurate cost estimates and ECMs impact.

7.1.1 Envelope upgrades

Sapphire balconies – a Glide-On balcony product which allows for a preassembled factory finished balcony to be attached to a building via thermally broken steel arms which protrude from the façade [5]. The thermally broken protruding steel arms have a very minimal thermal bridging effect on the building envelope compared to a traditional concrete balcony that allows heat to easily flow out of the building through the entire length of the balcony. The average price for this envelope upgrade is around $1,500 per meter square of balcony.

Schöck Isokorb balconies – The Schöck Isokorb is a type of thermal insulation system that is designed to be used in buildings where balconies or other external structural elements are attached to the building. The Isokorb is designed to reduce the thermal bridging in the structural elements connected to the building, which results in heat loss. The Isokorb system is composed of a thermal break material that is placed between the balcony slab and the building's concrete slab. This break is achieved by using a rigid foam insulation material, which is embedded in a reinforced concrete element. he average price for this envelope upgrade is around $400 per meter square of balcony.

Mitrex Building Integrated Photovoltaics (BIPV)- BIPV is a building cladding system which has an outward appearance of natural or engineered surface materials, with the ability to generate electricity. Mitrex technology can effectively take the place of vision glass, vision glass railings, spandrel panel glass, and metal panel walls [6]. Mitrex offers a variety of flexible financing options, including the Mitrex Power Agreement, which ranges from $50 to $55 per square foot of Mitrex BIPV, and the Direct Purchase Agreement, which costs between $75 and $80 per square foot of Mitrex BIPV.

7.1.2 HVAC upgrades

SolarWall – The SolarWall® [7] air heating system is a custom engineered solution designed to use solar energy as a passive heat source. Specially perforated collector panels are installed on the south and west exterior walls of the mechanical penthouse or alternatively on the roof as dictated by project constraints. This metal cladding (the SolarWall ® collector) is heated by solar radiation from the sun. The building's ventilation fans create negative pressure in the air cavity behind the collector, drawing in solar heated fresh air through the panel perforations (200 perforations/sqft). The average cost is around $30 per square foot of SolarWall.

PIRANHA wastewater heat recovery systems – The PIRANHA wastewater heat recovery system is a specialized water-to-water heat pump which recovers energy directly from the wastewater and uses it to produce hot water [8]. This system recovers heat energy from wastewater and provides additional cooling capabilities to significantly reduce energy consumption and greenhouse gas emissions, has a compact system size ,and is fully automated. The price per module is around $125,000. (include the size) unit rate by tons.

Electric air source boiler – AIR's electric air source boiler system is a specialized cold climate heating system that offers hot water at 130°F all the way down to -20°F ambient [9]. This technology is versatile as it can be used to replace traditional central natural gas boiler systems. It is optimized for cold weather and nonreversible, therefore it requires a different plant for cooling. The average price is $4,000 per ton of heating capacity.

7.2 Operational cost analysis

A financial analysis of operating cost was conducted for each proposed Scenario design suggested on section 5.1. The analysis was conducted over a 30-year life cycle and the financial assumptions used are described below.

Canada's Federal Carbon Tax is mandatory for buildings that consume natural gas with their annual operations. This Federal Carbon Tax charge is visible on all gas utility bills across Canada. The Federal Government has stated that the carbon price starts at $65 in 2023 and increases by $15 annually to a maximum cost of $245/ton$CO_2$ in 2035. Beyond this point, the Federal Carbon Tax has been assigned a 5% annual inflation rate as an assumption for the financial analysis.

The utility rates inflation and discount rate were set at 3%, and the general inflation rate at 2%. These values are as per CaGBC Zero Carbon Life Cycle Cost Calculator [10]. The virtual utility rates used are $0.16/kWh for electricity and $0.045/kWh for natural gas. CO2 emission factors are assumed to be 0.05 kgCo2e/kWh of electricity and 1.899 kgCo2e/m3 of natural as per Table 1.1.2.2. of MMA supplementary Standard SB-10 [5]. The first bar of the graph represents Scenario 1, the second Scenario 2, and the third Scenario 3.

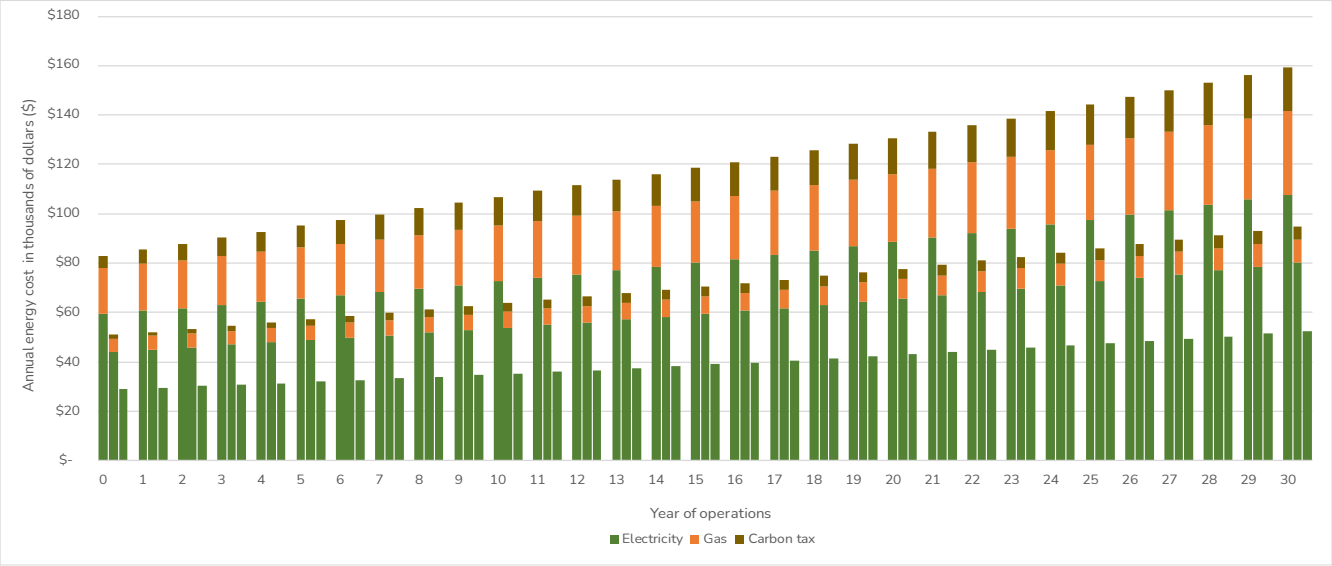


Figure 6 *– Annual energy cost per proposed design over 30 years*

7.3 Financial incentives

CMHC MLI Select –the MLI Select program offers insurance benefits through a point-based system that focuses on affordability, accessibility, and energy efficiency [11]. Projects that show significant improvements in energy efficiency and reductions in greenhouse gas emissions in comparison with NECB 2017, will receive points, making them eligible for more flexible financing choices and lower insurance premiums.

Enbridge Savings by Design – Savings by Design helps buildings to achieve improved performance through collaboration with industry experts and utilization of advanced technical tools [12]. The program applies to commercial, institutional or multi-residential projects, that are at their design phase, have a GFA of 25,000 ft^2 or greater, and are located in the Enbridge Gas service area. The program includes a visioning session, a free integrated design process workshop with the design team and industry experts, and an evaluation of final design choices.

7.4 Recommendations and conclusions

The preliminary energy study of the proposed development shows that the Building Code levels of EUI, TEDI and GHGI are achievable using conventional, commonly adopted mechanical systems but with enhancement in building envelope systems. A further improved overall effective envelope USI to meet the subsequent targets, is achievable through several detail combinations which emphasize the reduction of thermal bridges such as balconies and reducing WWR% and/or lowering effective glazing thermal conductivity. Furthermore, by implementing both passive and active energy conservation measures as outlined in section 2 of this report, the developments can move closer to complying with scenarios 2 and 3 level of performance.

As the design progresses, the design team should engage with the energy modelling process to evaluate the design alternatives expressed in this report to help optimize building design. Therefore, there will be further opportunity for exploring approaches for ambitious energy performance as the building design is advanced (which is the most appropriate point to make such decisions). It should be noted that nothing in the proposed package would preclude the potential to do this at a later stage.

Advanced measures such as geothermal, CHP, solar PV, solar air heating, and solar thermal could be undertaken on this project but further analysis outside the scope of this report would be required. As part of the third scenario, a low carbon district system as well as integrating both solar PV and solar thermal collectors on available rooftop space should be studied to achieve a near net zero-carbon building. As these alternatives are explored and design progresses, the proposed development is also encouraged to consider pursuing further external certifications such as LEED or Zero Carbon Desing, as well as seek additional incentives through the Enbridge Savings-by-Design Program.

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References

[5] MMA Supplementary Standard SB-10: Energy Efficiency Requirements (2017)

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Appendix A

High Rise MURB

Location	Waterloo		
Climate Zone	6A		
Schedules	Units: NECB schedule G I Amenities: NECB schedule B I Corridor and parking lighting: ON continuously		
Occupancy	Units: 27.9 m^2/person I Amenities: 5 m^2/person		
	Baseline - Tier1	**Tier 2**	**Tier 3**
	Envelope		
Window Wall Ratio	40%	40%	40%
Wall RSI (R_{imp})	Effective 1.76 (10.0)	Effective) 2.6 (15)	Effective 3.52 (20.0)
Roof RSI (R_{imp})	Effective 3.52 (20.0)	Effective 3.52 (20.0)	Effective 5.28 (30.0)
Window USI (U_{imp})	Overall, 1.9 (0.34)	Overall, 1.70 (0.3)	Overall, 0.8 (0.14)
Window SHGC	0.35	0.35	0.35
Infiltration	0.25 l/s.m^2 of façade @ 5 Pascal	0.22 l/s.m^2 of façade @ 5 Pascal	0.6 ACH @ 50 Pascal
	Internal Loads		
Receptacle	Suite: 5.0W/m^2 I Amenities: 1.0W/m^2	Suite: 4.5W/m^2 I Amenities: 1.0W/m^2	Suite: 3.8W/m^2 I Amenities: 0.8W/m^2
Lighting	Suite: 5.0W/m^2 I Amenities: 5.5W/m^2 Corridor: 5.0W/m^2	Suite: 5.0W/m^2 I Amenities: 5.5W/m^2 Corridor: 5.0W/m^2	Suite: 5.0W/m^2 I Amenities: 3.9W/m^2 Corridor: 3.6W/m^2
Service Hot Water	Lavatory: 4.8 LPM I Shower: 7.6 LPM Kitchen: 5.6 LPM	Lavatory: 3.8 LPM I Shower: 5.7LPM Kitchen: 5.7LPM	Lavatory: 3.8 LPM I Shower: 5.7LPM Kitchen: 5.7LPM
Ventilation	Suite: per ASHRAE 62.1-2010 Corridor: 14 L/s/unit	Suite: per ASHRAE 62.1-2010 Corridor: 7 L/s/unit (time of use)	Suite: per ASHRAE 62.1-2010 Corridor: 0.3 L/s.m^2
	Mechanical HVAC		
HVAC System	Suites: Hydronic fan coil & ERVs Corridor: MUA & hydronic baseboard Amenities: hydronic fan coil	Suites: Hydronic fan coil & ERVs Corridor: MUA & hydronic baseboard Amenities: hydronic fan coil & ERV	Suites: ASHP & ERV; electric backup Corridor: ASHP & electric backup Amenities: ASHP & ERV with DCV
Heat Recovery	65% eff.	75% eff.	85% eff.
Fans	ERV: 0.5W/cfm I Fan coils: 0.3W/cfm MUA: 0.5 W/cfm	ERV: 0.5W/cfm I Fan coils: 0.3W/cfm MUA: 0.5 W/cfm	ERV: 0.5W/cfm I HP: 0.3W/cfm MUA: 0.5 W/cfm
Ventilation Effectiveness	0.8	0.8	1
	Plant		
Heating	Condensing boiler, 90% eff.	Condensing boiler, 97% eff.	ASHP, COP 4.15 & electric top up
Cooling	Water cooled chiller, COP 5.2	Water cooled Magnetic bearing chiller, COP 7.0	ASHP. COP 3.15
Pumps	VSD	VSD	VSD
Service Hot Water	Condensing boiler 90% eff.	Condensing boiler 97% eff.	Heat Pump, COP 3.5
Drain Water Heat Recovery	NO	NO	YES (60% efficiency)

Commercial Retail

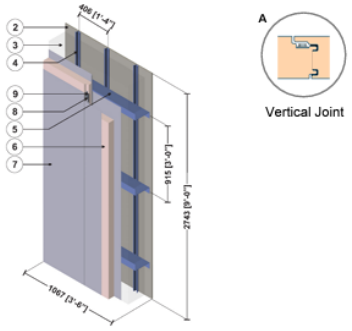
Location	Waterloo		
Climate Zone	6A		
Schedules	NECB schedule C		
Occupancy	30 m^2/person		
	Baseline - Tier1	**Tier 2**	**Tier 3**
	Envelope		
Window Wall Ratio	20%	20%	20%
Wall RSI (R_{imp})	Effective 1.76 (10.0)	Effective 3.52 (20.0)	Effective 5.28 (30.0)
Roof RSI (R_{imp})	Effective 3.52 (20.0)	Effective 5.28 (30.0)	Effective 7.04 (40.0)
Window USI (U_{imp})	Overall, 1.70 (0.3)	Overall, 1.13 (0.2)	Overall, 0.8 (0.14)
Window SHGC	0.35	0.35	0.35
Infiltration	0.25 l/s.m^2 of façade @ 5 Pascal	0.22 l/s.m^2 of façade @ 5 Pascal	0.6 ACH @ 50 Pascal
	Internal Loads		
Receptacle	2.5 W/m^2	2.5 W/m^2	2.5 W/m^2
Lighting	10.1 W/m^2	8.8 W/m^2	7.6 W/m^2
Service Hot Water	Lavatory: 2.2 LPM I Shower: 5.6 LPM Kitchen: 4.7 LPM	Lavatory: 2.2 LPM I Shower: 5.6 LPM Kitchen: 4.7 LPM	Lavatory: 2.2 LPM I Shower: 5.6 LPM Kitchen: 4.7 LPM
Ventilation	Per ASHRAE 62.1-2010	Per ASHRAE 62.1-2010 reduced by 20% for DCV	Per ASHRAE 62.1-2010 reduced by 20% for DCV
	Mechanical HVAC		
HVAC System	Package Rooftop unit with ERV	DOAS with DCV - ASHP & gas backup	DOAS with DCV - ASHP & electric backup
Heat Recovery	50% eff.	90% eff.	90% eff.
Fans	RTU with ERV: 1.0 W/cfm	Fan coils: 0.3W/cfm DOAS with ERV: 1.0 W/cfm	Fan coils: 0.3W/cfm DOAS with ERV: 1.0 W/cfm
Ventilation Effectiveness	0.8	1	1
	Plant		
Heating	Gas Fired Furnace 80% eff.	ASHP, COP 4.15 & gas top up	ASHP, COP 4.15 & electric top up
Cooling	DX Cooling COP 3.8	ASHP. COP 3.15	ASHP. COP 3.15
Pumps	VSD	VSD	VSD
Service Hot Water	Condensing boiler 90% eff.	Heat Pump, COP 3.5	Heat Pump, COP 3.5
Drain Water Heat Recovery	NO	NO	NO

Appendix B

IMP

High Performance

Detail 6.1.1 Vertical Insulated Metal Panel – Clear Wall with Vertical Connection Joint and Support Girt/Hat Track Backup Wall

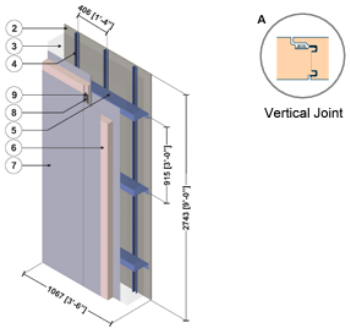


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	-	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	Hat Tracks @ 16" o.c.	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Z-Girts with 1 1/2" Flange	16 Gauge	430 (62)	-	489 (7830)	0.12 (500)
6	Polyisocyanurate Insulation	3" (76)	0.143 (0.02)	R-21 (3.70)	1.8 (28)	0.29 (1220)
7	Steel Facer Skin	24 Gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Sealant	Varies	2.4 (0.35)	-	-	-
9	#14 Steel Fasteners	1/4" (6) Ø	314 (45)	-	489 (7830)	0.12 (500)
10	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Near Zero Emissions

Detail 6.1.1 Vertical Insulated Metal Panel – Clear Wall with Vertical Connection Joint and Support Girt/Hat Track Backup Wall



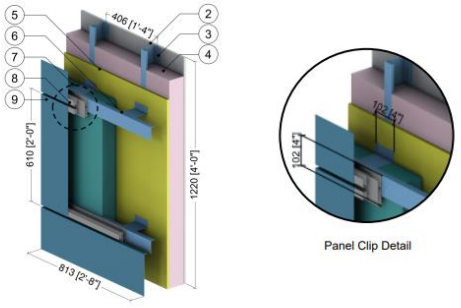
ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	-	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	Hat Tracks @ 16" o.c.	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Z-Girts with 1 1/2" Flange	16 Gauge	430 (62)	-	489 (7830)	0.12 (500)
6	Polyisocyanurate Insulation	3" (76)	0.143 (0.02)	R-21 (3.70)	1.8 (28)	0.29 (1220)
7	Steel Facer Skin	24 Gauge	430 (62)	-	489 (7830)	0.12 (500)
8	Sealant	Varies	2.4 (0.35)	-	-	-
9	#14 Steel Fasteners	1/4" (6) Ø	314 (45)	-	489 (7830)	0.12 (500)
10	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

ACM

High Performance

Detail 5.1.19 Exterior and Interior Insulated 3 5/8" x 1 5/8" Steel Stud (16" o.c.) Wall Assembly with Horizontal Clips (24" o.c.) Supporting Metal Cladding and R-12 Batt Insulation in Stud Cavity – Clear Wall

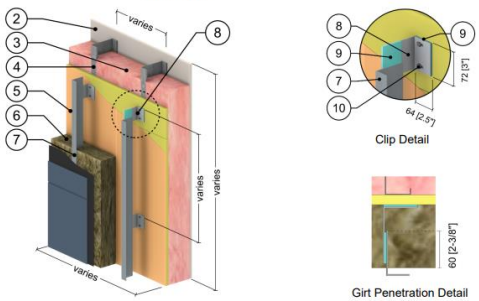


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	3 5/8" x 1 5/8" Steel Studs	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Fiberglass Batt Insulation	3 5/8" (92)	0.31 (0.044)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Horizontal Clips w/ 1 1/2" Horizontal Rail	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
7	Exterior Insulation	Varies	-	R-10 to R-20 (1.76 to 3.5 RSI)	1.8 (28)	0.29 (1220)
8	Panel Clip	14 Gauge	430 (62)	-	489 (7830)	0.12 (500)
9	Metal Cladding with 1/2" vented airspace incorporated into exterior heat transfer coefficient					
10	Exterior Film[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Near Zero Emissions

Detail 5.1.59 Exterior and Interior Insulated 6" x 1 5/8" Steel Stud (16" o.c. and 24" o.c.) Wall Assembly with Vertical Clips (24" o.c. and 36" o.c.) Supporting Cladding and R-20 Batt Insulation in Stud Cavity – Clear Wall



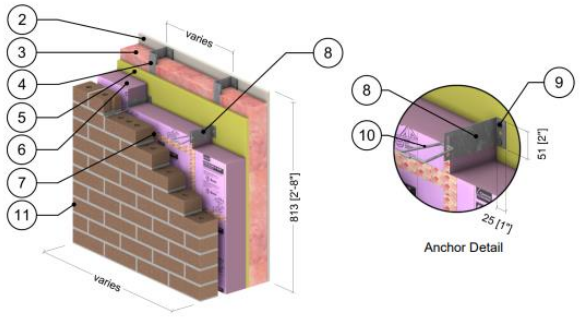
ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Films[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Fiberglass Batt Insulation	6" (152)	0.30(0.043)	R-20 (3.5 RSI)	0.55 (8.8)	0.17 (710)
4	6" x 1 5/8" Steel Studs	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	5/8" (16)	1.1 (0.16)	R-0.6 (0.10 RSI)	50 (800)	0.26 (1090)
6	Exterior Mineral Wool Insulation	Varies	0.24 (0.034)	R-16.8 to R-29.4 (2.96 to 5.18 RSI)	4 (64)	0.20 (850)
7	Vertical Aluminum L-girt – Aluminum 6005A alloy	0.09" (2.2)	1340 (193)	-	169 (2700)	0.22 (900)
8	Aluminum Bracket	0.09" (2.2)	1110 (160)	-	171 (2739)	0.22 (900)
9	HDPE Isolator	1/8" (3)	3.5 (0.5)	-	59 (950)	0.48 (2000)
10	#14 Stainless Steel Fasteners	1/4" (6) Ø	118 (17)	-	500 (8000)	0.12 (500)
11	Cladding with 1/2" vented airspace incorporated into exterior heat transfer coefficient					
12	Exterior Film[1]	-	-	R-0.7 (0.12 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Brick veneer

High Performance

Detail 5.1.60 Exterior and Interior Insulated 6" x 1 5/8" Steel Stud (16" o.c. and 24" o.c.) Wall Assembly with Steel Brick Anchors Supporting Brick Veneer and Owens Corning R-20 Batt Insulation in Stud Cavity – Clear Wall

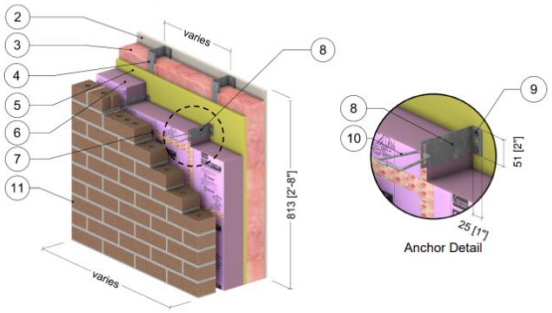


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Films[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Ecotouch Pink Fiberglass Batt	6" (152)	0.30 (0.043)	R-20 (3.5 RSI)	0.55 (8.8)	0.17 (710)
4	6" x 1 5/8" Steel Studs	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	5/8" (16)	1.1 (0.16)	R-0.6 (0.10 RSI)	50 (800)	0.26 (1090)
6	Foamular CodeBord/C-200 Extruded Polystyrene Rigid Insulation (XPS) Type 3	Varies	0.20 (0.029)	R-5 to R-15 (0.88 to 2.64 RSI)	Varies	0.29 (1220)
7	Vented Air Cavity	1 1/2" (38)	-	R-0.4 (0.07 RSI)	0.075 (1.2)	0.24 (1000)
8	Galvanized Steel Veneer Anchor	Varies	430 (62)	-	489 (7830)	0.12 (500)
9	Galvanized Steel Fasteners	0.28" (7) Ø	430 (62)	-	489 (7830)	0.12 (500)
10	Galvanized Steel Wire Pintle	-	430 (62)	-	489 (7830)	0.12 (500)
11	Brick Veneer	3 5/8" (92)	5.4 (0.78)	-	120 (1920)	0.19 (720)
12	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Near Zero Emissions

Detail 5.1.62 Exterior and Interior Insulated 6" x 1 5/8" Steel Stud (16" o.c. and 24" o.c.) Wall Assembly with Steel Brick Anchors Supporting Brick Veneer and Owens Corning R-24 Batt Insulation in Stud Cavity – Clear Wall



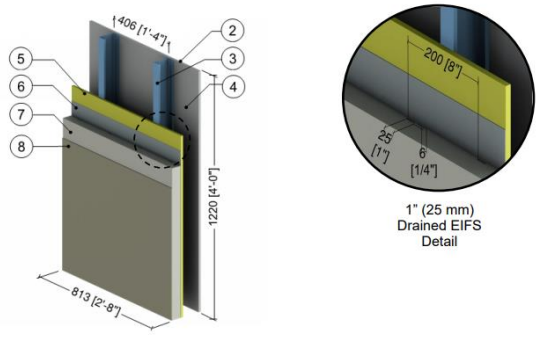
ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Films[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.09 RSI)	50 (800)	0.26 (1090)
3	Ecotouch Pink Fiberglass Batt	6" (152)	0.25 (0.036)	R-24 (4.2 RSI)	1.42 (22.7)	0.17 (710)
4	6" x 1 5/8" Steel Studs	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Exterior Sheathing	5/8" (16)	1.1 (0.16)	R-0.6 (0.10 RSI)	50 (800)	0.26 (1090)
6	Foamular CodeBord/C-200 Extruded Polystyrene Rigid Insulation (XPS) Type 3	Varies	0.20 (0.029)	R-5 to R-15 (0.88 to 2.64 RSI)	Varies	0.29 (1220)
7	Vented Air Cavity	1 1/2" (38)	-	R-0.4 (0.07 RSI)	0.075 (1.2)	0.24 (1000)
8	Galvanized Steel Veneer Anchor	Varies	430 (62)	-	489 (7830)	0.12 (500)
9	Galvanized Steel Fasteners	0.28" (7) Ø	430 (62)	-	489 (7830)	0.12 (500)
10	Galvanized Steel Wire Pintle	-	430 (62)	-	489 (7830)	0.12 (500)
11	Brick Veneer	3 5/8" (92)	5.4 (0.78)	-	120 (1920)	0.19 (720)
12	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Exterior Insulation and Finishing Systems (EIFS)

High Performance

Detail 5.1.3 Exterior Insulated 3 5/8" x 1 5/8" Steel Stud (16" o.c.) Drained EIFS Wall Assembly – Clear Wall

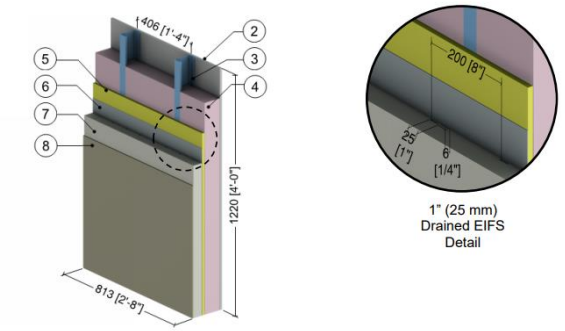


ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Films[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	3 5/8" x 1 5/8" Steel Studs (16"o.c.)	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Air in Stud Cavity	3 5/8" (92)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Weather Resistive Barrier with Adhesive	-	-	-	-	-
7	Insulation Board	2" to 4" (50 to 100)	0.27 (0.039)	R-7.5 to R-15 (1.32 to 2.64 RSI)	1 (16)	0.35 (1470)
8	Lamina	1/8" (4)	6 (0.9)	R-0.04 (0.01 RSI)	120 (1922)	0.20 (850)
9	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Near Zero Emissions

Detail 5.1.4 Exterior and Interior Insulated 3 5/8" x 1 5/8" Steel Stud (16" o.c.) Drained EIFS Wall Assembly with R-12 Batt Insulation in Stud Cavity – Clear Wall



ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Films[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	3 5/8" x 1 5/8" Steel Studs (16"o.c.)	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Fiberglass Batt Insulation	3 5/8" (92)	0.31 (0.044)	R-12 (2.1 RSI)	0.9 (14)	0.17 (710)
5	Exterior Sheathing	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
6	Weather Resistive Barrier with Adhesive	-	-	-	-	-
7	Insulation Board	2" to 6' (50 to 152)	0.27 (0.038)	R-7.5 to R-22.5 (1.32 to 3.96 RSI)	1 (16)	0.35 (1470)
8	Lamina	1/8" (4)	6 (0.9)	R-0.04 (0.01 RSI)	120 (1922)	0.20 (850)
9	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

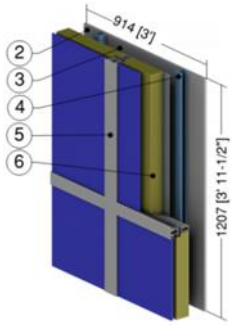
[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation

Window Wall

High Performance

Detail 1.1.3

Window Wall System – Full Height Spandrel with no Interior Stud Cavity Insulation



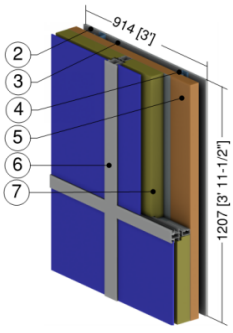
ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Films[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	3 5/8" (92)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs (16"o.c.) with Top and Bottom Tracks	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Full Height Aluminum Window Wall Spandrel System with Insulated Backpan: thermally broken frame, no insulation in mullions[2]					
6	Backpan Insulation	Varies	0.24 (0.034)	R-8.4 to R-16.8 (1.48 RSI to 2.96 RSI)	4 (64)	0.20 (850)
7	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation
[2] The thermal conductivity of air spaces within framing was found using ISO 100077-2

Near Zero Emissions

Detail 1.1.4

Window Wall System – Full Height Spandrel with Interior Spray Foam Insulation



ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Films[1]	-	-	R-0.7 (0.12 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	1 5/8" (41)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	3 5/8" x 1 5/8" Steel Studs (16"o.c.) with Top and Bottom Tracks	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Continuous Spray Foam Insulation	2" (51)	0.17 (0.024)	R-12 (2.11 RSI)	2.8 (39)	0.35 (1470)
6	Full Height Aluminum Window Wall Spandrel System with Insulated Backpan: thermally broken frame, no insulation in mullions[2]					
7	Backpan Insulation	Varies	0.24 (0.034)	R-8.4 to R-16.8 (1.48 RSI to 2.96 RSI)	4 (64)	0.20 (850)
8	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

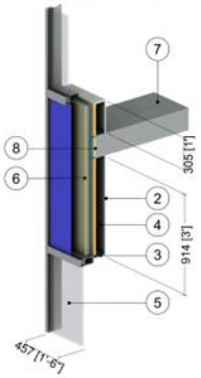
[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation
[2] The thermal conductivity of air spaces within framing was found using ISO 100077-2

Curtain wall

High Performance

Detail 2.1.2

Conventional Curtain Wall System with Insulated Spandrel Panel and 3 5/8" x 1 5/8" Steel Stud (16" o.c.) – Intermediate Floor Intersection & Spray Foam Insulation in Stud Cavity



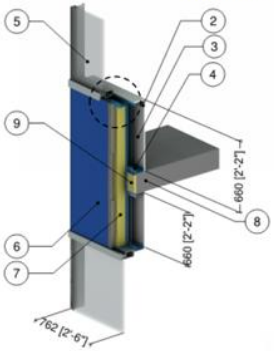
ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Film[1]	-	-	R-0.6 to R-0.9 (0.11 to 0.16 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	3 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
4	Air in Stud Cavity	2 5/8" (67)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
5	Conventional curtain wall system with insulated back pan (Pressure plates with minimal thermal break)[2]					
6	Backpan Insulation	Varies	-	R-8.4 to R-16.8 (1.48 to 2.96 RSI)	1.8 (28)	0.29 (1220)
7	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
8	Firestop Insulation	1" (25)	0.24 (0.034)	R-4.2 (0.74 RSI)	4 (64)	0.20 (850)
9	Spray Foam Insulation	2" (51)	0.17 (0.024)	R-12.0 (2.11 RSI)	2.4 (39)	0.35 (1470)
10	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

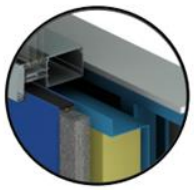
[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation & surface emissivity. Window values supplemented by ISO 1007-2, Annex B.
[2] The thermal conductivity of air spaces within curtain wall framing was found using ISO 10077-2.

Near Zero Emissions

Detail 2.1.8

Conventional Curtain Wall System with Vertical and Horizontal Pressure Plates and 5' x 5' Spandrel Section – AIM Applications and Improved Glazing at Intermediate Floor Intersection





Triple Glazed IGU with Silicone Warm Edge Spacer

ID	Component	Thickness Inches (mm)	Conductivity Btu·in / ft²·hr·°F (W/m K)	Nominal Resistance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)	Specific Heat Btu/lb·°F (J/kg K)
1	Interior Films[1]	-	-	R-0.6 to R-1.1 (0.12 to 0.20 RSI)	-	-
2	Gypsum Board	1/2" (13)	1.1 (0.16)	R-0.5 (0.08 RSI)	50 (800)	0.26 (1090)
3	Air in Stud Cavity	3 5/8" (92)	-	R-0.9 (0.16 RSI)	0.075 (1.2)	0.24 (1000)
4	1 5/8" x 1 5/8" Steel Studs (16"o.c.) with Top and Bottom Tracks	18 Gauge	430 (62)	-	489 (7830)	0.12 (500)
5	Conventional Curtain Wall Vision Section: triple glazed IGU with silicone warm edge spacer[2]					
6	Conventional Curtain Wall Spandrel Section with 1.5" (38) AIM between Glass and Backpan Insulation[2,3]					
7	Backpan Insulation	4" (100)	0.24 (0.034)	R-16.8 (2.96 RSI)	4 (64)	0.20 (850)
8	Concrete Slab	8" (203)	12.5 (1.8)	-	140 (2250)	0.20 (850)
9	Mineral Wool Insulation	1" (25)	0.24 (0.034)	R-4.2 (0.74 RSI)	4 (64)	0.20 (850)
10	Exterior Film[1]	-	-	R-0.2 (0.03 RSI)	-	-

[1] Value selected from table 1, p. 26.1 of 2009 ASHRAE Handbook – Fundamentals depending on surface orientation
[2] The thermal conductivity of air spaces within framing was found using ISO 100077-2
[3] For a window to wall ratio of 50%
AIM = Architectural Insulation Module