



ENERGY STRATEGY STUDY - Draft

Dunbar Road N. Residential Development Waterloo



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Executive Summary

DEI Consulting Engineers was retained by 360 Pacifica Capital Corporation to complete an Energy Strategy Study for a new residential building located at 1 Dunbar Road N in Waterloo. The intent of this Study is to develop an Energy Strategy as required by the zoning by-law amendment for the proposed site. The energy strategy will evaluate various energy conservation measures (ECMs) required to achieve the targets of a high-performance scenario and a Net-Zero Ready (NZR) performance scenario.

The targets for the high-performance scenario are 30% reduction in Total Energy Use Intensity (TEUI), Thermal Energy Demand Intensity (TEDI) and at least 50% reduction in Greenhouse Gas Emissions Intensity (GHGI), all relative to the Ontario Building Code (OBC) SB-10 baseline. NZR performance targets are at least 60% reduction in TEUI, TEDI and at least 90% reduction in GHGI, all relative to the baseline. The path followed for this analysis is NECB 2015 Division B part 8 as modified by OBC SB-10(2017) Division 3.

The architectural design intent for this building includes a few intentional energy efficient design elements. Firstly, the building form has been designed to reduce total perimeter walls, by maintaining straight wall elements and eliminating recessed balconies. This design improves the heat loss form factor and reduces overall energy consumption by reducing perimeter wall area. Secondly, the balcony system proposed for the site is a glide-on prefabricated system, which greatly reduces thermal bridging often seen in conventional construction.

A code minimum baseline energy model was made to analyze the strategies that can reduce the energy use intensity, annual emissions, and potential energy costs of the baseline model. The energy model consists of a 10-storey multi-unit residential building with 158 suites, 2 parking levels, and one amenity room. This energy model was created using IESVE.

A baseline model uses the OBC SB-10 building envelope thermal characteristics requirements. The Fenestration and Door area to gross Wall Ratio of the building is 0.387. The mechanical plant consists of a 4-pipe fan coil system which utilizes SB-10 compliant condensing boilers and chillers for heating and cooling, respectively. Multiple changes were made to the building envelope and the mechanical systems of the baseline model, and the resulting building energy performance was compared against the baseline.

The TEUI and TEDI of the baseline model were 230.2 kWh/m² and 101.1 kWh/m², respectively. The GHGI of the baseline model was 34.19 kg CO₂e/m². After making changes to the building envelope and the mechanical system, the high-performance building scenario had a 40.4% reduction in TEUI, 36.9% reduction in TEDI and 54.7% reduction in GHGI from the baseline model. For the NZR performance scenario, there was 70.3% reduction in TEUI, 64.6% reduction in TEDI and 90.0% reduction in GHGI from the baseline model. Various ECMs used to achieve these improvements are outlined in this report.

Regards,



Ann Demaille, P.Eng.
Partner

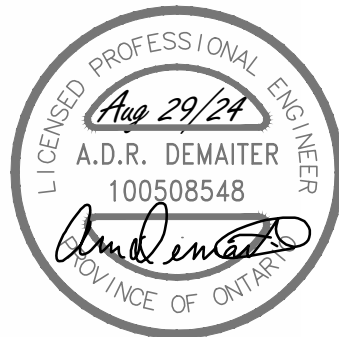


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1.0 Introduction

The purpose of this report is to explore how different approaches to energy efficiency can impact the proposed new development. Energy analysis of a building code baseline model was completed, and the impact of various Energy Conservation Measures (ECMs) was compared against the baseline. A combination of different ECMs was used to achieve a High-Performance building scenario and a NZR Performance scenario. This has resulted in a proposed building model with a considerably lower annual energy consumption and demand. The targets for the high-performance scenario are at least 30% reduction in TEUI, TEDI and at least 50% reduction in GHGI, all relative to the Ontario Building Code (OBC) SB-10 baseline. NZR performance targets are at least 60% reduction in TEUI, TEDI and at least 90% reduction in GHGI, all relative to the baseline.

The energy model consists of a 10-storey Multi-unit Residential Building (MURB) with 158 suites, 2 parking levels, and one amenity room. A baseline model uses the OBC SB-10 building envelope thermal characteristics requirements. The Fenestration and Door area to gross Wall Ratio of the building is assumed to be 0.387 (which is the maximum allowable FDWR for Waterloo under NECB prescriptive method).

The baseline mechanical plant consists of a 4-pipe fan coil system which utilizes SB-10 compliant condensing boilers and chillers for heating and cooling, respectively. The domestic hot water is provided by gas fired condensing boilers. A gas fired rooftop make up air unit with DX cooling supplies outdoor air to building corridors at the rate of 30 CFM/door. Space heating for stairwells, vestibules, storage rooms, etc. is provided by hydronic heaters. The building uses NECB 2015 default loads and profiles for domestic hot water and lighting power density.

Multiple changes were made to the building envelope and the mechanical system of the baseline model to create the proposed models. The impact of each change on the annual energy consumption is analyzed in this report.



2.0 3D Model

Figure 2-1 represents the 3D rendering of the building. It is a 10-storey MURB with 158 suites, 2 parking levels, and one amenity room.

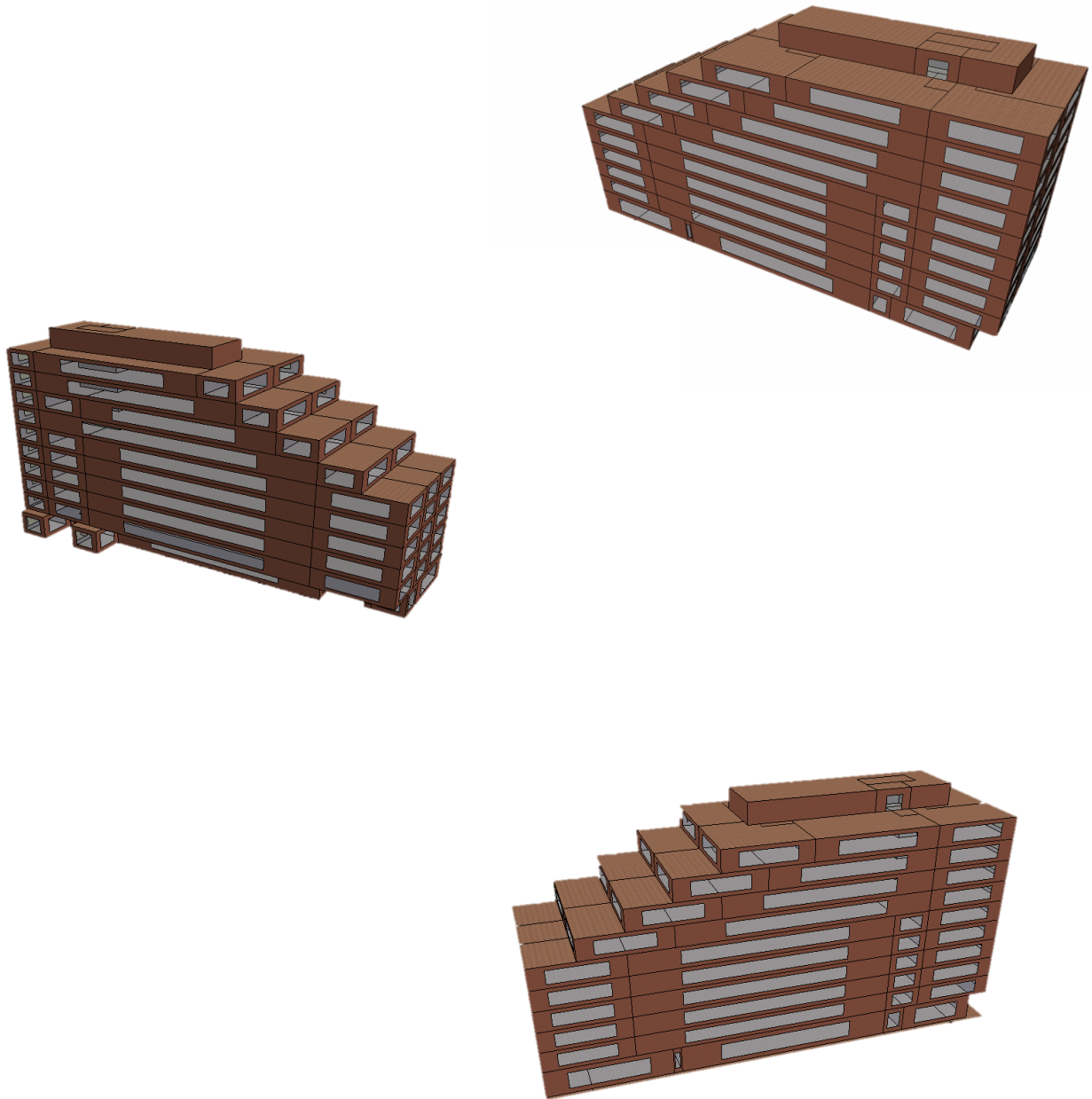


Figure 2-1 – Proposed Building 3D Rendering



3.0 Assumptions and Data

To calculate the annual energy consumption, thermal energy demand and annual emissions of the baseline building, and emissions for different upgrades, following assumptions were used:

3.1 Fenestration and Door area to gross Wall Ratio (FDWR)

As per NECB 2015 prescriptive method, the maximum FDWR ratio for a building in Waterloo is 0.387. Since the building envelope design for this project is still in the preliminary stages, the baseline building energy model has been constructed with FDWR of 0.387.

3.2 Baseline Building Mechanical System

Under the NECB 2015 energy modeling requirements, the mechanical system selection for the reference building model must match the mechanical system of the proposed building. Therefore, if an air source Variable Refrigerant Flow (VRF) system is selected for the proposed building to meet the Energy Strategy Report requirements, the corresponding mechanical system of the reference building changes to air source heat pump system.

Showing carbon and energy savings in this case is near impossible, with an already decarbonized building. For the purposes of this report, condensing boilers and chillers serving 4-pipe fan coil system were used for the baseline model to show appropriate savings of building improvements. The proposed model uses an air source VRF system for heating and cooling.

4.0 Model Inputs

Summary of inputs for the baseline energy model are presented here in Table 4.1.

Table 4.1: Summary of Inputs

General items	Simulation inputs
Location	Waterloo, Ontario
ASHARE Climate Zone	Zone 6 (As per NECB 2015)
Weather file	CAN_ON_Elora-RCS_6142286_CWEC
Modelling Software	IES-VE
Conditioned Floor Area	140,347 ft ²
Space Activity	Residential multi-family
Building Schedules	NECB Default Schedules C NECB Default Schedules G NECB Default Schedules H
Hours of Operation	24 Hours
Architectural Items	Baseline
Fenestration and Door to Wall Ratio (FDWR)	0.387
Windows U-value (Btu/h-ft ² -F°)	0.335 all windows (As per SB-10 Table SB 3.2.2.3)
Shading Coefficient	0.45
Visible Transmittance	0.71
Exterior Walls U-value (Btu/h-ft ² -F°)	0.0435 (As per SB-10 Table SB 3.2.2.2)



Roof U-value (Btu/h-ft²-F°)	0.027 (As per SB-10 Table SB 3.2.2.2)
Infiltration	0.0492 CFM/ft ² (As per NECB 2015)
Mechanical Items	Baseline
Mechanical Plant	4-Pipe fan coil units 2X boilers @ 90% thermal efficiency Water-cooled chiller COP 5.33 (As per SB-10 Table SB 5.2.12.1A-2017 and NECB-2017 Table 5.2.12.1)
Make Up Air System	Design Capacity 30 CFM/door Heating, 80% Thermal Efficiency Cooling, 9.5 EER (As Per NECB-2015 Table 5.2.12.1)
DHW	NECB-2015 default loads 90% Thermal Efficiency (As per SB-10 1.1.1.9)
Electrical Items	Baseline
Lighting, W/ft²	0.46 (W/ft ²) Suites 0.66 (W/ft ²) Corridor 0.58 (W/ft ²) Stairs 1.07 (W/ft ²) Amenity/Commercial 1.00 (W/ft ²) Lobby (As per SB-10 Table SB 4.2.1.6.-2017)
Plug Load, W/ft²	0.46 (W/ft ²) (As per NECB 2015)

5.0 Baseline Model Results

Summary of outputs for the energy model are presented here in Table 5.1. Charts 5.2 and 5.3 represent the annual and monthly energy breakdown for the baseline model.

Table 5.1: Summary of Outputs

Annual Energy Summary		
Annual consumption Summary	Baseline Building Energy	Units
Space Heating	1,561.84	MWh
Space Cooling	85.39	MWh
HVAC Auxiliary	189.36	MWh
Misc. Electrical	234.59	MWh
Service Hot Water	715.63	MWh
Interior Lighting	213.46	MWh
Total Annual Energy	3,000.26	MWh
Thermal Energy Demand Intensity (TEDI)	101.1	kWh/m ²
Total Energy Use Intensity (TEUI)	230.2	kWh/m ²
Greenhouse Gas Emissions Intensity (GHGI)	34.19	Kg CO ₂ e/m ²



Chart 5.2: Baseline Building Annual Energy Consumption Breakdown (MWh):

Range: Fri 01/Jan to Fri 31/Dec

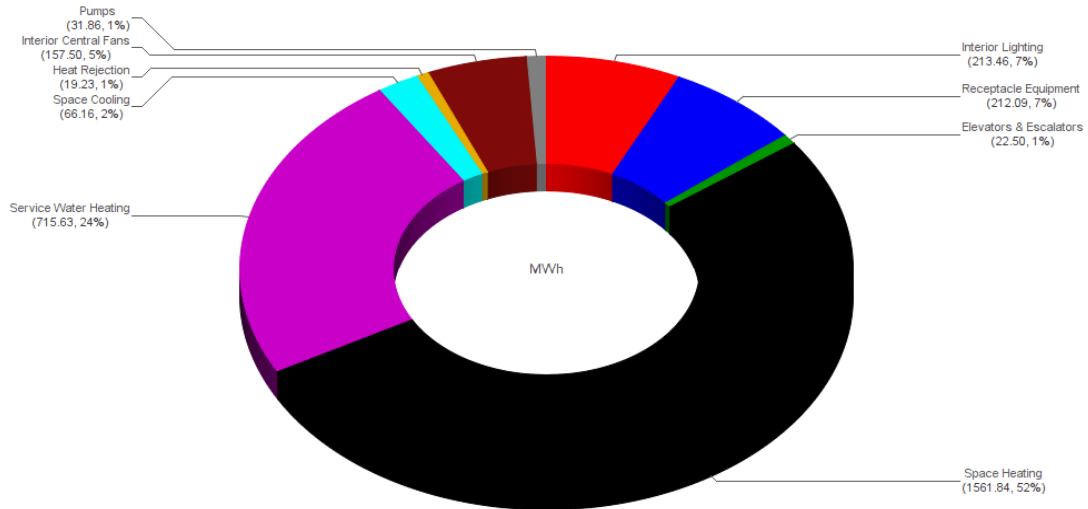
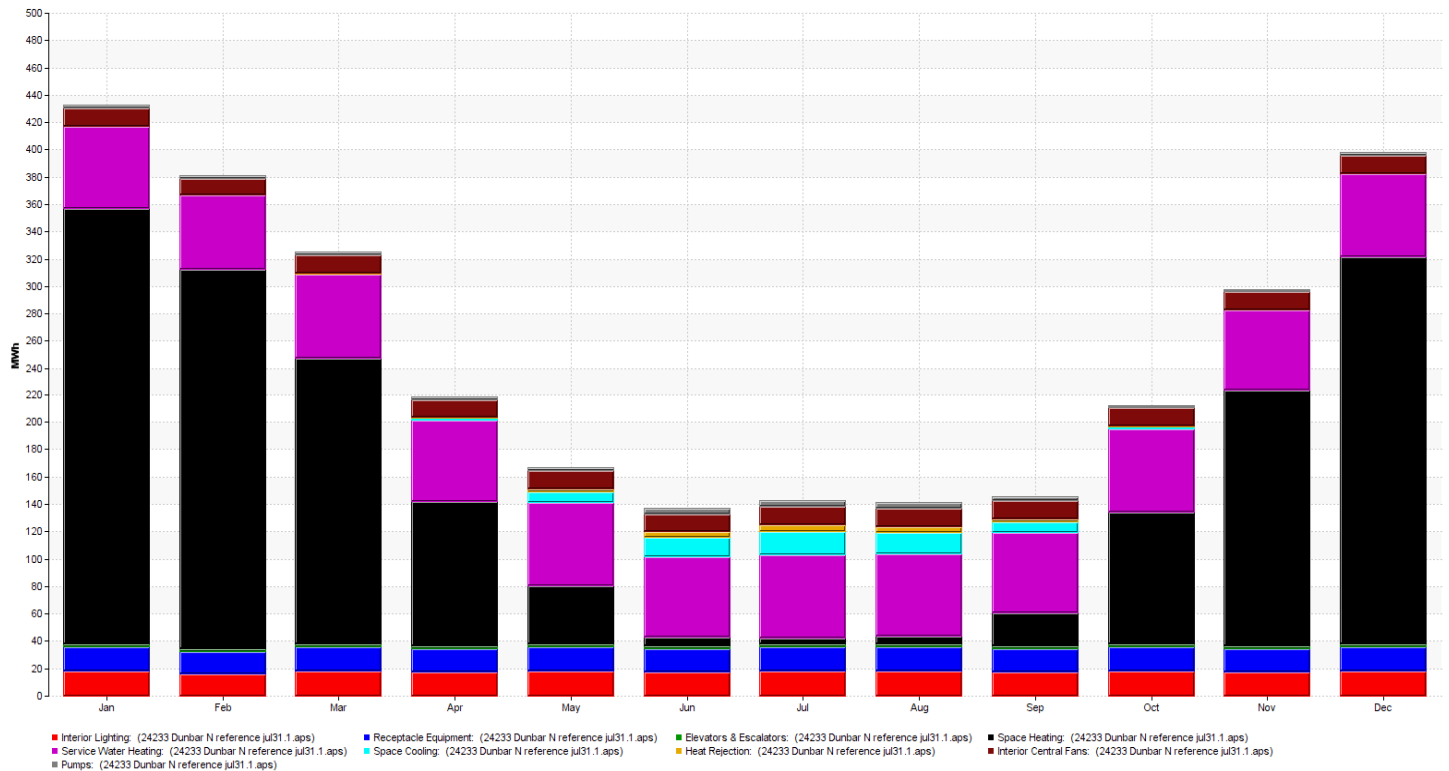


Chart 5.3: Baseline Building Monthly Energy Consumption (MWh):

Range: Fri 01/Jan to Fri 31/Dec



6.0 High Performance Scenario Energy Conservation Measures

The ECMs for the High-Performance scenario have been specified under three categories:

- (i) Building Envelope ECMs
- (ii) Building Equipment Loads ECMs
- (iii) Active System ECMs

6.1 Building Envelope & Orientation ECMs:

The building envelope design for this project is still in the preliminary stages. It is anticipated that a typical precast wall assembly will be used. The layout of the building on the site doesn't lend itself well to adjustments in orientation. As this is a MURB, windows for occupants are required throughout. As such, rotation of the building was not considered as an ECM.

The nature of energy modelling is to compare a baseline building to a proposed with the same building geometry. Strategic decisions to simplify the building form to reduce the amount of exterior walls and heat loss is not quantified through an energy model as a comparative improvement, but does result in an overall reduction in the amount of energy the building consumes when compared to other similar buildings.

Figure 2 below illustrates how geometry of a building can impact its overall thermal efficiency. By designing this building to reduce the number of recesses required for balconies (and subsequent increase in total exterior wall surface area), the overall efficiency of the building is greatly improved.

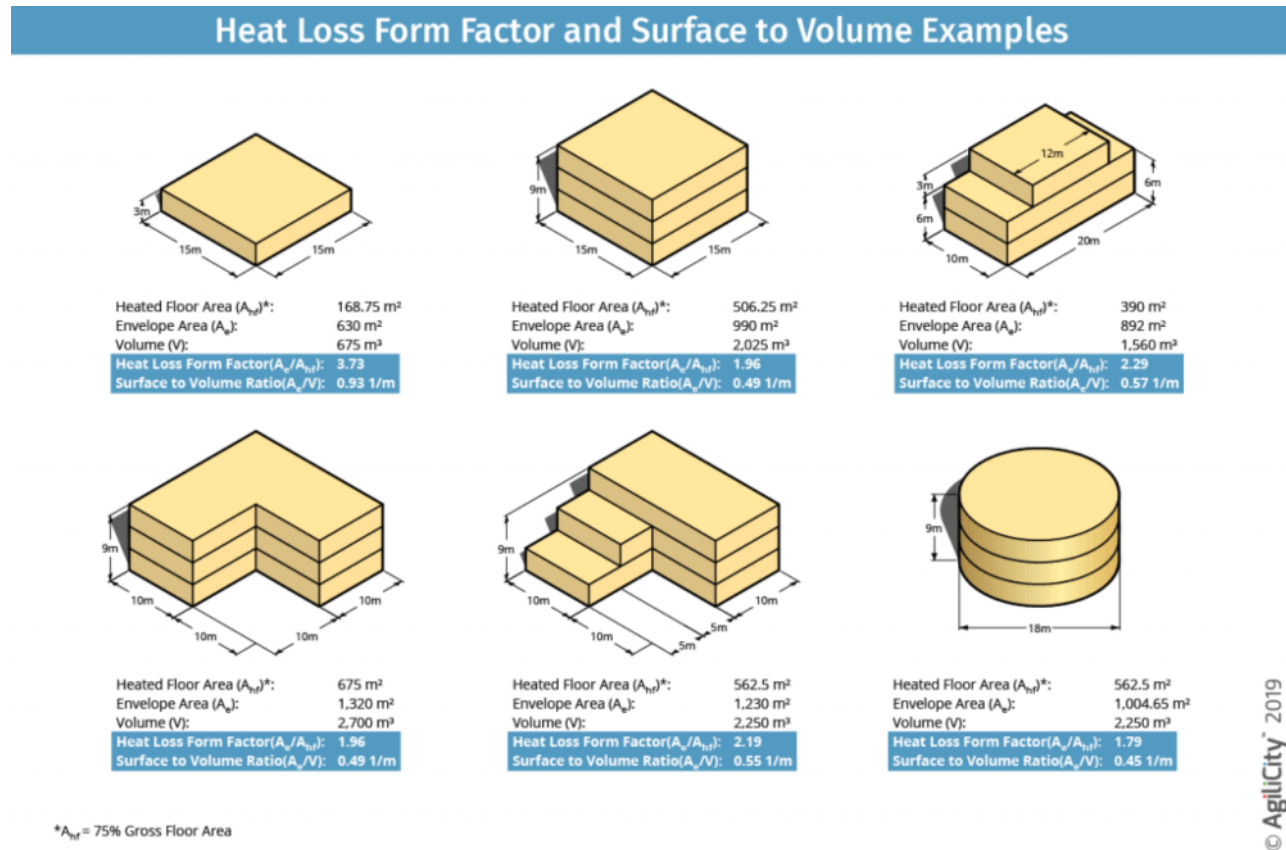


Figure 2: Heat Loss Form Factor

The following upgrades were made to the building envelope components of the baseline model to achieve High Performance Scenario Targets:

6.1.1 FDWR: The FDWR of the proposed building was reduced by 5% from 0.387 to 0.337.

6.1.2 Fenestration: Baseline windows were upgraded to composite framing (u-PVC or fiberglass). w/l.G. (sputtered twin-coat low e on side #2, 13mm stainless steel WES, side #4 ITO coating, 90% argon gas fill). Effective thermal performance of USI 1.42 W/m²K and SC of 0.30.

6.1.3 Exterior Opaque Wall: Precast wall assembly with 6-12" of concrete panels, R20 insulation, 1.5" of steel studs at 16" on center and 0.5" gypsum board as shown in Figure 6.1.3.1 was used as the exterior wall assembly.

For overall thermal transmittance and thermal bridging calculations, following wall assemblies' details from the Building Envelope Thermal Bridging Guide V1.6 were used:

- Glide-on prefabricated balconies with sapphire G60 anchors with point transmittance of 0.395 Btu/hr.°F^[1]
- Insulation at intermediate floor intersection with linear transmittance of 0.218 Btu/hr.ft°F (See Appendix A1.2)
- Glazing interface junction aligned with wall insulation with linear transmittance of 0.038 Btu/hr.ft.°F (See Appendix A1.3)
- Parapet and roof intersection with thermal break under parapet stud cavity; linear transmittance 0.227 Btu/ hr.ft.°F (See Appendix A1.4)

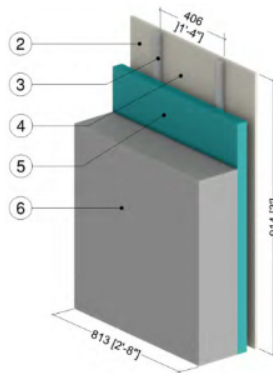


Fig 6.1.3.1 Exterior Wall Assembly

The resulting overall wall assembly thermal transmittance is R11.2 (See Appendix A1.1).

6.2 Building Equipment Loads ECMs: The building equipment loads from appliances and plumbing fixtures can account for a large percentage of the annual energy usage.

The following upgrades were made to the building equipment loads of the baseline model to achieve High Performance Scenario Targets:

6.2.1 LED Lighting: High-efficiency LED lighting resulting in 30% reduction in lighting power density from code is used in the upgraded model.

6.2.2 Ultra-low flow fixtures: Ultra-low flow water fixtures with flow rates of 5.5 LPM for shower faucets, 1.9 LPM for lavatory faucets and 4.5 LPM for Kitchen faucets are used for the upgraded model. To calculate



the reduction in DHW load, the LEED BD+C v4 Indoor Water Use reduction methodology was used. This resulted in 52.55% reduction in DHW load in the suites for the upgraded model. (See Appendix B1.1)

6.3 Active System ECMs: The active system of the building can have the most impact when it comes to implementing decarbonization strategies.

The following upgrades were made to the active systems of the baseline model to achieve High Performance Scenario Targets:

6.3.1 Air Source VRF system: The gas consumption for space heating in suites and commercial units is eliminated by switching the mechanical system for the baseline building from 4-pipe fan coil to air source VRF heat recovery heat pump system with backup electric heat. Each residential floor has its own outdoor unit paired to local in-suite fan coils.

6.3.2 Energy Recovery Ventilators (ERVs): In-suite ERVs with sensible effectiveness of 70% were used.

6.3.4 Domestic Hot Water Heaters: High efficiency gas fired water heaters with 96% thermal efficiency (up from 90%) were used.

7.0 Net Zero Ready Scenario Energy Conservation Measures

The ECMs for the NZR scenario have been specified under three categories:

- (i) Building Envelope ECMs
- (ii) Building Equipment Loads ECMs
- (iii) Active System ECMs

7.1 Building Envelope ECMs: In addition to ECMs mentioned in Section 6.1, following upgrades were made to the building envelope components of the baseline model to achieve NZR Performance Scenario Targets:

7.1.1 Fenestration: Baseline windows were upgraded to composite framing (u-PVC or fiberglass), triple glazing (sputtered twin-coat low e on side #2 and #5, 13mm stainless steel WES, 90% argon gas fill). Effective thermal performance of USI 1.05 W/m²K and SC of 0.30.

7.1.2 Roof: To meet the high-performance targets, the overall roof insulation was increased to R50.

7.1.3 Exterior Opaque Wall: Highly insulated precast concrete sandwich panel wall assembly with R40 continuous insulation, 3.5" of steel studs at 16" on center and 0.5" gypsum board as shown in Figure 7.1.3.1 was used as the exterior wall assembly to have a better overall opaque wall thermal performance.

For overall thermal transmittance and thermal bridging calculations, following wall assemblies' details from the Building Envelope Thermal Bridging Guide V1.6 were used:

- Glide-on prefabricated balconies with sapphire G60 anchors with point transmittance of 0.395 Btu/hr.°F^[1]
- Highly insulation intermediate floor intersection with linear transmittance of 0.004 Btu/hr.ft°F (See Appendix A2.2)
- Glazing interface junction aligned with wall insulation with linear transmittance of 0.008 Btu/hr.ft.°F (See Appendix A2.3)
- Roof to wall insulation with wood-framed parapet with linear transmittance 0.003 Btu/ hr.ft.°F (See Appendix A2.4)



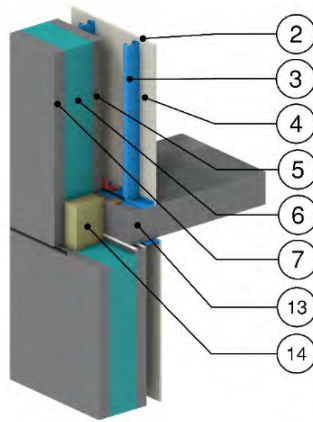


Fig 7.1.3.1 Exterior Wall Assembly

The resulting overall wall assembly thermal transmittance is R33.7 (See Appendix A2.1).

7.1.4 Infiltration: The building infiltration through the envelope for the baseline model was reduced by 20% from code to 0.0394 CFM/ft² of exterior wall area, down from 0.0492 CFM/ft².

7.2 Building loads ECMs: In addition to ECMs mentioned in Section 6.2, following upgrades were made to the building equipment loads of the baseline model to achieve NZR Performance Scenario Targets:

7.2.1 LED Lighting: High-efficiency LED lighting resulting in 50% reduction in lighting power density from code is used in the NZR model.

7.2.2 EnergyStar Appliances: EnergyStar rated appliances are provided in all suites, reducing the plug loads by 20%.

7.3 Active systems ECMs: In addition to ECMs mentioned in Section 6.3, following upgrades were made to the active systems of the baseline model to achieve NZR Performance Scenario Targets:

7.3.1 On-site Renewables: To offset the electric energy demand, potential for rooftop solar photovoltaic (PV) panels and Building-integrated photovoltaics (BIPV) on south facing façade was considered. To meet the NZR performance, PV system generating at least 192 MWh annually is required. A combination of rooftop PV and BIPV balcony glass is necessary to achieve this target.

7.3.2 Energy Recovery Ventilators (ERVs): In-suite ERVs were upgraded with sensible effectiveness of 80%.

7.3.3 ASHP MUA: Gas fired MUA was replaced with Air Source Heat Pumps (ASHP) with electric backup.

7.3.4 Hybrid Heat Pump Water Heaters: The gas fired water heaters were replaced with hybrid electric heat pump water heaters.

7.3.3 MUA airflow: Corridor Pressurization ventilation rate of 30 CFM/suite is reduced to 15 CFM/suite.

7.3.5 Unit Heaters: The hydronic heaters serving stairwells, vestibules, storage rooms, etc. were replaced with electric unit heaters.



8.0 Embodied Carbon

While the emissions associated with the operational energy consumption of a building are typically discussed, the emissions released during the lifecycle of building materials including extraction, transportation, manufacturing, construction, and disposal are often overlooked. A typical high-rise building has a bigger carbon footprint than mid or low-sized buildings due to its construction materials^[2].

It is found that the carbon emission of a standard residential apartment is 669 kg CO₂e/m² of floor area. Using precast concrete panels can lead to carbon emissions reduction of 10%^[3]. Precast concrete panels have an advantage over Cast in Place (CIP) assemblies as they use less concrete due to their design with center line holes/air space. The exterior wall assembly for the proposed building uses precast panels which give them an edge over the CIP construction in terms of embodied carbon.

No changes in the building construction are proposed in this report. It is an efficient system for a 10-storey non-combustible MURB application.

9.0 Resiliency

The building is expected to require a fire pump and associated emergency generator. Under OBC, this generator will also provide back-up power to smoke control systems & life safety, and emergency lighting.

As a good engineering practice, it will also power sump pumps and domestic water booster pumps. This will maintain potable water for residents.

Low Fenestration and Door area to gross Wall Ratio (FDWR) and the high concrete mass of the building will increase resiliency by maintaining building temperature for a prolonged period in case of an emergency.

Due to the nature of air source VRF systems containing multiple smaller systems with high electrical loads, it is not practical to place heating and cooling systems on emergency power.



10.0 Models Inputs

Summary of inputs for all energy models are presented here in Table 10.1.

Table 10.1: Summary of Inputs

General items	Simulation inputs		
Location	Waterloo, Ontario		
ASHARE Climate Zone	Zone 6 (As per NECB 2015)		
Weather file	CAN_ON_Elora-RCS_6142286_CWEC		
Modelling Software	IES-VE		
Conditioned Floor Area	140,347 ft ²		
Space Activity	Residential multi-family		
Building Schedules	NECB Default Schedules C NECB Default Schedules G NECB Default Schedules H		
Hours of Operation	24 Hours		
Architectural Items	Baseline	High Performance Scenario	NZR Performance Scenario
FDWR	0.387	0.337	0.337
Windows U-value (Btu/h-ft ² -F°)	0.335 all windows (As per SB-10 Table 3.2.2.3)	0.250 all windows	0.185 all windows
Shading Coefficient	0.45	0.30	0.30
Visible Transmittance	0.71	0.71	0.71
Exterior Walls U-value (Btu/h-ft ² -F°)	0.0435 (As per SB-10 Table 3.2.2.2)	0.089	0.030
Roof U-value (Btu/h-ft ² -F°)	0.027 (As per SB-10 Table 3.2.2.2)	0.029	0.020
Infiltration	0.0492 CFM/ft ² (As per NECB 2015)	0.0492 CFM/ft ² (As per NECB 2015)	0.0394 CFM/ft ²
Mechanical Items	Baseline	High Performance Scenario	NZR Performance Scenario
Mechanical Plant	4-Pipe fan coil units 2X boilers @90% thermal efficiency; Water Cooled Chiller COP 5.33 (As per SB-10 Table SB 5.2.12.1A-2017 and NECB-2015 Table 5.2.12.1)	Air Source VRF heat recovery heat pump system with backup electric heat Heating, COP 3.2 @ 47°F outside air temperature Cooling, EER 12.3 @ 95°F outside air temp	Air Source VRF heat recovery heat pump system with backup electric heat Heating, COP 3.2 @ 47°F outside air temperature Cooling, EER 12.3 @ 95°F outside air temp
Make Up Air System	Design Capacity 30 CFM/door; Heating, 80% Thermal Efficiency	Design Capacity 30 CFM/door; Heating, 80% Thermal Efficiency	Design Capacity 15 CFM/door; Air Source Heat Pump Heating,



	Cooling, 9.5 EER (As per NECB-2015 Table 5.2.12.1)	Cooling, 9.5 EER	CO 3.5 @ 47°F outside air temperature Cooling, EER 11.5 @ 95°F outside air temp
DHW	NECB-2015 default loads 90% thermal efficiency	Reduced In-suite DHW load due to ultra-low flow water fixtures; 96% Thermal Efficiency	Reduced In-suite DHW load due to ultra-low flow water fixtures; Hybrid Heat Pump Water Heaters Average COP 2.5
Unit Heaters	Hydronic heaters	Hydronic heaters	Electric Heaters
Electrical Items	Baseline	High Performance Scenario	NZR Performance Scenario
Lighting, W/ft²	0.46 (W/ft ²) Suites 0.66 (W/ft ²) Corridor 0.58 (W/ft ²) Stairs 1.07 (W/ft ²) Amenity 1.00 (W/ft ²) Lobby	0.32 (W/ft ²) Suites 0.46 (W/ft ²) Corridor 0.41 (W/ft ²) Stairs 0.75 (W/ft ²) Amenity 0.70 (W/ft ²) Lobby	0.23 (W/ft ²) Suites 0.33 (W/ft ²) Corridor 0.29 (W/ft ²) Stairs 0.53 (W/ft ²) Amenity 0.50 (W/ft ²) Lobby
Plug Load, W/ft²	0.46 (W/ft ²)	0.46 (W/ft ²)	0.37 (W/ft ²)
On-site Power generation	Baseline	High Performance Scenario	NZR Performance Scenario
Photovoltaic Panels (per year)	N/A	N/A	192 MWh



11.0 Proposed Models Outputs

Summary of outputs for the energy models are presented here in Table 11.1. Charts 11.2 and 11.3 represent the annual and monthly energy breakdown for the High-Performance proposed model. Charts 11.4 and 11.5 represent the annual and monthly energy breakdown for the NZR proposed model.

Table 11.1: Summary of Outputs

Annual Energy Summary					
Annual consumption Summary	Baseline Building Energy	High Performance Building Energy	Percentage change from the Baseline model (%)	NZR Performance Building Energy	Percentage change from the Baseline model (%)
Space Heating (MWh)	1,561.84	812.82	48.0%	402.60	74.2%
Space Cooling (MWh)	85.39	53.96	36.8%	48.70	43.0%
HVAC Auxiliary (MWh)	189.36	210.16	-11.0%	205.78	-8.7%
Misc. Electrical (MWh)	234.59	234.59	0.00%	192.64	17.9%
Service Hot Water (MWh)	715.63	327.79	54.2%	125.87	82.4%
Interior Lighting (MWh)	213.46	149.43	30.0%	106.90	49.9%
On-site Power Generation (MWh)	-	-	-	(192.0)	-
Total Annual Energy (MWh)	3,000.26	1,788.75	40.4%	890.48	70.3%
TEDI (kWh/m ²)	101.1	63.81	36.9%	35.74	64.6%
TEUI (kWh/m ²)	230.2	137.18	40.4%	68.30	70.3%
GHGI (Kg CO ₂ e/m ²)	34.19	15.50	54.7%	3.41	90.0%



Chart 11.2: High-Performance Proposed Building Annual Energy Consumption Breakdown (MWh):

Range: Fri 01/Jan to Fri 31/Dec

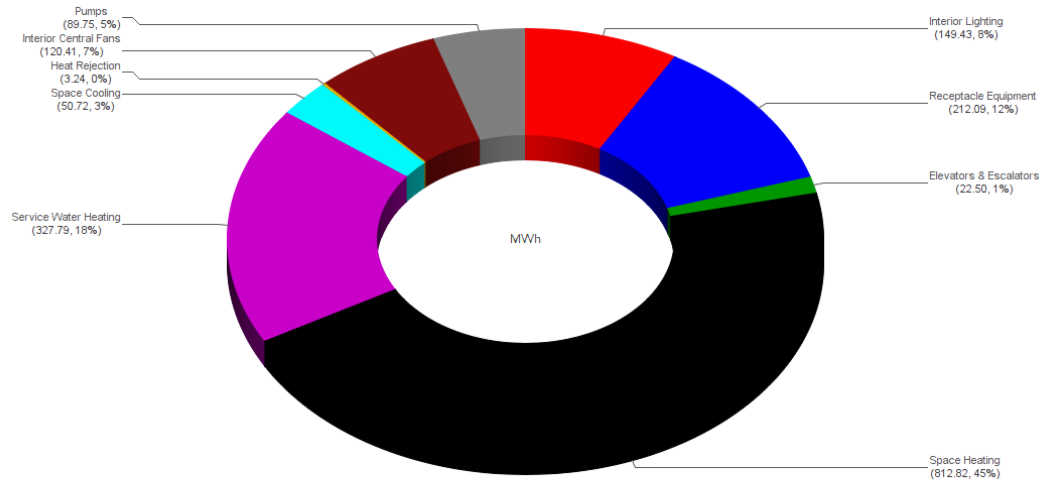


Chart 11.3: High-Performance Proposed Building Monthly Energy Consumption (MWh):

Range: Fri 01/Jan to Fri 31/Dec

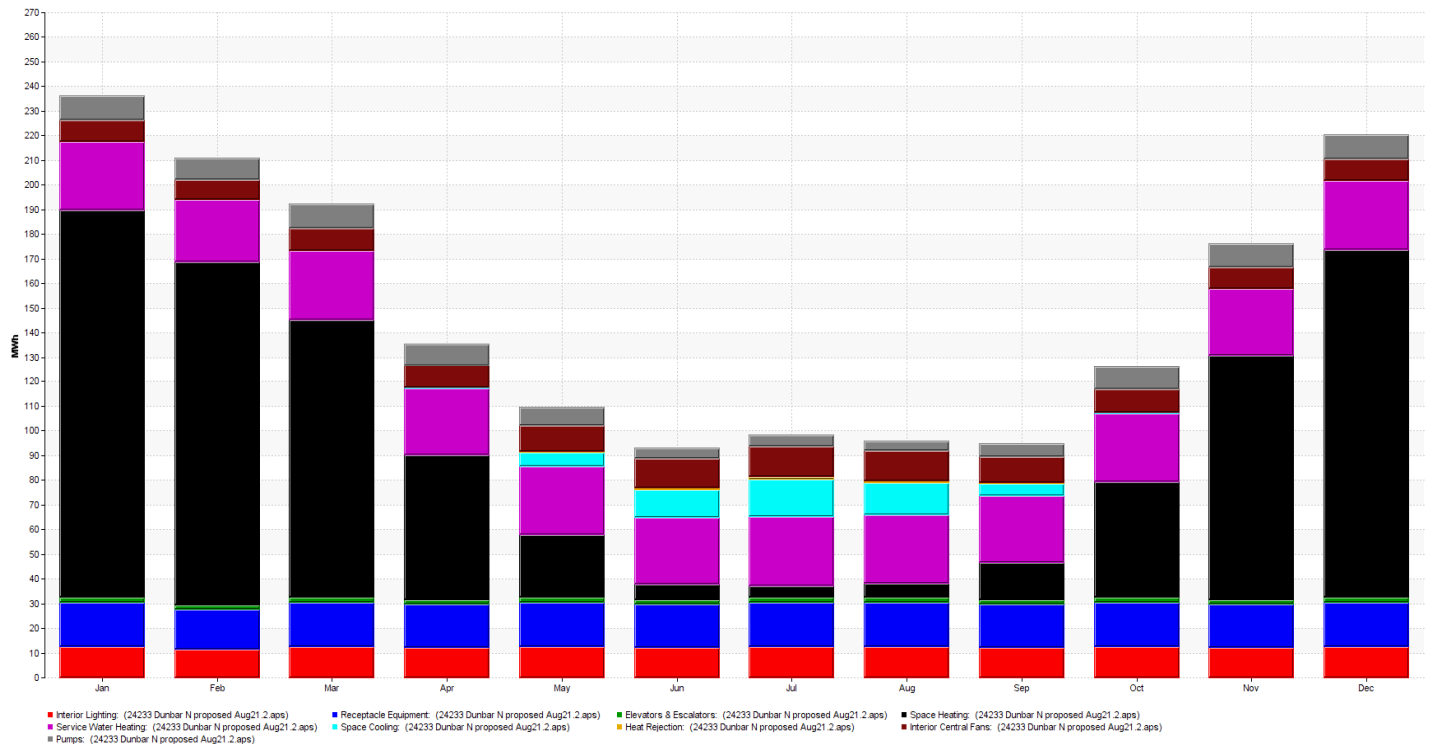


Chart 11.4: NZR Proposed Building Annual Energy Consumption Breakdown (MWh):

Range: Fri 01/Jan to Fri 31/Dec

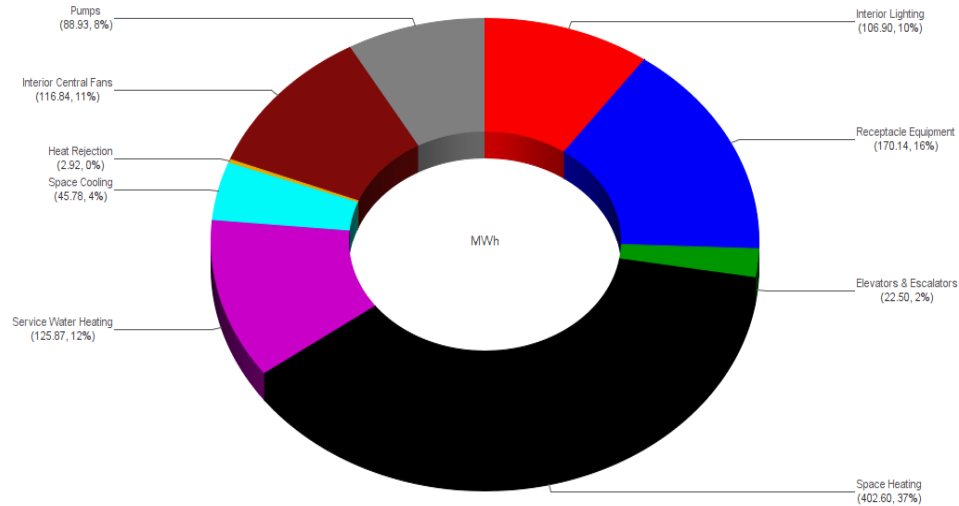
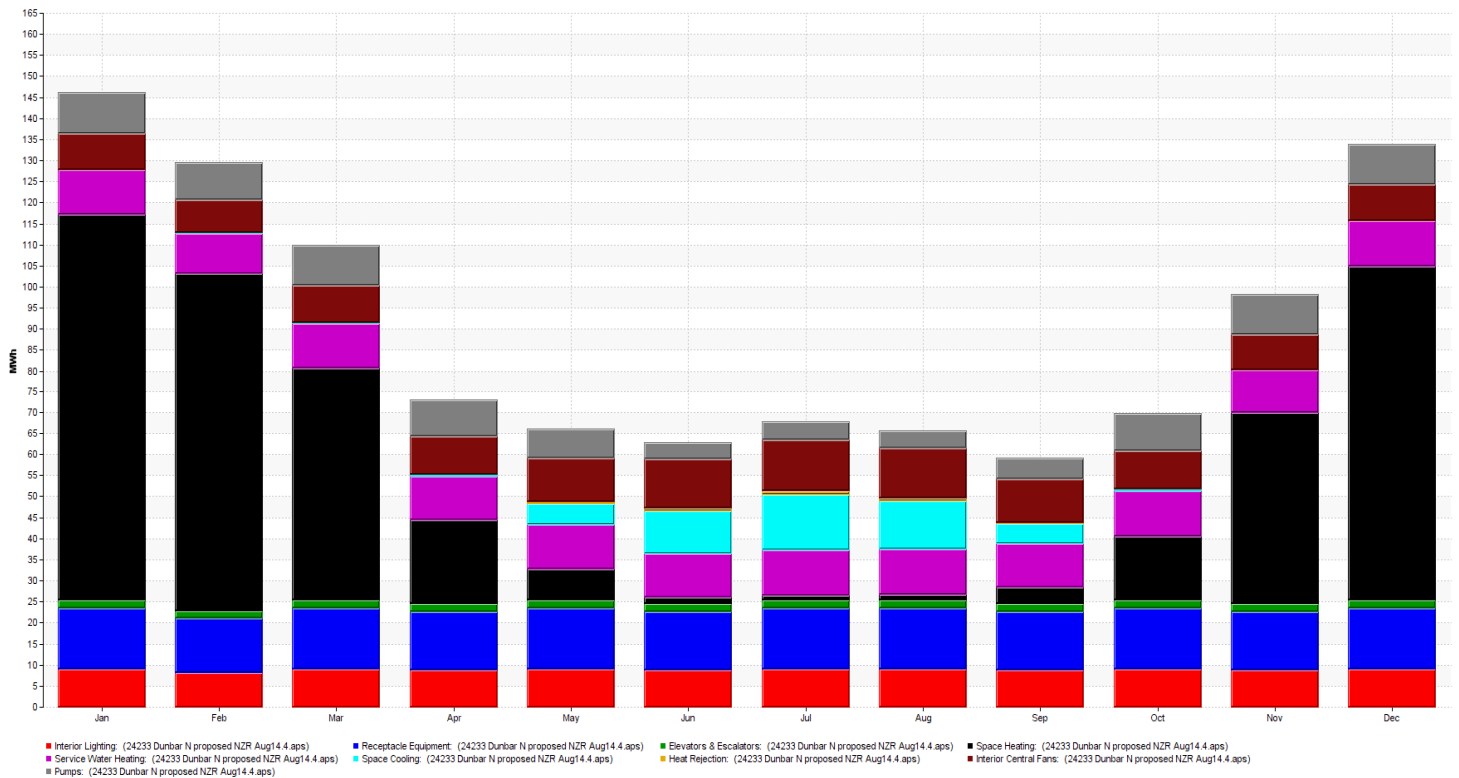


Chart 11.5: NZR Proposed Building Monthly Energy Consumption (MWh):

Range: Fri 01/Jan to Fri 31/Dec



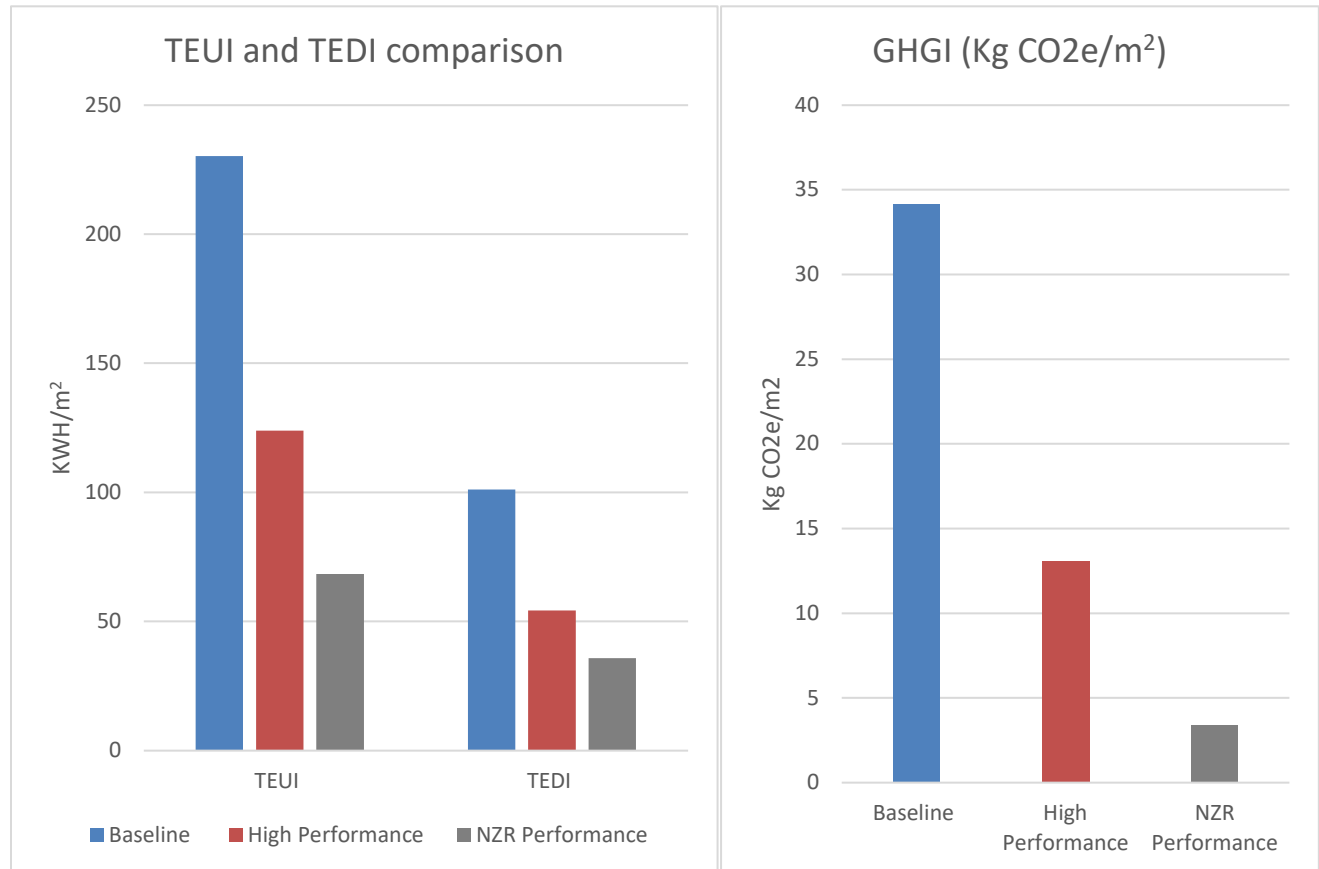
12.0 Conclusion & Recommendations

Passive design measures of reducing FDWR by 5%, using double/triple glazed fiberglass windows, upgrading roof insulation to R50, and using highly insulated wall assemblies with thermal breaks at major building junctions and penetrations to mitigate the effect of thermal bridging reduce the thermal energy demand and consumption of the proposed building.

Active design measures of using air source VRFs, In-suite energy recovery ventilators, reduced corridor pressurization, ASHP MUA units, heat pump water heaters, high efficiency condensing boilers, LED lighting, and ultra-low flow water fixtures reduce/eliminate the natural gas consumption and thermal energy demand whilst increasing the efficiency of mechanical systems. Using precast panels over CIP design helps proposed building to reduce its embodied carbon.

By comparing the baseline energy model with the upgraded models, the high-performance building scenario had a 40.4% reduction in TEUI, 36.9% reduction in TEDI and 54.7% reduction in GHGI from the baseline model. For the NZR performance scenario, there was 70.3% reduction in TEUI, 64.6% reduction in TEDI and 90.0% reduction in GHGI from the baseline model.

Chart 12.1: Baseline and Proposed building comparison:



13.0 References

- [1] [Thermal simulation report Sapphire Balconies](#)
- [2] [Minimizing carbon footprint of high-rise structure with parametric design](#)
- [2] [Comparing carbon emissions of precast and cast-in-situ construction methods – A case study of high-rise private building - ScienceDirect](#)



Appendix A – Thermal Bridging Analysis

Appendix A1.1: Effective thermal performance of opaque wall (from BETBG thermal performance spreadsheet)

Clear Field Area Method

Select Area Calculation (Choose One)	Area	Units
☐ Sum of Active Clear Field Areas (Default)	39619.00	ft ²
☐ User Defined Area	Enter User Defined Opaque Area	ft ²

Overall Opaque Wall Thermal Performance Values

Base Building		Proposed Building		% Below Baseline
Opaque U-Value (BTU/hr ft ² °F)	Enter Base Building U-Value	Opaque U-Value (BTU/hr ft ² °F)	0.089	-
Effective R-Value (hr ft ² °F/BTU)	-	Effective R-Value (hr ft ² °F/BTU)	11.2	

Proposed Building Entries

Proposed Building Entries								Totals	3535.7	100%
Add/Remove Detail	Transmittance Type	Include	Transmittance Description	Area, Length or Amount Takeoff	Units	Transmittance Value	Units	Source Reference	Heat Flow (BTU/hr°F)	%Total Heat Flow
Add Clear Field	Clear Field	☒	Exterior Wall	39619.00	ft²	0.043	BTU/ hr ft² °F	Enter Source Here	1703.6	48%
Remove Clear Field	Clear Field	☐	Roof	18229.00	ft²	0.020	BTU/ hr ft² °F	Enter Source Here	0.0	0%
Remove Clear Field	Clear Field	☐	Penetration	19855.00	ft²	0.250	BTU/ hr ft² °F	Enter Source Here	0.0	0%
Add Linear Interface Detail	Linear Interface Detail	☒	Slab Bypass	4546.00	ft	0.218	BTU/ hr ft °F	BETBG v16 7.2.7	991.0	28%
Remove Linear Interface Detail	Linear Interface Detail	☒	Glazing Interface Junction	11674.00	ft	0.038	BTU/ hr ft °F	BETBG v16 7.3.11	443.6	13%
Remove Linear Interface Detail	Linear Interface Detail	☒	Parapet	1100.00	ft	0.227	BTU/ hr ft °F	BETBG v16 7.5.7	249.7	7%
Add Point Interface Detail	Point Interface Detail	☒	Balcony connections	374	#	0.395	BTU/ hr °F	Sapphire Balconies	147.7	4%

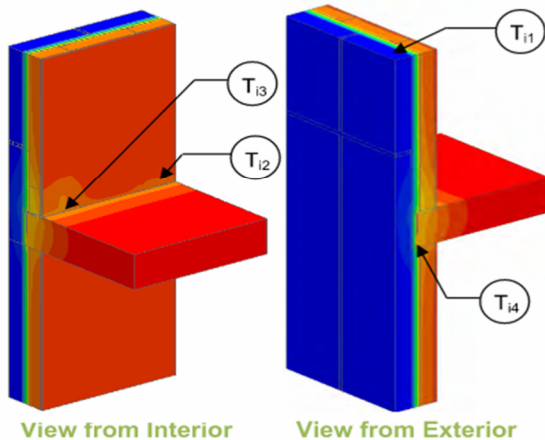
Appendix A1.2: Intermediate floor linear transmittance

Appendix B: Catalogue Thermal Data Sheets

BUILDING ENVELOPE THERMAL BRIDGING GUIDE v1.6

Detail 7.2.7

Precast Wall Assembly with 3 5/8" x 1 5/8" Steel Stud (16" o.c) and Rigid Insulation Outboard of Studs – Intermediate Floor Intersection



Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	Nominal thermal resistance of wall
Transmittance / Resistance without Anomaly	U_o, R_o	"clear wall" U- and R-value, without slab and anchor connections
Transmittance / Resistance	U, R	U- and R-values for overall assembly
Surface Temperature Index ¹	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	ψ	Incremental increase in transmittance per linear length of slab

¹Assumptions and limitations for surface temperatures identified in ASHRAE 1365-RP

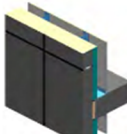
Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

R_{1D} ft ² ·hr·°F / Btu (m ² K / W)	R_o ft ² ·hr·°F / Btu (m ² K / W)	U_o Btu/ft ² ·hr ·°F (W/m ² K)
R-13.0 (2.29)	R-12.9 (2.26)	0.078 (0.44)

Slab Linear Transmittance²

R ft ² ·hr·°F / Btu (m ² K / W)	U Btu/ft ² ·hr ·°F (W/m ² K)	ψ Btu/ft hr °F (W/m K)
R-9.1 (1.60)	0.110 (0.63)	0.218 (0.377)



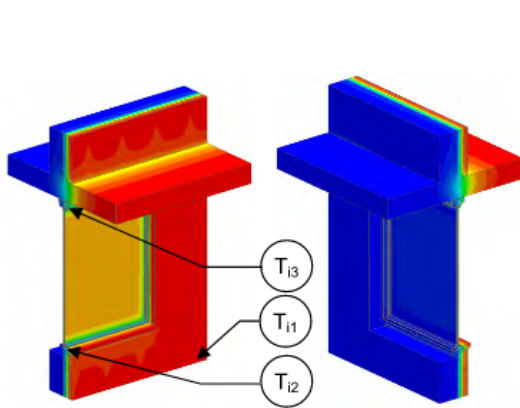
Appendix A1.3: Glazing Interface Junction linear transmittance

Appendix B: Catalogue Thermal Data Sheets

BUILDING ENVELOPE THERMAL BRIDGING GUIDE v1.6

Detail 7.3.11

Interior Insulated Concrete Mass Wall with 1 5/8" x 1 5/8" Steel Studs (16" o.c.) Supporting Interior Finish – Window & Projected Slab Intersection – Plywood Liner and Glazing Aligned with Wall Insulation



View from Interior

View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R-2.9 (0.51 RSI) + interior insulation
Transmittance / Resistance	U_t , R_t	U and R-values for: t = combined wall + slab + window
Surface Temperature Index ¹	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance ²	ψ_h , ψ_j , ψ_l , ψ_g	Incremental increase in transmittance per linear length of: h = head j = jamb l = sill g = overall glazing

¹Assumptions and limitations for surface temperatures identified in ASHRAE 1365-RP

²For performance of base assembly and slab linear transmittances, refer to Detail 7.3.3

Scenario

Scenario	Sill Shim Insulation
A, B	None
C, D	Yes

Nominal (1D) vs. Assembly Performance Indicators**Window Transition Transmittance**

Scenario	Interior Insulation 1D R-Value (RSI)	R_t ft ² ·hr·°F / Btu (m ² K / W)	U_t Btu/ft ² ·hr·°F (W/m ² K)	ψ_h Btu/ft·hr·°F (W/m K)	ψ_l Btu/ft·hr·°F (W/m K)	ψ_j Btu/ft·hr·°F (W/m K)	ψ_g Btu/ft·hr·°F (W/m K)
A	R-10 (1.76)	R-3.8 (0.68)	0.261 (1.48)	0.052 (0.09)	0.068 (0.118)	0.044 (0.076)	0.053 (0.092)
B	R-15 (2.64)	R-4.1 (0.72)	0.246 (1.39)	0.080 (0.139)	0.061 (0.106)	0.051 (0.088)	0.062 (0.107)
C	R-10 (1.76)	R-3.9 (0.69)	0.255 (1.45)	0.052 (0.090)	-0.004 (-0.007)	0.044 (0.076)	0.033 (0.056)
D	R-15 (2.64)	R-4.2 (0.73)	0.240 (1.36)	0.080 (0.139)	-0.023 (-0.040)	0.051 (0.088)	0.038 (0.066)

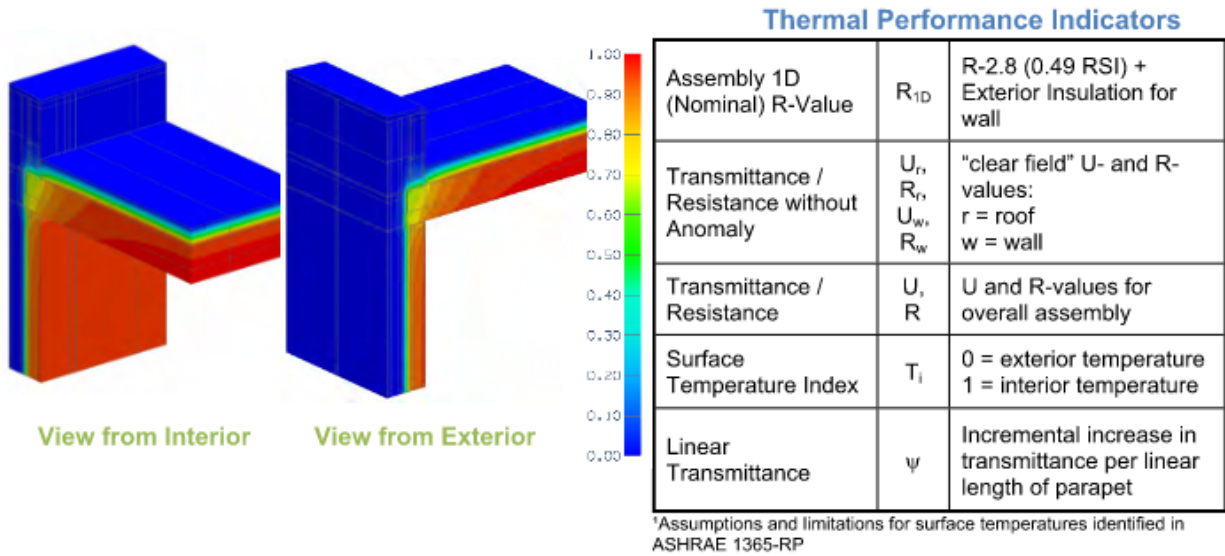
Appendix A1.4: Parapet and Roof Intersection linear transmittance

Appendix B: Catalogue Thermal Data Sheets

BUILDING ENVELOPE THERMAL BRIDGING GUIDE v1.6

Detail 7.5.7

Precast Wall Assembly with 3 5/8" x 1 5/8" Steel Stud (16" o.c) and Rigid Insulation Outboard of Studs – Parapet & Roof Intersection with Thermal Break under Parapet Stud Cavity and At Anchors



Scenario

Scenario	
A	Armatherm 500 beneath stud cavity
B	Armatherm 500 beneath stud cavity, 3/8" FRR at anchors

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft ² ·hr·°F / Btu (m ² K / W)	R_w ft ² ·hr·°F / Btu (m ² K / W)	U_w Btu/ft ² ·hr·°F (W/m ² K)
R-10 (1.76)	R-12.8 (2.25)	R-12.2 (2.15)	0.082 (0.47)

Base Assembly - Roof

Roof Exterior Insulation 1D R-Value (RSI)	R_r ft ² ·hr·°F / Btu (m ² K / W)	U_r Btu/ft ² ·hr·°F (W/m ² K)
R-20 (3.52)	R-21.9 (3.86)	0.046 (0.26)

Parapet Linear Transmittance

Scenario	R ft ² ·hr·°F / Btu (m ² K / W)	U Btu/ft ² ·hr·°F (W/m ² K)	ψ Btu/ft·hr·°F (W/m K)
A	R-10.6 (1.86)	0.095 (0.54)	0.227 (0.393)
B	R-10.7 (1.89)	0.093 (0.53)	0.125 (0.216)

Panel edges (caulked joints between panels) had negligible linear transmittance effects so values not presented

Appendix A2.1: Effective thermal performance of opaque wall (from BETBG thermal performance spreadsheet)**Clear Field Area Method**

Select Area Calculation (Choose One)	Area	Units
☐ Sum of Active Clear Field Areas (Default)	39619.00	ft ²
☐ User Defined Area	Enter User Defined Opaque Area	ft ²

Overall Opaque Wall Thermal Performance Values

Base Building		Proposed Building		% Below Baseline
Opaque U-Value (BTU/hr ft ² °F)	Enter Base Building U-Value	Opaque U-Value (BTU/hr ft ² °F)	0.030	-
Effective R-Value (hr ft ² °F/BTU)	-	Effective R-Value (hr ft ² °F/BTU)	33.7	

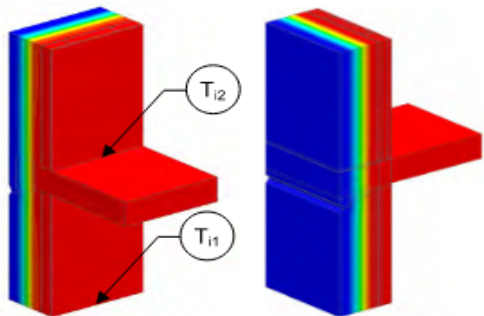
Proposed Building Entries

								Totals	1174.5	100%
Add/Remove Detail	Transmittance Type	Include	Transmittance Description	Area, Length or Amount Takeoff	Units	Transmittance Value	Units	Source Reference	Heat Flow (BTU/hr °F)	%Total Heat Flow
Add Clear Field	Clear Field	☒	Exterior Wall	39619.00	ft ²	0.024	BTU/ hr ft ² °F	Enter Source Here	936.6	80%
Remove Clear Field	Clear Field	☐	Roof	13229.00	ft ²	0.020	BTU/ hr ft ² °F	Enter Source Here	0.0	0%
Remove Clear Field	Clear Field	☐	Penetration	19835.00	ft ²	0.250	BTU/ hr ft ² °F	Enter Source Here	0.0	0%
Add Linear Interface Detail	Linear Interface Detail	☒	Slab Bypass	4546.00	ft	0.004	BTU/ hr ft °F	BETBG v16 7.2.21	16.4	1%
Remove Linear Interface Detail	Linear Interface Detail	☒	Glazing Interface Junction	11674.00	ft	0.006	BTU/ hr ft °F	BETBG v16 7.4.7	70.0	6%
Remove Linear Interface Detail	Linear Interface Detail	☒	Parapet	1100.00	ft	0.003	BTU/ hr ft °F	BETBG v16 7.5.10	3.7	0%
Add Point Interface Detail	Point Interface Detail	☒	Balcony connections	374	#	0.395	BTU/ hr °F	Sapphire Balconies	147.7	13%

Appendix A2.2: Intermediate floor linear transmittance

Appendix B: Catalogue Thermal Data Sheets

BUILDING ENVELOPE THERMAL BRIDGING GUIDE v1.6

Detail 7.2.21**Highly Insulated Precast Concrete Sandwich Panel Wall Assembly – Intermediate Floor Intersection with Inner Wythe Supported by Concrete Floor**

View from Interior

View from Exterior

Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R _{1D}	R-2.76 (0.49 RSI) + insulation
Transmittance / Resistance without Anomaly	U _o , R _o	"clear field" U- and R-value
Transmittance / Resistance	U, R	U- and R-values for the overall assembly
Linear Transmittance	Ψ	Incremental increase in transmittance for intermediate slab

Nominal (1D) vs. Assembly Performance Indicators**Base Assembly – Wall**

Wall Insulation R-Value/in	Wall Insulation 1D R-Value (RSI)	R _{1D} ft ² ·hr·°F / Btu (m ² K / W)	R _o ft ² ·hr·°F / Btu (m ² K / W)	U _o Btu/ft ² ·hr·°F (W/m ² K)
5	R-40 (7.04)	R-42.8 (7.53)	R-42.3 (7.45)	0.024 (0.134)
6	R-48 (8.45)	R-50.8 (8.94)	R-50.3 (8.86)	0.020 (0.113)
7	R-56 (9.86)	R-58.8 (10.35)	R-58.3 (10.27)	0.017 (0.097)

Slab Linear Transmittance

Wall Insulation R-Value/in	Wall Insulation 1D R-Value (RSI)	R ft ² ·hr·°F / Btu (m ² K / W)	U Btu/ft ² ·hr·°F (W/m ² K)	Ψ Btu/ft·hr·°F (W/mK)
5	R-42.8 (7.53)	R-41.4 (7.30)	0.024 (0.137)	0.0036 (0.0061)
6	R-50.8 (8.94)	R-47.9 (8.44)	0.021 (0.118)	0.0071 (0.0123)
6*	R-50.8 (8.94)	R-48.3 (8.52)	0.021 (0.117)	0.0057 (0.0099)
7	R-58.8 (10.35)	R-54.0 (9.52)	0.019 (0.105)	0.0098 (0.0169)

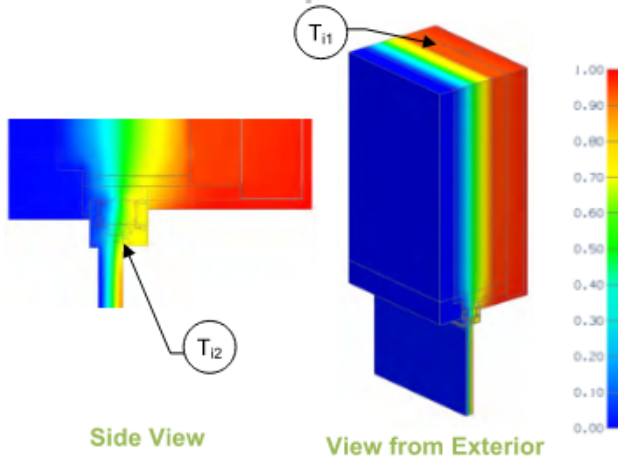
Appendix A2.3: Glazing Interface Junction linear transmittance

Appendix B: Catalogue Thermal Data Sheets

BUILDING ENVELOPE THERMAL BRIDGING GUIDE v1.6

Detail 7.4.7

Highly Insulated Precast Concrete Sandwich Panel Wall Assembly – High Performance Aluminum Window Head Detail



Thermal Performance Indicators

Assembly 1D (Nominal) R-Value	R_{1D}	R-2.76 (0.49 RSI) + insulation
Transmittance / Resistance without Anomaly	U_w, R_w, U_g, R_g	"clear field" U- and R-value w = wall g = glazing
Transmittance / Resistance	U, R	U- and R-values for the overall assembly
Linear Transmittance	ψ	Incremental increase in transmittance for sill detail

Scenarios

Scenario	Head/Jamb Detail Insulation
A	Spray Foam around opening
B	Aerogel around opening

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

Wall Insulation R-Value/in	Wall Insulation 1D R-Value (RSI)	R_{1D} ft ² ·hr·°F / Btu (m ² K / W)	R_w ft ² ·hr·°F / Btu (m ² K / W)	U_w Btu/ft ² ·hr·°F (W/m ² K)
5	R-40 (7.04)	R-42.8 (7.53)	R-42.3 (7.45)	0.024 (0.13)
6	R-48 (8.45)	R-50.8 (8.94)	R-50.3 (8.86)	0.020 (0.11)
7	R-56 (9.86)	R-58.8 (10.35)	R-58.3 (10.27)	0.017 (0.10)

Base Assembly – Glazing

$U_{\text{centre of glazing}}$ Btu/ft ² ·hr·°F (W/m ² K)	U_{frame} Btu/ft ² ·hr·°F (W/m ² K)	ψ_{spacer} Btu/ft·hr·°F (W/m K)	U_g Btu/ft ² ·hr·°F (W/m ² K)
0.123 (0.70)	0.261 (1.48)	0.040 (0.069)	0.172 (0.98)

Head and Jamb Linear Transmittance

Scenario	Wall Insulation R-Value/in	Wall Insulation 1D R-Value (RSI)	R ft ² ·hr·°F / Btu (m ² K / W)	U Btu/ft ² ·hr·°F (W/m ² K)	ψ Btu/ft·hr·°F (W/mK)
A	5	R-42.8 (7.53)	R-13.9 (2.44)	0.072 (0.41)	0.004 (0.007)
	6	R-50.8 (8.94)	R-14.4 (2.53)	0.070 (0.40)	0.004 (0.007)
	7	R-58.8 (10.35)	R-14.7 (2.60)	0.068 (0.39)	0.005 (0.008)
B	6	R-50.8 (8.94)	R-14.4 (2.54)	0.069 (0.39)	0.003 (0.006)



Appendix A2.4: Parapet and Roof Intersection linear transmittance

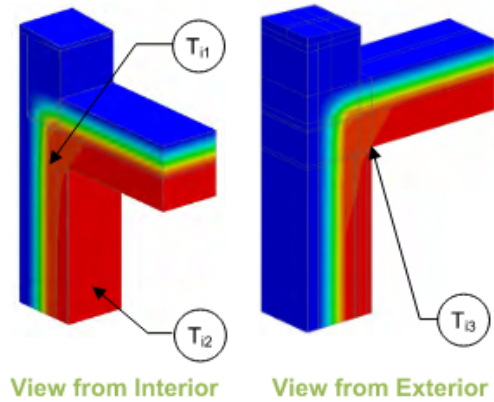
Appendix B: Catalogue Thermal Data Sheets

BUILDING ENVELOPE THERMAL BRIDGING GUIDE v1.6

Detail 7.5.10

Highly Insulated Precast Concrete Sandwich Panel Wall Assembly – Roof to Wall Intersection with Wood-Framed Parapet

Thermal Performance Indicators



Assembly 1D (Nominal) R-Value	R_{1D}	R-2.76 (0.49 RSI) + insulation
Transmittance / Resistance without Anomaly	U_w , R_w , U_r , R_r	"clear field" U- and R-value w = wall r = roof
Transmittance / Resistance	U , R	U- and R-values for the overall assembly
Surface Temperature Index ¹	T_i	0 = exterior temperature 1 = interior temperature
Linear Transmittance	Ψ	Incremental increase in transmittance per length of parapet

¹Assumptions and limitations for surface temperatures identified in ASHRAE 1365-RP

Nominal (1D) vs. Assembly Performance Indicators

Base Assembly – Wall

Wall Insulation R-Value/in	Wall Insulation 1D R-Value (RSI)	R_{1D} ft ² ·hr·°F / Btu (m ² K / W)	R_w ft ² ·hr·°F / Btu (m ² K / W)	U_w Btu/ft ² ·hr·°F (W/m ² K)
5	R-40 (7.04)	R-42.8 (7.53)	R-42.3 (7.45)	0.024 (0.134)
6	R-48 (8.45)	R-50.8 (8.94)	R-50.3 (8.86)	0.020 (0.113)
7	R-56 (9.86)	R-58.8 (10.35)	R-58.3 (10.27)	0.017 (0.097)

Base Assembly – Roof

Roof Insulation 1D R-Value (RSI)	R_{1D} ft ² ·hr·°F / Btu (m ² K / W)	R_w ft ² ·hr·°F / Btu (m ² K / W)	U_w Btu/ft ² ·hr·°F (W/m ² K)
R-48 (8.45)	R-50.0 (8.81)	R-50.0 (8.81)	0.020 (0.114)

Parapet Linear Transmittance

Wall Insulation R-Value/in	Wall Insulation 1D R-Value (RSI)	R ft ² ·hr·°F / Btu (m ² K / W)	U Btu/ft ² ·hr·°F (W/m ² K)	Ψ Btu/ft·hr·°F (W/mK)
5	R-42.8 (7.53)	R-47.2 (8.32)	0.021 (0.120)	-0.0066 (-0.0115)
6	R-50.8 (8.94)	R-50.4 (8.87)	0.020 (0.113)	-0.0008 (-0.0014)
7	R-58.8 (10.35)	R-52.9 (9.33)	0.019 (0.107)	0.0034 (0.0059)

*Clear Wall and Roof areas measured to the outside of the insulation



Appendix B – Indoor Water Use Reduction

Appendix B1.1: Suite DHW load reduction due to ultra-low flow fixtures (from LEED V4 Indoor Water Use Reduction Calculator)

Summary for Design and Construction Rating Systems									
Note: Baseline and design volumes are READ-ONLY. To edit, see the previous tab(s).									
Group Name	Percent Occupants using Group (%)	Baseline Case (liters/year)				Design Case (liters/year)			
		Annual Flush Volume	Annual Flow Volume	Annual Baseline Consumption	Total Baseline Consumption	Annual Flush Volume	Annual Flow Volume	Annual Design Consumption	Total Design Consumption
Group 1	100.00%	0.00	110,011.00	110,011.00	110,011.00	0.00	52,195.00	52,195.00	52,195.00
Annual baseline water consumption (liters/year)									110,011.00
Annual design water consumption (liters/year)									52,195.00
Percent reduction from baseline (%)									52.55%