Light House
Bringing Buildings to Life

COMPARATIVE LIFE CYCLE ASSESSMENT OF THE RELOCATION AND RETROFIT OF HENRY HUDSON ELEMENTARY SCHOOL

(AKA LITTLE YELLOW SCHOOL HOUSE)

ACKNOWLEDGEMENTS

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LIST OF ACRONYMS

AEC	Annual energy consumption
ACH	Air changes per hour
CRD	Construction, renovation and demolition
GHG	Greenhouse gas
IE4B	Athena Impact Estimator for Buildings
LCA	Life cycle assessment
LYSH	Little Yellow School House
MEP	Mechanical, electrical, and plumbing
NRC	National Research Council
wbLCA	Whole building life cycle assessment

EXECUTIVE SUMMARY

Henry Hudson Elementary School House (aka Little Yellow School House) landed at the Xwmélch'tstn Reserve.

Situated in Vancouver's Kitsilano Neighbourhood, the Henry Hudson Elementary School built in 1912, affectionately known as the Little Yellow School House (LYSH), faced the prospect of demolition by the Vancouver School Board to make way for a new modern school building. However, instead of being torn down, the Squamish Nation (Sḵwx̱wú7mesh Úxwumixw), in collaboration with Renewal Development and Nickel Bros., undertook the initiative to save, relocate, retrofit, and repurpose the building. The LYSH now serves as an early childhood language immersion Learning Nest on the Xwmélch'tstn Reserve in North Vancouver for mothers and their children to learn the Squamish language and culture.

> **"Overall, relocating the building and performing energy efficiency upgrades resulted in 11.9 tonnes (38.6%) less embodied carbon emissions... than an equivalent newly constructed Step Code 3 building."**

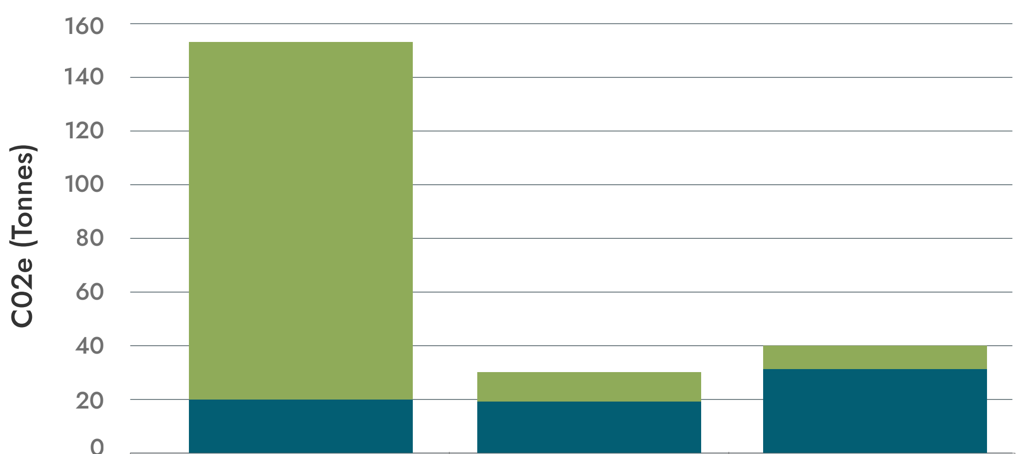
The primary objective of this study was to explore the life cycle benefits of relocating the LYSH in both the short and long (i.e., 60 years) term from both an embodied carbon and operational carbon emissions perspective. In order to accomplish this, Light House conducted three Life Cycle Assessments (LCA) comparing various options:

- **Option 1** (Move + no energy upgrade): Relocate the original LYSH to the Xwmélch'tstn Reserve without any upgrades.

- **Option 2** (Move + energy upgrade): Relocate the original LYSH to the Xwmélch'tstn Reserve with full electrification and upgraded building materials.

- **Option 3** (New construction): Demolish the original LYSH and build an equivalent new building to BC Step Code 3 requirements on the Xwmélch'tstn Reserve.

Overall, relocating the building and performing energy efficiency upgrades (Option 2) resulted in 11.9 tonnes (38.6%) less embodied carbon emissions and 9.6 tonnes (24.1%) less total life cycle carbon emissions (i.e., embodied and operational) than an equivalent newly constructed Step Code 3 building (Option 3) over a 60 year lifespan illustrating the benefit of relocating, retrofitting and repurposing a structure over building new. Relocating the building and performing energy upgrades generated 122.5 tonnes (80.3%) less total carbon emissions than moving the structure with no energy upgrades (Option 1).



	Option 1	Option 2	Option 3
Operational Carbon	132.7	11.2	8.9
Embodied Carbon	20.0	18.9	30.8

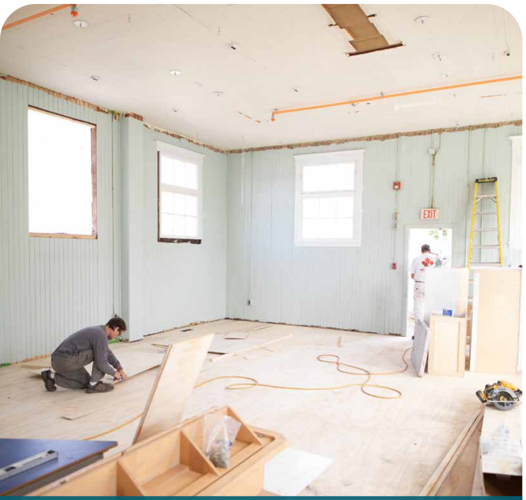
LYSH lifted and ready to move

LYSH original interior

Nickel Bros. team planning to lower the LYSH onto its new foundation

Jeremy Nickel, CEO, Nickel Bros. & Bob Sokol, Director of Planning & Capital Projects, Squamish Nation

Blanket ceremony honouring the Nickel Bros. moving crew



Renovation work on the LYSH

LYSH under renovation after being relocated to its new home on Squamish lands

All Photos: Renewal Development

1. INTRODUCTION

The Little Yellow School House in Kitsilano circa 1970s.

In 1877, under the Indian Act, the federal government allotted about 34 hectares of land to the Squamish Nation from their ancestral lands, which included the ancient village called Seṅáḵw, home to about 20 Squamish families or 150 people. They called it Kitsilano Indian Reserve no. 6., named after Squamish chief X̱ats'alanexw or the anglicized, August Jack Khatsahlano.

In 1912, the Henry Hudson Elementary School, affectionately known as the Little Yellow School House (LYSH) was built in Kitsilano.

> **In 1912, the Henry Hudson Elementary School, affectionately known as the Little Yellow School House (LYSH) was built in Kitsilano.**

Following amendments to the Indian Act in 1911, which made it legal to remove Indigenous people from reserves within an incorporated town or city without their consent, the residents of Seṅáḵw where evicted from their homes, offered a small amount of money and given just two days to leave. According to Rudy Reimer, an archeologist with Simon Fraser University and a member of the Squamish Nation, 'They were forced off their reserves, out of their homes and put on a barge to North Vancouver.'[1]

In 2023, one hundred and ten years later, the LYSH faced the prospect of demolition by the Vancouver School Board to make way for a new modern school building. However, instead of being torn down, the Squamish Nation (Sḵwx̱wú7mesh Úxwumixw), in collaboration with Renewal Development and Nickel Bros., intervened to save and relocate the LYSH by barge to the Xwmélch'tstn Reserve in North Vancouver, retracing the same journey of the residents of Seṅáḵw more than 100 years before. A symbol of colonization that carried the history of the mistreatment of the Squamish peoples had been reclaimed, retrofitted and repurposed to serve as an early childhood language immersion Learning Nest for mothers and their children to learn the Squamish language and culture.

The primary objective of this study was to explore the life cycle benefits of preserving and relocating the LYSH in both the short and long term from both an embodied carbon and operational carbon emissions perspective compared to demolishing the structure and building new.

1 Sterritt, A. (2019, April 21). The little-known history of Squamish Nation land in Vancouver. *CBC News Online*. https://www.cbc.ca/news/canada/british-columbia/little-known-history-of-squamish-nation-land-in-vancouver-1.5104584.

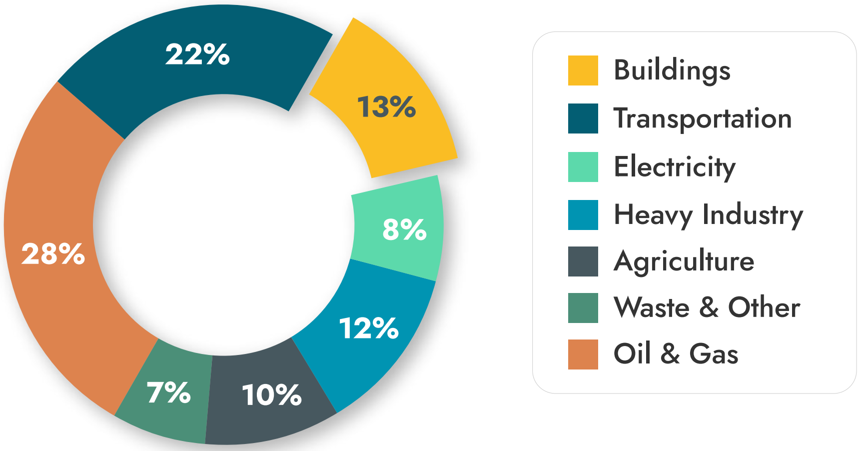
2. CONTEXT

The Little Yellow School House lifted and ready to leave its original home.

Residential, commercial and institutional buildings account for approximately 30% of total greenhouse gas (GHG) emissions in Canada; the nation's third highest source of carbon emissions. Building materials and construction comprise approximately 13% of those emissions (see Figure 1) with operational emissions associated with energy consumption making up the remaining 17%.[2]

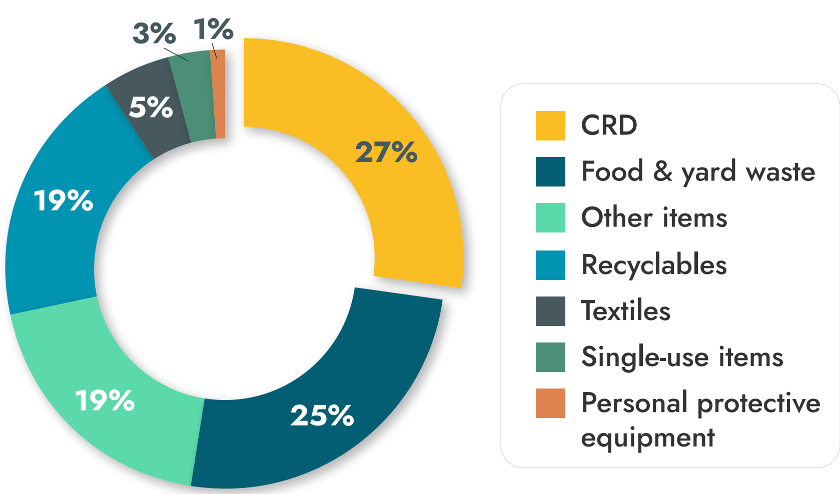
2 Canada Green Building Council. Building Climate Solutions: A proven path to lower carbon emissions. https://www.cagbc.org/why-green-building/building-climate-solutions/

Figure 1: Canada's GHG Emissions in 2021 by Sector (megatonnes of CO2e)3



The life cycle of the average home in Canada follows the traditional linear "take-make-waste" path. The home is built with virgin building materials, occupied for a period of time during which energy is consumed to operate it, and eventually demolished and the approximately 100 tonnes of materials dumped in a landfill along with all the associated environmental impacts. In Metro Vancouver alone, an average 2,621 ground dwellings were demolished each year between 2011-2021 representing a staggering 46.8% increase in demolitions during that period.[4] This translates into 27% of all waste generated in Metro Vancouver coming from construction, renovation and demolition (CRD) activity, representing the largest component of the region's waste.[5]

Figure 2: Metro Vancouver 2022 Functional Solid Waste Categories Composition (tonnes)



3 Environment and Climate Change Canada, Greenhouse Gas Emissions.
4 Metro Vancouver. (2022). *Housing Data Book 2022* (pp.68-72).
5 Metro Vancouver. (2023 May). 2022 Full-Scale Waste Composition Study (May 2023) (p.26).

A life cycle assessment (LCA) is a systematic analysis of the environmental impact associated with product over the product's life. In the context of buildings, LCA can be used to evaluate a single product—like a carpet tile, or a ready-mixed concrete design. It can also be used to analyze an entire building system by compiling data from all the individual building components. This is referred to as Whole Building Life Cycle Assessment (wbLCA) to differentiate it from product/component-specific assessments.

For the purposes of this report, the wbLCA measured ***embodied carbon*** (i.e., the carbon associated with the extraction, processing, transporting, installing and decommissioning) of building materials used in each life cycle option and the ***operational carbon*** (i.e., the carbon emissions resulting from the energy consumed to heat, cool and operate) generated during the building's operating life. Please refer to Figure 3 for activities associated with the wbLCA framework.

The wbLCA provides a means to understand the carbon footprint at each stage of a building's life cycle and allows the project team to pinpoint the stages where the highest carbon emissions occur. Understanding the total carbon emissions (both embodied and operational) associated with the life of a building is important because it informs decisions about how we design, use and ultimately manage the end-of-life of our buildings to minimize the impact of housing on our climate.

In the case of the LYSH, the question was whether the relocation and retrofitting of an existing structure could provide a similar level of comfort and resiliency to its occupants through improvements with similar operational efficiencies to a similar new building, while allowing for the preservation of the embodied carbon associated with the structure itself. In addition, the wbLCA sought to understand the relative contribution of embodied and operational carbon to the carbon profile of the building over its lifetime.

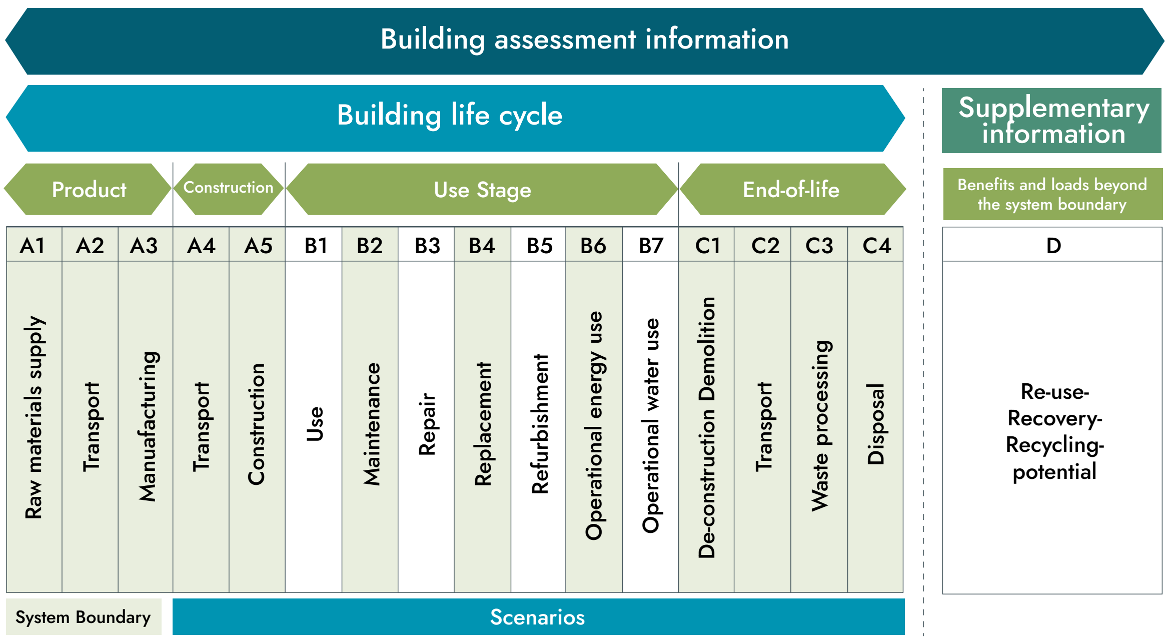
3. METHODOLOGY

Unloading the Little Yellow School House at the Xwmélch'tstn Reserve in North Vancouver.

3.1 Life Cycle Stages

A life cycle assessment considers all stages from cradle-to-grave in the life of a building. Each stage is broken into "modules" reflecting the contributions to the building's total emissions. The wbLCAs conducted in this study covered all modules highlighted in Figure 3. Appendix A explains the scope of each module in each stage of the wbLCA. Further details about the life cycle activities covered by each module can be found in Appendix C.

Figure 3: Life Cycle Assessment Stages



Modules B1, B3, B5, B7 and D were not included for the following reasons:

B1: There was insufficient consensus in terms of methodology and data to practically quantify these effects for all products used in the building.

B3: This module was not well-supported with data.

B5: This module applies to known future refurbishment and needs to be addressed on a case by case basis if applicable" with "and was not applicable to this project.

B7: This module was out of scope of this project.

D: This is typically out of scope for an LCA.

3.2 Software

The wbLCA tool *Athena Impact Estimator for Buildings* (IE4B) v5.5 was used to calculate embodied carbon emissions (modules A1-A5, B2, B4, C1-C4). Hot2000 was used to calculate operational carbon emissions (module B6).

3.3 International Standards

The study adhered to the *National guidelines for whole-building life cycle assessment (Guidelines)*[6] developed by the National Research Council of Canada (NRC), enhancing the quality and consistency of the EN 15978:2011 *Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method* standard, which complies with international standards set out in ISO 21930 (*Sustainability In Buildings and Civil Engineering Works — Core Rules for Environmental Product Declarations of Construction*

6 Bowick, M., O'Connor, J., Meil, J., Salazar, J., Cooney, R. (2022). *National guidelines for whole-building life cycle assessment.* National Research Council Canada.

Products And Services) and ISO 21678 (*Sustainability in Buildings and Civil Engineering Works — Indicators and Benchmarks — Principles for the Development and Use Of Benchmarks*).

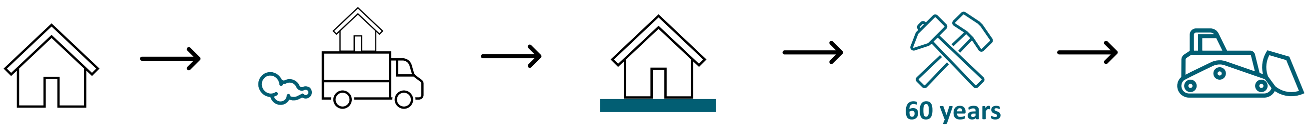
3.4 Options and Assumptions

The original LYSH features a wood joist and plywood decking floor system, 2x4 wood stud walls, and a light frame wood truss roof system. Additionally, the building's perimeter is supported by a concrete crawlspace foundation.

The wbLCA considered three options exploring three different potential outcomes.

Option 1 (Move + No Energy Upgrades)

Option 1 considered a hypothetical scenario where the LYSH was relocated with only functional/cosmetic improvements made to the structure (baseline). No energy upgrades were performed.



The model accounted for a new concrete foundation to support the relocated building. Functional/cosmetic upgrades were based on the building's assessment reports, including new building envelope fixes to replace rotting wood and new interior and exterior paint.[7,8] A specific list of materials used is provided in Appendix D. Based on the inspection report, the assumption was that the building had no insulation.

One of the benefits of relocating a home is the preservation of existing materials. The remaining lifespan of the non-retrofitted building materials were taken into consideration using Athena's building component lifespans assumptions.[9] It was assumed that after 60 years of operation, the building would be decommissioned, and deconstructed/demolished.

Option 2 (Move + Energy Upgrades)

Option 2 reflected the actual relocation and retrofit events, where the LYSH was moved and essential upgrades performed, including energy efficiency upgrades.

The retrofits undertaken were based on recommendations from Bernhardt Contracting with final upgrade decisions made by the Squamish Nation. In addition to the upgrades performed in Option 1, the actual retrofit included numerous energy efficiency upgrades, including a new low-carbon foundation and foundation insulation, roof shingles, roof insulation, full building electrification with an air-source heat pump, an electric conserver tank to replace the natural gas-based heating and domestic hot water system, and double-glazed

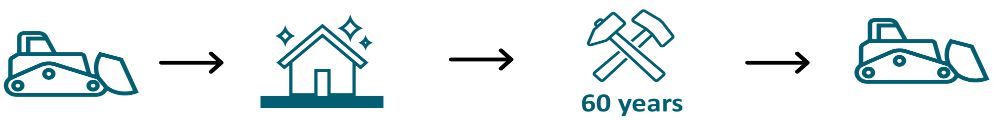
7 I.B.I. (2023). *Yellow School House Pre-Move Structural Report.*
8 Inspect Canada. (2023). *Yellow School House Building Inspection Report.*
9 Athena Sustainable Materials Institute. (2002). *Maintenance, Repair and Replacement Effects for Building Envelope Materials.*

windows[10]. Based on these upgrades, the airtightness performance of the LYSH was improved from 14 ACH compared with 7 ACH for Option 1.

A significant variation in Option 2 was the use of low-carbon concrete for the new foundation. In contrast, Options 1 and 3 used regular concrete in line with current industry practice. As in Option 1, the wbLCA took into consideration the remaining life of non-retrofitted building materials. Refer to Appendix E for a list of materials used in the retrofit.

Option 3 (New Construction)

Option 3 represented a theoretical scenario without the consideration of building relocation. In this option, the original LYSH was demolished and a new BC Step Code 3 (i.e., 2.5 ACH) equivalent building was built at the same destination location as the relocated building in Options 1 and 2 (i.e., the Squamish Nation).



Emissions associated with the hypothetical demolition of the original LYSH were estimated using the IE4B tool. Actual emissions could vary from the tool's assumptions as the tool does not incorporate regional considerations. For example, IE4B assumes the diversion rate for softwood lumber is 27.4%[11] as per the EPA's WARM model.[12] However, in Vancouver, homes constructed prior to 1950 are subject to a minimum demolition waste diversion rate of 90%.[13]

Consequently, the estimated emissions for the original structure applied by IE4B are actually higher than they would be in the Vancouver context. Actual emissions were likely lower due to avoidance of methane emissions from the decomposition of organic materials in landfill and the avoidance of carbon emissions associated with manufacturing new products, as building materials were preserved.

The new building in Option 3 was considered functionally equivalent to the structure in Options 1 and 2 to enable a valid basis for comparison. Option 3 had the same heating and domestic hot water system as Option 2 with better airtightness performance in accordance with Step Code 3 standards. Refer to Appendix F for the new building specifications and bill of materials and Appendix G for the original LYSH building specifications and bill of materials.

Appendix C provides a summary of the relationship between each LCA Module and the timeline. Each row in the table summarizes the activities associated with the relevant LCA module, the time at which the activity occurred and any assumptions associated with the activity.

The embodied and operational carbon emissions associated with each option are documented in the next section with total GHG emissions detailed in Table 3 and Figure 6.

10 The double-glazed windows were not installed in time for the completion of this wbLCA, but they were accounted for on the basis that they will be installed in 2024.
11 Athena Sustainable Materials Institute. (2002). *Athena Impact Estimator for Building User Manual and Transparency Document*.
12 EPA. (2023). *Landfilling and Landfill Carbon Storage for the Waste Reduction Model (WARM)*.
13 City of Vancouver. 2024. *Demolition permit with recycling and deconstruction requirements*.

4. RESULTS

Photo: Renewal Development

The Squamish Nation ceremony to receive their Learning Nest.

4.1 Embodied Carbon

Table 1 details the embodied carbon associated with each stage in the building's life cycle. While transportation of materials can often comprise a significant portion of a building's embodied carbon profile, in this instance, the relocation of the home represented a very small proportion of the total embodied carbon because the building was moved a relatively short distance and primarily by barge. To provide some perspective, the relocation of the building in Options 1 and 2 generated 2% fewer emissions than demolishing the building (see end of life (C1-C4)) in Option 3.

> **"...the relocation of the building in Options 1 and 2 generated 2% fewer emissions than demolishing the building...in Option 3."**

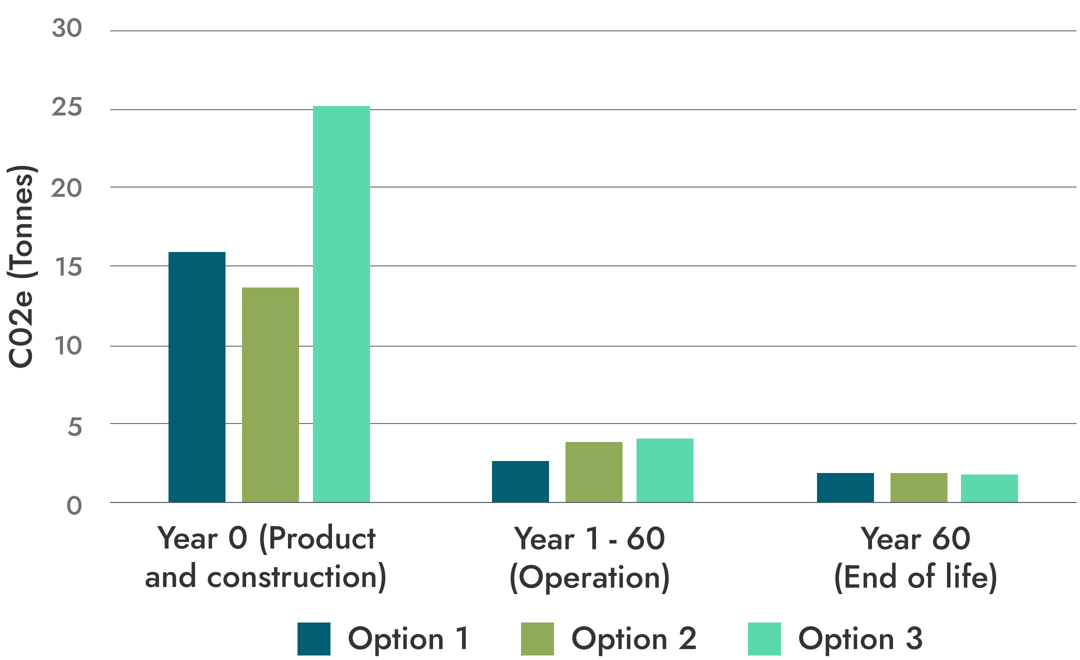
Table 1: Contribution of Modules to LYSH Embodied Carbon Results

LCA Module	Option 1	Option 2	Option 3
Transport of Relocated House	0.62	0.62	N/A
End of life[14] (C1-C4)	0.19	0.19	0.83
Product (A1-A3)	12.54	11.71	21.22
Construction (A4-A5)	2.47	1.04	3.16
Use stage (B2, B4), 60 years	2.49	3.67	3.94
End of life (C1-C4), after 60 years	1.69	1.68	1.68
Total Embodied Carbon (CO2e tonnes)	**20.0**	**18.9**	**30.8**

Similarly, the use of regular concrete for the foundation and other new building materials in Option 3 (represented by modules A1-A3) increased the total embodied carbon by 44.8% over the embodied carbon associated with using a low-carbon concrete for the foundation and preserving the structure in Option 2.

Considering the stages in the life of the building, Figure 4 highlights that the majority of embodied carbon savings is associated with improvements made prior to occupancy (i.e., during product and construction modules).

Figure 4: Embodied Carbon Emissions per LCA Stage



14 End-of-life stage of existing structure in original location.

The emissions during the use stage (B2, B4, 60 years) are higher in Option 2 compared to Option 1 due to the addition of insulation. In IE4B, where the roof system is replaced every 20 years, it is assumed that 80% of the insulation ends up in landfill, while 20% is reused on-site.[15] The variation in embodied emissions during the use stage (B2, B4) is attributable in part to different levels of insulation across the three options: Option 1 assumed no insulation, Option 2 included roof insulation and Option 3 also added wall insulation in addition to roof insulation.

Overall, the relocation and retrofitting of the LYSH (Option 2) resulted in a 38.6% reduction in total embodied carbon emissions relative to traditional practices. This is primarily due to the avoidance of new building materials and use of low-carbon concrete.

4.2 Operational Carbon

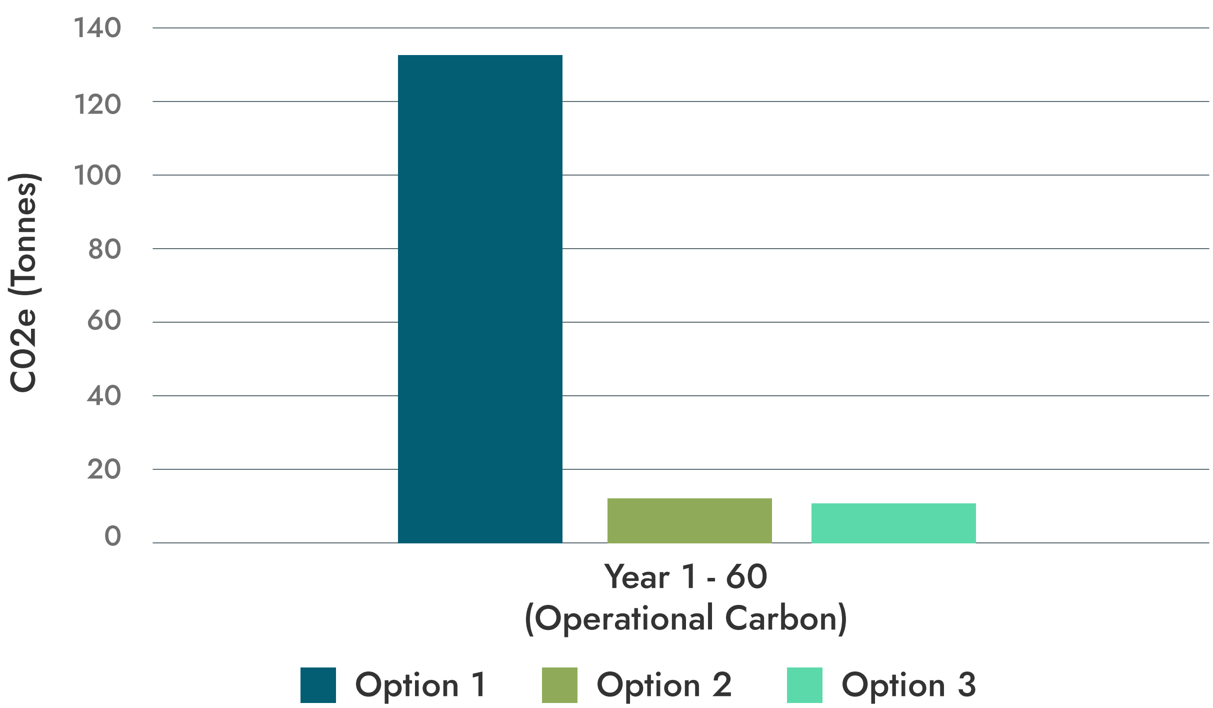
Table 2 details the operational energy use and associated carbon emissions for the three options. The energy upgrades, including full electrification and improved energy efficiency measures (more insulation and lower air infiltration) resulted in significant energy and emission savings over Option 1, which had no insulation and continued to use natural gas. In contrast, energy performance in Option 3 built to Step Code 3 resulted in a 21% improvement in operational energy performance and reductions in associated emissions compared to the energy upgrades completed for Option 2. This is graphically illustrated in Figure 5. It is worth mentioning that greater improvements could potentially be achieved in other regions with higher emission factors associated with less favourable energy sources.

Table 2: LYSH Energy Use and Operational Carbon Results

	Option 1		Option 2		Option 3	
Energy Consumption	**GJ**	**kWh**	**GJ**	**kWh**	**GJ**	**kWh**
From Gas	29.2	8,111	0.0	0	0.00	0
From Electrical	245.7	68,250	61.2	17,000	48.40	13,446
Total Annual Energy Consumption	274.9	76,361	61.2	17,000	48.4	13,446
Operational GHG total (kgCO2e/yr)	2210.75		187.00		147.90	
Operational GHG intensity (kgCO2e/m2/yr)	15.70		1.33		1.05	
Operational Emissions over 60 yrs	**132,645**		**11,220**		**8,874**	

15 Refer to footnote 8.

Figure 5 Operational Carbon Emissions

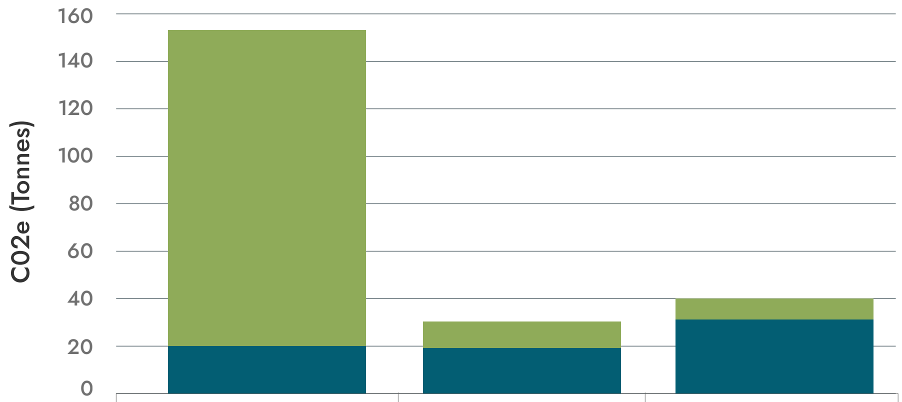


4.3 Total Life Cycle Carbon Emissions

Bringing together the findings from sections 4.1 and 4.2 above, Figure 6 below shows the total cumulative emissions over the entire life cycle for each of the three Options while Table 3 breaks down the contributions from life cycle stage components. The relocated and retrofitted Option (Option 2) had the lowest overall emissions as a result of the significant operational carbon emission reduction over Option 1 and the lower embodied carbon emissions relative to Option 3. It is important to note that while Option 3 showed slightly lower operational carbon emissions, this savings was offset by the additional embodied emissions associated with demolishing the existing structure and building a new structure using conventional concrete and virgin building materials.

It is important to note that since a blow door test was not conducted to measure performance for any of the options, a conservative ACH of 7 was applied to Option 2. However, it's entirely possible to achieve better airtightness performance in a deep retrofitted home, potentially widening the gap even further between Option 2 and Option 3.

Figure 6: Total Life Cycle GHG Emissions by Option



	Option 1	Option 2	Option 3
Operational Carbon	132.7	11.2	8.9
Embodied Carbon	20.0	18.9	30.8

Table 3: Information Module Contribution to LYSH LCA Results

LCA Module	Option 1	Option 2	Option 3
Transport of Relocated House	0.62	0.62	N/A
End of life (C1-C4)	0.19	0.19	0.83
Product (A1-A3)	12.54	11.71	21.22
Construction (A4-A5)	2.47	1.04	3.16
Use stage (B2, B4), 60 years	2.49	3.67	3.94
Use stage (B6), 60 years	132.65	11.22	8.87
End of life (C1-C4), after 60 years	1.69	1.68	1.68
Total	**152.7**	**30.1**	**39.7**

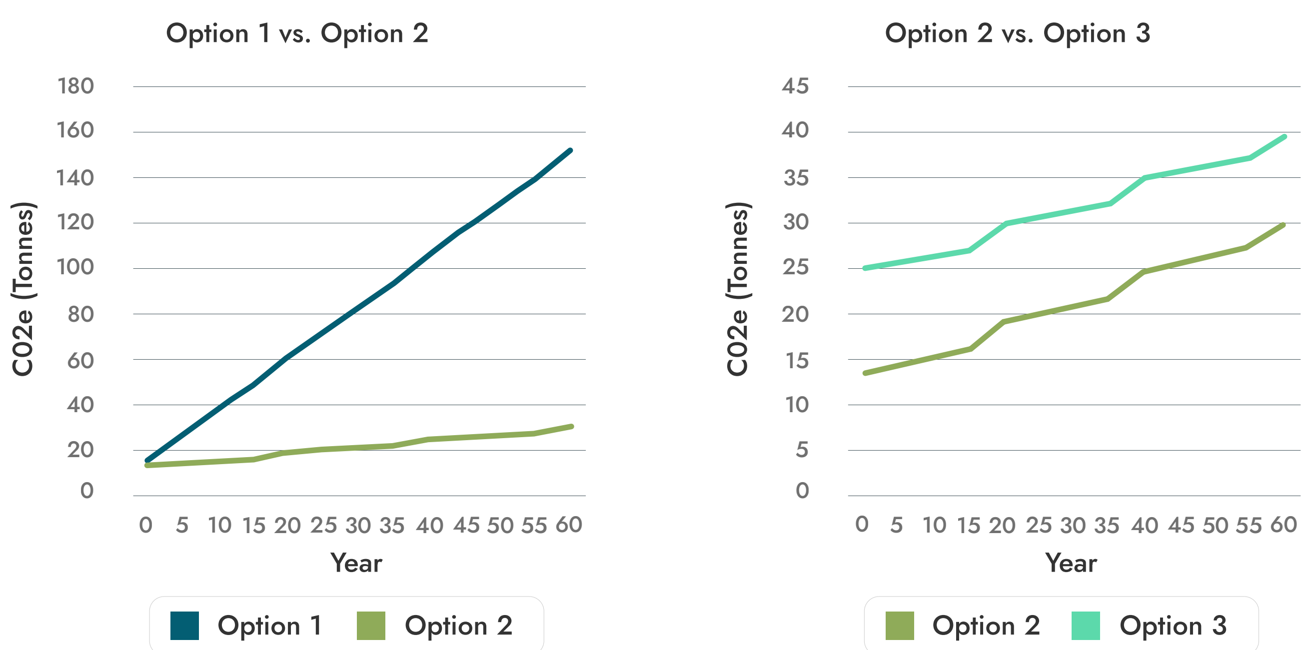
Overall, relocating the building and performing energy efficiency upgrades (Option 2) resulted in 11.9 tonnes (38.6%) less embodied carbon emissions and 9.6 tonnes (24.1%) less total life cycle carbon emissions (i.e., embodied and operational) than an equivalent newly constructed Step Code 3 building (Option 3) over a 60 year lifespan. Relocating the building and performing energy upgrades generated 122.5 tonnes (80.3%) less total carbon emissions than moving the structure with no energy upgrades (Option 1).

Looking at the 60-year lifespan for each Option shows that the relocated and retrofitted LYSH (Option 2) performs better consistently year-over-year than the other two Options. Option 1 and Option 2 start with similar emission values at year 0, although Option 2 is slightly lower due to the use of low-carbon concrete. As Option 3 involves new construction, its emissions at year 0 are 46% higher than Option 2. Throughout the operational phase, the lack of energy upgrades to Option 1 results in accumulated GHG emissions increasing significantly faster compared to the retrofitted Options.

The bumps at years 20 and 40 represent emissions from the replacement of building components such as the roof system, cladding, and windows. These replacements apply to all three Options, but are less noticeable in the case of Option 1 due to the significantly higher operational emissions.

Option 3 begins to generate lower overall GHG emissions due to superior wall insulation and airtightness (see Figure 7), however these improvements are not significant enough to reduce total emissions associated with Option 3 below those for Option 2 until year 366, exceeding the anticipated lifespan of the building.

Figure 7: Cumulative GHG Emissions Over 60 Years



5. CONCLUSIONS

The Little Yellow School House ready to welcome the Squamish community.

This comparative life cycle analysis illustrates the importance of considering the implications of both embodied and operational carbon on decisions to relocate and retrofit existing homes. From an embodied carbon perspective, it is generally preferable to relocate and retrofit a home than demolish and construct a new one. While there are practical and economic limitations to retrofitting existing homes, the different options presented demonstrate that maximizing the preservation of a building through relocation significantly reduces the use of new materials, leading to substantial reductions in upfront embodied carbon emissions. In contrast, constructing a new house typically involves a higher demand for new materials, contributing to increased embodied carbon emissions.

> **“Maximizing the preservation of a building through relocation significantly reduces the use of new materials...”**

For components of homes that need to be decommissioned, careful deconstruction and salvaging of building materials for reuse can further reduce embodied carbon emissions and material waste. In contrast, demolishing a whole building generates substantial waste, the disposal of this waste in landfills and the demand for new materials contribute to higher embodied carbon emissions.

Transportation appears to have a relatively low impact on overall carbon emissions associated with a project, however this is dependent on the distance travelled and the means of transportation. Generally speaking, carbon emissions from transporting a home are lower than transporting materials to a site for new construction, which is logical given the greater number of trips involved to move both labour and materials.

Operational GHG emissions play a relatively small role in relation to total GHG emissions when dealing with a retrofitted home or newly constructed home built to step code 3 or greater. However, with buildings designed to operate more than 60 years, operational carbon starts to take on a more significant portion of total emissions. While new construction allows for modern energy-efficient features and design optimization for the local climate, it often comes with higher demands for new materials and generates more waste. The time and resource-intensive nature of new construction can result in prolonged environmental impact. Accordingly, it is important for the project team to consider the trade-off between embodied and operational GHG emissions on each project depending on the nature of the retrofits involved and the intended life of the building.

In making decisions about housing projects, adopting sustainable practices such as material reuse, efficient transportation, waste reduction, and energy efficiency upgrades during both relocation and retrofitting and new construction are crucial for minimizing embodied carbon emissions. The specific circumstances of each project, including the condition of the existing structure and the environmental considerations of the new location, should guide the decision-making process to achieve the most significant overall reduction in carbon emissions. While a retrofitted home can achieve higher performance than achieved in this case study, potentially surpassing new build standards, the energy efficiency upgrades implemented on the LYSH were modelled and considered by the project team to follow a reasonable and cost-effective approach.

It is also valuable to reflect on the study's findings at a societal and global level. Preserving homes and the associated embodied carbon reduces GHG emissions emitted today, which is more important than those emitted in the future (through avoided operational emissions) because of the long atmospheric lifetime of greenhouse gases and their cumulative impact. Emissions today add to the total concentration of GHGs already present, exacerbating global warming and its associated effects immediately and over the long term and pushing us closer to critical tipping points and thresholds in the climate system that could lead to irreversible damage.

APPENDICES

APPENDIX A: ASSESSMENT SYSTEM BOUNDARY AND SCOPE SUMMARY

The following table details the scope of activities covered under each module within the four stages of this LCA.

Table 4: Life Cycle Stages and Information Modules

	Information Module	Module Scope
A	A1 Raw material supply	Primary resource harvesting and mining.
	A2 Transport	All transportation of materials up to the manufacturing plant gate.
	A3 Manufacturing	Manufacturing of raw materials into products.
	A4 Transport	Transportation of materials from manufacturing plant, and construction equipment, to site.
	A5 Construction/installation process	Construction equipment energy use and construction waste during A1-A4, C1, C2, and C4.
B	B1 Installed product in use	Not applicable to this analysis.
	B2 Maintenance	Painted surfaces are maintained (i.e. repainted periodically), but no other maintenance aspects are included.
	B3 Repair	Not applicable to this analysis.
	B4 Replacement	A1-A5 effects of replacement materials, and C1, C2, C4 effects of replaced materials.
	B5 Refurbishment	Not applicable to this analysis.
	B6 Operational energy use	Energy extraction, production, delivery, and use are addressed.
	B7 Operational water use	This module was not addressed.
C	C1 De-construction demolition	Demolition equipment energy use.
	C2 Transport	Transportation of materials from site to landfill.
	C3 Waste Processing	Most material data does not include waste processing effects, therefore this module is not addressed. However, the newer "avoided burden" methodology data for metals does include waste processing effects, but it is not separated into its own C3 module.
	C4 Disposal	Disposal facility equipment energy use and landfill site effects.
D	D Benefits and loads beyond the system boundary	This module is beyond the scope of a standard LCA. Includes such activities as carbon sequestration and metals recycling.

APPENDIX B: BUILDING SPECIFICATIONS SUMMARY

The following table provides the details, specifications and assumptions regarding the calculations for the three options in this wbLCA.

Table 5: Building Specifications Summary

	Option 1	Option 2	Option 3
Design notes	Original house - No Upgrades. Based on building plans, building inspection report.	Electrified home with energy upgrades. Based on recommended upgrades.	Equivalent new home built to min code (BC Step Code 3).
Airtightness	14 ACH[16]	7 ACH[17]	2.5 ACH[18]
Above Grade Walls	Wood cladding 1/2 sheathing 2x4 @12 in o/c No insulation Lath and plaster	Wood cladding 1/2 sheathing 2x4 @12 in o/c No insulation 1/2in GWB	Wood cladding 1/2 sheathing 2x4 @16 in o/c 1.5 in R6 rigid cont. insul. R14 insulation
Slab	4" concrete slab on grade No insulation	4" concrete slab on grade R12 under slab	4" concrete slab on grade R12 under slab
Ceilings	Gabled attic Framed 2x4 rafters @24" o/c No insulation	Gabled attic Framed 2x4 rafters @24" o/c R40 insulation	Gabled attic Framed 2x4 rafters @24" o/c R40 insulation
Windows	Wood single glazed	Vinyl double glazed, low e, with argon fill USI 1.2 -SHGC .25	Vinyl double glazed, low e, with argon fill USI 1.2 -SHGC .25
Doors	Hollow wood	Solid Wood	Solid Wood
Heating & Cooling	Mid efficiency gas furnace with spark ignition	Air Source Heat Pump HSPF: 10 – SEER:18	Air Source Heat Pump HSPF: 10 – SEER:18
Domestic Hot Water	50Gal conventional gas fired tank with pilot light	50Gal electric conserver tank	50Gal electric conserver tank
Ventilation	Continually running exhaust fan	Continually running exhaust fan	Continually running exhaust fan

16 Derived from ERS technical procedures Appendix D: Substitute airtightness ACH50 values.
17 Estimated based on proposed upgrades and evaluators experience. Equivalent to default value for home built from 1971-1980.
18 Set by BC STEP Code. SF home performance: TEDI=37 / 17% better than ref house MEUI= 45 / 48 % better than ref house.

APPENDIX C: BUILDING LCA MODULE AND TIMELINE SUMMARY

The following table provides the time during the building's life cycle when specific activities occurred.

Table 6: Building LCA Module and Timeline Summary

LCA Module/ Timeline	Option 1	Option 2	Option 3
Relocation transportation[19] (Year 0)	Yes	Yes.	No.
Module C (Year 0)	Crawlspace foundation concrete[20]	Crawlspace foundation concrete.	The original LYSH with crawlspace foundation[21]
Module A1-A3 (Year 0)	Regular concrete foundation; Building retrofit materials[22]	Low-carbon concrete foundation; Building retrofit materials.[23]	Regular concrete foundation; a functional equivalent new building.[24]
Module A4, A5 (Year 0)	LCA tool (based on A1-A3)	LCA tool (based on A1-A3). For Lafarge low-carbon concrete, the emissions from A4 were calculated based on the volume of the concrete and travel distance from Lafarge plant at Vancouver to the destination. Refer to Appendix I. The low-carbon concrete emissions from A5 were estimated based on the City of Vancouver Embodied Carbon Guidelines which is 6% of A1-A3.	LCA tool (based on A1-A3).

19 Refer to Appendix I for transportation greenhouse gas emissions calculation.
20 Refer to Appendix H for crawlspace foundation concrete information.
21 Refer to Appendix G.
22 Refer to Appendix D.
23 Refer to Appendix E.
24 Refer to Appendix F.

LCA Module/ Timeline	Option 1	Option 2	Option 3
Module B2, B4[25] (Year 0 – Year 60)	LCA tool (based on the original LYSH with new concrete foundation). The wood siding won't be replaced due to the stronger and longer lasting first growth lumber.	LCA tool (based on the functional equivalent new LYSH as Option 3 except wall insulations). The wood siding won't be replaced due to the stronger and longer lasting first growth lumber.	LCA tool (based on the functional equivalent new LYSH).
Module B6 (Year 0 – Year 60)	Hot2000	Hot2000	Hot2000
Module C (Year 60)	The original LYSH with new concrete foundation.	A functionally equivalent new LYSH as Option 3, except wall insulation.	A functionally equivalent new LYSH.

25 Material maintenance and replacement frequency is defined by Athena, see note 7.

APPENDIX D: BILL OF MATERIALS (OPTION 1)

Table 7: Bill of Materials (Option 1)

Material	Amount	Unit
1/2" lightweight gypsum board	2.70	m2
6 mil polyethylene	182.16	m2
Bolts, fasteners, clips	0.07	tonnes
Concrete Can 40 Mpa	0.11	m3
GluLam Sections	0.72	m3
Hollow structural steel	0.05	tonnes
Joint compound	0.02	tonnes
Modified bitumen membrane	6.76	m2
Nails	0.02	tonnes
Polyethylene filter fabric	55.19	m2
Portland cement	0.05	tonnes
Rebar, rod, light sections	0.03	tonnes
Roofing asphalt	19.28	kg
Screws nuts and bolts	0.00	tonnes
Small dimension softwood lumber, kiln-dried	6.43	m3
Softwood plywood	216.41	m2 (9mm)
Wood Tongue and Groove siding	31.29	m2
Organic felt shingles 25 yr	247.74	m2
Concrete Benchmark CAN 35 Mpa	31.44	m3
Unclad wood window frame	277.54	kg
Single glazed window	14.35	m2

APPENDIX E: BILL OF MATERIALS (OPTION 2)

For Option 2, the building retrofit materials information was provided by the Squamish Nation in invoice format. Subsequently, the quantities were identified, converted to IE4B units, and the materials were mapped to the IE4B material library. The following table details the bill of materials for Option 2.

Table 8: Bill of Materials (Option 2)

Description	Thickness (inch)	Width (ft)	Length (ft)	Invoice Quantity	Invoice Unit	Athena Quantity	Athena Unit	Athena Category
Delta Drain 6000 with Filter Cloth 4'X50'	n/a	4	50	1	roll	18.6	m2	Polyethylene filter fabric
KOROLITE, T2 3" 4X8	3	4	8	66	piece	598.1	m2 (25mm)	Expanded polystyrene
BLACK JACK® ROOF & FOUNDATION COATING				20	Litre	19.3	kg	Roofing asphalt
POLYFILM, 6 MIL CGSB 240"X100' 2000SQ'	6 mil	20	100	1	roll	185.8	m2	6 mil polyethylene
PLYWOOD, 1/2"X2" TREATED Strips	0.5	0.17	8	40	piece	6.99	m2 (9mm)	Softwood plywood
DELTA DRAIN, 4X50'	0.4	4	50	2	roll	37.2	m2	Polyethylene filter fabric
PIN-STUD, DR 1-1/2" 1512 100/Box	0.145		0.125	1.8	lb	0.81e-3	tonnes	Nails
2X4X14' KD SPRUCE 2&B				0.187	MBF	0.440	m3	Small dimension softwood lumber, kiln-dried
REBAR, 15MM 20'	15 mm		20	20	piece	8.45e-3	tonnes	Rebar, rod, light sections
6X6X10' PT GRN S4S	6	0.5	10	50	piece	3.539	m3	Small dimension softwood lumber, kiln-dried
SCREW, SDS SIMPSON 950/BOX 1/4"X3" BULK	0.25		0.25	2.85	lb	1.29e-3	tonnes	Screws nuts and bolts
PC SIMPSON PC6Z				10.8	lb	4.89e-3	tonnes	Bolts, fasteners, clips
POST HOLDER, 5.5X5.5 HOT DIPPED GALV				26.1	lb	0.011	tonnes	Bolts, fasteners, clips

Description	Thickness (inch)	Width (ft)	Length (ft)	Invoice Quantity	Invoice Unit	Athena Quantity	Athena Unit	Athena Category
PARALAM, 5-1/4X7	7	0.44	10	10	piece	0.72	m3	GluLam Sections
PLYWOOD, G1S 3/8"X4X8	0.375	4	8	47	piece	147.88	m2 (9mm)	Softwood plywood
6'X6' Rough 2&Btr Treated H/F 14'	6	0.5	14	2	piece	0.198	m3	Small dimension softwood lumber, kiln-dried
Concrete Fastset Mix 55lb				25	kg	0.025	tonnes	Portland cement
Quikrete Quick Setting Cement 4.5 kg				4.5	kg	0.0045	tonnes	Portland cement
Simpson URFP-UNIVERSAL RETRO FOUNDATION PLATE W/SDS				93.6	lb	42.45e-3	tonnes	Hollow structural steel
Simpson HDU2-8-11/16IN PREDEFLECTED HOLDOWN W/SCREWS				4.100598	lb	1.85e-3	tonnes	Bolts, fasteners, clips
Titen Bolt 1/2"X4"	0.5		0.3	21.6	lb	9.79e-3	tonnes	Bolts, fasteners, clips
2X12 2&BTR S-P-F KD-HT S4S 12'	2	1	12	2	piece	0.113	m3	Small dimension softwood lumber, kiln-dried
1X4 S/F STK KD Cedar T&G V/Joint R/L (6 PER BNDL)	1	0.33		192	LF	5.945	m2	Wood Tongue and Groove siding
1/2 Std Fir 4X8 Plywood	0.5	4	8	1	piece	4.20	m2 (9mm)	Softwood plywood
18" #1 Cedar Roofing Shingle				1	bundle	2.3	m2	Wood Tongue and Groove siding
Screw Titen FH 3/16"X3-1/4" Bulk (TNT18314TF)				2.03	lb	0.92e-3	tonnes	Bolts, fasteners, clips
Screw Titen FH 3/16"X2-3/4" Bulk (TNT18234TF)				2.6702	lb	001.21e-3	tonnes	Bolts, fasteners, clips
3/4 Std Fir Sq 4X8 Plywood	0.75	4	8	1	piece	6.29	m2 (9mm)	Softwood plywood

Description	Thickness (inch)	Width (ft)	Length (ft)	Invoice Quantity	Invoice Unit	Athena Quantity	Athena Unit	Athena Category
1X4 S/F STK KD Cedar T&G V/Joint R/L (6 PER BNDL)	1	0.33		96	LF	2.972	m2	Wood Tongue and Groove siding
2X2 S4S 2&Btr Grn H/F 10	2	0.17	10	5	piece	39.32e-3	m3	Small dimension softwood lumber, kiln-dried
Nail HDG Box 2"				1.6	lb	0.725e-3	tonnes	Nails
1X4 S/F STK KD Cedar T&G V/Joint R/L (6 PER BNDL)	1	0.33		204	LF	6.317	m2	Wood Tongue and Groove siding
2X2 S4S 2&Btr Grn H/F 08	2	0.17	8	4	piece	25.17e-3	m3	Small dimension softwood lumber, kiln-dried
Screw FH Yellow Zinc #8X3" (22lbs/Box)				2.3	lb	1.04e-3	tonnes	Bolts, fasteners, clips
Screw FH Yellow Zinc #8X2" (25lb/Box)				2	lb	0.90e-3	tonnes	Bolts, fasteners, clips
Screw Deck Brown Trim Head #8X2-1/2" 2M Box (22lbs/Box)				1	lb	0.45e-3	tonnes	Bolts, fasteners, clips
3/4 Std Fir Sq 4X8 Plywood	0.75	4	8	1	piece	6.29	m2 (9mm)	Softwood plywood
1/2 Std Fir 4X8 Plywood	0.5	4	8	2	piece	8.39	m2 (9mm)	Softwood plywood
1X4 S/F STK KD Cedar T&G V/Joint R/L (6 PER BNDL)	1	0.33		84	LF	2.601	m2	Wood Tongue and Groove siding
Concrete Mix Superpro 6000				11	bag	0.119	m3	Concrete Can 40 Mpa
1X2 S4S 2&Btr Grn H/F 08	1	0.17	8	4	piece	12.58e-3	m3	Small dimension softwood lumber, kiln-dried
Wedge All 5/8"X8-1/2" Simpson				3.32	lb	1.50e-3	tonnes	Bolts, fasteners, clips
T Strap 7Ga 12X12 Powdercoat				7.74	lb	3.51e-3	tonnes	Bolts, fasteners, clips

Description	Thickness (inch)	Width (ft)	Length (ft)	Invoice Quantity	Invoice Unit	Athena Quantity	Athena Unit	Athena Category
Screw Deck Green #8X3"				2.5	lb	1.13e-3	tonnes	Bolts, fasteners, clips
6X6 S4S #2 App WRC 08	6	0.5	8	3	piece	0.169	m3	Small dimension softwood lumber, kiln-dried
1X6 R/F STK GRN Cedar Channel Siding R/L	1	0.5		42	LF	1.950	m2	Wood Tongue and Groove siding
2X2 S4S 2&Btr Grn H/F 08	2	0.17	8	8	piece	50.34e-3	m3	Small dimension softwood lumber, kiln-dried
2X3 S4S 2&Btr Grn SPF 10	2	0.25	10	2	piece	23.59e-3	m3	Small dimension softwood lumber, kiln-dried
1/2 Std Fir 4X8 Plywood	0.5	4	8	2	piece	8.39	m2 (9mm)	Softwood plywood
18" #2 Cedar Roofing Shingle				1	bundle	2.3	m2	Wood Tongue and Groove siding
Screw FH Yellow Zinc #8X3" (22lbs/Box)				2.8	lb	1.27e-3	tonnes	Bolts, fasteners, clips
Screw SDS 4" Cut Tip 1/4"X2-1/2" Bulk				0.75	lb	0.34e-3	tonnes	Bolts, fasteners, clips
Titen Bolt 1/2"X3"				1.53	lb	0.69e-3	tonnes	Bolts, fasteners, clips
1X6 R/F STK GRN Cedar Channel Siding R/L	1	0.5		8	LF	0.371	m2	Wood Tongue and Groove siding
FRFP 7X9 Rtrofit Foundation Plate				13.12	lb	5.95e-3	tonnes	Hollow structural steel
Hanger Joist Double 2X8 LUS28-2Z				9	lb	4.08e-3	tonnes	Bolts, fasteners, clips
Post Saddle Rough 6 Heavy Duty Galv RCPS6HDG				1.5	lb	0.68e-3	tonnes	Bolts, fasteners, clips
Wedge All 1/2"X5-1/2" Simpson				7.75	lb	3.51e-3	tonnes	Bolts, fasteners, clips

Description	Thickness (inch)	Width (ft)	Length (ft)	Invoice Quantity	Invoice Unit	Athena Quantity	Athena Unit	Athena Category
Screw Deck Brown #8X 2″ 3.5M Box (26.9lbs/ Box)				3.4	lb	1.54e-3	tonnes	Bolts, fasteners, clips
Nail Duplex 3-1/4″				1.5	lb	0.680e-3	tonnes	Nails
Nail Bright Joist Hanger 1-1/2″				3.3	lb	1.49e-3	tonnes	Nails
5/8 Std Fir Sq 4X8 Plywood	0.6	4	8	3	piece	15.73	m2 (9mm)	Softwood plywood
6′X6′ Rough 2&Btr Treated H/F 10′	6	0.5	10	1	piece	70.79e-3	m3	Small dimension softwood lumber, kiln-dried
Nail Brad 23ga X 11/16″ Bisset (2.6M)				0.25	lb	0.11e-3	tonnes	Nails
Nail Brad 23ga X 1-3/8″ Bisset (1M)				0.23	lb	0.10e-3	tonnes	Nails
Nail Brad 16ga X 1-1/2″ 2.5M				3.27	lb	1.48e-3	tonnes	Nails
Nail Brads Galvanized 18ga X 1-1/2″ (5M)				3.93	lb	1.78e-3	tonnes	Nails
Hemlock Full Round- 1-1/2″ R/L (MH3228)	1.5	0.13	9	1	piece	3.98e-3	m3	Small dimension softwood lumber, kiln-dried
Hemlock Quarter Round- 11/16″ x 11/16″ R/L (MH3206)	0.7	0.06	16	1	piece	1.48e-3	m3	Small dimension softwood lumber, kiln-dried
Hemlock Cove- 1/2″ x 1/2″ R/L (MH3260)	0.5	0.04	11	1	piece	0.54e-3	m3	Small dimension softwood lumber, kiln-dried
2X6 Rough 2&Btr Cedar 10′	2	0.5	10	1	piece	23.59e-3	m3	Small dimension softwood lumber, kiln-dried
Nail Brads Galvanized 18ga X 1″ (5M)				2.57	lb	1.164e-3	tonnes	Nails
Nail Brad 16ga X 2″ 2.5M				4.26	lb	1.93e-3	tonnes	Nails

Description	Thickness (inch)	Width (ft)	Length (ft)	Invoice Quantity	Invoice Unit	Athena Quantity	Athena Unit	Athena Category
Screw FH Yellow Zinc #8X3″ (22lbs/Box)				1.8	lb	0.81e-3	tonnes	Bolts, fasteners, clips
Screw FH Yellow Zinc #8X1-1/2″ (35lbs/Box)				1	lb	0.45e-3	tonnes	Bolts, fasteners, clips
Nail Duplex 2-1/4″				4	lb	1.81e-3	tonnes	Nails
2X4 S4S 2&Btr KD SPF 08	2	0.33	8	8	piece	100.68e-3	m3	Small dimension softwood lumber, kiln-dried
2X4 S4S 2&Btr KD SPF 10	2	0.33	10	8	piece	125.85e-3	m3	Small dimension softwood lumber, kiln-dried
2X4 S4S 2&Btr KD SPF 14	2	0.33	14	3	piece	66.07e-3	m3	Small dimension softwood lumber, kiln-dried
2X4 S4S 2&Btr KD SPF 16	2	0.33	16	4	piece	100.68e-3	m3	Small dimension softwood lumber, kiln-dried
1X4 S4S Util&Btr Grn SPF 12	1	0.33	12	6	piece	056.63e-3	m3	Small dimension softwood lumber, kiln-dried
2X12 S4S 2&Btr KD SPF 08	2	1	8	1	piece	37.75e-3	m3	Small dimension softwood lumber, kiln-dried
2X12 S4S 2&Btr KD SPF 12	2	1	12	5	piece	0.283	m3	Small dimension softwood lumber, kiln-dried
2X12 S4S 2&Btr KD SPF 08	2	1	8	4	piece	0.151	m3	Small dimension softwood lumber, kiln-dried
1X2X18 Stakes	1	0.17	1.5	2	boundle	58.99e-3	m3	Small dimension softwood lumber, kiln-dried
Tie Wire 16ga X 300′				1	roll	1.13e-3	tonnes	Nails
Rebar 15mm X 20′ (same as 5/8″)	15 mm		20	36	piece	8.45e-3	tonnes	Rebar, rod, light sections

Description	Thickness (inch)	Width (ft)	Length (ft)	Invoice Quantity	Invoice Unit	Athena Quantity	Athena Unit	Athena Category
1X4 S4S Util&Btr Grn SPF 10	1	0.33	10	10	piece	78.65e-3	m3	Small dimension softwood lumber, kiln-dried
1X2 S4S 2&Btr Grn H/F 08	1	0.17	8	2	piece	6.29e-3	m3	Small dimension softwood lumber, kiln-dried
1X6 Primed Pine T&G R/L (6 PER BNDL)	1	0.5		208	LF	9.661	m2	Wood Tongue and Groove siding
6'X6' Rough 2&Btr Treated H/F 14'	6	0.5	14	2	piece	0.198	m3	Small dimension softwood lumber, kiln-dried
Concrete Fastset Mix 55lb				25	kg	0.025	tonnes	Portland cement
Post Saddle Rough 6 Heavy Duty Galv RCPS6HDG				3.75	lb	1.70e-3	tonnes	Bolts, fasteners, clips
Staple Narrow Crown Generic 18ga X 1-1/4 X 1/4" (5M)				3	lb	1.36e-3	tonnes	Nails
Nail Brad 16ga X 2" 2.5M				4.26	lb	1.93	tonnes	Nails
Tie Wire 16ga X 300'				1	roll	1.13e-3	tonnes	Nails
Screw FH Yellow Zinc #8X3" (22lbs/Box)				2.2	lb	0.997e-3	tonnes	Bolts, fasteners, clips
2X8 S4S 2&Btr Treated H/F 10'	2	0.67	10	4	piece	125.85e-3	m3	Small dimension softwood lumber, kiln-dried
1X6 Primed Comb Fascia 12	1	0.5	12	2	piece	28.31e-3	m3	Small dimension softwood lumber, kiln-dried
2X10 Primed Comb Fascia 12	2	0.83	12	1	piece	47.19e-3	m3	Small dimension softwood lumber, kiln-dried
Drywall Regular 4'X8'X1/2"	0.5	4	8	1	piece	3.0	m2	1/2" lightweight gypsum board
Filler Lite Joint Yellow Taping 17kg Synko				43.1	lb	0.019	tonnes	Joint compound

Description	Thickness (inch)	Width (ft)	Length (ft)	Invoice Quantity	Invoice Unit	Athena Quantity	Athena Unit	Athena Category
Screw Drywall Coarse 1-5/8" (22lbs/box)				1	lb	0.45e-3	tonnes	Bolts, fasteners, clips
Screw FH Yellow Zinc #8X2-1/2 (23lbs/Box)				0.8	lb	0.36e-3	tonnes	Bolts, fasteners, clips
Nail Bright Common 3-1/2"				1.8	lb	0.81e-3	tonnes	Nails
1X6 S1S2E #2BTR Cedar 10'	1	0.5	10	2	piece	23.59e-3	m3	Small dimension softwood lumber, kiln-dried
2X8 S1S2E #2BTR Cedar 08'	2	666.66e-3	8	2	piece	50.34e-3	m3	Small dimension softwood lumber, kiln-dried
2X4 S4S 2&Btr KD Fir 10	2	333.33e-3	10	5	piece	78.65e-3	m3	Small dimension softwood lumber, kiln-dried
1X6 Primed Comb Fascia 12	1	0.5	12	2	piece	28.31e-3	m3	Small dimension softwood lumber, kiln-dried
1X10 S1S Util&Btr H/F 14'	1	833.33e-3	14	2	piece	55.06e-3	m3	Small dimension softwood lumber, kiln-dried
Screw Deck Brown #10X3-1/2" 1.5M Box (27lbs/Box)				1.8	lb	0.81e-3	tonnes	Bolts, fasteners, clips
Simpson HDU2-SDS2.5				8.2	lb	3.71e-3	tonnes	Bolts, fasteners, clips
Vapour Barrier Blueskin 18"X50' 35 mil	35 mil	1.5	50	1	roll	6.97	m2	Modified bitumen membrane
Wedge All 5/8"X8-1/2" Simpson				1.66	lb	0.75e-3	tonnes	Bolts, fasteners, clips
Nail HDG Roofing 1-3/4"				1.1	lb	0.49e-3	tonnes	Nails
3/4 Std Fir Sq 4X8 Plywood	0.75	4	8	3	piece	18.88	m2 (9mm)	Softwood plywood
1/2 Std Fir 4X8 Plywood	0.5	4	8	1	piece	4.20	m2 (9mm)	Softwood plywood

Description	Thickness (inch)	Width (ft)	Length (ft)	Invoice Quantity	Invoice Unit	Athena Quantity	Athena Unit	Athena Category
Post Saddle Rough 6 Heavy Duty Galv RCPS6HDG				3.75	lb	1.70e-3	tonnes	Bolts, fasteners, clips
Staple Narrow Crown Generic 18ga X 1-1/4 X 1/4" (5M)				3	lb	1.36e-3	tonnes	Nails
Nail Brad 16ga X 2" 2.5M				4.26	lb	1.93e-3	tonnes	Nails
Tie Wire 16ga X 300'				1	roll	1.13e-3	tonnes	Nails
Screw FH Yellow Zinc #8X3" (22lbs/Box)				2.2	lb	0.99e-3	tonnes	Bolts, fasteners, clips
2X8 S4S 2&Btr Treated H/F 10'	2	666.66e-3	10	4	piece	125.85e-3	m3	Small dimension softwood lumber, kiln-dried
1X6 Primed Comb Fascia 12	1	0.5	12	2	piece	0.028	m3	Small dimension softwood lumber, kiln-dried
2X10 Primed Comb Fascia 12	2	833.33e-3	12	1	piece	0.047	m3	Small dimension softwood lumber, kiln-dried
Owens Corning Propink Fiberglas insulation				725.748	kg	3035.015	m2 (25mm)	Fibreglass loose fill
2X4X14' KD SPRUCE 2&B				0.14	MBF	0.3304	m3	Small dimension softwood lumber, kiln-dried
REBAR, 15MM 20'	15 mm		20	40	piece	8.45e-3	tonnes	Rebar, rod, light sections
CAP POST Z-MAX 6X6"				7.74	lb	3.51e-3	tonnes	Bolts, fasteners, clips
CertainTeed Landmark Shingles				6468	lb	2933.83e-3	tonnes	Organic felt shingles 25 yr

Since all purchased building retrofit materials represented the actual quantity used on-site (as *Net Amount* in IE4B), the equation below was employed to convert actual quantities to the quantity of material input in IE4B (as reported in Table 5), aiming to avoid double accounting:

Material amount in IE4B = Actual material amount / (1+ construction waste factor)

Table 9: IE4B Retrofitting building materials mapping information summary

Material	Construction waste factor	Amount	Unit
1/2" lightweight gypsum board	0.1	2.70	m2
6 mil polyethylene	0.02	182.16	m2
Bolts, fasteners, clips	0.03	0.06	tonnes
Concrete Can 40 Mpa	0.05	0.11	m3
Expanded polystyrene*	0.05	569.57	m2 (25mm)
Fibreglass loose fill*	0.05	2890.49	m2 (25mm)
GluLam Sections	0.01	0.71	m3
Hollow structural steel	0.01	0.04	tonnes
Joint compound	0.07	0.01	tonnes
Modified bitumen membrane	0.03	6.76	m2
Nails	0.03	0.02	tonnes
Polyethylene filter fabric	0.01	55.19	m2
Portland cement	0	0.05	tonnes
Rebar, rod, light sections	0.01	0.02	tonnes
Roofing asphalt	0	19.27	kg
Screws nuts and bolts	0.03	0.001	tonnes
Small dimension softwood lumber, kiln-dried	0.08	6.43	m3
Softwood plywood	0.05	216.41	m2 (9mm)
Wood Tongue and Groove siding	0.1	31.29	m2
Organic felt shingles 25 yr	0.05	247.74	m2
Double glazed Hard Coated Argon*[26]	0	28.70	m2
PVC Window Frame*[20]	0	354.66	kg
Lafarge ECOPACT Concrete Foundation*	n/a	33	m3

* Materials that were not installed in Option 1. Apart from insulations, Option 1 used single-glazed windows, unclad wood window frames, and standard concrete benchmarked at CAN 35Mpa.

26 Represents a future upgrade to the building.

APPENDIX F: NEW BUILDING SPECIFICATIONS & BILL OF MATERIALS (OPTION 3)

The quantity of building materials was estimated by IE4B through a take-off process from the original architectural drawings of the LYSH provided by the Vancouver School Board. Table 6 shows the take off from original LYSH architectural drawings and building specification assumptions based on BC Step Code 3 requirements and Table 7 shows the Bill of Materials report exported from Athena.

Table 10: Building Element Design Summary (Option 3)

Foundation					
Strip footing					
Length(m)	Width(m)	Thickness (mm)	Concrete		
59.2	1.00	200	25MPa		
Slab on grade					
Length(m)	Width(m)	Thickness (mm)	Concrete	Envelope Components	
19.6	10.00	100	25MPa	3" EPS insulation; 6 mil polyethylene	
Floor					
Wood Joist and Plywood or OSB Decking Floor System					
Floor width (m)	Span(m)	Decking type	Decking thickness (mm)		
37.77	4.00	Plywood	19		
Wall					
Wood stud					
Length(m)	Height (m)	Sheathing type	Stud thickness	Stud spacing	
56.75	4.17	Plywood	2x4	16 o.c.	
Opening					
Number of windows	Window area (m2)	Frame type	Glazing type	Number of doors	Door type
15	35.16	PVC window frame double pane	Double glazed Hard Coated Argon	3	Solid wood door
Envelope					
Cladding	Gypsum	Barrier	Insulation		
Wood siding	1/2" regular	Air and PSK	4" Blown Cellulose R14; 1.67" EPS		

Roof						
Light Frame Wood Truss Roof System						
	Roof width (m)	Span (m)	Decking type	Decking thickness (mm)		
	65.03	4	Plywood	19		
Envelope						
	Roof envelope	Ceiling	Barrier	Insulation		
	Organic felt shingles 25 yr	1/2" regular	PSK	12" Fibreglass R40		

Table 11: Bill of Material Summary (Option 3)

Material	Unit	Total Quantity	Floors	Foundations	Roofs	Walls	Mass Volume (tonnes)
#15 Organic Felt	m2	847.4	0.0	0.0	0.0	847.4	0.6
1/2" Lightweight Gypsum Board	m2	460.4	0.0	0.0	0.0	272.5	3.1
6 mil Polyethylene	m2	207.9	0.0	0.0	207.9	0.0	0.0
Air Barrier	m2	181.2	0.0	0.0	0.0	0.0	0.0
Blown Cellulose-Wall	m2 (25mm)	717.4	0.0	0.0	0.0	0.0	0.9
Concrete Benchmark CAN 35 MPa	m3	32.9	0.0	0.0	32.9	0.0	76.1
Double Glazed Hard Coated Argon	m2	57.4	0.0	0.0	0.0	0.0	0.9
Expanded Polystyrene	m2 (25mm)	916.2	0.0	0.0	616.9	0.0	0.7
Fiberglass Loose Fill	m2 (25mm)	3,031.6	0.0	0.0	0.0	3,031.6	0.7
Galvanized Sheet	Tonnes	0.3	0.0	0.0	0.0	0.3	0.3
Joint Compound	Tonnes	0.5	0.0	0.0	0.0	0.3	0.5
Large Dimension Softwood Lumber, kiln-dried	m3	4.7	0.0	4.7	0.0	0.0	2.2
Nails	Tonnes	0.1	0.0	0.0	0.0	0.0	0.1

Material	Unit	Total Quantity	Floors	Foundations	Roofs	Walls	Mass Volume (tonnes)
Organic Felt shingles 25yr	m2	780.5	0.0	0.0	0.0	780.5	8.9
Paper Tape	Tonnes	0.0	0.0	0.0	0.0	0.0	0.0
Polypropylene Scrim Kraft Vapour Retarder Cloth	m2	444.0	0.0	0.0	0.0	262.8	0.0
PVC Window Frame	kg	709.3	0.0	0.0	0.0	0.0	0.7
Rebar, Rod, Light Sections	Tonnes	1.1	0.0	0.0	1.1	0.0	1.1
Screws Nuts & Bolts	Tonnes	0.1	0.0	0.0	0.0	0.0	0.1
Small Dimension Softwood Lumber, kiln-dried	m3	8.8	0.0	0.0	0.0	5.4	4.0
Softwood Plywood	m2 (9mm)	1,076.1	0.0	317.3	0.0	520.3	5.0
Water Based Latex Paint	L	124.5	0.0	0.0	0.0	0.0	0.1
Welded Wire Mesh / Ladder Wire	Tonnes	0.2	0.0	0.0	0.2	0.0	0.2
Wood Tongue and Groove siding	m2	450.9	0.0	0.0	0.0	0.0	3.6

APPENDIX G: ORIGINAL LYSH BUILDING SPECIFICATIONS & BILL OF MATERIALS (OPTION 1)

For Option 1, the quantity of building materials was estimated by IE4B through a take-off process from the original architectural drawings of the LYSH provided by the Vancouver School Board. Table 8 shows the take off from the original LYSH architectural drawings, building specification assumptions from the building inspection report and Table 9 shows the Bill of Materials report exported from Athena.

Table 12: Building Element Design Summary (Original LYSH)

Floor					
Wood Joist and Plywood or OSB Decking Floor System					
Floor width (m)	Span(m)	Decking type	Decking thickness (mm)		
37.77	4.00	Plywood	19		
Wall					
Wood stud					
Length(m)	Height (m)	Sheathing type	Stud thickness	Stud spacing	
56.75	4.17	Plywood	2x4	16 o.c.	
Opening					
Number of windows	Window area (m2)	Frame type	Glazing type	Number of doors	Door type
15	35.16	Unclad wood window frame	Single glazed	3	Solid wood door
Envelope					
Cladding	Gypsum	Barrier	Insulation	Interior	
Wood siding	N/A	N/A	N/A	1/2" plywood	
Roof					
Light Frame Wood Truss Roof System					
Roof width (m)	Span (m)	Decking type	Decking thickness (mm)		
65.03	4	Plywood	19		
Envelope					
Roof envelope	Ceiling	Barrier	Insulation		
Organic felt shingles 25 yr	1/2" regular	N/A	N/A		

Table 13: Bill of Material Summary (Original LYSH)

Material	Unit	Total Quantity	Floors	Roofs	Walls	Project Extra Materials	Mass Volume (tonnes)
#15 Organic Felt	m2	889.6	0.0	889.6	0.0	0.0	0.6
1/2" Lightweight Gypsum Board	m2	286.1	0.0	286.1	0.0	0.0	2.0
Concrete Benchmark CAN 35 MPa	m3	7.2	0.0	0.0	0.0	7.2[27]	16.7
Double Glazed No Coating Air	m2	28.7	0.0	0.0	0.0	28.7	0.5
Galvanized Sheet	Tonnes	0.3	0.0	0.3	0.0	0.0	0.3
Joint Compound	Tonnes	0.3	0.0	0.3	0.0	0.0	0.3
Large Dimension Softwood Lumber, kiln-dried	m3	4.7	4.7	0.0	0.0	0.0	2.2
Nails	Tonnes	0.1	0.0	0.0	0.0	0.0	0.1
Organic Felt shingles 25yr	m2	819.4	0.0	819.4	0.0	0.0	9.4
Paper Tape	Tonnes	0.0	0.0	0.0	0.0	0.0	0.0
Screws Nuts & Bolts	Tonnes	0.1	0.0	0.0	0.1	0.0	0.1
Small Dimension Softwood Lumber, kiln-dried	m3	9.0	0.0	5.7	3.3	0.0	4.2
Softwood Plywood	m2 (9mm)	1,345.1	317.3	546.3	238.5	243.1[28]	6.2
Unclad Wood Window Frame	kg	555.1	0.0	0.0	555.1	0.0	0.5
Water Based Latex Paint	L	133.1	0.0	0.0	133.1	0.0	0.1
Wood Tongue and Groove siding	m2	450.9	0.0	0.0	450.9	0.0	2.7

27 The crawlspace foundation in the original LYSH was accounted for as Extra Material since it is not included in the wall assembly in IE4B.

28 The 1/2" plywood interior structure in the original LYSH was accounted for as Extra Material since it is not included in the wall assembly in IE4B.

APPENDIX H: CRAWLSPACE FOUNDATION CONCRETE INFORMATION

As calculated by Heatherbrae Builders, 242 cubic feet (6.85 m3) of concrete pedestals were removed on the original LYSH site. The amount of concrete was inputted in Athena to calculate the GHG emissions associated with demolition.

APPENDIX I: TRANSPORTATION GHG CALCULATION

Transportation of a relocated house scenario is not explicitly defined in the Guidelines. However, the project team utilized the calculation method outlined in *Table 10: Calculation of the environmental indicators* from the Guidelines to estimate associated carbon emissions.

The quantity of diesel fuel used for the barge was supplied by Nickel Bros. Consequently, the carbon emissions were calculated by multiplying the diesel fuel consumed by the diesel engine emission factor, as defined by Natural Resources Canada.[29]

The carbon emissions from truck transport were calculated using the following equation:

$$E_{truck} = L_{truck} \times W_{house} \times EF_{truck}$$

Where,

E_{truck} = Carbon dioxide equivalent emissions from truck, kg CO2e

L_{truck} = transport distances by truck mode, km

W_{house} = the weight of the house, tonnes

EF_{truck} = Truck transport emission factor, kg CO2e/km-tonnes

The distance of house relocation transport by truck was provided by Renewal Development. The weight of the LYSH was provided by Nickel Bros. and the truck transport emission factor was referenced from the Canadian National Railway Company.[30]

Mode of transportation	Weight of building	GHG emission rate	Distance
Truck	65 tonnes	77.23 g CO2/tonne-km	2.528 km

Mode of transportation	Fuel usage (Diesel)	Fuel GHG emission rate (Diesel)
Barge	225 Litres	2.7 kg CO2/litre

The GHG emissions resulting from the low-carbon concrete provided by Lafarge which is responsible for Option 2 A4 emissions are calculated below:

Mode of transportation	Volume of Concrete	Weight of concrete	GHG emission rate	Distance
Truck	33 m^3	76.4 tonnes	77.23 g CO2/tonne-km	13.7 km

29 Natural Resources Canada. (2014). *Auto$mart - Learn the facts: Emissions from your vehicle*.
30 Canadian National Railway Company. *CN's Carbon Calculator Emission Factors*.

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