Energy Study Report

170 Northfield Drive West Development,

170 Northfield Drive West, Waterloo, ON



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EXECUTIVE SUMMARY

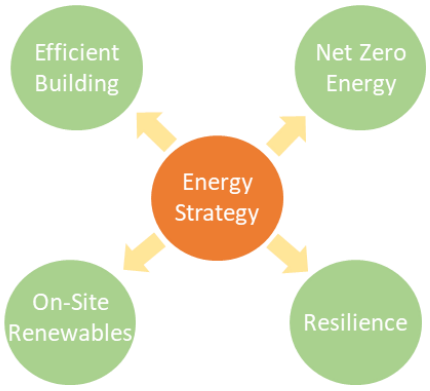
Forgestone Capital Management retained Internat Energy Solutions Canada (IESC) to undertake an Energy Study for a proposed new mixed-use development in Waterloo, Ontario located at 170 Northfield Drive West.

The proposed site is approximately 161,875 square meters and contains approximately thirteen high-rise mixed-use buildings, with a central outdoor amenity area and a planned park space to the north of the mixed-use buildings. Parking is accommodated through a combination of underground and above grade structured parking in a six-storey podium. Commercial and industrial spaces are planned for the latter phases of the site development, located north of the initial mixed-use buildings.

The purpose of this Energy Study is the early identification of opportunities to integrate design solutions that meet the guideline principles outlined in the Region of Waterloo's Energy Study Terms of Reference. This information will be then utilized as part of the building design process.

The following chart summarizes key metrics and performance benchmarks developed by the Region of Waterloo. The metrics include Total Energy Use Intensity (TEUI), Greenhouse Gas Emission Intensity (GHGI) and Thermal Energy Demand Intensity (TEDI). This report outlines design strategies to achieve each of the presented targets. Advanced measures such as geothermal and solar PV are recommended for highest targets. These measures were applied into the developed model and preliminary results are presented. Design options are also presented to provide enhanced resilience for the Proposed Development and should be evaluated further on a feasibility and cost basis.

As part of this study, IESC considered a variety of building level scale strategies with the potential to reduce the projects operational energy and carbon impact and to improve resilience and wellness.



Various measures were studied to develop low energy and low carbon strategy for the building. As the energy models were developed for the various Energy Study Performance tiers, there was an overall strategy for primary consideration on improved envelop performance, then advanced mechanical systems followed by onsite energy generation. Some of the energy conservation measures included: efficient low carbon HVAC systems, improved envelope performance, air tightness design, plug load reduction, improved energy recovery efficiencies and solar photovoltaic systems. Additionally, the impact of adding solar PV and other renewables was assessed with solar PV providing significant energy and GHG reductions. Advanced energy solutions including the feasibility of district energy, geothermal loops and other advanced energy reduction technologies was discussed.

A qualitative analysis on building envelop thermal bridging was provided for the design team to consider. A complimentary analysis on embodied carbon in building materials for the proposed project was completed. Concrete is the material estimated to have the highest embodied carbon content for the project. Several mitigation measures and approaches were recommended to reduce the embodied carbon content of concrete for the project.

Finally, a discussion on resiliency was provided for the building systems and energy including recommendations on design techniques to be implemented to improve the overall resiliency of the project. The recommendations and measures within the report should be studied further as the design develops.

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1 INTRODUCTION AND OVERVIEW OF PROPOSED DEVELOPMENT

The proposed development is located at the northeast corner of the Weber Street North and Northfield Drive West intersection in Waterloo, Ontario. The development plan is divided into phases with the initial phases focusing on the residential and mixed-use buildings. The project is early in the development process; therefore, the contents of the report will provide input into the design development of the project.

The proposed site is approximately 161,875 square meters and contains approximately thirteen high-rise mixed-use buildings, with a central outdoor amenity area and a planned park space to the north of the mixed-use buildings. Parking is accommodated through a combination of underground and above grade structured parking in a six-storey podium. Commercial and industrial spaces are planned for the latter phases of the site development, located north of the initial mixed-use buildings. To summarize the development will contain approximately:

- 2,210 residential units
- 3,020 square meters of building floor area for ancillary commercial uses
- 16,715 square meters of building floor area for employment uses
- 2,505 parking spaces
- 24,200 square meters of parks and public land uses

This report outlines the details of the energy study performed on the development site to be used to address the Region of Waterloo's TransformWR requirements and initiatives.

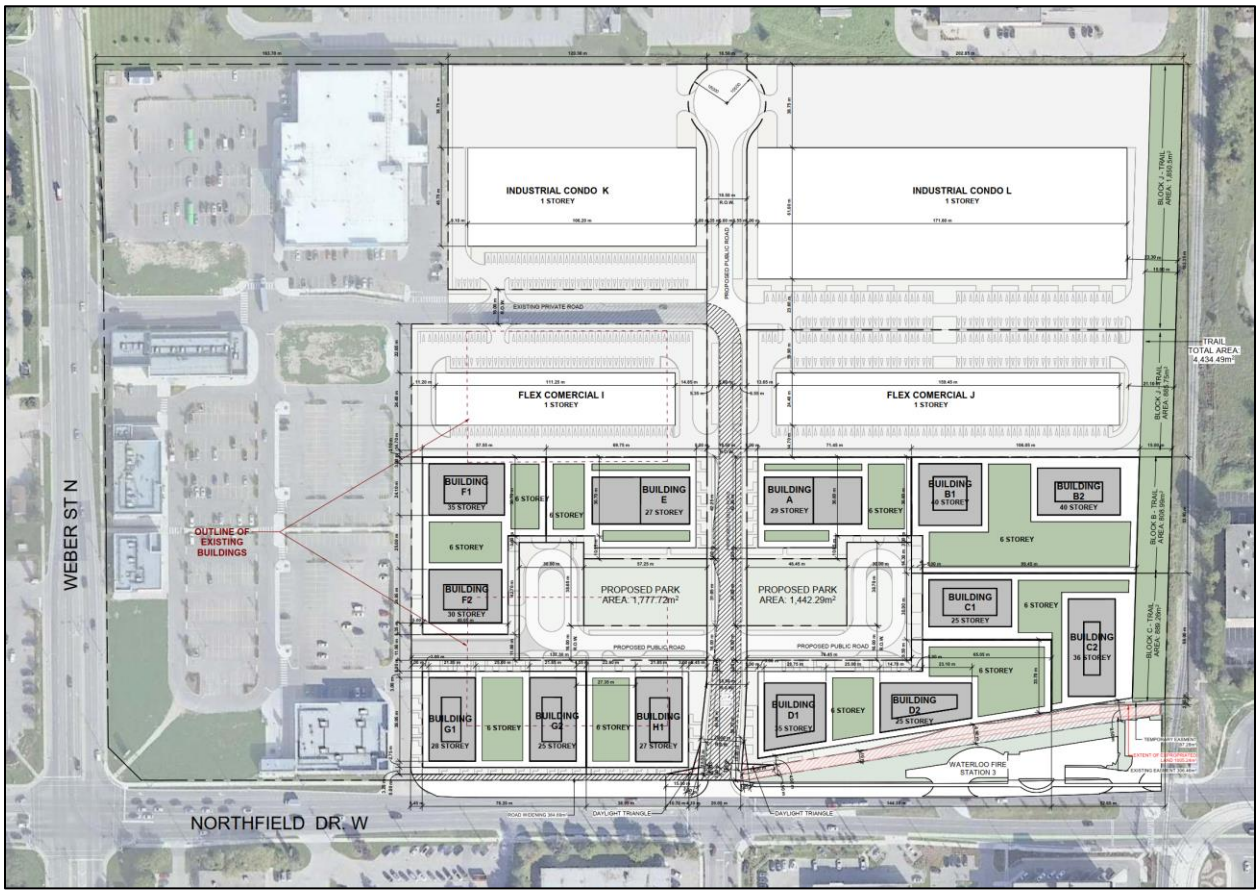


Figure 1: Proposed development site layout.

2 PURPOSE

The Region of Waterloo has developed several sustainability policies in order to address climate change, with particular focus on net-zero development and energy resilience. For buildings within a Community Energy Plan area approved by Council, the Region of Waterloo introduced the requirement for an Energy Study. The intent of the Energy Study is found in the City of Waterloo Terms of Reference.

The purpose of the Energy study is to identify strategic energy options early in the development process, with a focus on promoting communication between applicants and sustainable building designers as well as informing subsequent design decisions to reduce energy consumption and greenhouse gas (GHG) emissions with minimal project disruption and cost.

The City has committed to reducing community-based GHG emissions by 50% by 2030 and 80% by 2050 relative to 2010 levels. Performing an Energy Study at the early stages of the development including Zoning By-Law Amendments and Draft Plans of Subdivision is intended to facilitate the following[1]:

- Identification of opportunities to increase energy efficiency and reduce greenhouse gas emissions in new development at the conceptual design stage.
- Consideration of opportunities to site buildings and configure blocks to take advantage of existing or proposed energy infrastructure, energy capture, and/or solar orientation.
- Consideration of opportunities to optimize the installation of future building energy systems that will allow the development to cost-effectively achieve net-zero energy performance.
- Consideration of opportunities to increase resiliency.
- Consideration of embodied carbon and material selection.
- Exploration of potential operational cost savings and capital cost incentives.

3 DESIGN OPPORTUNITIES

3.1 PASSIVE DESIGN MEASURES

At this stage of design, the details of the building envelope are still under consideration. Given the typical built for multi unit residential buildings, spandrel panels and a moderate window to wall ratio are expected. While it is too early in design for envelope interface details to be developed, the project team should carefully consider these details as design progresses. Following the Terms of Reference modelling requirements all thermal bridging of the sample building envelope must be accounted for. This introduces new focus on architectural elements, including:

- Opaque Wall and Glazing Interfaces

- Interior and Exterior Wall Interfaces

- Slab bypasses

- Balconies

- Parapet and terrace details

Additionally, focusing on thermal insulation, air tightness and ventilation can provide significant advantages in energy reduction, thermal comfort and indoor air quality. Figure 1 shows a summary of these passive design principles.

[1] City of Waterloo. *Energy Study Terms of Reference*. Accessed February 12, 2024 from: https://www.waterloo.ca/en/government/resources/Documents/Planning/terms-of-reference/TOR_EnergyStudy.pdf

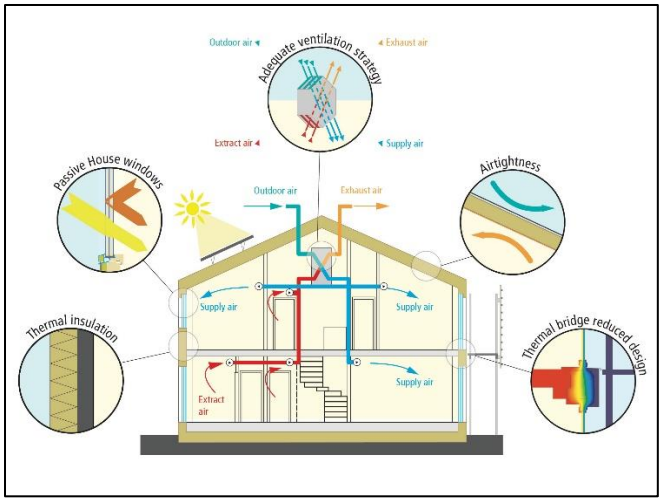


Figure 2: Passive design principles[2].

By fully accounting for all thermal bridging, a more accurate representation of thermal performance of the envelope can be used in the model, reflecting more accurate energy use estimation. A typical wall assembly after considering all the losses through thermal bridging will have a significantly lower R-value that needs to be accounted in the modelling and design stages. This will reduce the performance and consequently increase the energy consumption of the building. Linear Thermal Transmittance, Clear Wall / Clear Field R-Value, and linear/point thermal bridges are the key factors that need to be considers for opaque wall design. Considering these details early in design can significantly improve the envelope performance and overall energy performance in a passive way.

Section 3 of BC Hydro's Building Envelope Thermal Bridging Guide (BETBG)[3] provides useful information for the design of high-performance envelope. Floor slabs commonly connect directly to exterior concrete walls in cast-in-place construction. Insulation is often installed on the interior of the wall in lieu of the exterior to allow the concrete to serve as the exterior finish. The use of interior insulation allows significant heat loss through the edge of the floor slab and high resulting linear transmittance values. Non-structural precast panels present an opportunity to add a thermal break where a gap between floor slabs and wall panels that can be filled with non-combustible mineral wool insulation. Canadian Precast/Prestressed Concrete Institute (CPCI) guide suggest an alternative design for floor-to-wall interface for structural precast walls including an interior corbel added to the panels to support the floor. This allows insulation between the ends of the floor slab and walls. Projecting balconies are commonly cast-in-place and precast concrete that adds significant thermal bridging. An alternative approach is to install balconies within alcoves providing support on two opposing sides or providing perimeter columns to carry the moment load. This will allow the use of similar insulation to floor slab to wall method. Window and door flanking loss as well as roof parapet losses also need to be considered in the total heat loss calculations[4]. Full thermal bridging calculations not only better reflect the energy usage in a building, but also give a better representation of the thermal comfort within a space. Improving the performance of the wall can increase occupant comfort significantly and can allow for mechanical equipment to be downsized. Additionally, as interior spaces are better able to maintain their temperature set-points, HVAC run times and system cycling can be reduced leading to increased HVAC system lifetimes. Passive design measures can also affect the resilience of a building.

Due to the early stages of the building design, the window-wall ratio has not been finalized. It is recommended to reduce the vision ratio of the building to 40%. In terms of glazing for the project, a high-performance product with a low solar heat gain coefficient will be encouraged. This will provide daylight while reducing over-heating in shoulder

[2] Passive House Institute. *Passive House Requirements.* Accessed February 12, 2024 from: https://passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm

[3] BC Hydro. *Building Envelope Thermal Bridging Guide (BETBG) Version 1.4*, 2020. Accessed February 12, 2024 from https://www.bchydro.com/

[4] Sustainable Buildings Canada. *Thermal Analysis of Total Precast Concrete MURB Walls*, 2020. Accessed February 12,2024 from: https://sbcanada.org/

seasons and cooling loads in the summer. Enhanced aluminum frames with thermal breaks and hybrid aluminum frames are two recommended options for higher performance buildings and sputtered low e coating triple glazed argon filled windows are recommended for the best results. Electrochromic glazing (glass which tints in response to solar intensity or sun position) can also serve this purpose, while maximizing daylighting and view in the residential spaces. It is expected these measures will have a positive impact on the building cooling and heating loads. Moving to higher performance and net-zero ready performance, energy standards become stricter, targeting a 40% window to wall ratio will be needed in the future to improve the overall envelope performance. The proposed designs must aim to achieve a balance of daylighting and a high energy performance for the building envelope. As design progresses for the project the design team should consider several passive design principles that should provide a strong envelop strategy that reduces energy lose and improves occupant comfort.

3.2 ACTIVE DESIGN MEASURES

At the current design stage, mechanical systems have been considered only at a conceptual level. Typical design for similar buildings in the Waterloo area includes a dedicated mechanical heating and cooling via a gas-fired hot water boiler and electric chilled water plant. In order to develop the energy analysis for the three performance tiers, preliminary mechanical systems were selected. These systems show one path to achieve the energy and emission savings required, however the design must evaluate and develop systems that are feasible, cost effective and meet the project goals including energy reduction and sustainability.

A mechanical system that achieves slightly better performance was developed to establish the building case baseline of the project. For the residential buildings, gas fired boilers in conjunction with air-cooled chillers were used to supply a 4-pipe fan coil loop to the suites. Gas-fired make-up air units with heat recovery were used to provide fresh air to the corridors. The commercial and industrial spaces were supplied with single-zone gas-fired rooftop units with direct-expansion cooling coils. Domestic hot water is supplied with a gas-fired water heater with storage.

Compared to the baseline the mechanical systems need to be improved to achieve the High-performance targets. The residential building operation could utilize the same central boiler/chiller supplying 4-pipe fan coil units as the baseline case however, to achieve the performance targets is would require condensing boilers with higher efficiencies and variable flow, along with a higher COP air-cooled chiller with variable flow. The corridors would also be supplied with gas-fired make-up air units with more efficient heat recovery. Domestic hot water would be supplied with higher efficiency condensing hot water heaters. The commercial and industrial buildings require electric variable air packaged units with direct expansion cooling coils.

To achieve the Net-Zero Ready Energy Performance Targets, the building envelope has to be designed to be thermal-bridge free by following passive house design principles. Reduction of thermal bridging has a profound impact on reduction of heating demand which is dominating end use energy consumption as will be shown in the next section. To reduce the dominating heating demand even further, the window-to-wall ratio was reduced by 10% for residential type of buildings. Windows are major heat loss component across the envelope and reduction of relative proportion of transparent wall has a major effect in thermal energy demand.

In order to achieve the GHGI and energy targets the primary residential HVAC system had to be reconfigured to a geothermal heat pump loop, supplying in-suite water source heat pumps. Having constant access to the relatively non-changing ground temperature optimized heat pumps' performance which performance otherwise decreases with a decrease in outdoor temperatures like in case of air-source systems. The heating and cooling system for corridor pressurization has also been replaced by heat pump which further reduces the heating and cooling energy consumption in the building. The water heating system has also been switched to hybrid heat pump units which can be placed inside of each suite and enable easily accessible submetering. The domestic hot water system should also be reconfigured to utilize electric heat pumps with a COP of 4.25.

There may be additional methods to achieving the energy and emission reduction targets that are not included in the energy modelling. At this stage of the design, various low carbon solutions should be under consideration. For example, using high efficiency systems such as heat pumps or VRF systems will reduce the energy use associated with space heating and cooling and consequently lower emissions. Additionally, coupling the water cooled VRF system to ground loop will enhance the performance of the building. The use of high-performance modulating

condensing boilers for domestic hot water and/or auxiliary space heating will also reduce the energy use. It is also recommended to consider implementing gas fired absorption heat pumps for domestic hot water production that provides COP of 1.2 and higher. This is a newer technology that is being promoted by natural gas distribution companies such as Enbridge. The design team is highly encouraged to consider drain water heat recovery systems along with low flow fixtures to reduce the energy consumption of the domestic hot water plant.

3.3 ADVANCED ENERGY SOLUTIONS

3.3.1 District Energy Systems

District energy systems are systems that distribute thermal energy to multiple buildings in an area or neighborhood. These systems typically consist of a heating and cooling plant or source and a thermal network of pips connected to a group of buildings to distribute the energy. These systems not only reduce greenhouse gas emissions and improve energy resiliency but also deliver economies of scale and use of less carbon intensive energy sources, allowing for large emission reductions at lower costs than individual building systems. District energy systems already exist in mid-size municipalities across Ontario including Windsor, London, Hamilton, Markham and Toronto.

At the time of this study, according to the Region of Waterloo, assessments have been completed on 12 district energy systems, with a pilot feasibility study centered around the King and Victoria intersection in downtown Kitchener completed. However, future plans to include the larger Kitchener-Waterloo Region are in development. It is recommended for the design team to monitor changes in the proposed district energy systems to assess any new opportunities in the future that might benefit the project as well as seek out opportunities with the city.

It is recommended the design team consider 'Future Proofing' the project by designing the building to be district energy-ready (DE-ready) in the event DES services become available at the project's location. It is suggested that the following key items be incorporated into a building's design for a future district energy connection:

- Install heating and cooling plant equipment on the lower levels for easier integration into a future district system, or provide for a future connection point into the building's thermal piping at ground level
- Provide adequate space at or below ground level for a future energy transfer station
- Provide an easement between the mechanical room and the property line to allow for thermal piping
- Provide 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 would be located
- Install a low temperature hydronic heating system (e.g., heat pump loop) that is compatible with a district energy system in order to reduce the pipe sized and associated valves, fitting, etc.
- Include provisions for appropriate future thermal energy metering

3.3.2 Geothermal Energy Exchange

Geothermal exchange systems use natural heating and cooling exchange from the earth, groundwater or surface water sources. The Region of Waterloo contains many available geothermal resources including:

- Surface water features (reservoirs, ponds, lakes etc.)
- Groundwater aquifers
- Overburden materials below the water table
- Bedrock formations

These geothermal resources typically require drilling and a certain degree of engineering to access and harness the energy source. The design team should proceed with investigating the feasibility of implementing a geothermal loop to provide a constant source of carbon free energy.

Considering the general hydrogeological conditions of the Waterloo region, typically open loop systems located above bedrock aquifers are considered to have the greatest potential for geothermal exchange for urban areas. The systems function by circulating the water from the aquifer to the building loop. The Waterloo Region contains over 120 municipal wells, each with a Wellhead Protection Areas (WHPA) zone. Open loop systems are not permitted within a few hundred metres of these wells. Figure 2 shows WHPA zones as well as bedrock depth for areas in the Kitchener, Waterloo and Woolwich areas[5]. The proposed development is not within the prohibited areas.

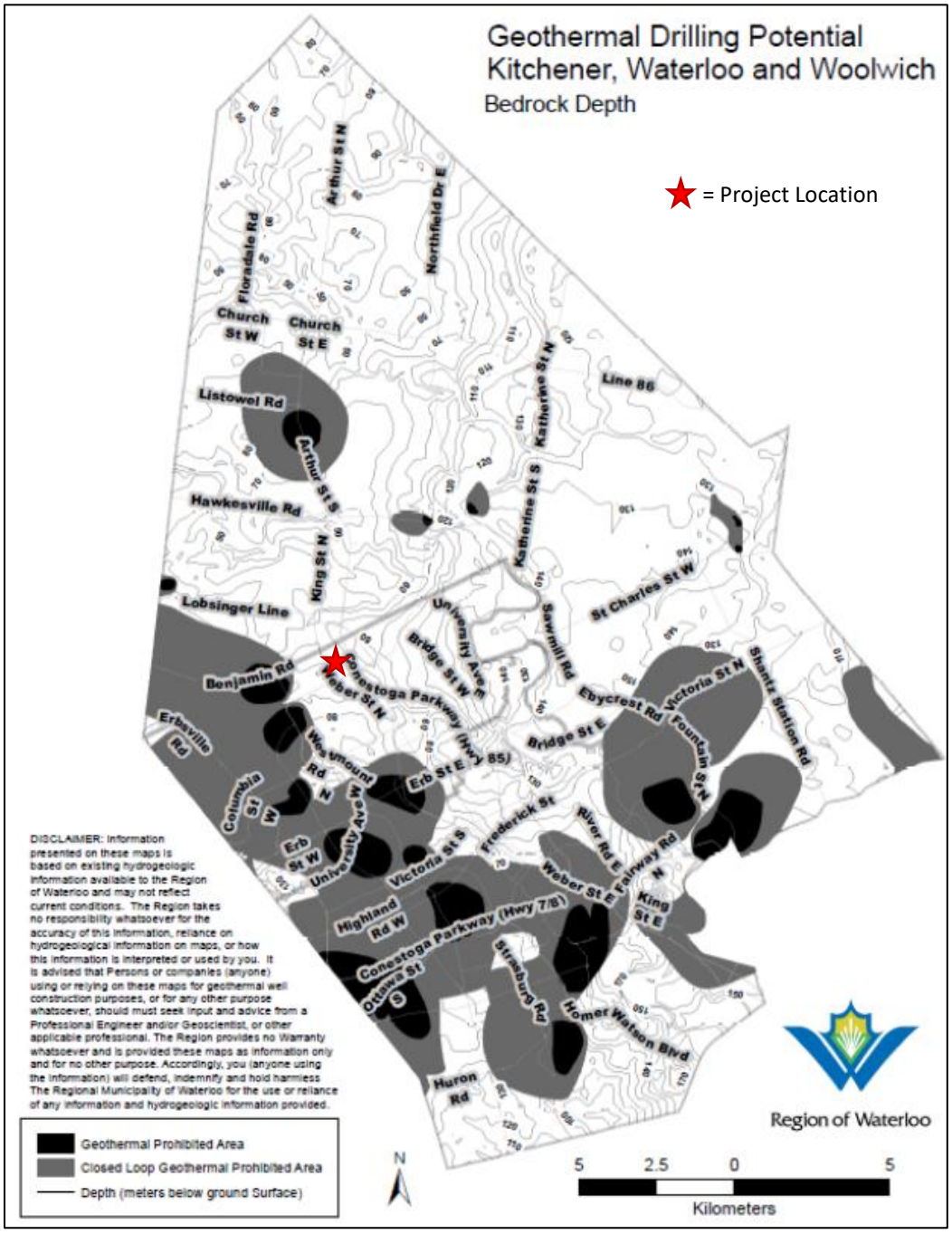


Figure 3: Bedrock depth and geothermal feasibilty locations.

[5] Beatty Geothermal Consulting. *Opportunities for Open Loop Geoexchange Waterloo Region*, November 2021. Accessed February 12, 2024 from https://wrcommunityenergy.ca/

3.3.3 Alternative Advanced Energy Solutions

There are other advanced energy solutions that design team can consider. A summary of alternative options are as follows:

- **Combined Heat and Power (Co-generation/CHP)**
  A gas fired engine that generates electricity on-site and waste heat can be recovered to pre-heat the water for domestic hot water plant. It is becoming more common to use cogeneration system as backup generators in buildings.
- **Solar Collectors (Air Based)**
  There are various types of solar collectors such as air based or liquid-based systems. However, the air-based systems are easier and more feasible to use in multi unit residential buildings. This system can pre-heat the air for makeup air units to reduce the ventilation load and save energy and cost.
- **Drain Water Heat Recovery (DWHR)**
  Drain water heat recovery system can be implemented in buildings to reduce the energy consumption in DHW plant. It is a spiral copper-based heat exchanger that replaces a vertical section of the main waste drain to transfer thermal energy from wastewater to incoming cold water into the building. DWHR system is easy to integrate to the plumbing system in MURBs and provides significant savings. DWHR option is used in Tier 4 model of this study.
- **Earth Tubes**
  Earth tube is a passive technology that supplies required fresh air to the building through underground concrete pipes. The air can be warmed in the winter and cooled in the summer after the tubes and depending on the size of the tube and building and required fresh air the energy savings are significant.
- **Spectrally Selective Glazing**
  Spectrally selective glazing is high-performance glazing that admits as much daylight as possible, while preventing transmission of as much solar heat as possible. This system significantly reduces building energy consumption by controlling solar heat gains in summer, preventing loss of interior heat in winter and allowing occupants to reduce electric lighting use by making maximum use of daylight.
- **Battery Storage**
  Battery storage has started to receive broad interest in the building industry. With newer technologies, costs are declining significantly because of improved manufacturing efficiencies and technological development, including increased capacities and lifespan. They can be used for peak load shifting that provides cost savings as well as being integrated to the solar PV system or smart grid options. The battery storage can also be part of the backup power system to improve resilience of the building.
- **Rainwater Harvesting**
  Rainwater harvesting is a sustainable practice that involves collecting and storing rainwater for later use. The system can provide several key benefits including lower water consumption and costs, minimizing storm run-off, providing a buffer against drought or water shortages and easing the demand on municipal water supply and treatment.

3.4 RENEWABLE ENERGY

Photovoltaic (PV) panels are made up of a number of PV cells that convert solar radiation into DC electricity which can then be used to power equipment directly or stored in the form of a battery for later use. The life expectancy of a typical PV panel is 25+ years with little maintenance required. The expected operations and maintenance (O&M) costs associated with the installation of a PV system at this site is low. Associated O&M activities over the lifetime of this system would include light cleaning work (only when deemed necessary to ensure performance) and the replacement of the system inverter after 10 years of operation.

Various solar PV system installation types were considered as a part of this study: a rooftop mounted system, Building Integrated Photovoltaic (BIPV) and a carport system installation.

3.4.1 Rooftop PV System

A conventional rooftop PV system is mounted on a racking system and secured to the roof via a ballast such concrete. This type of mounting approach has the benefit of avoiding the need to penetrate the existing roofing system and secure to the building structure, however it adds significant mass to the building structure. If the existing building structure cannot accommodate for this additional load, reinforcements will need to be made. It has been determined that structural reinforcement of the Town Hall will be required in order to support the rooftop mounted solar PV system that is proposed in this report. This work would involve the addition of fiber reinforced panels (FRP) to structural beam faces and to the underside of floor/ceiling slabs. The budget that should be allocated for this structural reinforcement has been accounted for in the cost estimate for the rooftop mounted PV system. It should also be noted that an intrusive reinforcement project such as this would likely result in the disruption of normal building operations while the work is being completed. The extent of this disruption is unknown; however, it is a negative aspect of this approach that should be considered. Figure 2, below shows potential layouts of solar PV for the proposed industrial buildings.

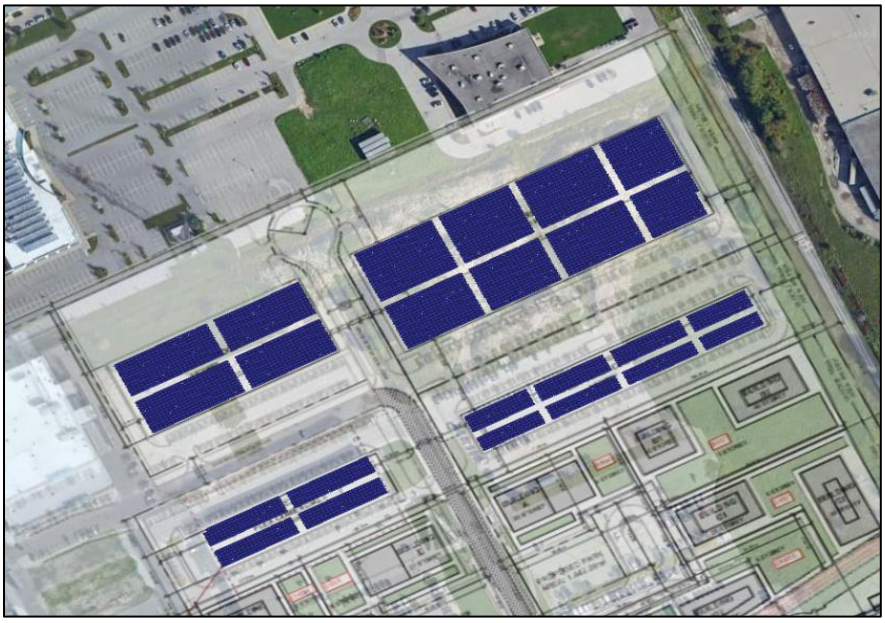


Figure 4: Industrial and commercial building PV proposed layout.

The solar PV system could potentially offset over two million kilowatt-hours in electricity consumption and over 60,000 kgCO2 emissions. The details of potential solar PV systems and savings for the industrial and commercial buildings are summarized in Table 3, below.

Table 1: Industrial and Commercial Building PV Summary

Scenario	System Size	System Cost	Electricity Production	Offset Utility Cost	Offset GHG Emissions
	kW	$CAD	kWh	$CAD*	ekgCO2
Flex Commercial I	196.4	$569,560	253,786	$30,454.28	7,106
Flex Commercial J	294.8	$854,920	380,937	$45,712.43	10,666
Industrial Condo K	441.6	$1,280,640	570,630	$68,475.60	15,978
Industrial Condo L	989.6	$2,869,840	1,278,749	$153,449.85	35,805

*Assumption cost of utility cost at 0.12/kWh

3.4.2 Building Integrated Photovoltaics (BIPV)

Building Integrated Photovoltaics (BIPV) are photovoltaic products and materials that function as part of building envelopes, replacing conventional construction materials such as roofs, skylights, canopies, facades, glazing and shades. The PV modules serve a dual purpose: they replace conventional building envelope materials and they generate power. The life expectancy of a typical BIPV is 25+ years with little maintenance required.

BIPV glass lowers the amount of energy consumed by minimizing solar heat gained and thereby demands on HVAC systems. Peak power consumption can also be offset simultaneously by peak energy production from BIPV. During the day, maximum sunlight hours and solar power system energy production generally correspond with peak electricity demand. This is even more important because peak production from the system is realized during daylight hours when utility prices are highest.

3.4.3 Carport PV Systems

Carport PV systems are versatile installations that can be located in existing parking lots offer other benefits such as vehicle coverage and integration with electric vehicle (EV) infrastructure. The system presented here represents the maximum capacity, with carport PV systems located at each of the site's existing parking spots.

4 ENERGY AND EMISSIONS ANALYSIS

The City of Waterloo Terms of Reference: Energy Study (TOR) sets out the minimum requirements that must be included in the energy study. The purpose of the Energy study is to identify strategic energy options early in the development process, with a focus on promoting communication between applicants and sustainable building designers as well as informing subsequent design decisions to reduce energy consumption and greenhouse gas (GHG) emissions with minimal project disruption and cost.

The current version of the TOR defines three relative targets for buildings. The intent of relative target is to encourage all buildings to meet the same relative standards of performance. The targets are defined in terms of following Key Performance Indices (KPIs):

- **Total Energy Use Intensity (EUI) [kWh/m^2]:** Annual building energy use, divided by the conditioned floor area.
- **Thermal Energy Demand Intensity (TEDI) [kWh/m^2]**: Annual heating load, divided by the conditioned floor area. TEDI excludes the effects of mechanical efficiencies (e.g., condensing boilers) but does include passive systems such as air heat recovery, solar gains, and internal gains.
- **Green House Gas Intensity (GHGI) [kgCO_2e/m^2]:** Annual greenhouse gas emissions, divided by the conditioned floor area.

The TOR also specifies three performance levels that must be explored. These include:

- **Building Code Baseline** – used as a reference for comparison.
- **High Performance** – where TEUI and TEDI are reduced by 30% each and GHGI is reduced by 50% relative to the Building Code Baseline.
- **Net-Zero Ready Performance** – where TEUI and TEDI are reduced by 60% each and GHGI is reduced by 90% relative to the Building Code Baseline.

4.1 BUILDING CODE BASELINE

Since the project is at concept design phase, the following envelope, mechanical and electrical system design assumptions were made to develop the model. The assumptions are developed from the Ontario Building Code SB-10 based on NECB-2015.

A mechanical system that achieves slightly better performance was developed to establish the building case baseline of the project. For the residential buildings, gas fired boilers in conjunction with air-cooled chillers were used to supply a 4-pipe fan coil loop to the suites. Gas-fired make-up air units with heat recovery were used to provide fresh air to the corridors. The commercial and industrial spaces were supplied with single-zone gas-fired rooftop units with direct-expansion cooling coils. Domestic hot water is supplied with a gas-fired water heater with storage.

The model is developed using DesignBuilder software that uses EnergyPlus engine to simulate the building. The following Table outlines the parameters used in the Building Code Baseline energy model.

Table 2: Building Code Baseline Energy Model Parameters

Component	Residential	Commercial	Industrial
Opaque Wall	Effective: R-22.9	Effective: R-22.9	Effective: R-22.9
Below Grade Wall	Effective: R-19.9	Effective: R-19.9	Effective: R-19.9
Roof	Effective: R-36.4	Effective: R-36.4	Effective: R-36.4
Floor (in contact with ground)	Effective R-7.6 for 1.2 m	Effective R-7.6 for 1.2 m	Effective R-7.6 for 1.2 m
Fenestration	U-1.9 W/m^2-°K + SHGC 0.40	U-1.9 W/m^2-°K + SHGC 0.40	U-1.9 W/m^2-°K + SHGC 0.40
Window-to-Wall Ratio	40.0%	40.0%	40.0%
Infiltration	0.25 L/(s.m^2) @ 5 Pa	0.25 L/(s.m^2) @ 5 Pa	0.25 L/(s.m^2) @ 5 Pa
Lighting Power Density (W/m^2)	Whole Building – 7.3 Suites – 5.0	Whole Building – 8.5	Whole Building – 9.7
Plant	Heating: Condensing Boiler 83% Efficient Constant Flow Cooling: Air Chiller 2.96 COP Constant Flow	Heating: Condensing Boiler 90% Efficient Constant Flow	Heating: Condensing Boiler 90% Efficient Constant Flow
HVAC	Residential and amenity: 4-pipe fan coil units Parking: Furnace 80% AFUE	Single-zone packaged rooftop unit with hydronic baseboard heating Furnace: 80% AFUE DX coil: 3.0 COP Fans: Constant volume, 40% total efficiency	Single-zone packaged rooftop unit with hydronic baseboard heating Furnace: 80% AFUE DX coil: 3.0 COP Fans: Constant volume, 40% total efficiency
Corridors Ventilation	Gas Fired MUA 80% efficient, 40 cfm/door	-	-
Heat Recovery	Residential: Sensible 55% | Latent 55% Amenity: Sensible 55% | Latent 55%	Sensible 55% | Latent 55%	Sensible 55% | Latent 55%
Domestic Hot Water	Direct-fired Storage water heater, 80% AFUE	Direct-fired Storage water heater, 70% AFUE	Direct-fired Storage water heater, 70% AFUE
Exhaust Ventilation	Residential: 50 cfm/suite Amenity: 2.5 l/s-person + 0.3 l/s-m^2 Parking: 3.7 l/s-m^2	Office: 2.5 l/s-person + 0.3 l/s-m^2 Restaurant: 3.8 l/s-person + 0.9 l/s-m^2	Industrial Facility: 5.0 l/s-person + 0.9 l/s-m^2
Supply Ventilation	Residential: 50 cfm/suite Corridor: 40 cfm/door Amenity: 2.5 l/s-person + 0.3 l/s-m^2	Office: 2.5 l/s-person + 0.3 l/s-m^2 Restaurant: 3.8 l/s-person + 0.9 l/s-m^2	Industrial Facility: 5.0 l/s-person + 0.9 l/s-m^2
Plug Load (W/m^2)	Whole Building – 5.0	Whole Building – 7.5	Whole Building – 10.0
Occupancy (m^2/person)	Whole Building – 25.0	Whole Building – 25.0	Whole Building – 30.0
Schedules (from NECB 2015 Table 8.4.3.2)	Schedule G	Office: Schedule A Restaurant: Schedule B	Schedule A

The following table summarizes the estimated performance values for the Building Code Baseline and absolute targets to be achieved as part of this study.

Table 3: Project KPI Performance Targets

Building Code Baseline	Total	Intensity	High Performance Target	Net-Zero Ready Performance Target
Energy Use	54,960,326 (ekWh)	115.1 (ekWh/m^2)	80.5 (ekWh/m^2)	57.5 (ekWh/m^2)
GHG Emissions	6,306,212 ($kgCO_2$)	13.2 ($kgCO_2/m^2$)	6.6 ($kgCO_2/m^2$)	1.3 ($kgCO_2/m^2$)
Thermal Energy Demand	13,054,895 (kWh)	27.3 (kWh/m^2)	19.1 (kWh/m^2)	13.7 (kWh/m^2)

With the targets established the analysis can be performed for the high performance and net-zero ready performance for comparison.

4.2 HIGH PERFORMANCE DESIGN

To achieve the Higher Performance Energy Targets, both envelope and mechanical systems have been significantly improved. First of all, from the envelope perspective, significant effort has to be placed on minimizing linear thermal bridging to maximize the return from the investment into exterior envelope insulation. It is recommended to go at least with “Mitigated Path” as shown in the BC Hydro Building Envelope Thermal Bridging Guide where all the “Psi values” (measure of linear thermal heat loss in W/m-K) are kept at maximum 0.2 W/m-K[6]. Both opaque wall insulation and roof insulation have been improved relative to the Baseline. High-tier windows are also recommended given the high % window-to wall ration of the majority of buildings.

Compared to the baseline the mechanical systems need to be improved to achieve the High performance targets. The residential building operation could utilize the same central boiler/chiller supplying 4-pipe fan coil units as the baseline case however, to achieve the performance targets is would require condensing boilers with higher efficiencies and variable flow, along with a higher COP air-cooled chiller with variable flow. The corridors would also be supplied with gas-fired make-up air units with more efficient heat recovery. Domestic hot water would be supplied with higher efficiency condensing hot water heaters. The commercial and industrial buildings require electric variable air packaged units with direct expansion cooling coils.

The energy modelling parameters used for the high-performance energy model are summarized in Table X.

[6] (from Table 2 BC Hydro Building Envelope Thermal Bridging Guide)

Table 4: High Performance Energy Model Parameters

Component	Residential	Commercial	Industrial
Opaque Wall	Clear-field: R-25	Clear-field: R-22.9	Clear-field: R-22.9
Linear Thermal Bridging	Mitigated with linear transmittance 0.2 W/m-K	Mitigated with linear transmittance 0.2 W/m-K	Mitigated with linear transmittance 0.2 W/m-K
Below Grade Wall	Clear-field: R-19.9	Clear-field: R-19.9	Clear-field: R-19.9
Roof	Clear-field: R-50	Clear-field: R-50	Clear-field: R-36.4
Floor (in contact with ground)	Clear-field: R-7.5	Clear-field: R-7.5	Clear-field: R-7.5
Fenestration	U-1.42 W/m^2-°K + SHGC 0.43	U-1.90 W/m^2-°K + SHGC 0.40	U-1.90 W/m^2-°K + SHGC 0.40
Window-to-Wall Ratio	50%	48%	42%
Infiltration	0.25 L/(s.m^2) @ 5 Pa	0.25 L/(s.m^2) @ 5 Pa	0.25 L/(s.m^2) @ 5 Pa
Lighting Power Density (W/m^2)	Whole Building – 7.3 Suites – 5.0	Office – 5.0 Restaurant – 5.0	Whole Building – 5.0
Plant	Heating: Condensing Boiler 90% Efficient Variable Flow Cooling: Air Chiller 5.0 COP Variable Flow	-	-
HVAC	Residential and amenity: 4-pipe fan coil units Parking: Furnace 90% AFUE	Packaged VAV with electric reheat Heating coil: 100% efficient electric DX coil: 3.0 COP Fans: Variable volume, 70% total efficiency	Packaged VAV with electric reheat Heating coil: 100% efficient electric DX coil: 3.0 COP Fans: Variable volume, 70% total efficiency
Corridors Ventilation MUA	Gas Fired Central ERV 80% efficient, 40/20 cfm/door	-	-
Heat Recovery	Residential: Sensible 81% | Latent 81% Amenity: Sensible 81% | Latent 81%	Sensible 70% | Latent 70%	Sensible 70% | Latent 70%
Domestic Hot Water	Direct-fired Storage Condensing water heater, 93% AFUE	Direct-fired Storage Condensing water heater, 95% AFUE	Direct-fired Storage Condensing water heater, 95% AFUE
Exhaust Ventilation	Residential: 50 cfm/suite Amenity: 2.5 l/s-person + 0.3 l/s-m^2 Parking: 3.7 l/s-m^2	Office: 2.5 l/s-person + 0.3 l/s-m^2 Restaurant: 3.8 l/s-person + 0.9 l/s-m^2	Industrial Facility: 5.0 l/s-person + 0.9 l/s-m^2
Supply Ventilation	Residential: 50 cfm/suite Corridor: 40 cfm/door Amenity: 2.5 l/s-person+0.3 l/s-m^2	Office: 2.5 l/s-person + 0.3 l/s-m^2 Restaurant: 3.8 l/s-person + 0.9 l/s-m^2	Industrial Facility: 5.0 l/s-person + 0.9 l/s-m^2
Plug Load (W/m^2)	Whole Building – 5.0	Office – 7.5 Restaurant – 1.0	Whole Building – 10.0
Occupancy (m^2/person)	Whole Building – 25.0	Office – 25.0 Restaurant – 10.0	Whole Building – 30.0
Schedules (from NECB 2015 Table 8.4.3.2)	Schedule G	Office: Schedule A Restaurant: Schedule B	Schedule A

The following table summarizes the estimated energy and carbon emissions performance values for a High Performance compliant design, based on the system design assumptions specified.

Table 5: High Performance Energy Model Results

High Performance Building	Total	Intensity	High Performance Target
Energy Consumption	33,019,539 (ekWh)	69.1 (ekWh/m^2)	80.5 (ekWh/m^2)
GHG Emissions	2,505,506 ($kgCO_2$)	5.2 ($kgCO_2/m^2$)	6.6 ($kgCO_2/m^2$)
Thermal Energy Demand	9,006,479 (kWh)	18.9 (kWh/m^2)	19.1 (kWh/m^2)

The energy model results show that the proposed building systems and envelope are one prescribed path to meeting the High performance energy targets.

4.3 NET-ZERO READY PERFORMANCE

To achieve the Net-Zero Ready Energy Performance Targets, the building envelope has to be designed to be thermal-bridge free by following passive house design principles. Reduction of thermal bridging has a profound impact on reduction of heating demand which is dominating end use energy consumption as will be shown in the next section. To reduce the dominating heating demand even further, the window-to-wall ratio was reduced by 10% for residential type of buildings. Windows are major heat loss component across the envelope and reduction of relative proportion of transparent wall has a major effect in thermal energy demand.

In order to achieve the GHGI and energy targets the primary residential HVAC system had to be reconfigured to a geothermal heat pump loop, supplying in-suite water source heat pumps. Having constant access to the relatively non-changing ground temperature optimized heat pumps' performance which performance otherwise decreases with a decrease in outdoor temperatures like in case of air-source systems. The heating and cooling system for corridor pressurization has also been replaced by heat pump which further reduces the heating and cooling energy consumption in the building. The water heating system has also been switched to hybrid heat pump units which can be placed inside of each suite and enable easily accessible submetering. The domestic hot water system should also be reconfigured to utilize electric heat pumps with a COP of 4.25.

As the GHGI target for the net-zero ready performance is aggressive, the design team must consider electrification of all or nearly all building systems. As discussed later in the report, back-up options to improve resiliency must also be considered when utilizing electric systems in the event of a power outage.

Details of the proposed design for Net-Zero Ready performance are shown in the table below.

Table 6: Net-Zero Ready Energy Model Parameters

Component	Residential	Commercial	Industrial
Opaque Wall	Clear-field: R-25	Clear-field: R-22.9	Clear-field: R-22.9
Linear Thermal Bridging	Thermal bridge free – passive house design <0.01 W/m-K	Mitigated with linear transmittance 0.2 W/m-K	Mitigated with linear transmittance 0.2 W/m-K
Below Grade Wall	Clear-field: R-19.9	Clear-field: R-19.9	Clear-field: R-19.9
Roof	Clear-field: R-50	Clear-field: R-50	Clear-field: R-50
Floor (in contact with ground)	Clear-field: R-7.5	Clear-field: R-7.5	Clear-field: R-7.5
Fenestration	U-1.42 W/m^2-°K + SHGC 0.33	U-1.90 W/m^2-°K + SHGC 0.40	U-1.42 W/m^2-°K + SHGC 0.33
Infiltration	0.25 L/(s.m^2) @ 5 Pa	0.25 L/(s.m^2) @ 5 Pa	0.25 L/(s.m^2) @ 5 Pa
Window-to-Wall Ratio	40% (Reduced by 10%)	48%	42%
Lighting Power Density (W/m^2)	Whole Building – 5.0 Suites – 5.0	Office – 5.0 Restaurant – 5.0	Whole Building – 5.0
Plant	Geothermal hydronic loop for heating and cooling	-	-
HVAC	Residential and amenity: in-suite water-air heat pump for heating (COP 3.2) and cooling (COP 7.0) Parking: electric resistance	Packaged heat pump VAV with electric backup Heating DX coil: 3.5 COP with electric backup Cooling DX coil: 3.0 COP Fans: Variable volume, 70% total efficiency	Packaged heat pump VAV with electric backup Heating DX coil: 3.5 COP with electric backup Cooling DX coil: 4.0 COP Fans: Variable volume, 70% total efficiency
Corridors Ventilation MUA	Heat Pump Air Handler with 90% efficient heat recovery, 40/20 cfm/door	-	-
Heat Recovery	Residential: Sensible 81% | Latent 81% Amenity: Sensible 81% | Latent 81%	Sensible 70% | Latent 70%	Sensible 78% | Latent 78%
Domestic Hot Water	Heat Pump Water Heater, 4.25 COP	Heat Pump Water Heater, 4.25 COP	Heat Pump Water Heater, 4.25 COP
Exhaust Ventilation	Residential: 50 cfm/suite Amenity: 2.5 l/s-person + 0.3 l/s-m^2 Parking: 3.7 l/s-m^2	Office: 2.5 l/s-person + 0.3 l/s-m^2 Restaurant: 3.8 l/s-person + 0.9 l/s-m^2	Industrial Facility: 5.0 l/s-person + 0.9 l/s-m^2
Supply Ventilation	Residential: 50 cfm/suite Corridor: 40 cfm/door Amenity: 2.5 l/s-person + 0.3 l/s-m^2	Office: 2.5 l/s-person + 0.3 l/s-m^2 Restaurant: 3.8 l/s-person + 0.9 l/s-m^2	Industrial Facility: 5.0 l/s-person + 0.9 l/s-m^2
Plug Load (W/m^2)	Whole Building – 5.0	Office – 7.5 Restaurant – 1.0	Whole Building – 10.0
Occupancy (m^2/person)	Whole Building – 25.0	Office – 25.0 Restaurant – 10.0	Whole Building – 30.0
Schedules (from NECB 2015 Table 8.4.3.2)	Schedule G	Office: Schedule A Restaurant: Schedule B	Schedule A

The following table summarizes the estimated energy and carbon emissions performance values for a Net-Zero Ready performance compliant design, based on the system design assumptions specified.

Table 7: Net-Zero Ready Performance Energy Model Results

Net-Zero Ready Performance Building	Total	Intensity	Net-Zero Ready Performance Target
Energy Consumption	21,524,126 (ekWh)	45.1 (ekWh/m^2)	57.5 (ekWh/m^2)
GHG Emissions	645,723 ($kgCO_2$)	1.3 ($kgCO_2/m^2$)	1.3 ($kgCO_2/m^2$)
Thermal Energy Demand	6,215,680 (kWh)	13.0 (kWh/m^2)	13.7 (kWh/m^2)

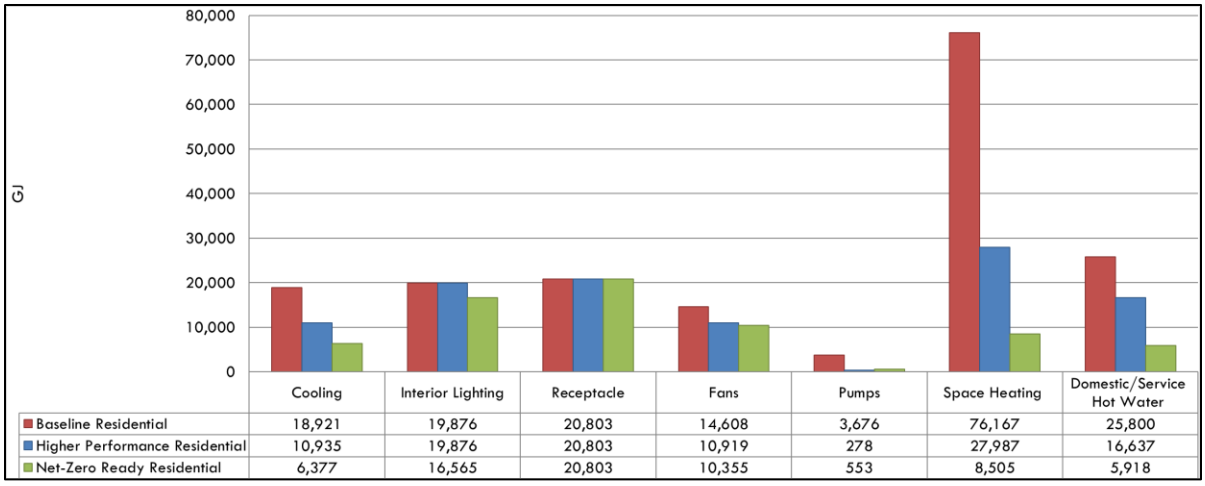
The energy model results show that the proposed building systems and envelope are one prescribed path to meeting the Net-Zero Ready performance energy targets. The design team may consider other options to meeting the targets, however, as shown, the design must move away from conventional building systems to achieve the desired results.

4.4 ENERGY ANALYSIS

Table below summarizes how each design meets the requirement of the Energy Study performance tier requirements.

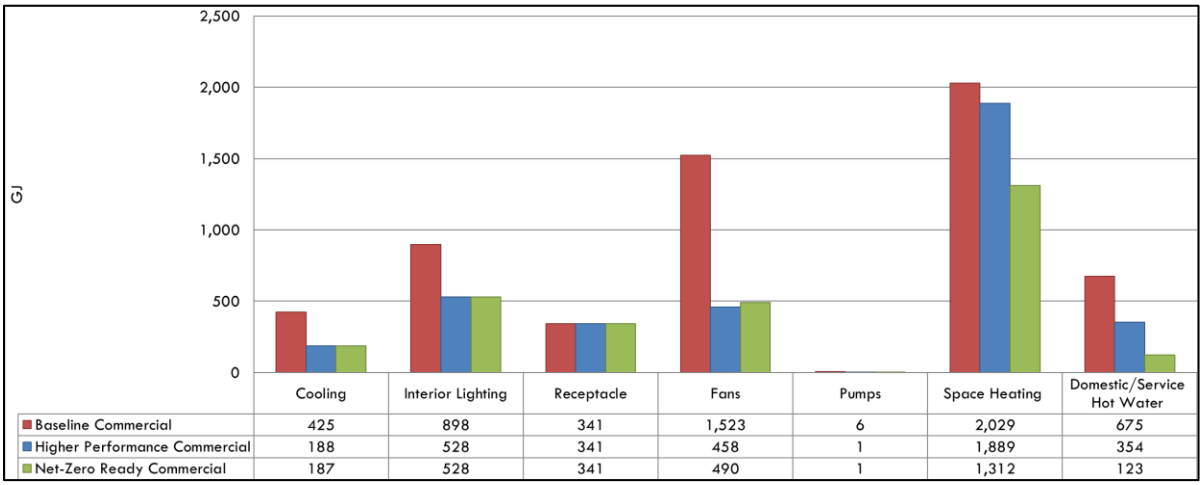
	Baseline Design	High Performance Requirement	High Performance Design	Net-Zero Ready Requirement	Net-Zero Ready Design
Total Energy Use Intensity (ekWh/m^2)	115.1	80.5	69.1	57.5	45.1
GHG Emission Intensity ($kgCO_2/m^2$)	13.2	6.6	5.2	1.3	1.3
Thermal Energy Demand Intensity (kWh/m^2)	27.3	19.1	18.9	13.7	13.0

For each space type the energy use for each system was broken down. The energy consumption results for the residential, commercial and industrial spaces are summarized in Figures 4, 5 and 6, below. The energy consumption breakdown can be used to determine the dominant energy uses within the proposed buildings in order to determine where the biggest energy reduction impacts can occur. The consumption is also split between the baseline, High performance and Net-Zero Ready performance.



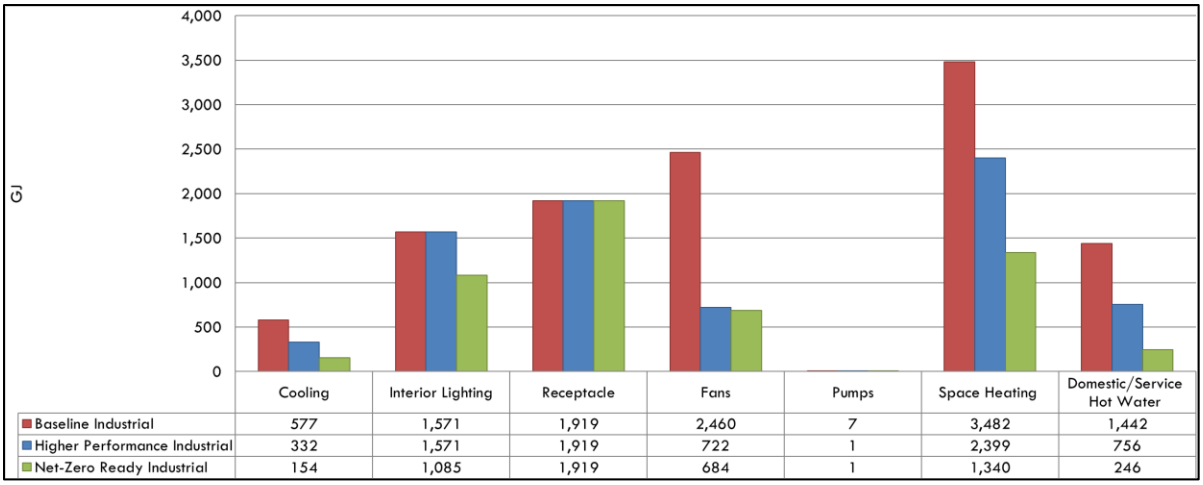
	Cooling	Interior Lighting	Receptacle	Fans	Pumps	Space Heating	Domestic/Service Hot Water
Baseline Residential	18,921	19,876	20,803	14,608	3,676	76,167	25,800
Higher Performance Residential	10,935	19,876	20,803	10,919	278	27,987	16,637
Net-Zero Ready Residential	6,377	16,565	20,803	10,355	553	8,505	5,918

Figure 5: Energy consumption breakdown for proposed residential buildings.



	Cooling	Interior Lighting	Receptacle	Fans	Pumps	Space Heating	Domestic/Service Hot Water
Baseline Commercial	425	898	341	1,523	6	2,029	675
Higher Performance Commercial	188	528	341	458	1	1,889	354
Net-Zero Ready Commercial	187	528	341	490	1	1,312	123

Figure 6: Energy consumption breakdown for proposed commercial buildings.



	Cooling	Interior Lighting	Receptacle	Fans	Pumps	Space Heating	Domestic/Service Hot Water
Baseline Industrial	577	1,571	1,919	2,460	7	3,482	1,442
Higher Performance Industrial	332	1,571	1,919	722	1	2,399	756
Net-Zero Ready Industrial	154	1,085	1,919	684	1	1,340	246

Figure 7: Energy consumption breakdown for the proposed industrial buildings.

As shown in the energy consumption breakdown the proposed buildings are largely heating dominant. The proposed systems for the High performance and Net-Zero Ready performance requirements drastically reduce the building energy consumption for heating. The improvements made to cooling and domestic hot water energy consumption are also apparent.

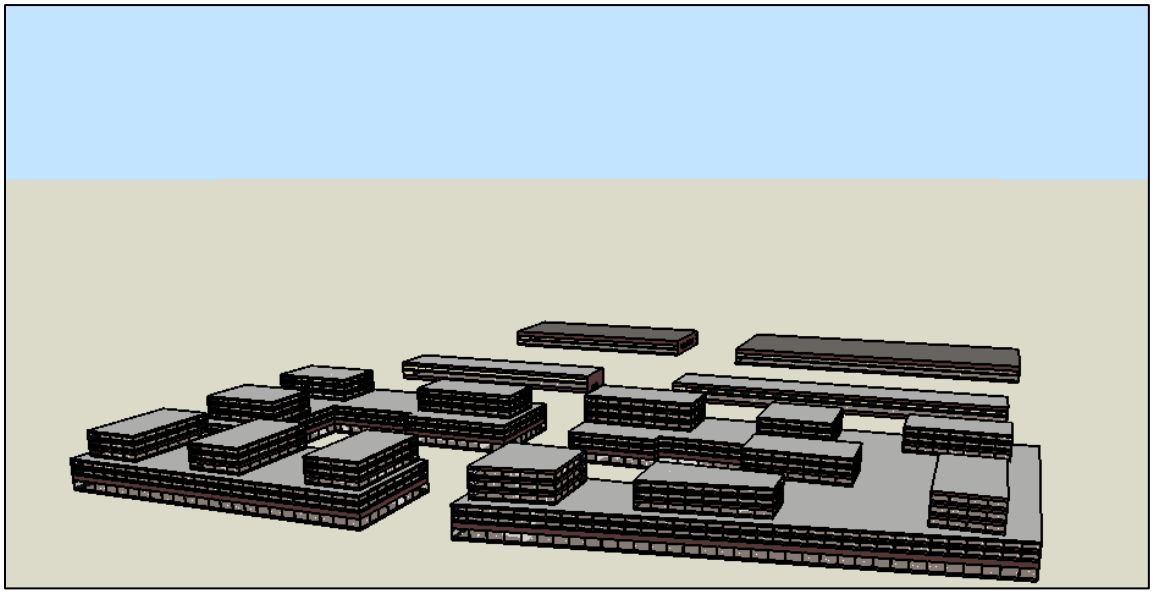


Figure 7: 3D Energy Model visualization with floor levels in multiplication factor mode to represent identical floors.

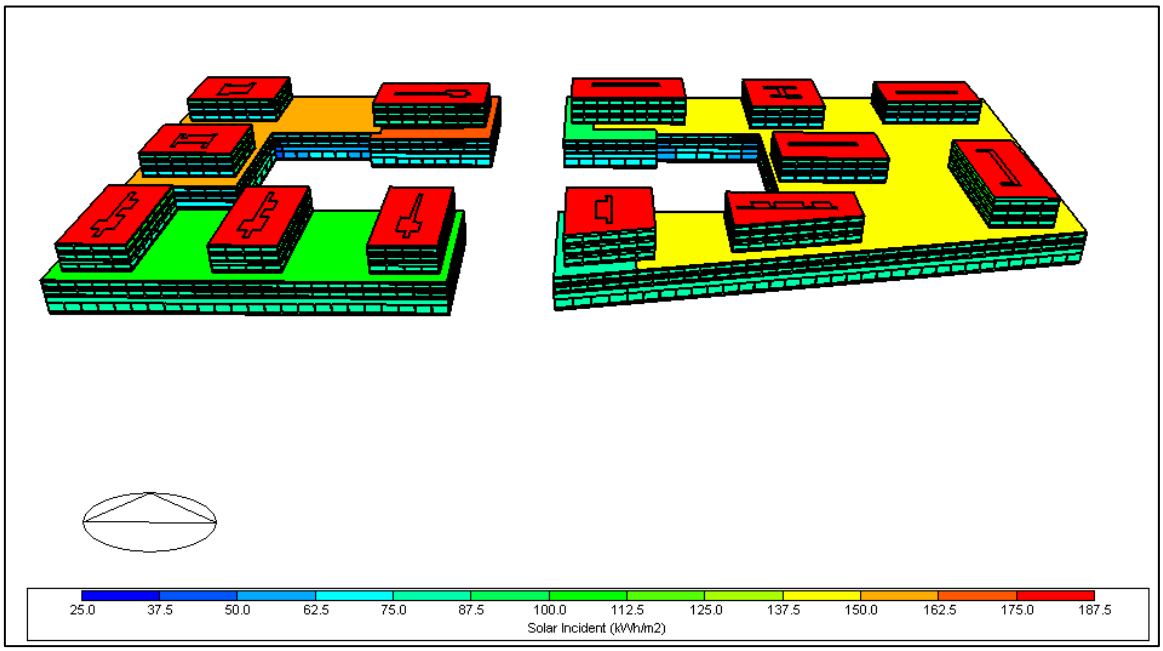


Figure 8: Normalized annual solar incidence on the residential buildings.

5 ENVELOPE ANALYSIS

Thermal performance is key to energy efficiency alongside to air leakage, and moisture safety as they pertain to durability, occupant comfort, and indoor air quality. The role of the building enclosure and the importance of integrating design of the opaque envelope, fenestration, and mechanical system is demonstrated through energy simulation as discussed in the section above.

Based on the available schematic drawings and building types two major design options have been identified for residential and non-residential buildings as follows:

5.1 RESIDENTIAL

To preserve the original 50% window-wall ratio (WWR) while achieving higher performance targets set by the city of Waterloo it is necessary to implement integrated design principles at the concept design phase of the project while minimizing thermal bridging. The proportion of total heat loss through the different sections of the building envelope has the following breakdown for the Baseline Building:

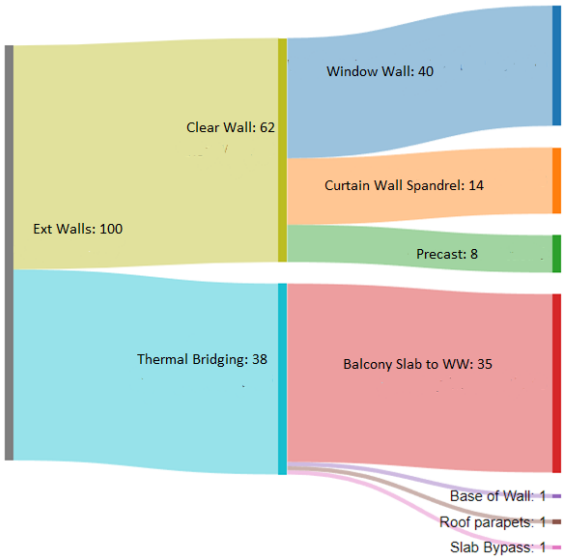


Figure 8: Relative heat loss through the components of enclosure in the Baseline building.

In a high-rise residential building with a substantial amount of WWR, most of the heat loss due to thermal bridging occurs at the transition of the window to the wall followed by the penetrating balconies slab through the wall and thus the necessary emphasis has to be made to minimize heat loss across those sections. Window transition transmittance is the heat flow through the frame; Importance of window perimeter reductions - window and wall combination choices affect the performance of the entire building. The typical envelope system for the high-rise residential building would be window-wall or spandrel panel system with interior spray foam and backpan insulation. Spandrel sections are considered part of the opaque assembly, but they do not perform as “real walls”. The effective insulation of the spandrel section is limited because of the conductive framing and repetitive bracing elements which introduce the significant heat loss through point-based thermal bridging. The large format spandrel panels with 25 mm of continuous interior insulation are key to the panels used in the buildings today, however improving the spandrel beyond R-12 is not feasible; The design team will need to evaluate the need for spandrel panels and should

consider converting to a “real wall”. The typical wall assembly that can be used in the high-rise residential building and that was assumed in the energy model is shown in Figure 10:

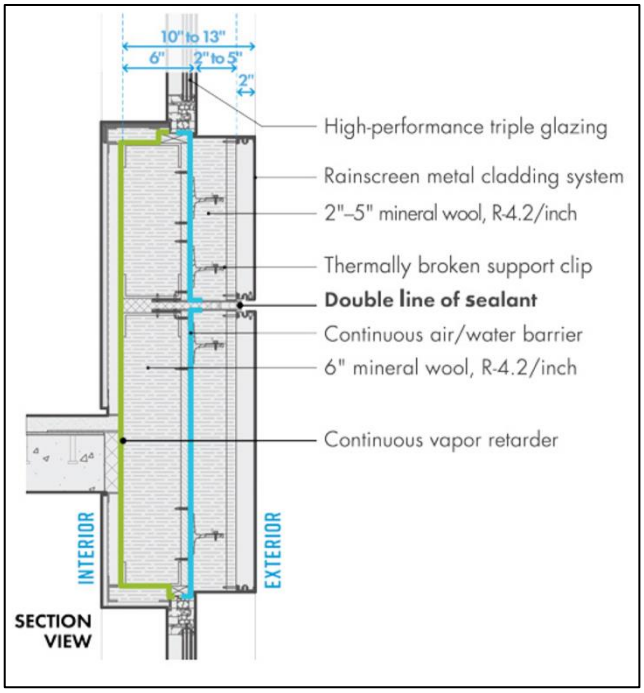


Figure 9: Typical high-performance wall assembly for a high-rise residential building. Note: 2” mineral wool is assumed for the High-Performance Design and 5” for the Net-Zero ready.

Another feasible option that would enable to use curtain wall system while achieving clear-field R-value above R-20 would be using Large Format Prefabricated facade panels that, for example, was successfully implemented in the CURV building in Vancouver – tallest Passive House certified building in the world.

Unlike the opaque enclosure, windows are tested assemblies; The U-value of the window assembly measures the insulating characteristics of the glass, or how much heat flow or heat loss occurs through the glass due to the difference between indoor and outdoor temperatures, and accounts for the whole window, including glazing, frame, and spacers. Center-of-glass (COG) describes the performance of the glazing alone without the effects of the frame whereas U-values are effective and take into consideration the thermal bridging through the frame elements. The

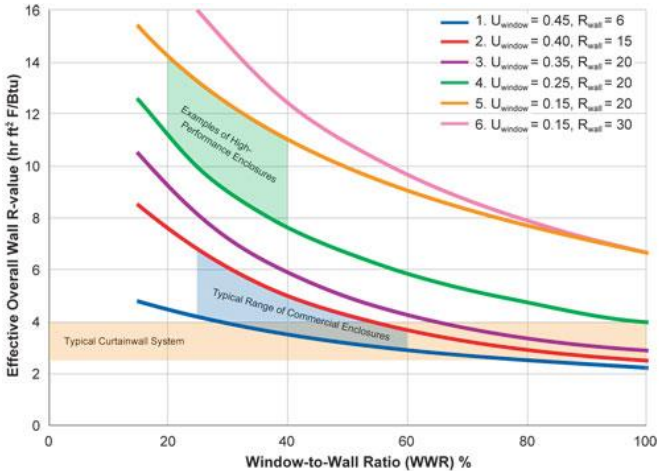


Figure 10: Relationship between nominal and effective insulation against the WWR in a high-rise building.

proposed building has a WWR of 50%, whereas 40% is the maximum for the Reference Building under the Building Code. Even with high performance products it would be challenging to achieve an R-12 effective for the overall wall R-value with such a high WWR (Figure 11).

While frames are only 5%-8% of the window system, they have a significant impact on performance, it is important to understand how heat can be lost through the frame. Aluminum frame is non-combustible, lightweight, strong, and flexible, it is also highly conductive. Aluminum windows are typically poorer performing frames and the heat loss through these can impact the functionality of the space. High-performance framing includes hybridized systems and non-metal framing. More consideration is being given to non-metal components and engineered composites which are very efficient in cold climates. For the curtain wall system to be designed for entrance and amenity areas of the building, it is advised to use structured silicone glass (SSG) curtainwall products with fiberglass or polyamide pressure plate which improve energy performance by 8-10% due to reduced frame and thermal bridging by replacing metal components with silicone bond joints. Punched window systems are the most thermally efficient and allow more flexibility with respect to the products that can be used in their construction. The triple-glazed punch windows with USI 1.42 have been assumed for residential buildings with SHGC between 0.3 and 0.4. Provisions should be made so that the new windows can be installed in the new insulation layer.

For the roof system, R-50 clear-field is required for both High Performance and Net-Zero ready designs to achieve required targets. It is recommended to consider an inverted roof system as it has a higher life span with the membrane being more protected, and its durability is enhanced because the roof is subject to less stress, e.g., temperature changes. With multiple layers of insulation, it is recommended to use ship-lapped insulation boards to minimize thermal bridging at insulation joints and stagger the joints to prevent/minimize losses that can occur when insulation joints open due to movement caused by thermal expansion and contraction. It is also recommended to consider hybrid installation where the layer of mineral wool keeps the base layer of Polyiso warm. Polyiso performance decreases as temperature decreases whereas the performance of mineral wool improves as it gets colder. Polyiso expands and contracts and is less dimensionally stable than mineral wool during hot and cold temperatures.

There are similar challenges with precast and a cast in place concrete balcony. Linear transmittance at various balcony conditions has to be considered. The project is considering cassette balconies which will provide the same level of improvement as a continuous structural thermal break with an insulated curb; This can have a significant impact on keeping the steel structure on the inside warm and help to manage the risk of condensation and ameliorate comfort.

5.2 COMMERCIAL/INDUSTRIAL.

For the one-story commercial and industrial buildings, a different approach has to be taken due to lower window-wall ratios, absence of significant thermal bridging sources like balconies and less stringent architectural aesthetics requirements.

Exterior Finish:

The exterior finish would consist of durable and weather-resistant materials, such as insulated panels or high-performance light cladding systems, providing both aesthetic appeal and protection against the elements. Using the lightweight cladding in lieu of brick or precast allows a reduction in losses at slab edges and bearing points. Clip thermal conductivity can have a significant impact on the thermal performance of the wall assembly; low conductivity or thermally broken cladding attachments should be considered for lightweight cladding. Thermally efficient cladding attachments improve the clear-field value of the insulation; continuous Z-girts derate the value of the insulation significantly and a thermal break offers a slight improvement. It is recommended to use fibreglass clips, thermally broken clip systems or galvanized clips with holes. Some suppliers will have their own clip, rail and cladding; some systems may be proprietary and others may be specific installation of an assembly of preferred components.

Thermal Insulation:

The wall assembly would feature a continuous highly insulated 5” semi-rigid mineral wool exterior layer to minimize thermal bridging. Commonly used insulation materials include rigid foam boards or mineral wool, achieving a high R-value to meet passive house standards.

Air Barrier:

A continuous air barrier would be integrated into the wall assembly to prevent unwanted air leakage. This might involve the use of specialized membranes or airtight sheathing materials.

Vapor Barrier:

A vapor barrier would be included to control the diffusion of moisture through the wall assembly. This barrier helps prevent condensation issues within the insulation layer.

Structural Framing:

The structural framing could be steel or concrete, providing strength and stability to the building. The framing would be designed to minimize thermal bridging, through the use of thermal breaks.

Window Openings:

Window openings would be carefully framed to accommodate the chosen punched double-pane, low-emissivity coated windows with composite frame and associated thermal characteristics of USI 1.9 and SHGC of 0.4. The framing would incorporate thermal breaks to reduce heat transfer around the window perimeter and installed to be aligned with exterior insulation.

Interior Wall Finish:

The interior wall finish would typically consist of materials with low VOC (volatile organic compound) emissions to maintain good indoor air quality. Drywall or other sustainable interior finishes may be used.

Thermal Mass:

Depending on the design, thermal mass elements, such as concrete blocks or phase change materials, might be incorporated into the wall to help stabilize indoor temperatures by absorbing and releasing heat.

Interior Insulation:

Additional insulation may be added on the interior side of the structural framing to reduce thermal bridging and enhance overall energy efficiency.

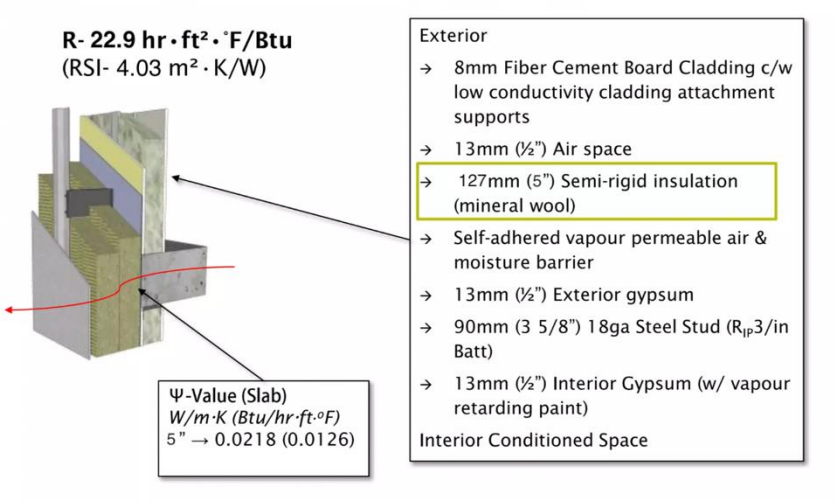
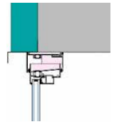
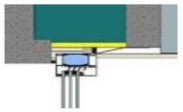
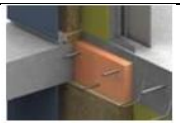
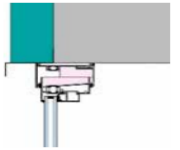


Figure 11: Proposed wall assembly for industrial and commercial buildings. Applicable to both High Performance Design and Net-Zero Ready

The typical wall section proposed below (Figure 12) is designed to provide a balance between thermal performance, durability, and functionality for a commercial or industrial building incorporating passive house design principles.

Recommended clear-field roof insulation is R-50 and R-34 for commercial and industrial to achieve High Performance targets and R-50 for both designs to achieve Net-Zero ready targets. The attention has to be given to parapets and fasteners by the design team to minimize thermal bridging through the roof; the parapets should have the continuous insulation on all sides that is close to the value of the insulation of the attached wall. It is recommended to design hybrid installation where the layer of mineral wool keeps the base of the Polyiso warm; Polyiso performance decreases as temperature decreases, and the performance of mineral wool improves as it gets colder.

Overall, based on the Building Envelope Thermal Bridging Guide analysis method, the following linear thermal bridging coefficients are assumed for the transitional components in the building enclosure:

Building Type	Performance Target	Thermal bridge category	Transmittance φ	Description and Examples	
Residential	High Performance	Mitigated	0.2 W/m K	**Thermally broken connections with good aliment of adjacent thermal insulation** Examples: large structural thermal breaks where the thickness of the thermal break is similar in size as the thermal insulation.	
				Well aligned glazing with minimal conductive bypasses Examples: the glazing thermal break is within the wall insulation, but there is thermal bridging related to conductive window frames, flashing partially bypasses the exterior insulation, and un-insulated window perimeters.	
	Net-Zero Ready	Thermal-bridge free	<0.01 W/m K	**Fully exterior insulated and fully aligned thermal insulation between components** Examples: exterior insulated walls at intermediate floors.	
				Well aligned glazing without conductive bypasses and minimal thermal bridging in clear wall Examples: wall insulation is aligned with the glazing thermal break and insulation is provided around the perimeter of the window framing. Flashing does not bypass the thermal break. Low conductive window frames and/or insulation outboard of the window frame.	
Non-residential	High Performance	Mitigated	0.2 W/m K	**Thermally broken connections with good aliment of adjacent thermal insulation** Examples: large structural thermal breaks where the thickness of the thermal break is similar in size as the thermal insulation.	
				Well aligned glazing with minimal conductive bypasses Examples: the glazing thermal break is within the wall insulation, but there is thermal bridging related to conductive window frames, flashing partially bypasses the exterior insulation and uninsulated window perimeters.	
	Net-Zero Ready	Mitigated	0.2 W/m K	**Thermally broken connections with good aliment of adjacent thermal insulation** Examples: large structural thermal breaks where the thickness of the thermal break is similar in size as the thermal insulation.	
				Well-aligned glazing with minimal conductive bypasses Examples: the glazing thermal break is within the wall insulation, but there is thermal bridging related to conductive window frames, flashing partially bypasses the exterior insulation, and uninsulated window perimeters.	

6 EMBODIED CARBON ANALYSIS

In the dynamic landscape of the construction industry, sustainable practices have become a focal point in addressing the environmental impact of building projects. While much attention has traditionally been given to operational energy use and efficiency, there is a growing recognition of the significance of embodied carbon in materials. Reducing a project's embodied carbon can provide additional value besides reducing carbon emissions. These reductions can often reduce costs, improve air quality and public health and help the building design be better prepared for future code and policy changes that incentivize or require low embodied carbon or carbon reduction.

As the building design is still in preliminary stages it is important to consider the impact of material selection prior to final design and construction when changes are more easily implemented due to cost and time constraints. In determining what material would have the highest embodied carbon content the embodied carbon per kilogram can be referenced from Figure 13, below.

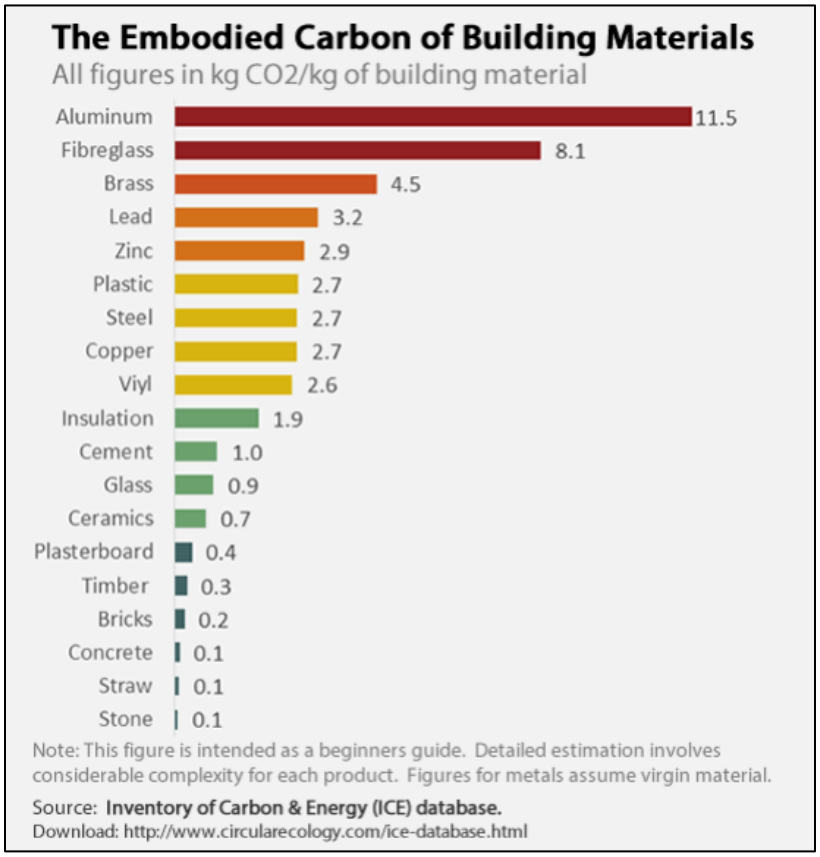


Figure 12: Embodied carbon per unit mass of typical building materials.

This suggests that aluminium should have the highest embodied carbon per unit mass while less processed materials including stone and concrete have much less. Due to the size of the proposed development it is expected that a large amount of concrete will be used to create the building foundations and structures. Therefore, the Energy Study will consider concrete as the material with the highest embodied carbon content for the project even though concrete does not have a high carbon content per unit mass relative to other standard building materials.

It should be noted that concrete and cement in this case are not interchangeable. Concrete is a mix of cement water and aggregate with cement being key ingredient used to bind the materials together to form concrete. Nearly 60% of CO2 emissions from cement production comes from chemical reactions that occur when producing clinker, an

intermediate component of cement[7]. Therefore, one way to reduce the embodied carbon content of cement is by replacing clinker with supplementary cementitious material (SCMs) such as slag or fly ash. Additionally, higher quality aggregate can reduce the amount of cement needed to produce concrete as it offers better adhesion properties. Increasing the concrete curing time can reduce the amount of cement required and lower the embodied carbon content. The project team should evaluate where this is possible as extending the curing time may not be feasible for certain structural elements such as foundations and columns.

The fuel used to produce clinker typically requires fossil fuels to heat the kilns. Electrification of the cement production including the use of alternative fuels such as biomass are key to lowering the embodied carbon content of concrete. Where possible the project should be aware of the source of the cement being used on the project and try procure from manufacturer's pursuing these alternative fuel sources.

The project team should also consider mass timber construction where feasible. Mass timber construction is built using engineered wood products typically manufactured off-site for load-bearing walls, floors and roofs. Mass timber can be engineered for high strength ratings similar to concrete and steel but is significantly lighter. It can complement light-frame or hybrid construction options and is much less carbon intensive than cement or steel.

In order to reduce embodied carbon in the design other options for the design and project team to consider are:

- Consider salvaging or reusing materials from buildings that are to be deconstructed.
- Ensure structural systems are compact, efficient and not oversized.
- Design flexible and efficient spaces that allow for long-term changes in use.
- Implement and consider strategies to reduce construction material waste.
- Incentivize bidders to offer lower embodied carbon materials and methods.

7 RESILIENCY

In addition to establishing energy and performance targets the Region of Waterloo has recognized the need to prepare its built environment for the impact of climate change. Projected conditions for the Waterloo region include[8]:

- regularly experience extreme heat days with temperatures above 39 degrees Celsius.
- the number of extreme heat days (i.e. temperatures above 32 degrees Celsius) experienced each year could double by 2050, and increase to 50 days annually by 2100.
- Average annual precipitation is estimated to be 12% higher for the 2051-2080 period and 17% higher for the last 30 years of this century.
- More frequent storms are likely to occur, including short duration, high intensity precipitation events that lead to flash flooding in urban areas.

New buildings must be constructed in a way which reduces the impact of the future climate on Waterloo's buildings. This includes design considerations intended to mitigate flood events, improve thermal resilience, and extend the duration of back-up power generation. Building resilience can be modeled using temperature decay after 72 hours and two weeks using a typical weather file for Waterloo following a power outage beginning January 24th. A lower TEDI has a clear correlation with improved thermal comfort resiliency for the built environment. This will play an increasingly important role as our climate changes.

To increase building resiliency, it is recommended that design team consider advanced back-up power solutions instead of minimum code requirements for emergency power. The emergency power provides life safety

[7] Gagg. *Cement and Concrete as an Engineering Material,* 2014; and US Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, 2020.

[8] Region of Waterloo. *Our Climate and Energy Transition*. Accessed February 12, 2024 from: https://www.regionofwaterloo.ca/en/living-here/climate-change-and-extreme-weather.aspx#Projected-Conditions

requirements for occupant evacuation and firefighters access, while back-up power provides non-life safety requirements such that occupants can remain in their units safely for at least 72 hours when evacuation is not necessary. See the table below for more details.

Table 8: Emergency and Back-up Power Requirements

	Emergency Power	Back-up Power
Purpose	Minimum life safety requirements	Non-life-safety requirements for occupant wellbeing
Duration	2 hours (Building Code requirement)	72 hours (Federal emergency preparedness guideline)
Loads	Fire pumps, fire elevator, stair pressurization fans, alarm system	Water supply, minimum space heating, domestic booster pumps, additional elevators, power to common refuge area

In Waterloo, the list of likely threats includes extended heat waves, severe rainfall events, and power outages. These can be mitigated by the following strategies:

- Locate critical equipment above the flood plain.
- Protect critical areas with both permanent and temporary flood barriers to ensure spillover elevation into the building is greater than the identified flood level.
- Rely on sump pumps or wet flood proofing only when reliable stand-by power is available.
- Use mold resistant materials in areas that are at risk of becoming wet during a flood.
- Provide on-site stand-by power generation. It is important to assess the risk of fuel supply failure and determine if on-site fuel storage is required.
- Provide emergency back-up and dedicated HVAC systems to small amenity areas to creates “cool rooms (and/or heating rooms)” during power outages causes by heat (and/or cold) waves so that vulnerable populations can shelter in place.
- Enable “islanding” capability for on-site renewable electric generation during utility outages or grid disconnects.
- Improve passive survivability with super-insulated envelopes by allowing residents to shelter in place longer during a power outage (Once a power outage occurs, spaces with poor performing envelopes such as heavy glazing and spandrel panel will become unbearable in a few days’ time. Areas designed with better envelopes stay comfortable longer during winter and summer).

Incorporating these measures into the design will allow the buildings to maintain functionality during and after extraordinary events.

8 CONCLUSIONS

The energy study was performed for a new mixed-use, 161,875 square meter development located in Waterloo, Ontario. Energy models for the residential, commercial and industrial buildings were created using Energy Plus and Design Builder and the Total Energy Use Intensity (TEUI), Thermal Energy Demand Intensity (TEDI) and Greenhouse Gas Emissions Intensity (GHGI) were estimated for three scenarios. These scenarios included the Building Code as a baseline, compared to the High performance and Net-Zero Ready performance scenarios. The high-performance scenario required TEUI and TEDI reductions of 30% and GHGI reductions of 60% while the Net-Zero Ready performance required TEUI and TEDI reductions of 50% and GHGI reductions of 90%.

The development project and design team should be able to achieve all three target scenarios according to the energy model results. To achieve the Higher Performance Energy Targets, both envelope and mechanical systems have been significantly improved. First of all, from the envelope perspective, significant effort has to be placed on minimizing linear thermal bridging to maximize the return from the investment into exterior envelope insulation where all the “Psi values” (measure of linear thermal heat loss in W/m-K) are kept at maximum 0.2 W/m-K. To achieve the Net-Zero Ready energy performance targets, the building envelope has to be designed to be thermal-bridge free by following passive house design principles. To reduce the dominating heating demand even further, the window-to-wall ratio was reduced by 10% for residential type of buildings.

Compared to the baseline the mechanical systems need to be improved to achieve the high-performance targets. The residential building operation could utilize the same central boiler/chiller supplying 4-pipe fan coil units as the baseline case however, to achieve the performance targets is would require condensing boilers with higher efficiencies and variable flow, along with a higher COP air-cooled chiller with variable flow. The corridors would also be supplied with gas-fired make-up air units with more efficient heat recovery. Domestic hot water would be supplied with higher efficiency condensing hot water heaters. The commercial and industrial buildings require electric variable air packaged units with direct expansion cooling coils. In order to achieve the GHGI and energy targets for the Net-Zero Ready case, the primary residential HVAC system had to be reconfigured to a geothermal heat pump loop, supplying in-suite water source heat pumps. Having constant access to the relatively non-changing ground temperature optimized heat pumps’ performance which performance otherwise decreases with a decrease in outdoor temperatures like in case of air-source systems. The heating and cooling system for corridor pressurization has also been replaced by heat pump which further reduces the heating and cooling energy consumption in the building.

Additionally, the impact of adding solar PV and other renewables was assessed with solar PV providing significant energy and GHG reductions. Advanced energy solutions including the feasibility of district energy, geothermal loops and other advanced energy reduction technologies was discussed. The design team may consider these to help improve building energy performance moving forward.

An embodied carbon analysis was completed for the proposed development with concrete being identify as the largest embodied carbon material consumed for the construction of the development. Several opportunities to reduce the concrete use and embodied carbon of concrete consumed during construction provided. Finally, several options to increase building resiliency were provided for the design team’s consideration.