

CONCRETE HIGH RISE LCA STUDY CITY OF VANCOUVER

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Anthony Pak



Introduction

This study was developed for the City of Vancouver in order to understand what level of embodied carbon reduction may be possible for a typical concrete high-rise residential building in Vancouver. Embodied carbon refers to the carbon footprint associated with building materials and is calculated using the scientific method of Life Cycle Assessment (LCA). While the City of Vancouver has a strong focus on reducing carbon emissions associated with operational energy usage, it is also interested in developing future policy focused on reducing embodied carbon.

Note that this was a preliminary study developed for the City of Vancouver under short time constraints, intended only to provide initial estimates on the upper range of embodied carbon reduction that is possible for a concrete high-rise building in Vancouver. It did not address other factors such as cost, local availability, construction scheduling etc. It is our understanding that the City of Vancouver plans to procure a far more comprehensive embodied carbon reduction study in the future, which would be used to inform the development of future policy.

Methodology

The City of Vancouver's green building policy for rezoning requires projects to conduct a Whole Building Life Cycle Assessment (WBLCA) and disclose the LCA results as part of their rezoning submission. As a result of this policy requirement, the city has WBLCA results from over 60 projects.

The City suggested that the 5055 Joyce Street project be used for this study as an example of a typical concrete high-rise residential building. This is a 33-storey concrete high-rise residential building with curtain wall assembly.

Integral Group developed the rezoning submission for this project and as part of it, conducted a WBLCA of this project using the Athena Impact Estimator for Buildings (IE4B) software. We did not have access to their Athena LCA model for this project, so we developed a WBLCA of this project independently based on the floor plans and structural and envelope-related modeling assumptions that were included in the rezoning submission.

As this project was at the concept design stage for the rezoning submission, detailed structural and envelope information was not available. As a result, there may be some differences in modeling assumptions between our LCA model and Integral Group's model, however our final Global Warming Potential (GWP) results were within a 4% difference. Note that the purpose of this study is not to model this particular building as accurately as possible, but rather to use this building design as a reference for a typical concrete high-rise building in Vancouver and explore a range of alternate design options.

The baseline building design is defined as the current design for the 5055 Joyce Street project, which includes benchmark concrete mixes and curtain wall assembly. We then modelled a range of alternative structural and envelope design options and compared these LCA results with the baseline design to calculate the percentage embodied carbon reductions.

Baseline Building

The baseline building assumptions are derived from the parameters used by Integral Group for the 5055 Joyce St rezoning submission. Note that all concrete mixes below refer to the Canadian Ready-Mixed Concrete Association (CRMCA) Industry Average EPD data, with benchmark mixes representing 10% Substitute Cementitious Materials (SCM) comprised of 4% Fly Ash and 6% Slag Cement.



	Parkade	Above Grade		
Floor Area	9,515 m2	23,060 m2		
Building Footprint	1,482 m2	1,183 m2		
Columns & Beams	Type: 30MPa Concrete Benchmark Height (m): 3 m	Type: 30MPa Concrete Benchmark Height (m): 2.75 m (4.8 m for L1 only)		
Foundations	Concrete Footings and Concrete Slab: 35MPa Concrete Benchmark w/ XPS insulation	n/a		
Interior Walls	Elevator Cores: 55 MPa Cast in place Concrete Benchmark	Elevator Cores: Cast in place 55 MPa Concrete Benchmark		
Exterior Walls	35 MPa Concrete XPS insulation, Vapour Barrier Curtain Wall Construction Metal Spandrel, Fibre Glass Insulation			
Floors	35 MPa Suspended Concrete Slab Benchmark	35 MPa Suspended Concrete Slab Benchmark		
Roof	n/a	35 MPa Suspended Concrete Slab Benchmark XPS insulation, PVC Membrane, Filter Fabric, Gravel Ballast		
Glazing	n/a	50/50 Glazing ratio on Curtain wall		

Design Option Scenarios

The baseline building scenario defined above is the reference point from which all embodied carbon reduction percentages are calculated in relation to. We model a range of Embodied Carbon Reduction Measures (ECRMs) grouped together in the scenarios defined in the table below. Each scenario makes a change relative to the previous scenario. The ECRM options we explored focused on structural and envelope-related design options.

For all of the Cast In Place Concrete used in the building (i.e. foundation, floors, columns and beams, floors, and roof), we compared Portland Cement (GU) with Portland Limestone Cement (GUL) and increased the Substitute Cementitious Material (SCM) from the industry average benchmark of 10% to 35%. Note that Athena IE4B utilizes the industry average Environmental Product Declaration (EPD) data from CRMCA. The highest SCM percentage mix in the CRMCA EPD is Portland Limestone Cement (GUL) with 35-50% SCM. While each mix within the CRMCA EPD shows a range of SCM content (e.g. 35% - 50%), the lowest end of this range (e.g. 35%) is what is modeled in the EPD. In addition to this industry average EPD data, Athena IE4B has the ability to model custom concrete mixes if this data is available, however it cannot import manufacture specific EPDs. For parkade and above grade floor slabs, we explored replacing the Cast in Place Concrete slabs with Precast Hollow-core slabs. For the envelope, we compared the baseline curtain wall design with a steel stud wall assembly, both of which had 50% glazing ratio and double pane windows. A triple pane option for the steel stud assembly was also modeled to understand the embodied carbon impact of switching from double glazing to triple glazing. Finally, we modelled a 50% reduction in parkade area to understand the impact of potential policies focused on reducing parking requirements.

See table below for comments on the changes between each scenario. For a full description of each scenario, refer to Appendix 1.

Scenario Name	Comments (Changes in each scenario is relative to previous scenario)
1 - Baseline	Baseline assumptions matching 5055 Joyce St. All concrete uses CRMCA 10% SCM benchmark mix.
2 - SCM	Change the Substitute Cementitious Mix (SCM) for all concrete, from Portland Cement (GU - 10% SCM) to Portland Limestone Cement (GUL - 35% SCM). This applies to all foundation, floors, columns and beams, and roof.
3 - SCM, SS Triple	Convert exterior walls from double glazed curtain wall to triple-glazed steel stud.
4 - SCM, SS Double	Convert exterior walls from triple glazed steel stud to double glazed steel stud.
5 - SCM, SS Double, 50% Parking	Reduce parkade area by 50%.
6 - SCM, HC Slabs, SS Double	Change all floor slabs (parkade and above grade) from Cast in Place GUL - 35% SCM concrete to Precast Hollow-core slabs (full parkade area)
7 - SCM, HC Slabs, SS Double, 50% Parking	Change all floor slabs (parkade and above grade) from Cast in Place GUL - 35% SCM concrete to Precast Hollow-core slabs (50% parkade area)

LCA Results

The following chart shows the total Global Warming Potential (GWP) results for each scenario with the colors representing the assembly groups, including foundation, walls, columns and beams, roof, and floors. "Project Extra Materials" refers to the elevator core. The baseline scenario is approximately 4% higher than the GWP results modeled by Integral Group as part of their rezoning submission and may be due to minor differences in modeling assumptions for details that were not available from the concept design drawings.



The graph below shows the percentage reduction in embodied carbon (GWP) relative to the baseline scenario. The individual percentage reductions across each of the assembly categories are shown in order to isolate where the greatest percentage reductions come from. On the right side of the graph, we see the total percentage reductions of each scenario. The embodied carbon reductions achieved across the scenarios range from 22% to 47%. Most of these reductions occur in the wall and floor assembly groups.

It is important to keep in mind what the baseline scenario assumptions are when looking at percentage reduction figures. For example, this baseline uses the concrete benchmark GU - 10% SCM mix for all assembly groups, whereas it may be more appropriate to define the baseline concrete mix to reflect common local practice for typical SCM content in each assembly group (foundation, floors, columns and beams, walls, and roof). Also, the baseline design uses a curtain wall assembly, which is a reasonable assumption, however it should be noted that curtain wall assemblies have among the highest embodied carbon impacts of any exterior wall assembly modelled within Athena IE4B. That means that if the baseline design assumes different concrete mixes or wall assemblies, it may decrease the percentage embodied carbon reductions available.



Since each scenario contains multiple ECRMs and builds from previous scenarios, the impact of each ECRM has been isolated below to understand the percentage reduction that each is responsible for. The percentage reduction figures in the table were derived from subtracting the two scenarios stated in square brackets on each row.

Relative Reductions of Individual Measures				
Change the Substitute Cementitious Mix (SCM) for all concrete, from Portland Cement (GU - 10% SCM) to Portland Limestone (GUL - 35% SCM). This applies to all foundation, floors, columns and beams, and roof. [Scenario $1-2$]				
Convert exterior walls from double glazed curtain wall to double glazed steel stud [Scenario 2 – 4]				
Convert exterior walls from double glazed steel stud to triple glazed steel stud [Scenario 4 – 3]				
Reduce parkade area by 50% [Scenario 4 – 5]				
Change floor and roof slabs from Cast in Place GUL 35% SCM to Precast Hollow-core slabs (full parkade) [Scenario 4 – 6]				
Change all floor and roof slabs from Cast in Place GUL 35% SCM to Precast Hollow-core slabs (50% parkade) [Scenario 5 – 7]	7.6%			

Changing the Substitute Cementitious Mix (SCM) for all concrete from Portland Cement (GU - 10% SCM) to Portland Limestone (GUL - 35% SCM) led to a reduction of 22.6% from the baseline. Note that for this study, we did not look at other factors such as construction scheduling and cost, which may affect how much SCM content would be used for various aspects of the building (i.e. foundation vs above grade slabs). Such considerations should be addressed in a future comprehensive study.

Curtain wall, with its high aluminum content, has one of the highest embodied carbon impacts of all wall assemblies modeled within Athena IE4B. In comparison, switching to a steel stud double glazed wall assembly led to an 11% reduction. For the steel stud assembly, we see that triple glazing has a 2% increase in embodied carbon impacts compared to double glazing. Note that going from double glazing to triple glazing would also impact operational carbon and may be a bigger factor than embodied carbon.

We modeled a scenario to reduce parking area by 50% to understand what the impact of reducing parking requirement policies may have on embodied carbon, which led to a 6% reduction. Typically, when modeling baseline and proposed designs in LCA, we need to ensure functional equivalence. In this case, reducing parking area does not maintain functional equivalence, however it serves to illustrate the potential reduction that is available from such a change.

Finally, we modelled the impact of changing all floor and roof slabs from Cast-In-Place Concrete to Precast Hollow-core slabs. Switching to Precast Hollow-core slabs from GUL-35% slabs leads to a 9.3% reduction for full parkade and a 7.6% reduction for 50% parkade. Note that the Hollow-core percentage reductions shown in the table above are in relation to Portland Limestone Cement GUL with 35% SCM and not compared to the baseline concrete mix. If instead, we were to compare with the baseline concrete benchmark mix GU - 10% SCM for the roof and floor slabs, the Precast Hollow-core slabs would lead to a reduction of 25.0% for full parkade and 28.0% for 50% parkade.

Conclusion

The purpose of this study was to develop an early estimate of what might be the higher end of embodied carbon reduction possible for a concrete high-rise residential building. For this 33-storey residential building, we identified strategies that can reduce embodied carbon between 22% to 47%. The range of strategies include changing all concrete mixes from Portland Cement GU - 10% SCM to Portland Limestone Cement GUL - 35% SCM, incorporating Precast Hollow-core slabs for all floor and roof slabs, changing exterior wall assemblies from curtain wall to steel stud, and reducing parking area by 50%. Many of these changes may represent the higher end of embodied carbon reductions that are possible, and some of these may have practical barriers to their implementation including cost, availability, buildability etc. For future work, we recommend a comprehensive study that includes such considerations, while expanding the study to model to a range of building archetypes and explore other structural materials such as mass timber.



Appendix 1 – Scenario Modeling Assumptions

Scenarios	Foundatio ns	Walls	Columns and Beams	Roofs	Floors	Project Extra Materials
1 - Baseline	Foundation Slab and Footings: Concrete GU-10 Benchmark	Parkade Walls: Concrete GU-10 Benchmark Above Grade Walls: Curtain Wall 50% Double Glazing / Metal Spandrel	Columns: Concrete GU-10 Benchmark	Roof: Concrete GU-10 Benchmark	Parkade and Above Grade Floors: Concrete GU-10 Benchmark	Stair Core: Concrete GU-10 Benchmark
2 - SCM	Foundation Slab and Footings: Concrete GUL-air- 35SL	Parkade Walls: Concrete GUL-air-35SL Above Grade Walls: Curtain Wall 50% Double Glazing / Metal Spandrel	Columns: Concrete GUL-35SL	Roof: Concrete GUL-air- 35SL	Parkade Floors: Concrete GUL- air-35SL Above Grade Floors: Concrete GUL- 35SL	Stair Core: Concrete GUL-35SL
3 - SCM, SS Triple	Foundation Slab and Footings: Concrete GUL-air- 35SL	Parkade Walls: Concrete GUL-air-35SL Above Grade Walls: Steel Stud 50% WWR Triple Glazed w/ Fibreglass Window Frame	Columns: Concrete GUL-35SL	Roof: Concrete GUL-air- 35SL	Parkade Floors: Concrete GUL- air-35SL Above Grade Floors: Concrete GUL- 35SL	Stair Core: Concrete GUL-35SL
4 - SCM, SS Double	Foundation Slab and Footings: Concrete GUL-air- 35SL	Parkade Walls: Concrete GUL-air-35SL Above Grade Walls: Steel Stud 50% WWR Double Glazed w/ Fibreglass Window Frame	Columns: Concrete GUL-35SL	Roof: Concrete GUL-air- 35SL	Parkade Floors: Concrete GUL- air-35SL Above Grade Floors: Concrete GUL- 35SL	Stair Core: Concrete GUL-35SL
5 - SCM, SS Double, 50% Parking	Foundation Slab and Footings: Concrete GUL-air- 35SL	Parkade Walls: Concrete GUL-air-35SL, 50% Parking Above Grade Walls: Steel Stud 50% WWR Double Glazed w/ Fibreglass Window Frame	Columns: Concrete GUL-35SL	Roof: Concrete GUL-air- 35SL	Parkade Floors: Concrete GUL- air-35SL, 50% Parking Above Grade Floors: Concrete GUL- 35SL	Stair Core: Concrete GUL-35SL
6 - SCM, HC Slabs, SS Double	Foundation Slab and Footings: Concrete GUL-air- 35SL	Parkade Walls: Concrete GUL-air-35SL, 50% Parking Above Grade Walls: Steel Stud 50% WWR Double Glazed w/ Fibreglass Window Frame	Columns: Concrete GUL-35SL	Roof: Precast Hollow Core Concrete	Parkade Floors: Precast Hollow Core Concrete Above Grade Floors: Precast Hollow Core Concrete	Stair Core: Concrete GUL-35SL
7 - SCM, HC Slabs, SS Double, 50% Parking	Foundation Slab and Footings: Concrete GUL-air- 35SL	Parkade Walls: Concrete GUL-air-35SL, 50% Parking Above Grade Walls: Steel Stud 50% WWR Double Glazed w/ Fibreglass Window Frame	Columns: Concrete GUL-35SL	Roof: Precast Hollow Core Concrete	Parkade Floors: Precast Hollow Core Concrete, 50% Parking Above Grade Floors: Precast Hollow Core Concrete	Stair Core: Concrete GUL-35SL