Canadian Precast Concrete Institute
Institut Canadien du Béton Préfabriqué

Whole Life Carbon
Whole-Building Life Cycle Assessment (wbLCA)

For Precast Envelope with Cast-in-Place (CIP) Structure in Various Canadian Cities

Prepared by: Mantle Climate
Prepared for: Canadian Precast/Prestressed Concrete Institute

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FINAL REPORT

Prepared By:
Ryan Zizzo, Founder and CEO
Eslam Elshorbagy, Senior Advisor
Mai-Yin Johnston, Advisor

MANTLE CLIMATE

Executive Summary

Mantle Climate is pleased to present the Canadian Precast/Prestressed Concrete Institute (CPCI) with this report estimating and comparing whole-life carbon (operational carbon + embodied carbon) for the Precast envelope with Cast-in-Place (CIP) Structure building making use of different precast concrete structural and envelope systems across five Canadian cities (Vancouver, Edmonton, Toronto, Montreal, and Halifax). The study evaluates both embodied carbon emissions (due to manufacture, transport, and construct/assembly of structure and envelope) and operational carbon emissions (due to annual heating, cooling, ventilation, etc). The life cycle stages considered include A1-A5 (product manufacture, transport, and construction), B1-B5 (use stage), and C1-C4 (end-of-life), aligned with the National Whole-Building LCA Practitioner's Guide.[1]

The building typology modelled is Precast envelope with Cast-in-Place (CIP) Structure – Cast-in-Place concrete structure and slabs + precast envelope.

The building has two levels of parking, one underground and one at grade. To help isolate and compare the embodied carbon impact of the various structural systems, the parking levels of the buildings have been excluded from the main results presented below. Section 2.5 provides additional results with parking added and using various area definitions (with and without parking being included in the normalization areas).

The embodied carbon emissions were calculated using the appropriate regions in the precast concrete industry average CPCI EPDs (Western Canada, Central Canada, and Eastern Canada).

The calculated embodied carbon was compared against several targets, mainly from the Canada Green Building Council's Zero Carbon Building Design Standard v4 which is 425 kg CO_2e/m^2.

In all cases, the embodied carbon emissions for the buildings calculated in this study were below these industry limits, demonstrating precast concrete's ability to achieve low-carbon construction below current market limits in all Canadian markets examined.

Total embodied carbon (life cycle stages A-C) ranges from 197-239 kg CO_2e/m^2 across the cities as follows (see **Figure ES.1)**:

[1] National Research Council Canada: National whole-building life cycle assessment practitioner's guide

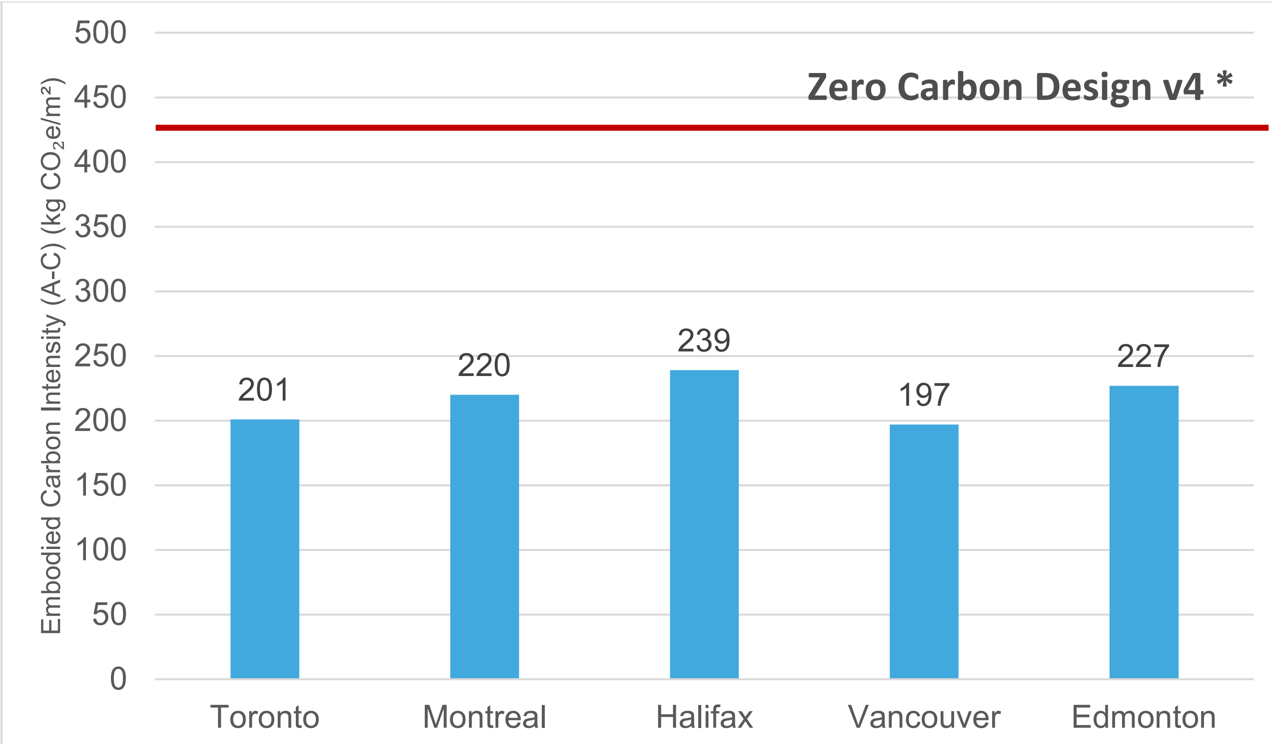

***Figure ES. 1**: Total Embodied Carbon (A-C) for the building across the five cities.*

** The Canada Green Building Council's [Zero Carbon Building Design Standard v4] sets an embodied carbon limit of 425 kg CO2e/m2 of building built floor area.*

The majority of these values represent low-carbon construction. A comprehensive embodied carbon benchmarking report for 292 buildings in the US and Canada was released by the Carbon Leadership Forum (CLF) in April 2025.[2] It shows the following results for multifamily residential buildings of the same LCA scope (structure and envelope) and life cycle stages (A-C):

- 75th percentile "high" = 520 kg CO_2e/m^2
- 50th percentile "typical" = 390 kg CO_2e/m^2
- 25th percentile "low" = 320 kg CO_2e/m^2

In comparison:

- All buildings modelled in this study are below the the CLF "low" benchmark (25th percentile = 320 kg CO_2e/m^2) for the same LCA scope (structure + envelope, A–C).
- All city results fall below 250 kg CO_2e/m^2, indicating very low embodied carbon intensity relative to current North American benchmarks.

[2] Carbon Leadership Forum: The Embodied Carbon Benchmark Report

Carbonation:

- **Carbonation uptake**, calculated and reported separately in accordance with relevant standards. The value is nominal, at roughly 1% of embodied carbon sequestered over 60 years. The building Structure system reaches an uptake intensity of 3.2 kg CO_2e/m² over 60 years.

Operational carbon observations as shown in **Figure ES.2** include:

- In cities like **Montreal and Vancouver (and to a lesser extent Toronto)**, where operational carbon is already low, **embodied carbon becomes the dominant factor** in whole-life carbon emissions. Therefore, projects in these regions should pay special attention to prioritizing low embodied carbon construction.

Operational carbon intensity (GHGi, kg CO_2e/m² annually) values were calculated based on current policy / regulation for new building construction in each market, which applies equally to all building types (no matter what type of material they are made from). Currently, the operational carbon impact is roughly 182 times higher in Halifax than it is in Montreal (largely due to Montreal's new ban on combustion heating):

- **Halifax** has the highest operational carbon intensity (75 kg CO_2e/m²).
- **Montreal** has the lowest operational carbon intensity (0.41 kg CO_2e/m²).

Overall lowest and highest whole-life carbon buildings:

- **Lowest-carbon scenario**: *The building in Montreal*
- **Highest-carbon scenario**: *The building in Halifax*

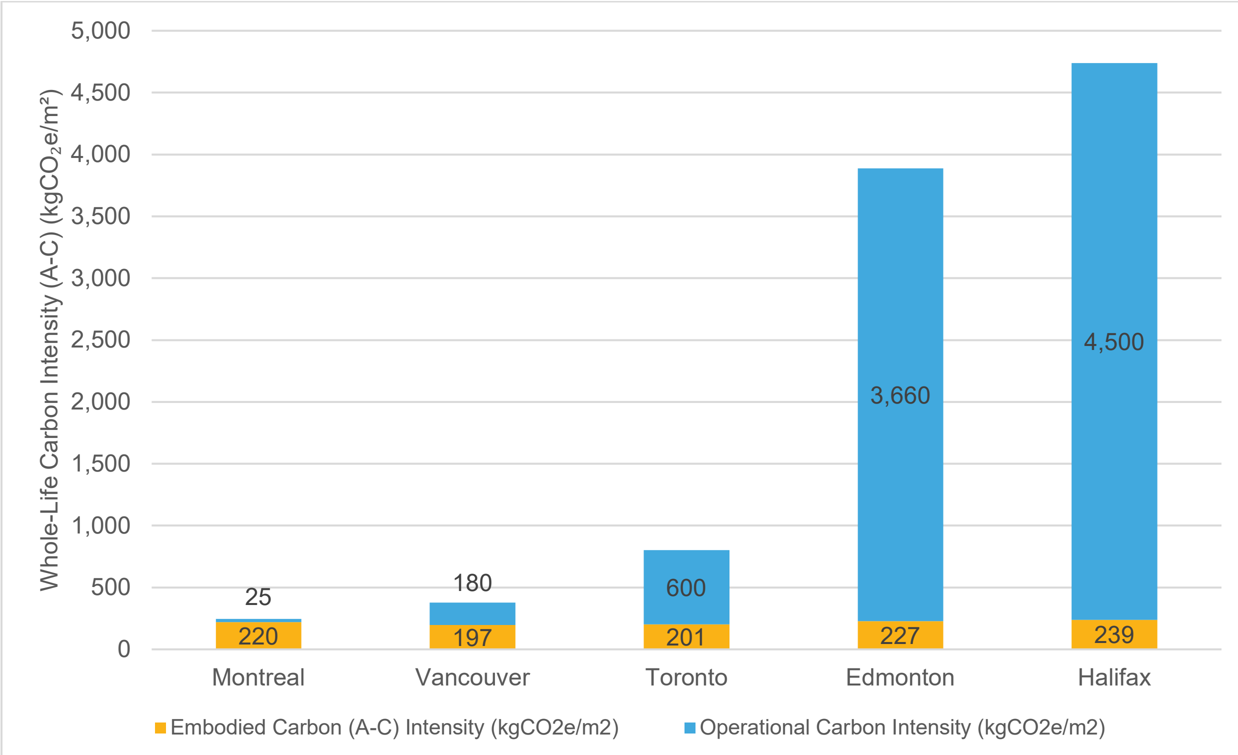

Figure ES. 2: Whole-life carbon intensity (A-C) over 60 years. Embodied emissions are orange and operational emissions are blue.

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1. Introduction

Precast concrete presents an opportunity to meet Canada's dual housing needs of speed and low-carbon. Accordingly, CPCI seeks to better understand the whole life carbon (embodied carbon from materials and construction plus the operational carbon from operations) of various applications of precast concrete, while considering regional differences, various service life scenarios, and the impact of carbonation. This study compares the embodied and operational carbon (together, the "whole life carbon") intensity of precast envelope with cast-in-place (CIP) structure and slab building design. The building design is from a real-world recently constructed building by a CPCI member company.

The building design is evaluated in five major Canadian cities: Halifax, Montreal, Toronto, Edmonton, and Vancouver. These cities were chosen as key markets representing a range of material embodied carbon footprint varying for Eastern, Central, and Western Canada, alongside these regions' variable climates and electricity carbon intensity values. ***Figure 1*** illustrates the building archetype selected for the analysis.

Figure 1: 3D illustration of the Precast *envelope* with *CIP structure building included in this study.*

Building Details:

- **Building height:** 7 storeys, plus 2 below-grade / at-grade parking levels
- **Built floor area (including parking):** 19,745 m²
- **Gross floor area (excluding parking):** 15,750 m²
- **Total dwelling units:** 98
- **Structural system:** Cast-in-place concrete
- **Envelope:** Single-wythe precast concrete panels with 4 inches of spray foam insulation
- **Floor system:** Cast-in-place concrete slabs

Detailed descriptions of the building assemblies—including structural systems, envelope components, and material specifications—are provided in the Bill of Quantities (BOM) and mapped Environmental Product Declarations (EPDs) in Appendix F. This appendix present comprehensive quantities and associated Global Warming Potential (GWP) data used for life cycle assessment (LCA) modeling in One Click LCA. Material breakdowns are categorized by function and location (above/below grade).

2. Embodied Carbon

2.1 Product Stage Carbon (A1-A3)

The building design was modelled based on the materials used in that particular design and the same quantity of building materials was used to assess the design's carbon across all five cities. No modifications were made in building design across regions, including structural seismic system, insulation, and foundation.[3] The industry average global warming potential (GWP) of each material, which indicates the embodied carbon, was sourced from published environmental product declarations (EPDs). Additionally, regional variations in industry averages were accounted for, as demonstrated in Table 1.2, for precast concrete and ready-mix concrete.[4]

This relied on the Canadian Precast/Prestressed Concrete Institution's (CPCI) available EPDs representing regionalized industry averages for precast concrete produced by CPCI members across Western, Central, and Eastern Canada. These EPDs are business-to-business type III EPDs and have been prepared in accordance with the governing precast concrete category rules, ISO 14025:2006 and ISO 21930:2017, and ASTM International's EPD program operator rules (Table 1). For ready-mix concrete, the provincial average values published by the Carbon Leadership Forum (CLF) were used, representing standard industry practice across Canada.[5]

[3] **Disclaimer:** All building material quantities were provided by members of the CPCI Task Group. In cases where information was missing, Mantle Climate followed industry best practices to develop estimates and utilized the services of a professional quantity surveying firm (BTY).
[4] Mantle used the regional industry average ready-mix concrete EPDs and picked the mix GWPs associated with the cement and SCMs specified per major building element; the buildings primarily used low carbon ready-mix concrete; when this information was not available, the "baseline" mix GWPs are used.
[5] The Carbon Leadership Forum - 2023 CLF North American Material Baselines Report

To ensure consistency across regional comparisons, it is important to clarify the distinction between Built Floor Area (BFA) and Gross Floor Area (GFA), as this directly affects embodied carbon intensity metrics. According to the National Whole Building Life Cycle Assessment Practitioner's Guide[6], BFA refers to the total enclosed floor area including attached parking, while GFA excludes attached parking.

All intensity calculations in this report have been standardized by removing parking from the embodied carbon and using GFA unless otherwise noted such as in Section 2.5.

[6] National Research Council Canada: National whole-building life cycle assessment practitioner's guide

Table 1: *CPCI EPDs used in this study, provided by CPCI.*

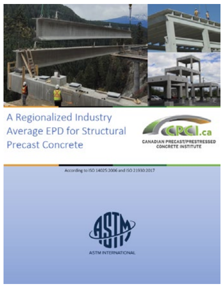
	EPD Name	Purpose in this Study
	[A Regionalized Industry Average EPD for Structural Precast Concrete]()	Columns, Slabs, Beams
	[A Regionalized Industry Average EPD for Insulated Precast Panel Concrete]()	In any insulated precast assemblies
	[A Regionalized Industry Average EPD for Below Grade Precast Concrete]()	Not used
	[A Regionalized Industry Average EPD for Architectural Precast Panel Concrete]()	Building Facade/ envelope

Table 2: *Example of EPDs and GWPs used in different locations in this study.*

City	Precast concrete	Ready-mix concrete	All other materials
Toronto	"Central Canada" GWP in industry average EPD	Concrete Ontario Member Industry-Wide EPD	Industry average EPDs using single national values
Montreal	"Eastern Canada" GWP in industry average EPD	Association béton Québec Member Industry-Wide EPD	
Halifax		Atlantic Concrete Association Member Industry-Wide EPD	
Vancouver	"Western Canada" GWP in industry average EPD	Concrete BC Member Industry-Wide EPD	
Edmonton		Concrete Alberta Member Industry-Wide EPD	

2.2 Cradle-to-Grave (A-C)

For transportation and construction factors, default values provided by the One Click LCA software were applied for life cycle phases after the manufacturer's gate (A4 onward), including the use phases (B) (e.g., maintenance, repair) and end-of-life phases (C). As per the NRC's National Whole-Building Life Cycle Assessment Practitioner's Guide[7], interim assumptions should only be used when the tool does not estimate values for full life cycle stages. Since One Click LCA provides these estimates,[8] its values have been adhered to, ensuring compliance with the guide's methodology and maintaining consistency across the assessment. Overall, both upfront embodied carbon emissions (A1-A5) and cradle-to-grave embodied carbon emissions (A-C) were calculated and are reported. Table 3 outlines the default transportation (A4) distances and associated transport modes used in One Click LCA for key construction materials. Distances reflect assumed average supply chain scenarios, with typical vehicle types and fill rates applied in the embodied carbon analysis.

[7] National Research Council Canada: National whole-building life cycle assessment practitioner's guide
[8] One Click LCA is a comprehensive lifecycle assessment software widely used in the construction industry to estimate environmental impacts across all life cycle stages of building materials and systems.

***Table 3:** Default Transportation Distances (A4) and Modes Used in One Click LCA*

No.	Material	Distance (km)	Mode of Transportation
1	Ready-mix concrete	200	Concrete mixer truck, appr. 8 m3, 100% fill rate
2	Structural precast concrete	200	Trailer combination, 40 ton capacity, 100% fill rate
3	Reinforcement steel (rebar)	580	
4	Structural Steel	580	
5	Steel Studs	580	
6	Architectural steel framing	580	
7	Wood	560	
8	Concrete masonry unit (CMU)	200	
9	Gypsum board	200	
10	XPS/ foam Insulation	350	
11	Roof insulation - Board/ Bitumen	350	
12	Mineral wool insulation	200	
13	Acoustic Insulation	200	
14	Vapour barrier	350	
15	Metal doors	550	
16	Fiberglass doors	200	
17	PVC Windows	650	
18	Aluminium curtain walls	200	

2.3 Carbonation

The effects of concrete carbonation were assessed using data provided by a CPCI Member Company, as detailed in Appendix A, according to the National Research Council (NRC) National guidelines for whole-building life cycle assessment [9] (and as outlined in the previous Mantle memo dated October 16, 2024; included in Appendix A). These values were applied proportionally to each building based on gross floor area. A link to the full calculation methodology is provided in Appendix B.

As outlined in the National Whole-Building Life Cycle Assessment Practitioner's Guide, carbonation should be reported separately from the LCA results, similar to biogenic carbon. The estimated CO_2 uptake from carbonation over 60 years, normalized per square meter per year, is summarized in **Figure 2**.

The carbonation value calculated is nominal for all buildings, at roughly 1% of embodied carbon sequestered over 60 years. The corresponding carbonation uptake intensity is estimated at 3.2 kg CO_2e/m^2, equivalent to approximately 51 t CO_2e over a 60-year service life.

[9] National Research Council (NRC) - National guidelines for whole-building life cycle assessment ("NRC guidelines")

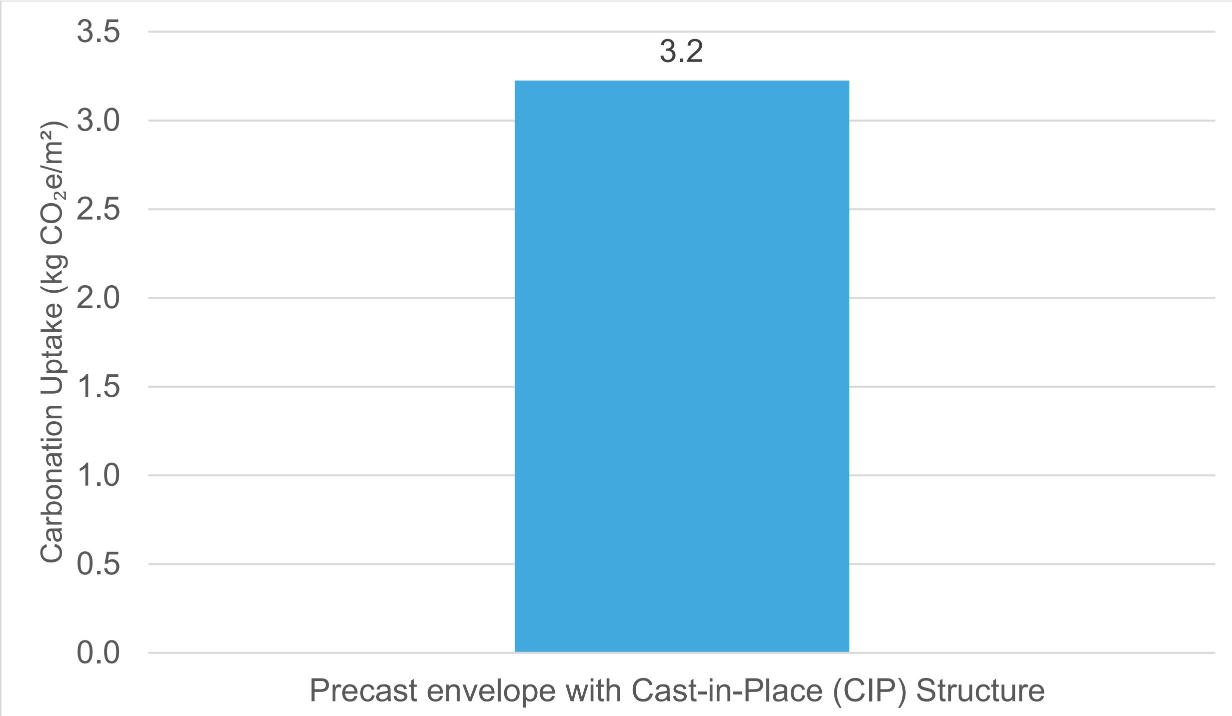


Figure 2: *Carbonation uptake intensity (kg CO_2e/m^2) over 60 for the structural system.*

The embodied carbon intensity and total embodied carbon emissions for each building design in each city were calculated, measured in kg CO_2e/m^2 and t CO_2e, respectively. These values are displayed in tables and figures throughout this report and do not include carbonation (as per the NRC Practitioner's Guide).

When comparing carbonation and embodied carbon values, take care to compare the absolute values only (t CO_2e,) or the intensity values only (kg CO_2e/m^2).

2.4 Embodied Carbon Results

Figure 3 shows the embodied carbon intensity cover stages (A-C) for the building and region compared against the Zero Carbon Design v4 limit of 425 kg CO_2e/m^2. **In all cases, the embodied carbon emissions for the buildings calculated in this study were below these industry limits, demonstrating precast's ability to achieve low-carbon construction below current market limits.**

Table 4 presents the embodied carbon values for the building, excluding the effects of carbonation. Refer to **Appendix D** for a detailed breakdown of embodied carbon by element and life-cycle stage. **Appendices E** and **F** provide the list of materials included in each structural design and the corresponding EPDs mapped in One Click LCA.

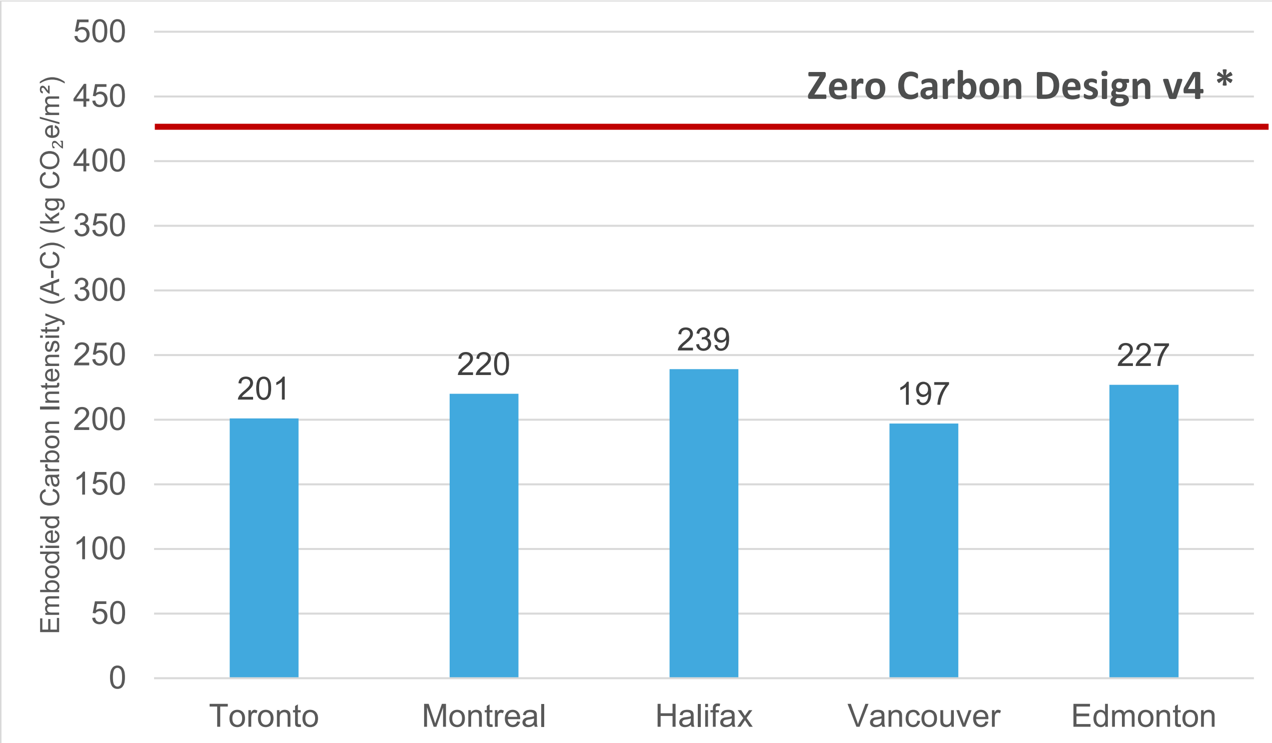


Figure 3 : *Total embodied carbon intensity (Modules A–C) for the structural designs across five Canadian cities.*

** The Canada Green Building Council's [Zero Carbon Building Design Standard v4] sets an embodied carbon limit of 425 kg CO2e/m2 of building built floor area.*
**** All intensity values are calculated based on Gross Floor Area (GFA).*

Table 4: *Total embodied carbon emissions intensity and absolute values in five cities.*

City	Cradle-to-Grave Embodied Carbon (A-C)	
	Intensity (kg CO_2e/m^2)	Absolute (t CO_2e)
Toronto	201	3,164
Montreal	220	3,459
Halifax	239	3,759
Vancouver	197	3,096
Edmonton	227	3,576

2.4.1. Alternative Results Using CPCI Member Facility-specific EPDs Instead of CPCI Industry Average EPDs

To provide a more representative comparison, this section includes an alternative analysis using CPCI member facility-specific EPDs. This was necessary due to the limited product specialization available in the CPCI's industry-average EPDs. The member-specific EPDs include a broader range of product categories, allowing for a more accurate and detailed assessment of embodied carbon.

Figure 4 shows that using product-specific precast EPDs in place of CPCI industry averages can lower the embodied carbon in some cases (see Total Precast and Steel Frame buildings reports), while the Cast-in-Place building remains unchanged. **Appendix G** presents a comparison of the embodied carbon values between the CPCI industry-average EPDs and the member EPDs used.

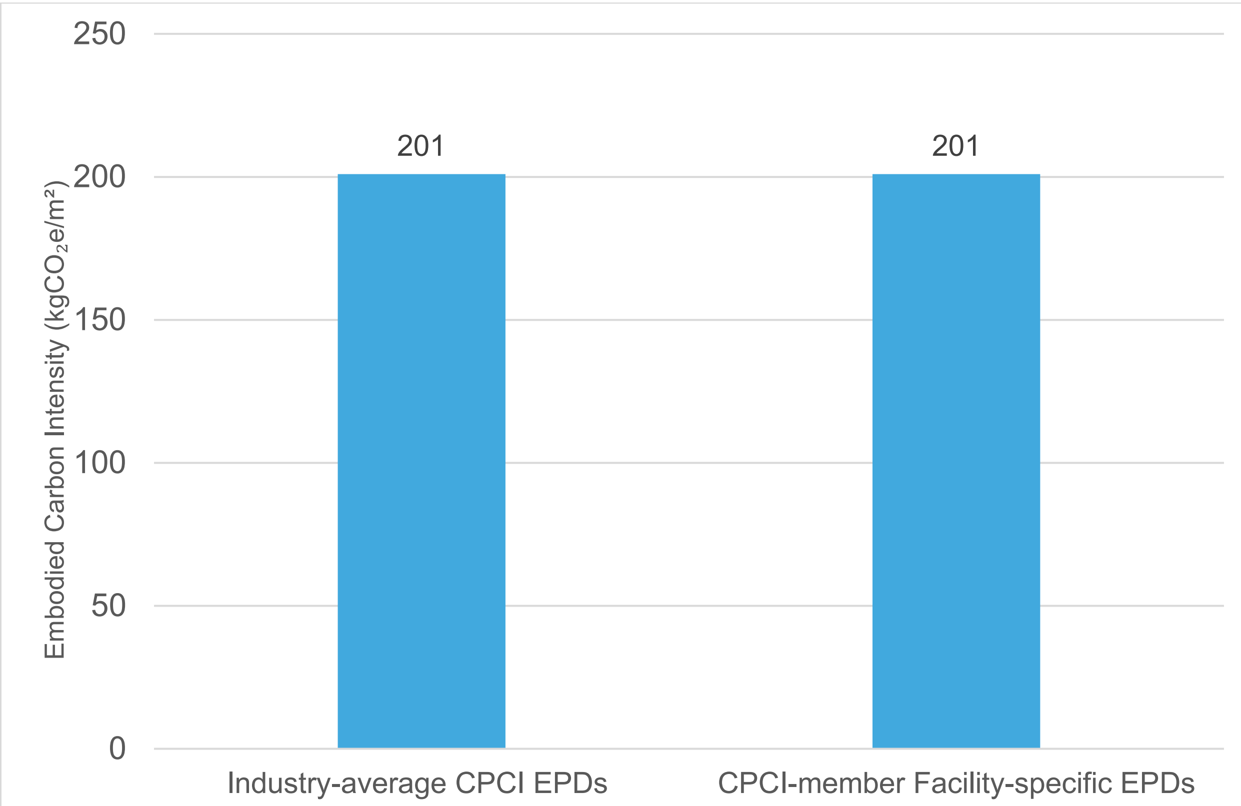


Figure 4: *Total embodied carbon intensity (Modules A–C) for the structural design in Toronto, using a CPCI member's product-specific precast concrete EPDs instead of the industry-average CPCI EPDs.*

2.5 Underground Parking and Embodied Carbon

The embodied carbon results for the Toronto buildings are presented for two scenarios: one including underground parking and one excluding it, to assess the impact on both embodied carbon intensity and total (absolute) emissions. The building has two parking levels (one underground and one at grade)

The results, summarized in **Table 5**, show that removing parking reduces absolute embodied carbon (tCO_2e) due to a smaller building scope but increases the carbon intensity ($kgCO_2e/m^2$). This is because the gross floor area (GFA) used to calculate intensity is reduced when parking is excluded, while the structural elements contributing to carbon emissions remain significant.

For example, in the building, removing the two parking levels reduces the total embodied carbon from 3,722 tCO_2e to 3,164 tCO_2e. However, the embodied carbon intensity changes from 189 $kgCO_2e/m^2$ (includes parking embodied carbon, using BFA) or 236 $kgCO_2e/m^2$ (includes parking embodied carbon, using GFA) to 201 $kgCO_2e/m^2$ because the normalizing area in the denominator is significantly reduced when parking is excluded.

This highlights how removing underground parking lowers total emissions but can raise the intensity value if the reference floor area is reduced. If GFA remains constant in both scenarios, carbon intensity would also decrease alongside total emissions.

Table 5: *Total embodied carbon intensity (A–C) and absolute emissions with variations in gross floor area (GFA) or building floor area (BFA) depending on parking inclusion.*

* Intensity values in this table—and throughout the report—are reported based on Gross Floor Area (GFA) unless otherwise stated.

Parking Inclusion	GFA (m^2) or BFA (m^2) *See section 2.1*	Embodied Carbon Intensity (A-C) (kg C O_2e/m^2)	Embodied Carbon Absolute (t CO_2e)
Excluding Parking	GFA = 15,750 m2	201	3,164
Including Two Parking Levels	BFA = 19,745 m2	189	3,722
	GFA = 15,750 m2	236	3,722

3. Operational Carbon

Operational carbon emissions vary across regions due to differences in climate (energy demand), energy efficiency requirements from provincial building codes and municipal green development standards, and the emission intensity of local energy systems including the electricity grid.

To quantify the operational energy for new buildings in each region, Mantle used standard values derived from relevant provincial and municipal building codes / green development standards. When possible, city-specific greenhouse gas intensity (GHGi) targets were used as indicated in Table **6** below.

Table 6 **:** City-specific operational GHGi values:

No.	City	GHGi Values (kg CO_2e/m^2)
1	Montreal	0.41
2	Vancouver	3
3	Toronto	10
4	Edmonton	61
5	Halifax	75

See below for further details on each location.

3.1 Montreal

Quebec's electricity grid is nearly carbon-free, predominantly powered by hydroelectricity, with a carbon intensity of 0.0017 kg CO_2e/kWh.[10] Additionally, Montreal has recently enacted a ban on

[10] Government of Canada -Emission factors and reference values 2025

combustion heating in new buildings. [11] As a result, the GHGi per square meter in Montreal is negligible, calculated at 0.41 kg CO_2e/m².

3.2 Vancouver

In Vancouver, the requirements for Part 3 buildings are guided by the Vancouver Building By-law (VBBL) and the Green Building Policy for Rezoning, which are components of the Zero Emissions Building Plan (ZEBP). [12] These policies align with Emissions Level 3 (EL-3) or higher, depending on the building type and use. Updates to these policies, approved by the City Council, took effect in January 2025, as outlined in the City of Vancouver Climate Emergency Report – Bylaw and Policy Updates Applicable to New Buildings, May 17, 2022. These updated requirements were used in this analysis (3 kg CO_2e/m²). [13]

3.3 Toronto

In Toronto, although the current Toronto Green Standard (TGS) Part 3 building GHGi limit is 15 kg CO_2e/m^2, [14] the city reported that the average value built for new construction over the past few years is 10 kg CO_2e/m^2. Therefore, this value was used instead as it is representative of the current new building performance in Toronto.

3.4 Edmonton

Edmonton does not have a building-level emissions requirement therefore operational carbon estimates were derived from energy models used in three recent case studies. The 'reference building' results from these case study energy models represent the current 2020 National Energy Code for Buildings (NECB). Then, emissions factors provided by Environment and Climate Change Canada (ECCC) [15] were applied (0.49 kgCO_2e/kWh for electricity and 0.191 kgCO_2e/kWh for natural gas). The averaged GHGi for three recently modelled buildings in Edmonton was calculated as 30 kgCO_2e/m² for electricity and 31.4 kgCO_2e/m² for natural gas, and the total GHGi per square meter for Edmonton was calculated as 61.4 kgCO_2e/m². [16]

A similar approach to that used for the City of Edmonton was applied to both Montreal and Halifax due to the absence of GHGi targets or historical GHGi data repositories for buildings in these cities.

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[11] City of Montreal: Ban on combustion heating devices in new buildings. Existing buildings are not targeted by this by-law. The by-law will come into force gradually, starting on October 1, 2024 for small buildings and then on April 1, 2025 for all others.
[12] Zero Carbon Step Code / British Columbia Building Code
[13] City of Vancouver - Climate Emergency Report – Bylaw and Policy Updates Applicable to New Buildings
[14] Toronto Green Stabdard Version 4 - Buildings Energy, Emissions & Resilience
[15] Government of Canada -Emission factors and reference values 2025
[16] The modeled buildings are mid-rise multi-unit residential buildings, ranging from four to seven storeys in height and gross floor area range from 18,000 m² to 22,000 m². These buildings were modeled in 2023 following the NECB 2020 standards. For cases where a building was originally modeled to NECB 2017, an adjustment factor was applied to align the energy requirements with those specified in NECB 2020.

3.5 Halifax

The Edmonton case studies were also used as a conservative baseline. Mantle adjusted the Energy Use Intensity (EUI) for electricity and natural gas based on differences in Heating Degree Days (HDD) and Cooling Degree Days (CDD), using historical climate data from 1976–2005 obtained from the Climate Atlas of Canada.[17] Based on these values, space heating was reduced by 23% to account for Halifax's milder climate, while space-cooling was increased by 24%. This adjustment resulted in an overall reduction of Halifax's building EUI by 11% (kWh/m²). Subsequently, emission factors from Environment and Climate Change Canada (ECCC)[18] were applied (0.7 kg CO_2e/kWh for electricity and 0.187 kg CO_2e/kWh for natural gas). The total GHGi per square meter in Halifax was calculated as 75 kg CO_2e/m². Note that even though Halifax has a relatively mild climate, it's increased summertime cooling requirements combined with a very carbon-intensive electricity grid resulted in the highest operational emissions.

Operational carbon modeling was performed for the three building archetypes across five cities, considering 60-year (typical wbLCA duration), as detailed in **Tables 7** in this section. **Figure 5** present the absolute operational emissions for the 60-year scenarios.

[17] Prairie Climate Centre - Climate Atlas of Canada. Heating Degree Days and Cooling Degree Days historical respiratory,
[18] Government of Canada -Emission factors and reference values 2025

3.6 The Building Operational Carbon

Table 7: *Total operational carbon emissions intensity and absolute values in five cities for the building.*

* Intensity values (kg CO_2e/m²) are reported based on Gross Floor Area (GFA).

City	Operational Carbon	
	Intensity (kg CO_2e/m²)	Absolute (t CO_2e) (60 years)
Montreal	0.41	387
Vancouver	3	2,835
Toronto	10	9,450
Edmonton	61	58,023
Halifax	75	70,752

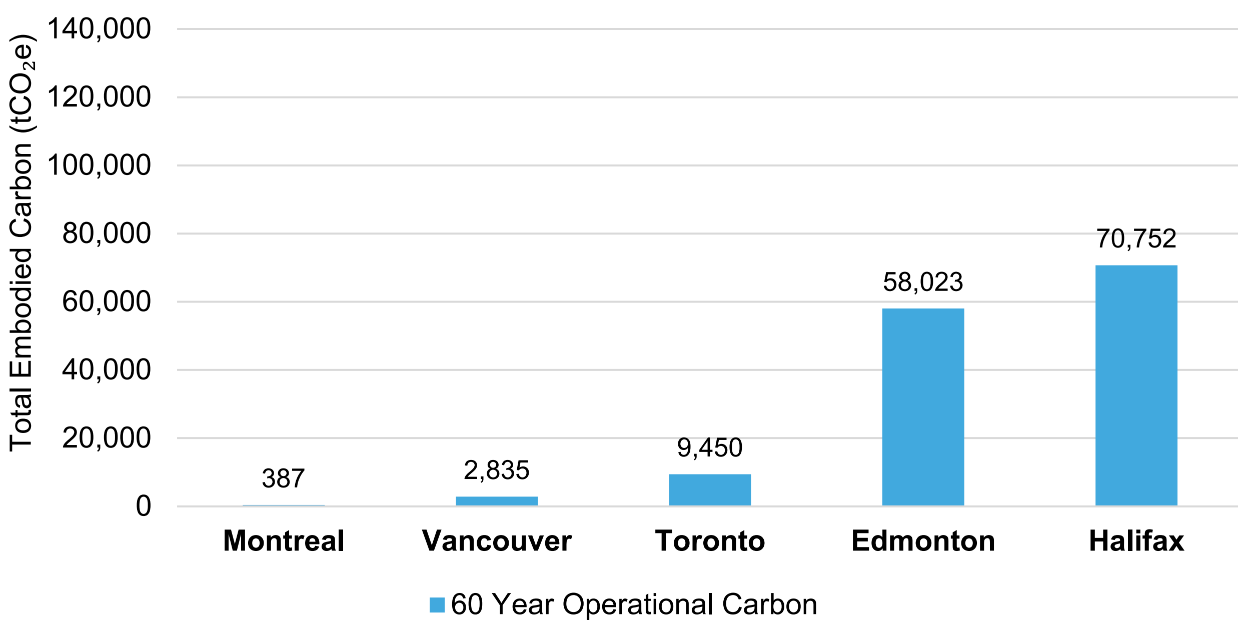

Figure 5: *Absolute operational emissions for the 60-year for the building.*

4. Whole Life Carbon

To compare the carbon contributions over the lifecycle of the building, both embodied and operational carbon were assessed. Region-specific operational energy use data, as detailed in the previous section, was incorporated alongside the embodied carbon calculations. The following section presents the combined embodied and operational carbon emissions to illustrate the whole-life carbon impact of the building design across all five cities (does not include carbonation removed as per the current rules in the NRC Practitioner's Guide).

Table 8 summarizes the whole-life carbon emissions (life cycle stages A–C) for the building type across the five cities.

Table 8: *Whole-life carbon emissions in five cities (A-C).*

* Intensity values (kg CO_2e/m²) are reported based on Gross Floor Area (GFA).

City	Absolute (t CO_2e)	Intensity (kgCO_2e/m²·y)	Carbon Contribution 60 Y	
	60 Y	60 Y	Embodied	Operations
Montreal	3,847	4	90%	10%
Vancouver	5,931	6	52%	48%
Toronto	12,614	13	25%	75%
Edmonton	61,599	65	6%	94%
Halifax	74,511	79	5%	95%

Figure 6 further illustrates and compares the contributions of embodied and operational carbon over 60 years. These graphs highlight the proportion of emissions attributed to embodied emissions (in orange) and operational emissions (in blue) using the same scale to make comparisons easier.

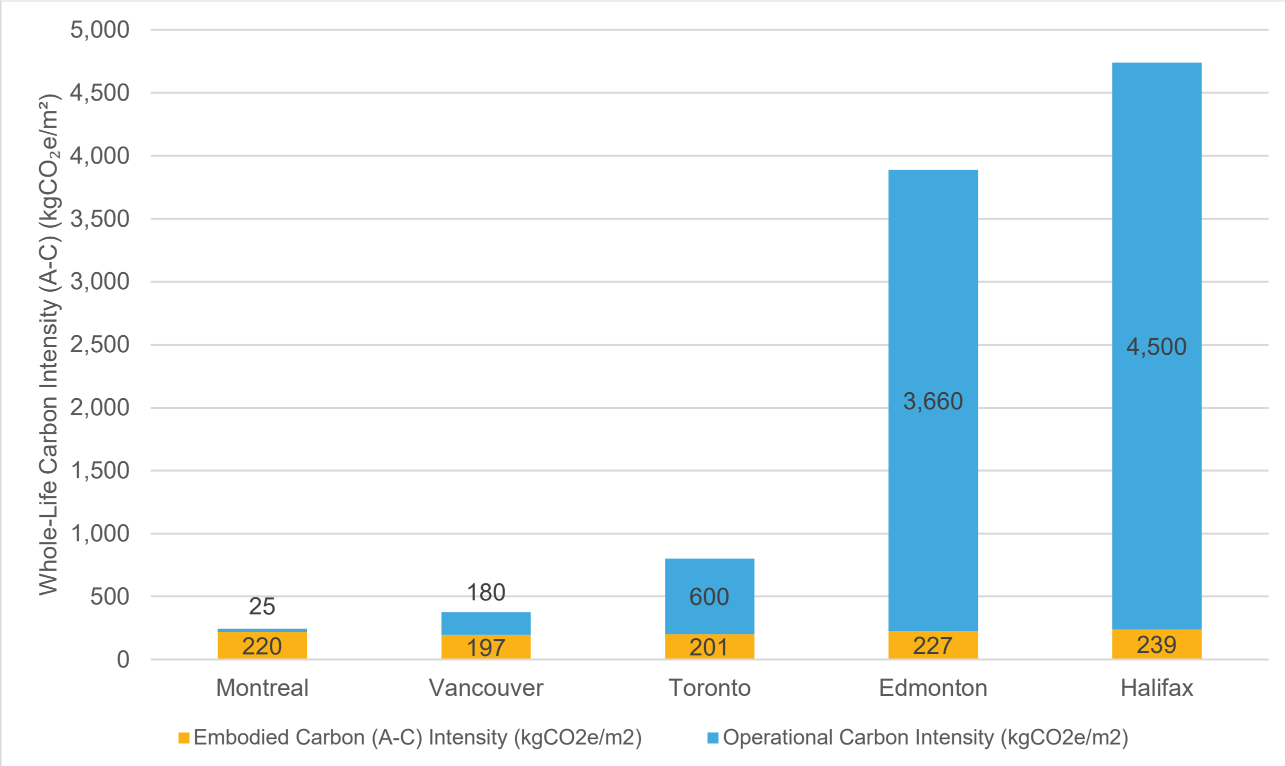

Figure 6: *Whole-life carbon intensity (A-C) over 60 years. Embodied emissions are orange and operational emissions are blue.*

5. Conclusion

In all cases, the embodied carbon emissions for the buildings calculated in this study were below the industry limits, demonstrating precast concrete ability to achieve low-carbon construction below current market limits. Both material selection and geographic location significantly influence a building's embodied carbon impact. [19] In this study, differences in embodied carbon results across locations are solely attributable to regional variations in material GWP factors.

Embodied Carbon of building ranges from 197 kg CO_2e/m² in Vancouver to 239 kg CO_2e/m² in Halifax.

Operational carbon varies by city, with Halifax having the highest emissions at 75 kgCO_2e/m² annually due to its carbon-intensive electricity grid, and Montreal performing best at just 0.41 kgCO_2e/m² due to its low-carbon grid and newly enacted ban on combustion for heating.

Carbonation uptake, calculated separately in accordance with applicable standards, offers modest reduction in embodied carbon over time. For the building, carbonation uptake is estimated at 3.2 kg CO_2e/m², corresponding to approximately 51 t CO_2e over a 60-year service life, representing roughly 1% of total embodied carbon.

While carbonation provides incremental mitigation, it is insufficient to offset the higher embodied emissions of more carbon-intensive systems. As such, selecting lower-carbon structural options and minimizing upfront emissions remain critical for meeting climate targets.

[19] See **Appendix C** for a comparison of carbon emission intensities between 25 MPa non-air-entrained ready-mix concrete and precast concrete across five Canadian cities.

6. Appendix A – Carbonation Methodology

Mantle Developments performed the carbonation quantification scenario in alignment with the National Research Council (NRC) National guidelines for whole-building life cycle assessment ("NRC guidelines") which is considered the official approach to WBLCA in Canada. The NRC guidelines are recognized as industry best practices for completing whole building life cycle assessments in Canada. The guideline is aligned with and recommends the carbonation calculation methodology from the European PCR for concrete products, EN 16757:2017, Annex BB.

The NRC guideline approach required the following data from CPCI to support this carbonation quantification:

1. Exposed concrete surface area (m^2).
2. Concrete exposure type per compressive strength class (from options presented in NRC guidelines Table 13, pg. 109).
3. Additional mineral components for cement or concrete by weight % (from options presented in NRC guidelines Table 14, pg. 109).
4. Confirm using the average reactive CaO "w" factor, as per NRC guidelines, or CPCI to provide an alternative value.
5. Estimated concrete waste during transportation and construction, if applicable (for exposed concrete products).

Estimated percentage or surface area of exposed concrete products replaced or refurbished at specified intervals during the building's life cycle, if applicable.

Mantle received the below data from a CPCI Member Company and adjusted it linearly to be used across all the three buildings' concrete areas.

Element Type	Area (m2)	s-factor	k-value	Comments
Foundations	6,753	1.10	k-value = 0.8	Foundations are all below grade - 25 to 35 Mpa
Exterior Walls	N/A	1.10	k-value = 0	All exterior walls are painted on the outside and sprayed foamed on the inside so the carbonation of these walls will be 0
Interior Walls	11,186	1.10	k-value = 2.7	Interior walls are studded and drywalled on the interior. Because these are covered with drywall will have to use the 2.7 value
Balconies	1,611	1.10	k-value – Top = 1.1	Balconies - Top side exposed to rain
	1,611	1.10	k-value – Bottom = 2.7	bottom side sheltered from rain
HollowCore	N/A	1.00	k-value – Top = 0	HC – top will get a skim coat and then flooring.
	17,103	1.00	k-value – Bottom = 2.7 for drop ceiling.	HC Bottom is covered by a drop ceiling
Stairwells	N/A	1.10	k-value = 0	Inside stairwells are generally painted

Note: if interior walls are not covered with drywall or paint, the k value would revise from 2.7 above to 3.8. A sensitivity analysis was performed to understand the impact of this change, which was calculated at 13% more carbonation removals for this case study.

7. Appendix B – Carbonation Calculations

Equation 7: d = k × s × t^0.5						
Elements types (Stubbe's)	depth of carbonation	depth of carbonation	k-factor	s-factor	(60 years)	(100 years)
	d (mm) (60 years)	d (mm) (100 years)	k (mm/year0.5)	s (unitless)	t^0.5	t^0.5
Foundations	6.8	8.8	0.8	1.1	7.75	10
Exterior Walls	0.0	0.0	0	1.1	7.75	10
Interior Walls	23.0	29.7	2.7	1.1	7.75	10
Balconies (Top)	9.4	12.1	1.1	1.1	7.75	10
Balconies (Bottom)	23.0	29.7	2.7	1.1	7.75	10
Hollow Core (Top)	0.0	0.0	0	1	7.75	10
Hollow Core (Bottom)	20.9	27.0	2.7	1	7.75	10
Stairwells	0.0	0.0	0	1.1	7.75	10

Equation 8: CO2 = d / 1000 × A × Utcc × C × Dc								
Elements types (Stubbe's)	uptake of CO2 by the concrete element (60 years)	uptake of CO2 by the concrete element (100 years)	depth of carbonation (60 years)	depth of carbonation (100 years)	surface area of the concrete product that is undergoing carbonatio	maximum theoretical uptake of CO2	cement content of the concrete	degree of carbonation
	CO2 (kg)	CO2 (kg)	d(mm)/1000	d(mm)/1000	A	Utcc (CO2/kg)	C (kg/m3)	Dc (%)
Foundations	5,499	7,099	0.0068	0.0088	5,909	0.491	327.07	0.85
Exterior Walls	0	0	0.0000	0.0000	0	0.491	321.55	0.85
Interior Walls	16,599	21,429	0.0230	0.0297	9,788	0.491	375.29	0.4
Balconies (Top)	1,773	2,289	0.0094	0.0121	1,410	0.491	321.55	0.85
Balconies (Bottom)	3,841	4,958	0.0230	0.0297	1,410	0.491	321.55	0.75
Hollow Core (Top)	0	0	0.0000	0.0000	0	0.491	375.29	0.4
Hollow Core (Bottom)	23,072	29,786	0.0209	0.0270	14,965	0.491	375.29	0.4
Stairwells	0	0	0.0000	0.0000	0	0.491	375.29	0.85
Total > Final Values	**50,784**	**65,562**		3	4			

Cement Content (C)		
	kg/tonne	kg/m3
Precast below grade	136.28	327.07
Preacast: structural	156.37	375.29
Precast: Insulated	133.98	321.55
Concrete density (kg/m3)	**2400**	

8. Appendix C – Baseline Concrete Mix GWP Comparison

The graphs below present the baseline Global Warming Potential (GWP) for 25 MPa ready-mix concrete (without air) and structural precast concrete in five Canadian cities, based on regional industry-average Environmental Product Declarations (EPDs). The comparison illustrates significant regional variation in carbon intensity, driven by differences in material sourcing, mix designs, manufacturing methods, and transportation.

For 25 MPa ready-mix concrete, Vancouver reports the lowest GWP at 220 kg CO_2e/m^3, while Halifax has the highest at 354 kg CO_2e/m^3—a difference of over 60%. This variation reflects differences in cement content, supplementary cementitious material (SCM) usage, and local supply chains.

For structural precast concrete, Toronto reports the lowest GWP at 0.21 kg CO_2e/kg, followed closely by Montreal and Halifax at 0.22 kg CO_2e/kg. Vancouver and Edmonton, however, show significantly higher intensities at 0.28 kg CO_2e/kg.

These findings highlight that regional strengths vary by product: for instance, Vancouver performs best in ready-mix concrete, while Toronto and Montreal lead in precast performance.

As noted earlier in the report, operational carbon differences across locations are even more pronounced. Together, this data provides an essential benchmark for evaluating the carbon intensity of materials and guiding regionally informed low-carbon construction strategies across Canada.

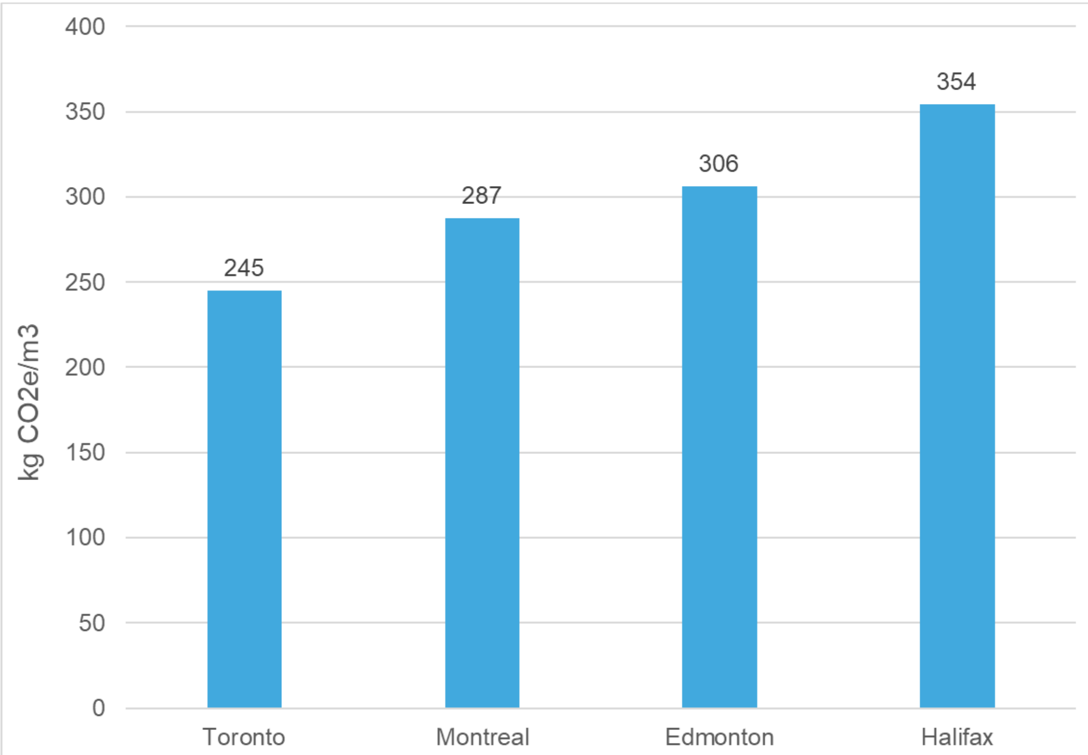

Figure 7: *GWP of* Ready-mix *Concrete, 25MPA (without air) - GUL 15SL across five cities.*

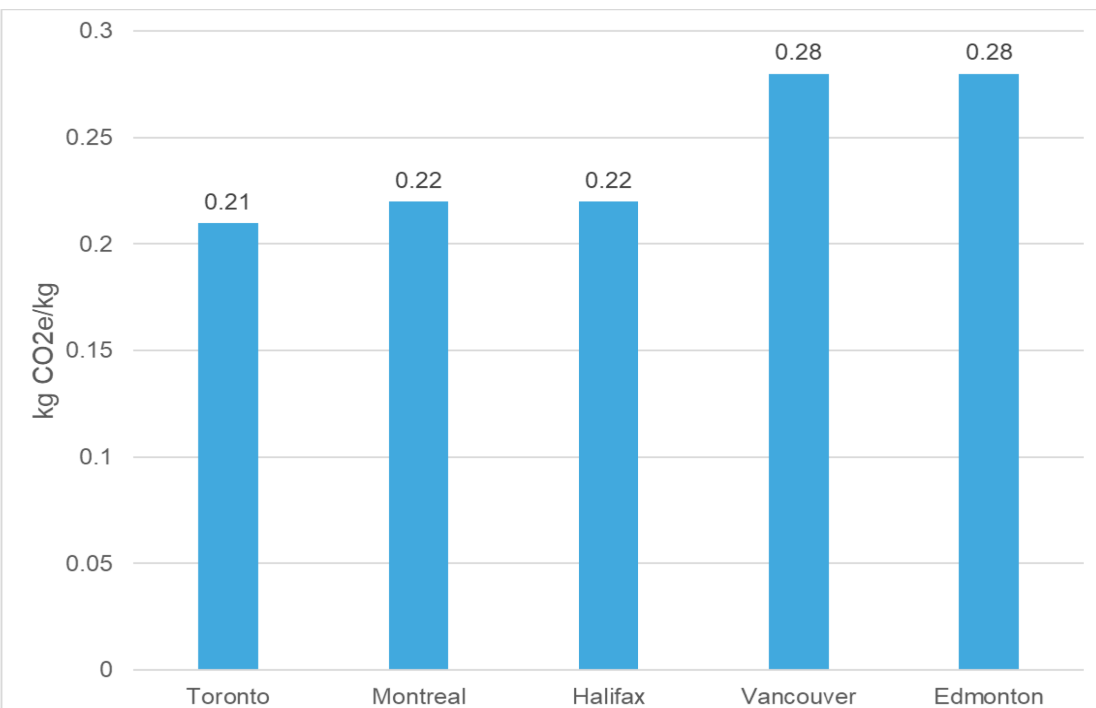

Figure 8: *GWP of Structural Precast Concrete across five cities.*

9. Appendix D – Embodied Carbon Breakdown Graphs for the Building in the City of Toronto (Example)

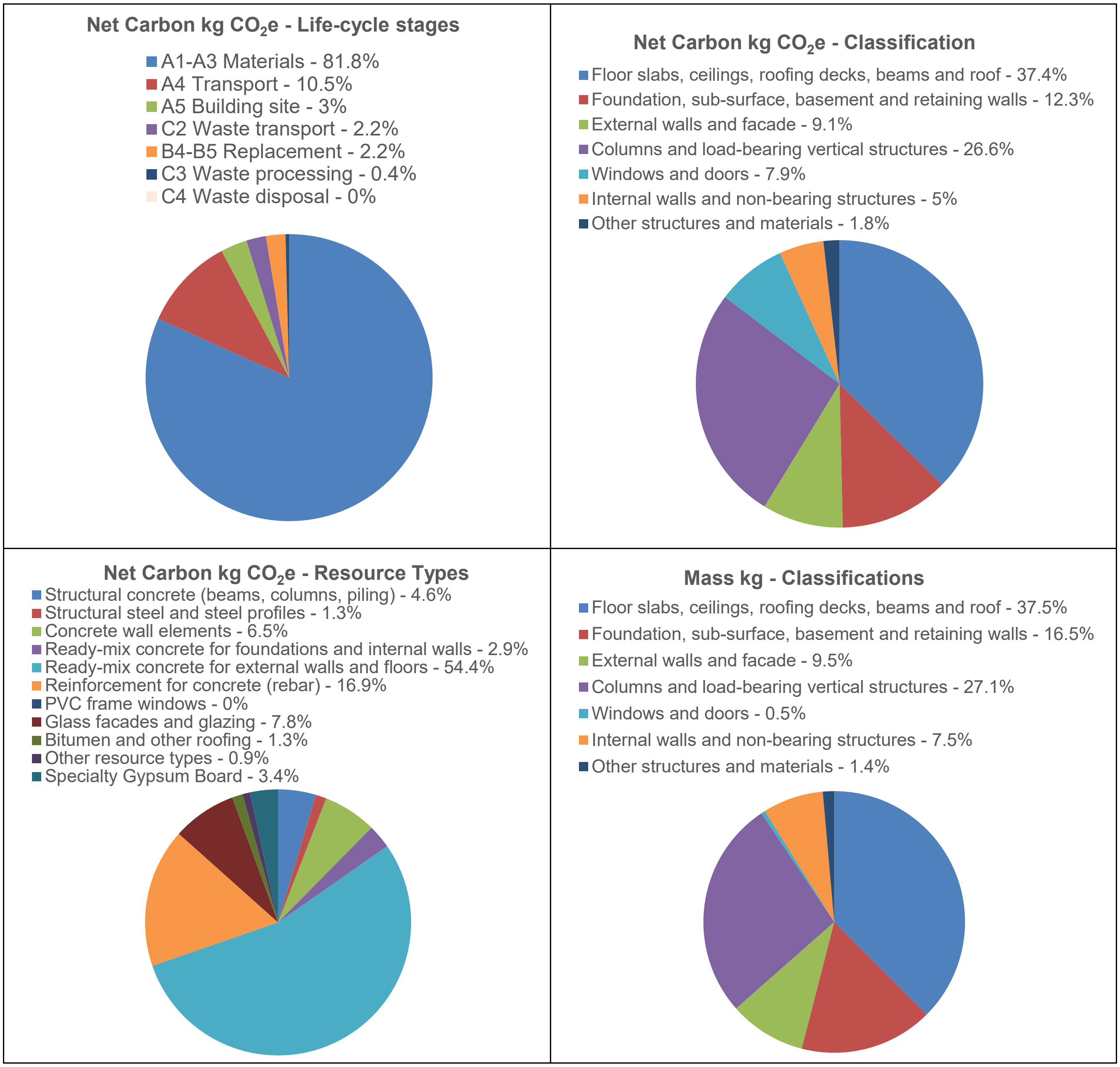

Figure 9: *Life-cycle distribution of embodied carbon and material mass for the building, broken down by life-cycle stages, resource types, and building element classifications.*

10. Appendix E – Construction Materials Included for the Design

		Cast-In-Place (CIP) Structure + Precast Facade	
	No.	Current	Proposed to remove
Below Grade	1	Concrete reinforcement rebar	
Below Grade	2	Blinding Course Conc. Supply	
Below Grade	3	25 MPa Concrete Volume	
Below Grade	4	30 MPa Concrete Volume	
Below Grade	5	35 MPa Concrete Volume	
Below Grade	6	40 MPa Concrete Volume	
Below Grade	7	50 MPa Concrete Volume	
Below Grade	8	Rigid Insulation: SOG	
Below Grade	9	Rigid Insulation: Wall	
Above Grade	10	Concrete reinforcement rebar	
Above Grade	11	30 MPa Concrete Volume	
Above Grade	12	35 MPa Concrete Volume	
Above Grade	13	40 MPa Concrete Volume	
Above Grade	14	50 MPa Concrete Volume	
Below Grade	16	Vapour Barrier - Ground Floor Slab	
Above Grade	18	Steel Studs	Kept
Above Grade	19	Drywall	Kept
Above Grade	20	Wall Grout	
Above Grade	21	Architectural Steel Framing	
Above Grade	22	CMU Block Wall	
Above Grade	23	Insulation Area	Kept
Above Grade	24	Entry Doors - dimensions 95.09*207.01	
Above Grade	25	Patio Doors	
Above Grade	26	Window Area	
Above Grade	28	Roofing Material	
Above Grade	29	Roofing Material	
Above Grade	30	Roofing Material	
Above Grade	31	Roofing Material	
Above Grade	32	Polyethylene Isolation Board	
Above Grade	33	Architectural Precast Panels - **CPCI EPD**	

--> Grey indicates structural concrete and steel elements.

Figure 10: *Summary of construction materials included in the bill of materials for the building structural design —categorized by building level (above or below grade) and material type.*

11. Appendix F – The Building Bill of Quantities & One Click LCA Mapping

Level	No.	Description	Specs Used in OneClick	Quantity (Including Parking)	Quantity (Excluding Parking)	Units	Envelope	Structure	CLF Reference baseline GWP	Mapped Product GWP
Below Grade	1	Concrete reinforcement rebar	Reinforcement steel (rebar), ASTM A615, ASTM A706, 7850 kg/m3 (CRSI)	97,151.7	57,902	kg		x	854 kg CO2e/ton	0.85 kg CO2e/kg
Below Grade	2	Blinding Course Conc. Supply (without air)	Ready-mix concrete, Canadian national average, British Columbia, without air entrainers, 15 MPa, (N) GU 30 SCM	51.0		m3		x	179.42 KgCO2e/m3	179.42 KgCO2e/m3
Below Grade	3	25 MPa Concrete Volume (without air)	Ready-mix concrete, Canadian national average, British Columbia, without air entrainers, 30 MPa, (N) GU 20 SCM	223.2		m3		x	219.7 kgCO2e/m3	219.7 kgCO2e/m3
Below Grade	4	30 MPa Concrete Volume (without air)	Ready-mix concrete, Canadian national average, British Columbia, without air entrainers, 30 MPa, (N) GU 20 SCM	479.1	456	m3		x	258.92 kgCO2e/m3	258.92 kgCO2e/m3
Below Grade	5	35 MPa Concrete Volume (without air)	Ready-mix concrete, Canadian national average, British Columbia, without air entrainers, 35 MPa, (N) GU 20 SCM	206.9		m3		x	293.75 kgCO2e/m3	293.75 kgCO2e/m3
Below Grade	6	40 MPa Concrete Volume (without air)	Ready-mix concrete, Canadian national average, British Columbia, without air entrainers, 40 MPa, (N) GU 20 SCM	62.4	47	m3		x	329 KgCO2e/m3	329 KgCO2e/m3
Below Grade	7	50 MPa Concrete Volume (without air)	Ready-mix concrete, Canadian national average, British Columbia, without air entrainers, 50 MPa, (N) GU 25 SCM	3.4	0	m3		x	359.49 kgCO2e/m3	359.49 kgCO2e/m3
Below Grade	8	Rigid Insulation: SOG	XPS insulation board, (incl. A5 installation and B1 use phase impacts), R=1 m2K/W, L=0.0288 W/mK, 28.8 mm, 0.777 kg/m2, 26.98 kg/m3, FOAMULAR® NGX™ (Owens Corning)	162.0	113	m2	x		9.59 kg CO2e/m2	9.59 kg CO2e/m2
Below Grade	9	Rigid Insulation: Wall	XPS insulation board, (incl. A5 installation and B1 use phase impacts), R=1 m2K/W, L=0.0288 W/mK, 28.8 mm, 0.777 kg/m2, 26.98 kg/m3, FOAMULAR® NGX™ (Owens Corning)	224.2	157	m2	x		NA	9.59 kg CO2e / m2
Above Grade	10	Concrete reinforcement rebar	Reinforcement steel (rebar), ASTM A615, ASTM A706, 7850 kg/m3 (CRSI)	644,256.4	611,679	kg		x	854 kg CO2e/ton	0.85 kg CO2e/kg
Above Grade	11	30 MPa Concrete Volume (with air)	Ready-mix concrete, Canadian national average, British Columbia, with air entrainers, 30 MPa, (F-2) GU 20 SCM	276.7	254	m3		x	269.83 kgCO2e/m3	269.83 kgCO2e/m3
Above Grade	12	35 MPa Concrete Volume (with air)	Ready-mix concrete, Canadian national average, British Columbia, with air entrainers, 35 MPa, (F-2) GU 20 SCM	4,298.9	3,352	m3		x	310.51 kgCO2e/m3	310.51 kgCO2e/m3
Above Grade	13	40 MPa Concrete Volume (with air)	Ready-mix concrete, Canadian national average, British Columbia, with air entrainers, 40 MPa, (C-1) GU 20 SCM	353.0	291	m3		x	344.04 KgCO2e/m3	344.04 KgCO2e/m3
Above Grade	14	50 MPa Concrete Volume (with air)	Ready-mix concrete, Canadian national average, British Columbia, with air entrainers, 50 MPa, (C-XL) GU 30 SCM	6.6	3	m3		x	345.16 kgCO2e/m3	345.16 kgCO2e/m3
Below Grade	16	Vapour Barrier - Ground Floor Slab	Polyethylene vapour barrier membrane, 0.15 mm, 0.14 kg/m2(One Click LCA)	2,021.3		m2	x		N/A	0.44 kg CO2e/m2
Above Grade	18	Steel Studs	Cold roll formed steel panels, 7800 kg/m3 (Canadian Sheet Steel Building Institute (CSSBI))	24.9		tonne	x		2440 kg CO2e/ton	2.43 kg CO2e/m2
Above Grade	19	Drywall	Gypsum plaster board, fire resistant, 10.7 kg/m2, 15.875 mm (Gypsum Association)	17,118.2		m2	x		277 kg CO2e/1000 ft2	2.98 kg CO2e / m2
Above Grade	20	Wall Grout	Ready-mix concrete, 45 MPa; Curing time 28d; Cement type: Manufacturer specific, Mix GROUT450 (Butler Concrete, Victoria plant)	36.8		tonne		x	N/A	300 kg CO2e/m3
Above Grade	21	Architectural Steel Framing	Fabricated hot-rolled structural steel sections, painted, 7800 kg/m3 (487 lb/ft3) (CISC)	7.4		tonne	x		1220 kg CO2e/ton	1.19 kg CO2e/m2
Above Grade	22	CMU Block Wall	Concrete masonry unit (CMU), normal weight, 15 Mpa, GU cement, 2186.12 kg/m3 (CCMPA, East Region)	13.1		m3	x		170-200 kg CO2e/m3	205.38 kg CO2e/m3
Above Grade	23	Insulation Area	(R.S.I. 3.6 / R20) SPRAY FOAM POLYURETHANE INSULATION (TYPE INS-FIP-1)	5,372		m2	x		3.7-4.8 kg CO2e/m2	3.83 kg CO2e/m2
Above Grade	24	Entry Doors - dimensions 95.09*207.01	Galvanized steel door with steel stiffened core, 44.5 mm (1.75 inch), 49.5 kg/unit, 570.9 kg/m3 (DE LA FONTAINE)	30		Units	x		NA	136.0 kg CO2e/unit
Above Grade	25	Patio Doors	Aluminium curtain walls, 37 kg/m2	343		m2	x		NA	141.0 kg CO2e/m2
Above Grade	26	Window Area	Aluminium curtain walls, 37 kg/m2	1,166		m2	x		N/A	141.0 kg CO2e/m2
Above Grade	28	Roofing Material	SBS polymer-modified bitumen roofing membrane, 7.92 kg/m2 (Certain Teed, IKO, Malarkey Roofing, Polyglass, Siplast, Soprema)	1,964.2		m2	x		4.2-8.3 kg CO2e/m2	5.54 kg CO2e/m2
Above Grade	29	Roofing Material	Mineral wool insulation board, R = 1m2K/W, 36.6 mm, 1.4 kg/m2, 38.3 kg/m3 (NAIMA)	1,964.2		m2	x		2.67 kg CO2e/m2	2.68 kg CO2e/m2
Above Grade	30	Roofing Material	Polyisocyanurate (PIR) roof insulation boards, coated glass faced (CGF), 0.941kg/m2 (2.07 lb/m2), 25 mm (0.984 in) (Atlas Roofing Corporation, Carlisle Construction Materials, Firestone Building Products, GAF, IKO, Johns Manville, Rmax - A Sika Brand, Soprema, Inc. (USA))	1,964.2		m2	x		3.04 kg CO2e/1 m2 @ RSI-1	2.95 kg CO2e/m2
Above Grade	31	Roofing Material	Polyethylene vapour barrier membrane, 0.15 mm, 0.14 kg/m2(One Click LCA)	1,964.2		m2	x		N/A	0.44 kg Co2e/m2
Above Grade	32	Polyethylene Isolation Board	Acoustic insulation panel, 25.4 mm, 2.75 kg/m2, Decoustics Claro® Lay-In (CertainTeed Architectural Products)	29.9		m2	x		N/A	8.1 kg CO2e/m2
Above Grade	33	Architectural Precast Panels	Precast concrete panel for Canadian western region, Fly ash 1.74% (Canadian Precast Concrete Institute)	1,149,418	933,932	kg	x			0.25 CO2e/kg

Vancouver - GFA | Edmonton - GFA | Toronto - GFA | Montreal - GFA | Halifax - GFA | Toronto - BFA | Panel Calcs

Figure 11: *Bill of quantities and mapped Environmental Product Declarations (EPDs) for the building assemblies in Vancouver. Quantities are categorized by location (above/below grade), material type, and function, with associated GWP values used in One Click LCA software.*

12. Appendix G – Precast EPDs Used and Corresponding GWPs

The table below shows the EDPs used to model the embodied carbon for key structural building systems and the corresponding GWP. These values are shown for the main models ("CPCI EPD") and for the secondary version using a CPCI member facility-specific EPD ("Member EPD"); see Section 2.4.1.

		Corresponding CPCI EPD		Corresponding CPCI Member EPD (facility-specific)	
Building Modelled	**Structural Element**	**EPD Product Type**	**GWP (kg CO2e/tonne)**	**EPD Product Type**	**GWP (kg CO2e/tonne)**
Total Precast	Structural Precast - Exterior Walls	Structural precast concrete for Canadian central region (Canadian Precast Concrete Institute)	0.21	Precast concrete exterior non-loadbearing walls (Precast Commercial)	0.22
	Structural Precast - Interior Walls			Precast concrete structural loadbearing walls (Precast Commercial)	0.23
	Structural Precast - Stairs and landings			Precast concrete flat balconies, landings and solid slabs (Precast Commercial)	0.22
	Structural Precast - Balconies			Precast concrete flat balconies, landings and solid slabs (Precast Commercial)	0.22
	Structural Precast - Solid slabs for Floor/Roof			Precast concrete flat balconies, landings and solid slabs (Precast Commercial)	0.22
	Structural Precast - Exterior Columns			Precast concrete structural beams and columns (Precast Commercial)	0.28
	HC Floor		0.21	Precast concrete hollow core slabs, 203-356 mm (8-12 in) (Precast Commercial)	0.17
	Insulated Precast - Exteiror Walls	Insulated precast panels, Central Region (Canadian Concrete Pipe and Precast Association)	0.24	Precast concrete insulated structural exterior loadbearing walls (Precast Commercial)	0.24
Steel	10" HC slabs	Structural precast concrete for Canadian central region (Canadian Precast Concrete Institute)	0.21	Precast concrete hollow core slabs, 203-356 mm (8-12 in) (Precast Commercial)	0.17
	Balcony Slabs	Insulated precast panels, Central Region (Canadian Concrete Pipe and Precast Association)	0.24	Precast concrete flat balconies, landings and solid slabs (Precast Commercial)	0.22
	Ext Wall Panels	Insulated precast panels, Central Region (Canadian Concrete Pipe and Precast Association)	0.24	Precast concrete insulated structural exterior loadbearing walls (Precast Commercial)	0.24
CIP	Architectural Precast Panels	Precast concrete panel for Canadian central region, Fly ash 1.74% (Canadian Precast Concrete Institute)	0.23	Precast concrete exterior non-loadbearing walls (Precast Commercial)	0.22

Figure 12: *CPCI vs Member EPDs GWP*