Kuugalak Community Centre Embodied Carbon: Upfront Emissions Assessment

Final Report

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Prepared by: Mantle Climate
Prepared for: Pitquhirnikkut Ilihautiniq / Kitikmeot Heritage Society (PI/KHS)

Authors

Eslam Elshorbagy - Advisor, Mantle Climate

Mandi Wesley - Senior Advisor, Mantle Climate

Marco A. Rico Thirion - Senior Advisor, Mantle Climate

Ryan Zizzo - CEO and Founder, Mantle Climate

Contributors

Brendan Griebel - *Munaqhiyi, Inuinnait Pitqhuhirnikkut Tutkuqhimajut,* Manager, Collections and Archives, Pitquhirnikkut Ilihautiniq / Kitikmeot Heritage Society (PI/KHS)

Sophie Pantin - Ikajuqtiujuq Nunamiutuqakkut / Consultant for Nunamiutuqaq, Pitquhirnikkut Ilihautiniq / Kitikmeot Heritage Society (PI/KHS)

Samantha Lewis - Innovation Procurement & Contractor Handler, Qillaq Innovations

Kelsey Chegus - Operations Lead, Green Building Technologies, Applied Research and Innovation Services, Southern Alberta Institute of Technology (SAIT), Green Building Technologies (GBT) Lab

Ching-Yi (Leo) Lu - Laboratory Technician, Architectural Technologist, Applied Research and Innovation Services (ARIS), Southern Alberta Institute of Technology (SAIT), Green Building Technologies (GBT) Lab

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Executive Summary

This report summarizes the upfront embodied carbon[1] emissions associated with constructing the Kuugalak Community Centre in Cambridge Bay, Nunavut (the "Project"). Results are calculated using a methodology called life cycle assessment (LCA) to evaluate the environmental impacts. Mantle Climate completed the LCA in alignment with recognized international standards ISO 14040, ISO 14044, and North American industry best practices.

This project also compared the environmental impacts of the "designed" case against the "actual" (as-built) scenario accounting for a few things that didn't go to plan, resulting in some additional materials and effort. Finally, results were compared against a scenario if a similar building was built in a less remote location; Edmonton was selected for this "south" comparison. See Table 1.

Table 1: LCA scenarios and assumptions

Scenario	**1 (Designed)**	**2 (Actual)**	**3 (South)**
Location	Cambridge Bay, NU		Edmonton, AB
Description	Intended construction without any schedule delays or incidents	Actual construction on site	Hypothetical scenario by taking the project to be constructed in the south.
Foundation system	Granular pad with steel screw jacks		Concrete grade beams connected with steel piles.
Design inputs	Manufacturer-specific products (where data permits), actual construction methods, operational energy use data from a third-party consultant, transportation of materials, air travel of staff, shipping materials, and equipment		Manufacturer-specific products (where data permits)

The results demonstrate a 30% reduction in embodied carbon when building in the south compared to a project in Cambridge Bay. Table 2 summarizes the results of the three scenarios.

[1] Upfront carbon emissions: considers A1-A3 product, A4 transportation, and A5 construction stages of life cycle assessment (LCA)

Table 2: Life Cycle Assessment (LCA) results for the three scenarios (in kCO2e / m2)

Scenario	1 (Designed)	2 (Actual)	3 (South)
Core Scope[2] (A1-A5)	626	633	563
Expanded Scope[3] (A1-A5)	948	955	805
Site Works[4] (A5)	184	302	93
Pad Spill[5] (A5)	0	38	0
Other: Workers Air-travel	162	161	108
Other: Workers Accommodation	31	31	28
Total Upfront Emissions	**1324**	**1487**	**1034**
Emissions % difference	-	+12% (between scenarios 1 & 2)	-30% (between scenarios 2 & 3)

The building elements and systems with the highest embodied emissions are facility power generation, floor and roof construction for all three scenarios. Scenario 1 and 2 shows that out of the total 107 tonnes of carbon dioxide equivalent (t CO^2e) calculated (expanded scope), services contribute up to 34% of the total building emissions, followed by the structure with 30% and envelope elements with 18%. This is illustrated in Figure 1.

2 Core scope: structure and envelope materials
3 Expanded scope: core scope + mechanical, electrical, plumbing (MEP) products
4 Site works: non-building site energy use, construction equipment used for non-building land and site work, and crates
5 Pad spill scope: foundation pad replacement due to accidental oil spill during construction

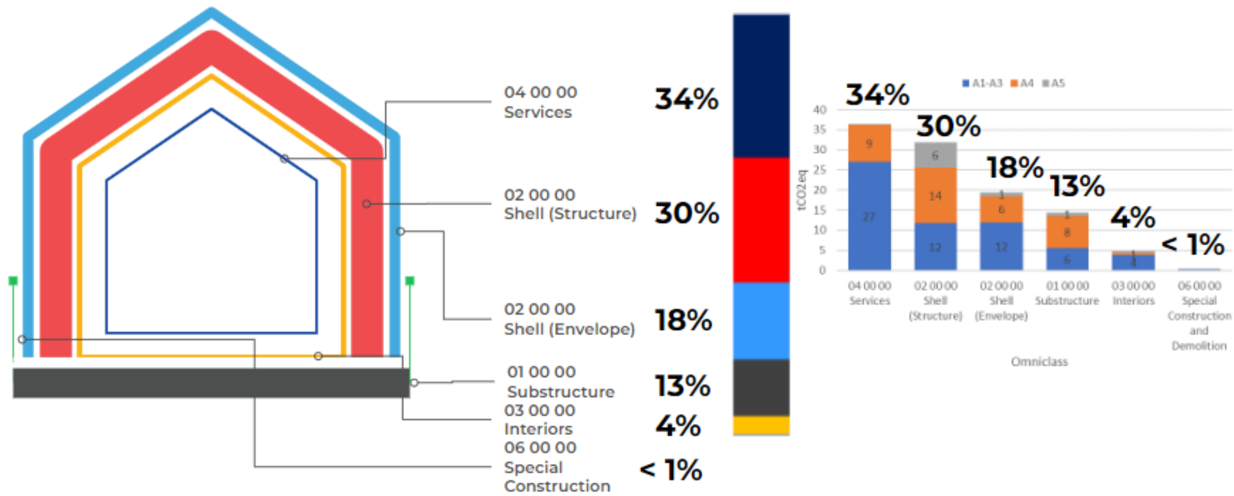

Figure 1: Distribution of upfront carbon emissions by building element diagram

The top three material contributors were the studs required to create pre-fabricated panels type ZS2 with 26% overall emission contribution, followed by screw jacks with 13%, and solar panel assemblies containing the panels themselves, the racking and battery pack systems with 13%. Appendix B provides a breakdown of all materials used (expanded scope).

Transportation Emissions

If the project was in Edmonton, Alberta, 91% savings in transportation-related carbon emissions were estimated considering all materials associated with the top three highest Omni-class material categories identified (facility power generation, floor construction, and roof construction). When looking at the workforce required to manage, coordinate, and construct the building, the study found that 33% less flight-related emissions are expected for a site between a project in the south.

Construction and Worker Emissions

Construction-related emissions (A5 life cycle stage) were calculated 65% higher in Cambridge Bay compared to constructing the project in Edmonton. For skill trades working on-site, 8% more emissions are expected in Cambridge Bay than in Edmonton. The study also found that 5 tCO_2e carbon emissions were accounted for when shipping materials via wooden crates, representing 5% of the expanded scope total embodied carbon emissions.

Whole-life carbon payback

The study found that solar panels offset 5% of the embodied carbon (expanded scope) annually compared to operational carbon emissions calculated by a third-party consultant. As shown in Figure 2, it would take 13 years to offset all the building's embodied carbon (core scope only) emissions, 20 years when the expanded scope is considered, and 37 years to offset all carbon emissions when building the project, including replacing all solar panels after 25 years of operation. Due to the high operational carbon, the building has from using diesel power generators, there are more annual emissions from operating the building than the solar panels can offset; therefore, whole life carbon is never 'paid back.'

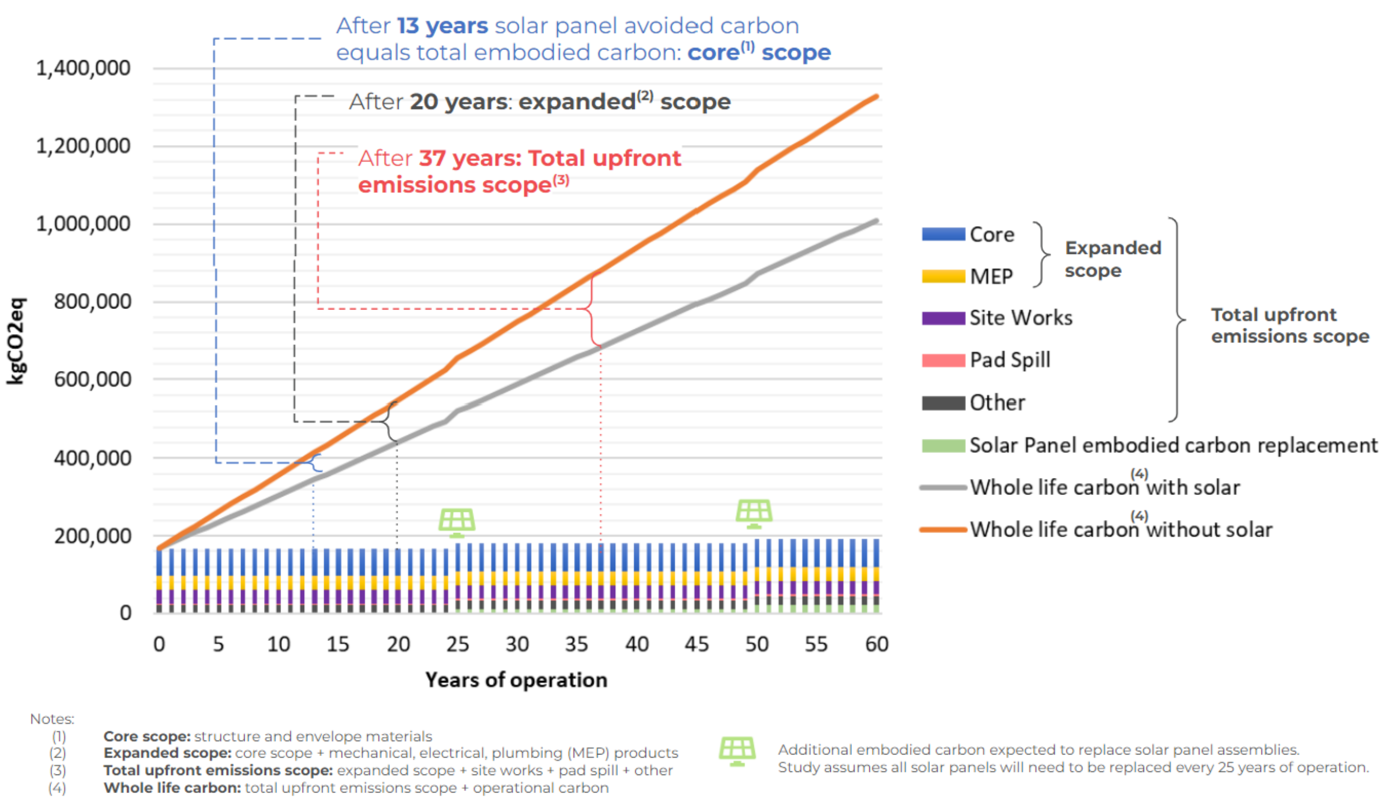

Figure 2: Whole life cycle carbon payback from installed solar panels over the building roof

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1. General Information

Located in Cambridge Bay, Nunavut, Canada – in Canada's far north – the Kuugalak Community Centre serves the Copper Inuit, also known as Innuinnait and Kitlinermiut, a Canadian Inuit group living north of the tree line in Canada's far north.

This report provides a useful benchmark for future energy-efficient buildings in the Arctic. By understanding and visualizing the total carbon footprint of the Kuugalak Community Center building, the study aims to bring greater awareness of embodied carbon accounting and management to the Arctic and the Inuit Nunavut community in general across the construction and energy sectors. This study is intended to be a pivotal resource to help educate funders, academics, and industry professionals about the realities of construction and low-carbon buildings in the North.

The Kuugalak building's embodied carbon was calculated for the actual location of Cambridge Bay and, secondly, in a southern community, selected as Edmonton, Alberta. The purpose of conducting a second LCA simulating the same building but in the south is to understand the difference in carbon emissions of delivering and constructing buildings in the Arctic vs the south and to illustrate the current challenges of minimizing carbon emissions when building in the Arctic. Edmonton, AB, was selected because most of the materials were procured from there, and it has a relative proximity to Cambridge Bay compared to other major cities in Canada.

Mantle also analyzed the carbon emissions from three different transportation modes for the top three material categories that contributed the most carbon emissions to the project. Once obtained, a proportion of these was calculated to simulate the total transportation-related carbon emissions of all materials for each alternative transportation mode considered. The analysis provides insights for future consideration in optimizing transportation plans for material delivery to Cambridge Bay and the Arctic more generally to minimize the carbon footprint. The study also considered construction-based emissions ("upfront embodied carbon") at the pre-occupancy stage for each of the three scenarios considered (designed, actual, and south), including other types of carbon emissions assessments such as air-travel transportation for workers, workers' accommodations, and added scope due to accidental oil spill during construction and vapor barrier replacement across the walls of the building.

A final portion of the study calculated the carbon payback associated with the solar panels. The LCA models considered industry average materials[6] and Environmental Product Declarations[7] were available and applicable.

Table 3 provides a summary of the information on the Kuugalak Community Center project.

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6 The average environmental impacts of a product of multiple companies in a clearly defined sector and/or geographical area.

7 Transparently reports objective, comparable, and third-party verified data about products and services' environmental performances from a lifecycle perspective.

Table 3: Kuugalak Community Center Project Information

Parameter	Description
Embodied Emissions Assessor's Team	Eslam Elshorbagy Mandi Wesley Marco A. Rico Thirion
Embodied Emissions Assessor Firm	Mantle Climate
Date of Assessment Completion	March 4, 2024
Software & Version Number	One Click LCA Version: 0.19.3, Database version: 7.6
Above grade storeys (#) & gross floor area (m^2) including parking	1 113 m^2 (1216.32 ft^2)
Below-grade storeys (#) & gross floor area (m^2) including parking	0 0
Total storeys (#) & gross floor area (m^2) including parking	1 113 m^2 (1216.32 ft^2)
Parking levels (#) & gross parking floor area (m^2)	0 0
Project Life	60 years
Object of assessment	Footings and foundations Structural and envelope wall assemblies Structural and envelope floor assemblies Structural and envelope roof assemblies Mechanical, electrical, plumbing (MEP) equipment Construction site works Project Staff air travel transportation and workers' construction hours.
Project data sources	Architectural, structural, MEP Issued-for-construction drawings BIM Revit model Invoices for structural lumber, MEP products Shop drawings for solar panels and ZS2 Panels Site photographs for crates and construction issues Client input on railings and acoustic insulation.

2. Object of Assessment

The International Standard ISO 21930 and European Standard EN 15804 set out a common life-cycle model for building and construction works. The life-cycle model includes modular definitions for the life-cycle stages, allowing each stage to be compared in isolation with other projects.

The life cycle stages included in these LCAs were the product stage (A1-A3), transportation (A4), and construction and installation processes (A5). A third-party consultant calculated operational energy use (B6) separately. Use (B1-B5), end of life (C1-C4), and benefits and loads beyond the building life cycle were excluded from the scope, except that the embodied emissions associated with solar panel replacements at year 25 were included in the 'avoided emissions' analysis (section 5.4).

Upfront Carbon																
Product stage			Construction process stage		Use stage							End-of-life stage				Benefits and loads beyond the building life cycle
A1	A2	A3	A4	A5	B1	B2	B3	B4 8	B5 9	B6 10	B7	C1	C2	C3	C4	D
R	T	M	T	C	U	M	R	R	R	O	O	D	T	W	D	Re use D
✓	✓	✓	✓	✓												

Figure 3: System boundary for Kuugalak Community Center carbon assessment

Reference study period
The reference study period is the same as the required service life of the building, which is 60 years. Hence, there is no need to develop adjustment scenarios for the Life Cycle Assessment (LCA).[11]

Building model scope

Three distinct LCA scopes were carried out as part of this project. These were:

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[8] Only used when analyzing replacement cycles of solar panels
[9] See footnote 8
[10] Referring to a third-party energy model from Southern Alberta Institute of Technology (SAIT).
[11] Bowick, M., O'Connor, J., Meil, J., Salazar, J., Cooney, R. (2022). National guidelines for whole-building life cycle assessment. National Research Council Canada: Ottawa, ON. 112 pp.

1. **Core scope:** structure and envelope materials
2. **Expanded scope:** core scope plus mechanical, electrical, plumbing (MEP)
3. **Total upfront emissions scope:** expanded scope plus the following:
    a. Site works: non-building site energy use, construction equipment used for non-building land and site work, and crates.
    b. Pad spill scope: foundation pad replacement due to accidental fuel spill during construction.
    c. Other - Workers' air travel taken during the planning and construction phases of the project, and
    d. Other - Workers' accommodation based on the carbon intensity of the region.

Core scope is typically used in the industry to measure the carbon intensity of a building. The project expanded this scope by adding MEP products, site works, pad spill, and other scopes into a 'Total Upfront Emissions' scope. To accomplish this, Tables 4 through 6 lists materials considered for each of the above scopes described.

The following items were excluded from the LCA due to a lack of representative materials in the software materials library to get equivalent products:
1. Electrical: conduit stub-out, loop panel, comm board, data and ceiling data ports, junction boxes, door contact
2. Plumbing: elbows and HVAC turns
3. Sealants


Photo credit: Margaret Thompson (provided by Pitquhirnikkut Ilihautiniq/Kitikmeot Heritage Society)

Figure 4: Kuugalak Community Center under construction

Table 4: Core scope - structural

Building Element	Material

Foundation	Screw jacks and lumber
Walls, floor, and roof	Lumber used in wood panels, studs, and ZS2 tech boards

Table 5: Core scope - envelope

Building Element	Material
Walls	Walls insulation, metal flashing, gypsum board, siding, vapor barrier
Floor	Flooring finishes, flooring membranes, and acoustic insulation
Roof	Seam metal roof decking, roof insulation, and vapor barrier
Other	Doors, windows, railings, and external decking

Table 6: Mechanical, electrical, and plumbing (MEP)

Building Element	Material	
Electrical	Conduit	Security fixtures
	Lighting fixtures	Power fixtures
Mechanical	Tanks	Pumps
	Heating fixtures	Ventilation fixtures
Plumbing	Plumbing fixtures	Pipe runs
Other	HVAC runs	MEP insulation

3. Embodied Carbon Results

3.1. Core Scope

The embodied carbon results for the Kuugalak Community Center LCA for the core scope, using industry-average materials and construction processes, are summarized in Table 7. The total upfront[12] embodied carbon results found is 71 tonnes CO_2e or 633 kg CO_2e/m^2.

Table 7: Kuugalak upfront carbon emissions: core scope

Upfront Carbon Emissions			Carbon emissions within the scope			
			Absolute (tonnes CO_2e)		Intensity (kg CO_2e/m2)	
			Core: Structure	Core: Envelope	Core: Structure	Core: Envelope
Product	A1	Raw Material Supply	17	16	154	144
	A2	Transport (to factory)				
	A3	Manufacturing				
Transportation	A4	Transport (to site)	22	7	191	63
Construction	A5	Construction & Installation	7	2	64	17
	Sub-total		**46**	**25**	**409**	**223**
	TOTAL			**71**		**633**

3.2. Total Upfront Emissions

The building's full embodied carbon extends beyond the structural materials and envelope. The LCA also includes MEP, non-building construction, machinery, and site energy use. The study also carefully considered the materials transportation emissions to ship the materials to the project's location.

When addressing the total upfront emissions, Tables 8 and 9 show 168 tonnes CO_2e or 1487 kg CO_2e/m^2 upfront embodied carbon results.

[12] Upfront carbon represents the emissions from resource extraction through end of life. See Figure 2 for the life cycle stages and modules included within the system boundary.

Table 8: Kuugalak upfront carbon emissions: total upfront emissions scope (absolute)

Upfront Carbon Emissions			Carbon emissions within the scope - Absolute (tonnes CO_2e)				
			Core	Expanded[13]	Site works	Pad spill	Other
Product	A1	Raw Material Supply	34	61	-	-	-
	A2	Transport (to factory)			-	-	-
	A3	Manufacturing			-	-	-
Transportation	A4	Transport (to site)	29	38	-	-	-
Construction	A5	Construction & Installation	9	9	34	4	-
Other[14]		Other	-	-	-	-	22
	Sub-total		**71**	**108**	**34**	**4**	**22**
	TOTAL		**71**				**168**

Table 9: Kuugalak upfront carbon emissions: total upfront emissions scope (intensity)

Upfront Carbon Emissions			Carbon emissions within the scope - Intensity (kg $CO_2e/m2$)				
			Core	Expanded[13]	Site works	Pad spill	Other
Product	A1	Raw Material Supply	298	537	-	-	-
	A2	Transport (to factory)			-	-	-
	A3	Manufacturing			-	-	-
Transportation	A4	Transport (to site)	254.	335	-	-	-
Construction	A5	Construction & Installation	81	83	302	38	-
Other[14]			-	-	-	-	192

[13] Expanded scope: core scope (structural and envelope) + mechanical, electrical, plumbing (MEP)
[14] Other: worker's air travel and worker's accommodation emissions

	Sub-total	633	955	302	38	192
	TOTAL	633				1487

Lastly, Figure 5 shows a comparison between results obtained when analyzing core (Figure 5a) and total upfront emissions scopes (Figure 5b).

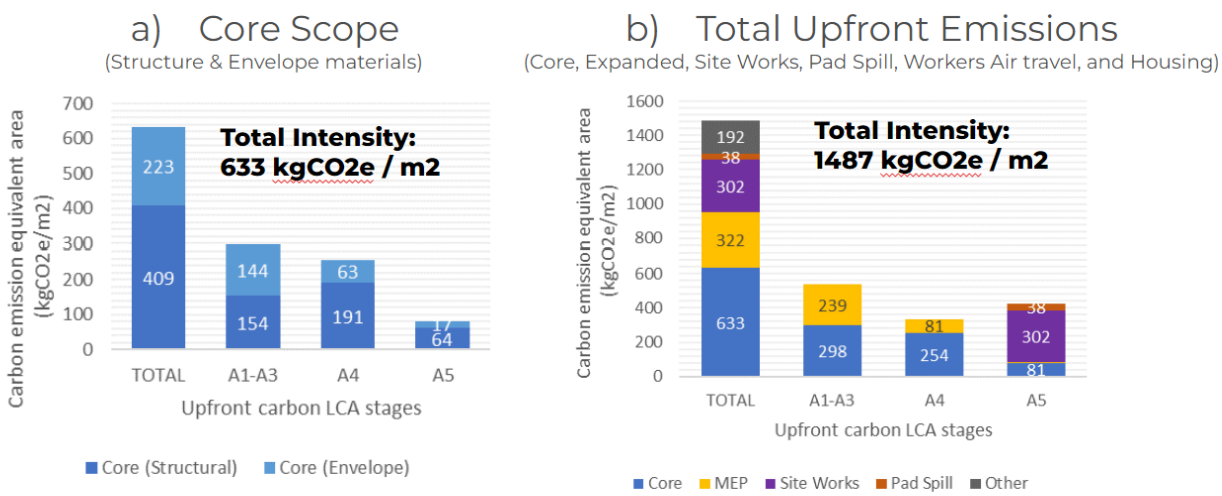


Figure 5: Upfront carbon intensity: core and total scope comparison (actual scenario)

4. Contribution Analysis

4.1. Embodied Emissions by Materials and Elements

When using the Canadian National Master Construction Specification (NMS) system, Figure 6 shows each material grouped by construction specification divisions with respect to their total volumes (in cubic meters) and the embodied carbon emissions. Figure 7 shows another way of representing these by using a Sankey diagram and Omni-class material categories.

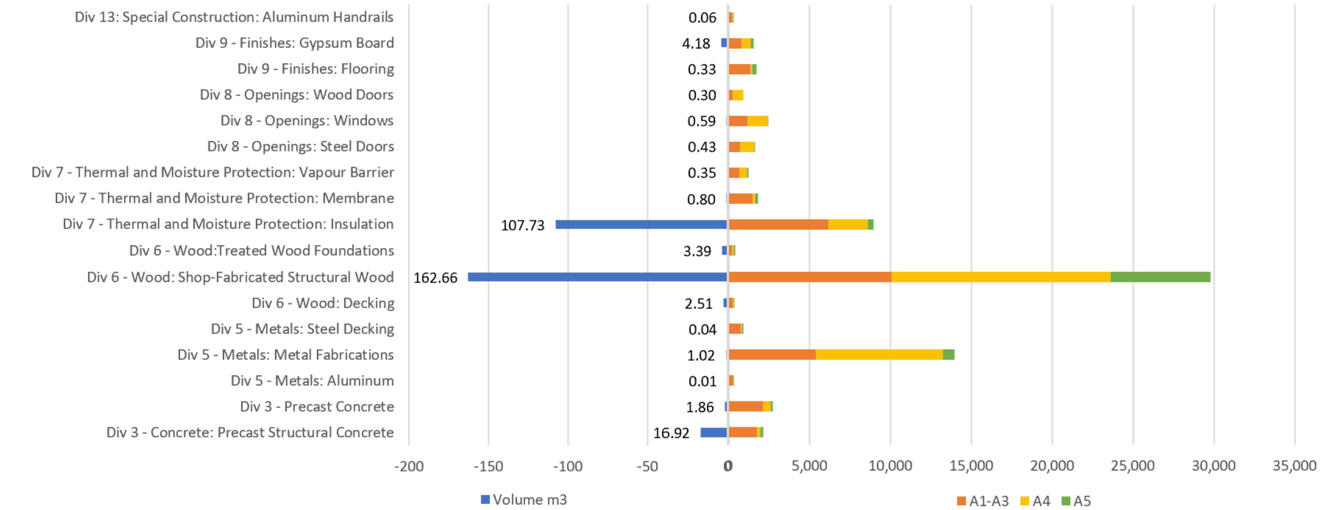


Figure 6: Global warming potential by material classification (NMS)

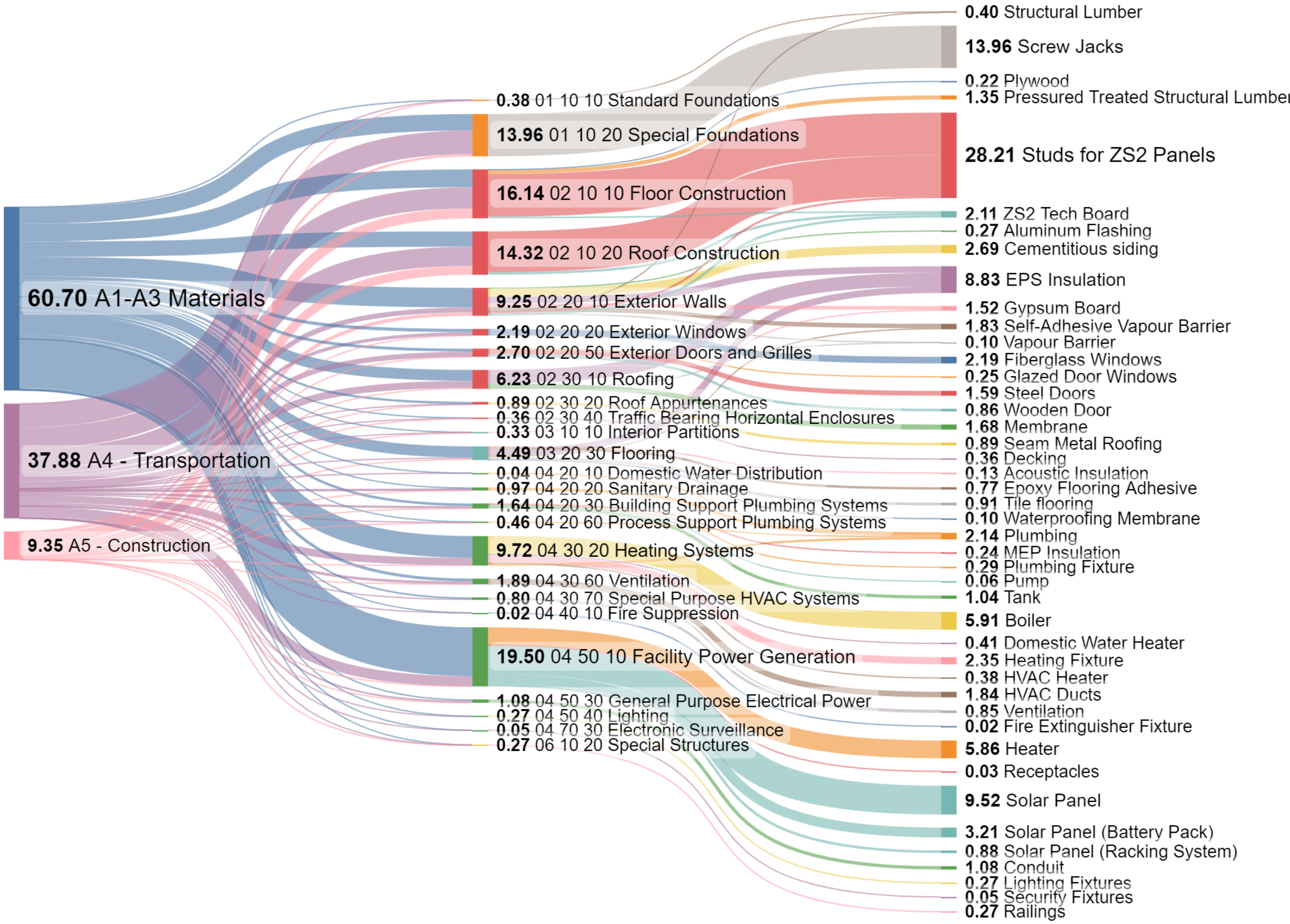


Figure 7: Distribution of upfront carbon emissions by Omni class (Sankey diagram)

Figure 8 shows facility power generation, floor construction, and roof construction have the highest emissions with 18%, 15%, and 13%, respectively. Each material in these categories is also presented, showing their contribution to carbon emissions across the A1-A5 stages. Furthermore, Table 10 summarizes all other materials present in each omniclass, showing standard and special foundations contribute 13%, heating systems 9%, exterior walls 9%, roofing 6%, flooring 4%, and exterior windows and doors 5%. The remaining building components are overall embodied carbon emissions (8%).

Figure 8: Top 3 material categories identified

Table 10: Embodied carbon emissions (absolute and intensity) by material category

Building Element (NRC OmniClass Table 21)	Absolute (kgCO2e)	Intensity (kg CO2e/m2)	%
01 10 10 Standard Foundations	384	340	< 1%
01 10 20 Special Foundations	13955	12350	13%
02 10 10 Floor Construction	16142	14285	15%
02 10 20 Roof Construction	14321	12673	13%
02 20 10 Exterior Walls	9245	8181	9%
02 20 20 Exterior Windows	2185	1934	2%
02 20 50 Exterior Doors and Grilles	2699	2388	3%
02 30 10 Roofing	6229	5512	6%
02 30 20 Roof Appurtenances	886	784	1%
02 30 40 Traffic Bearing Horizontal Enclosures	358	317	< 1%
03 10 10 Interior Partitions	330	292	< 1%
03 20 30 Flooring	4487	3971	4%
04 20 10 Domestic Water Distribution	37	33	< 1%
04 20 20 Sanitary Drainage	967	855	1%
04 20 30 Building Support Plumbing Systems	1632	1445	2%
04 20 60 Process Support Plumbing Systems	463	410	< 1%
04 30 20 Heating Systems	9712	8594	9%
04 30 60 Ventilation	1888	1671	2%
04 30 70 Special Purpose HVAC Systems	803	711	1%
04 40 10 Fire Suppression	16	14	< 1%
04 50 10 Facility Power Generation	19500	17257	18%
04 50 30 General Purpose Electrical Power	1076	952	1%
04 50 40 Lighting	272	241	< 1%
04 70 30 Electronic Surveillance	50	44	< 1%
06 10 20 Special Structures (Handrail)	268	237	< 1%

5. Scenario Analysis

As shown in Table 2, Mantle carried out three scenarios to understand and compare the embodied emissions values for the Kuugalak Community Centre:

1. Scenario 1 (designed) represents the intended construction without deviation from the original schedule or design.
2. Scenario 2 (actual) represents actual conditions on-site, including a fuel spill and replacement of the foundation pad, and
3. Scenario 3 (south) represents a hypothetical scenario that takes the project location to be constructed in Edmonton, AB, for comparison purposes.

The comparison between scenarios 2 and 3 provides insights into the difference in carbon emissions of constructing the same building but in different locations. The results aim to assist decision-makers in setting embodied carbon goals that would be more appropriate for the northern communities and consider the additional carbon emissions stemming from material shipping, team transportation, lodging, and on-site energy usage, to name a few.

Table 2: Life Cycle Assessment (LCA) results for the three scenarios (in kCO2e / m2)

Scenario	1 (Designed)	2 (Actual)	3 (South)
Core Scope[15] (A1-A5)	626	633	563
Expanded Scope[16] (A1-A5)	948	955	805
Site Works[17] (A5)	184	302	93
Pad Spill[18] (A5)	0	38	0
Other: Workers Air-travel	162	161	108
Other: Workers Accommodation	31	31	28
Total Upfront Emissions	**1324**	**1487**	**1034**

15 Core scope: structure and envelope materials

16 Expanded scope: core scope + mechanical, electrical, plumbing (MEP) products

17 Site works: non-building site energy use, construction equipment used for non-building land and site work, and crates

18 Pad spill scope: foundation pad replacement due to accidental oil spill during construction

Emissions % difference	-	+12% (between scenarios 1 & 2)	-30% (between scenarios 2 & 3)

Results show that scenario 2 (actual) had a total carbon emissions of 1,487 kgCO2e/m2, or 12% higher carbon emissions than the designed case. The main reasons attributed to this is based on two factors:

1. The replacement of a contaminated foundation pad due to an oil spill during construction.
2. Additional vapor barrier throughout the building envelope to guarantee design requirements.

Scenario 2 also considered air travel affected by wildfires during construction, with only one flight affected from the planned scenario, yielding lower emissions but significantly longer travel times. If the project were located in Edmonton, Alberta, a total of 1,034 kgCO2e/m2 or 30% lower emissions would be expected. The lower carbon emissions were attributed to significantly reduced travel distances when shipping the materials purchased, travel times for staff, and lower carbon intensities of the region for on-site construction equipment energy use and labor.

In the case of scenario 3, the foundation used for Cambridge Bay was replaced with a hypothetical typical foundation type[19] that can be found in Edmonton. This assumed replacing all structural lumber and steel screw jacks underneath the deck used for scenarios 1 and 2 with concrete-grade beams connected to steel piles. Figure 9 shows the difference between the two.

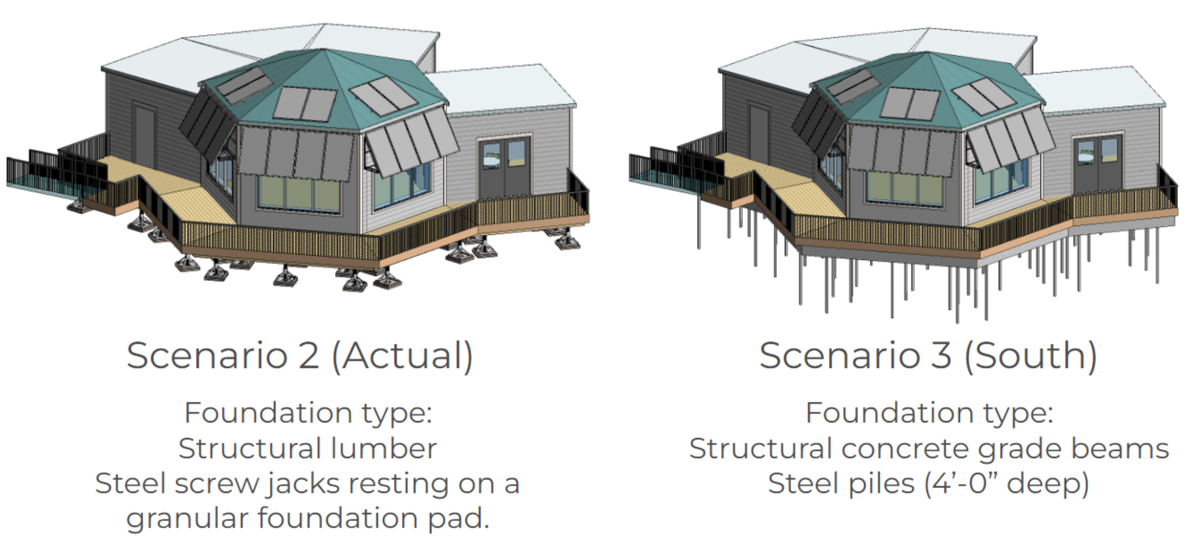


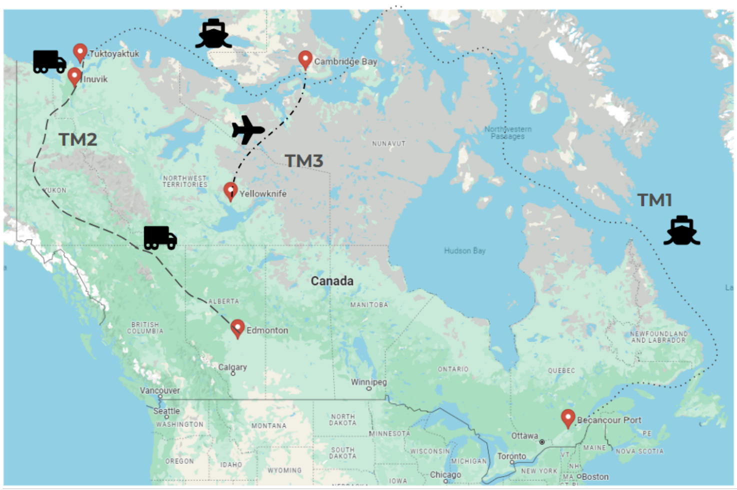
Figure 9: Scenario 2 and 3 foundation type comparison

[19] Foundation type was provided by a third-party consultant retained by PI/KHS

5.1. Alternate Transportation Modes

In addition to the actual transportation scenario in the project, three alternative transportation modes provided by PI/KHS were explored to compare potential carbon savings when shipping materials to the site using different methods. The aim was to understand the carbon emissions associated with each route so it could help decision-making for future shipping of construction materials in the region.

Figure 10 presents three alternative transportation modes considered, while Figures 11 through 13 show details of each.



Transportation Mode 1 (TM1):

1. *By truck to Port of Becancour, QC*
2. *By boat from Port of Becancour, QC to Cambridge Bay, NU*

Transportation Mode 2 (TM2):

1. *By truck to Edmonton, AB,*
2. *By truck from Edmonton, AB to Inuvik*
3. *By truck from Inuvik to Tuktoyaktuk*
4. *By boat from Tuktoyaktuk, Inuvik to Cambridge Bay, NU*

Transportation Mode 3 (TM3):

1. *By truck to Yellowknife, NWT*
2. *By air from Yellowknife, NWT to Cambridge, NU*

Figure 10: Alternative Transportation modes considered for the project

Transportation Mode 1 (TM1):

1. *By truck to Port of Becancour, QC*
2. *By boat from Port of Becancour, QC to Cambridge Bay, NU*

Large delivery truck, 9 ton capacity, 100% fill rate

Origin: Edmonton, AB	Solar Panels (Racking, Battery, Panel) Heaters Receptacles

Trailer combination, 40 ton capacity, 100% fill rate

Origin: Calgary, AB	ZS2 Panels
Origin: Montreal, QC	Pressure Treated Lumber + Plywood

Ship, Big bulk

Figure 11: Alternative Transportation Mode 1 (TM1): via Quebec

Transportation Mode 2 (TM2):

1. *By truck to Edmonton, AB,*
2. *By truck from Edmonton, AB to Inuvik*
3. *By truck from Inuvik to Tuktoyaktuk*
4. *By boat from Tuktoyaktuk to Cambridge Bay, NU*

Large delivery truck, 9 ton capacity, 100% fill rate

Origin: Calgary, AB	Heaters Receptacles Solar Panel (Racking)
Origin: Montreal, QC	Heaters Solar Panel (Panel, Battery)

Trailer combination, 40 ton capacity, 100% fill rate

Origin: Calgary, AB	ZS2 Panels
Origin: Montreal, QC	Pressure Treated Lumber + Plywood

Ship, Big bulk

Figure 12: Alternative Transportation Mode 2 (TM2): via Inuvik

Transportation Mode 3 (TM3):

1. *By truck to Yellowknife, NWT*
2. *By air from Yellowknife, NWT to Cambridge, NU*

Large delivery truck, 9 ton capacity, 100% fill rate

Origin: Edmonton, AB	Solar Panels (Racking, Battery, Panel) Heaters Receptacles

Trailer combination, 40 ton capacity, 100% fill rate

Origin: Calgary, AB	ZS2 Panels
Origin: Montreal, QC	Pressure Treated Lumber + Plywood

Flight

Figure 13: Alternative Transportation Mode 3 (TM3): via Yellowknife

Results show for TM1, the total transportation emissions for the 3 top omni-class material categories yielded 14 tCO_2e, followed by TM3 and TM2 with 13 and 12 tCO_2e, respectively. Scenario 2 (actual) results suggest it was the highest carbon-emitting path compared to all modes considered. If the project was to be built in Edmonton, 91% of transportation-related carbon emissions savings were calculated. Figure 14 shows each material's contribution when being shipped to the site. while Table 11 shows the difference in percentage between each case against scenario 2.

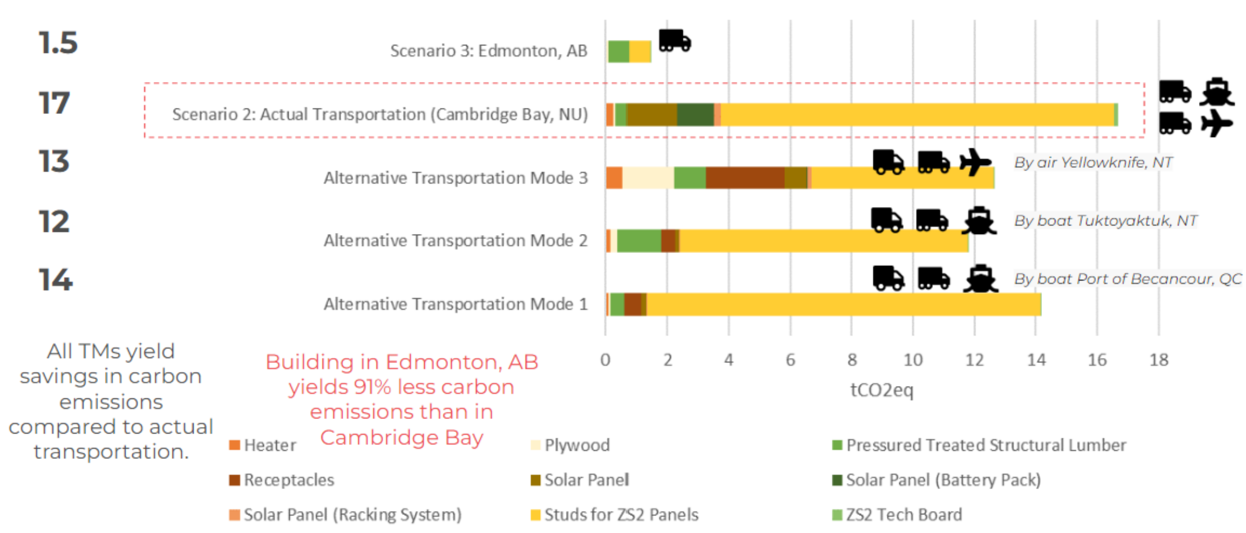


Figure 14: Transportation Modes (scenario and alternative modes considered)

As shown in Table 11, the expected total transportation-related emissions for all materials used in the project was calculated (expanded scope). To do so, Mantle used the A4 emissions obtained from the 3 top omni-class material categories. Each result was compared against the actual case (scenario 2) to obtain a percentage difference between these. Lastly, by referring to the total A4 transportation-related emissions of all materials (expanded scope) obtained from Table 8, a proportion was calculated allowing to estimate the total transportation-related materials for each case.

Results suggest alternative transportation mode 2 (TM2 - shipping via Inuvik) will emit the lowest A4 transportation emissions compared to all other modes. Figure 15 sorts these graphically.

Table 11: Transportation-related emissions for all materials per transportation mode

Case	GWP[20] (tCO_2e)	% difference in relation to Cambridge, Bay	Cambridge Bay total A4 GWP (tCO_2e)[21]	Total transportation-related emissions for all materials GWP (tCO_2e)
Scenario 2: Cambridge Bay	17		38	
Scenario 3: Edmonton	1.5	-91%		3
Alternative Transportation Mode 1	14	-18%		31
Alternative Transportation Mode 2	12	-29%		27
Alternative Transportation Mode 3	13	-24%		29

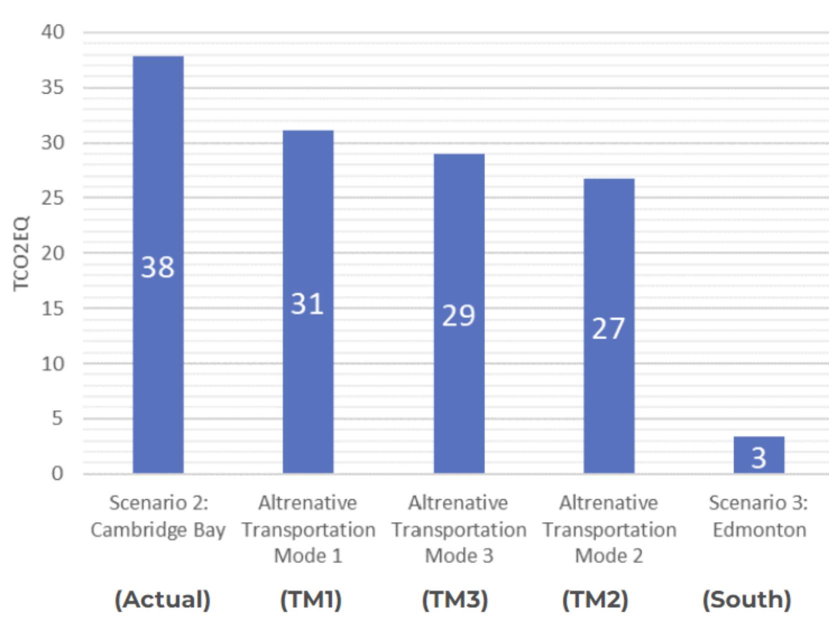


Figure 15: Estimated A4 emissions (all materials) for each alternative transportation mode

[20] **GWP** | Global Warming Potential: a measure of how much energy the emissions of 1 tonne of a gas will absorb over a given period of time, relative to the emissions of 1 tonne of carbon dioxide (CO2) EPA. (2016, January 12). Understanding Global Warming Potentials [Overviews and Factsheets]. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

[21] Refer to Table 8

5.2. Construction Emissions

Construction usually requires several design changes and additional materials since things don't always go according to the design plans. Kuugalak Community Center was no exception, as it required additional construction work to address the following events:

- Replacement of a portion of the foundation pad[22] due to accidental oil spills that caused the site to be contaminated. The replaced materials enabled the project foundation to be safely constructed and to comply with environmental regulations.
- An additional air/vapor barrier (Tyvek) was needed to be installed on all external building walls to meet building performance requirements.
- Minor insulation inside the building floor and walls was replaced due to damages that occurred to existing ones during construction.

For all construction activities, the type of machinery used is presented in Table 12.

Table 12: Construction used to build Kuugalak

Site & Soil Contamination machinery		
Equipment	**Model**	**Operating hours**
Excavator	Kubota KX-808	61
Wheel Loader	544k	107
Skid Steer (Trac Loader)	Cat 277B	20
Dump Truck	Sterling Tandem	256
Pick Up Trucks	Ford 150	46.2
Rolling Compactor	Walker Neuson	25
Telehandler	Skytrack 1054	46

Results show that if the building was to be constructed in Cambridge Bay as designed without any construction incidents, no significant difference was found between Cambridge Bay and Edmonton case. However, if one looks at actual conditions that occurred on site (site being contaminated, calling to replace a portion of the foundation pad), it is projected Edmonton will have 46% lower construction-related (A5) embodied carbon emissions than Cambridge Bay. It is important to note Edmonton also requires a foundation pad for grade beams to rest on these. Results addressed in this section must also consider the emissions from workers flying to the site (section 5.3).

Figure 16 compares construction-related emissions in each scenario.

[22] Foundation pad was composed of granular compacted material.

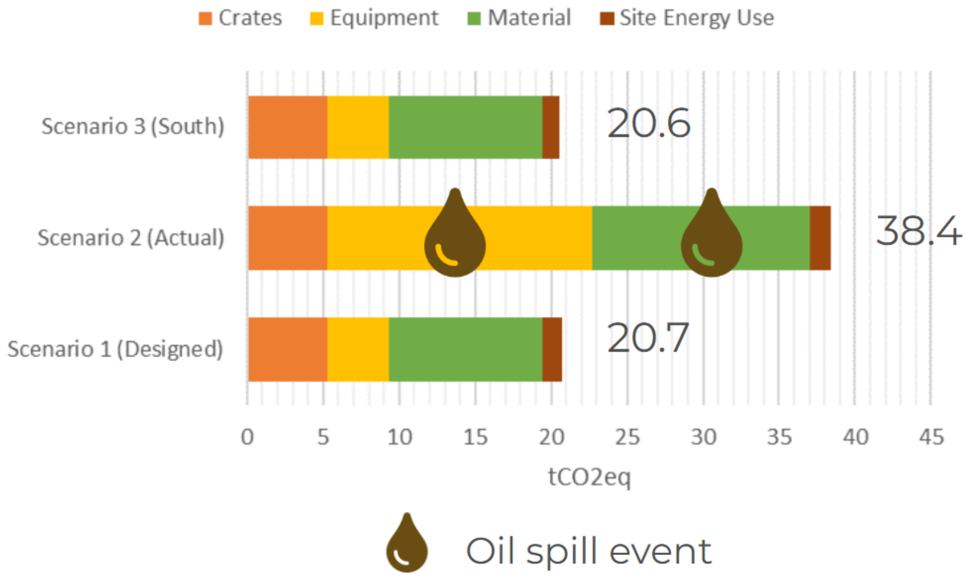


Figure 16: Construction (A5) emissions between scenarios

Lastly, the carbon emissions generated from using wood crates to transport materials were also considered. Figure 17 presents examples of typical crates used for the project. Results show crates generated five tonnes of carbon emissions during the project. This value was equivalent to 5% of the total building carbon emissions (expanded scope). In future, consider using reusable shipping containers, which can have lower carbon impacts over the long term.

Crates used to ship MEP and finished products

Crates used to ship prefabricated panels

Figure 17: Wood crates used to ship materials to Cambridge Bay, NU

5.3. Worker Travel and Accommodation Emissions

The study found if workers were to build the project in Edmonton, AB, 33% less carbon emissions would be expected associated with worker travel when air-traveling from their original destinations to the construction site. The total amount of 18.2 tCO_2e emitted for Scenario 2 represents approximately 16.8% of the total upfront carbon emissions of the building (expanded scope). It is important to note that scenario 2 yielded fewer emissions than scenario one because only one flight was affected by wildfires in 2023, which resulted in lower emissions but significantly longer travel times. The contribution each worker had in the project is presented in Figure 18.

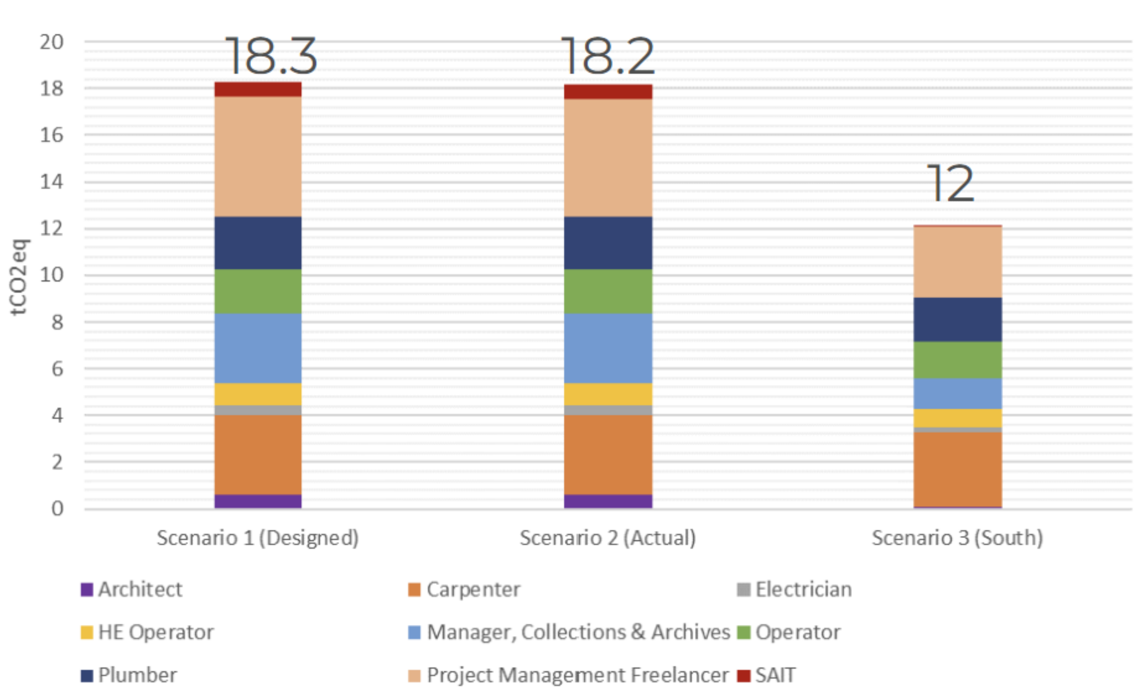


Figure 18: Worker transportation carbon impact: flying workers to the construction site

For worker accommodation-related emissions, Mantle used each city's yearly carbon emission per capita, as shown in Table 13. The total amount of trade workers' hours was used to calculate the percentage of hours spent on the project in a year. Using the carbon intensity of each region, total emissions were calculated. Results show worker accommodation-related emissions in Edmonton will yield 8.45% less than in Cambridge Bay.

Table 13: Lodging Carbon Impact (Skilled trades workers)

	Unit	Cambridge Bay, NU	Edmonton, AB
Emissions per capita	tCO_2e	15.4	14.2
Hours in a year	hr		8,760
Percentage of skilled trades working in a year[23]	%		23%
Carbon Intensity of the region	kgCO2/person/hr	1.76[24]	1.62[25]
Total emissions	$kgCO_2e$	3,464	3,194
Emissions intensity	$kgCO_2e/m2$	29	27

5.4. Avoided Emissions

Using a third-party energy modeler, the annual operational energy for the project in the north for scenarios 1 and 2 was found to be 12,745 kWh for electricity consumption and 32,706 kWh for diesel consumption, yielding 19 tCO2e/year carbon emissions. Appendix B shows expected annual operational and carbon emissions for the site with total kWh per fuel type and expected avoided emissions using solar panels.

The annual electricity generated from the solar panels is expected to be 6,717 kWh, equivalent to 5 tCO_2e avoided emissions each year.

Assuming solar panels have a life expectancy of 25 years, it will require two replacement cycles over the life span of the building. The study assumed that solar panels are treated as an assembly and that all system components are replaced simultaneously.

Table 14 presents the expected additional embodied carbon from replacing all solar panel assemblies.

[23] Based on number of hours from July, 2023 to Dec 3,2023
[24] The Government of Canada, Provincial and Teeritotial Energy Profiles - Nunavut (2024). Retrieved March 1, 2024
[25] The CIty of Edmonton, Budget 2023 - 2026 Carbon Budget Highlight.Retrieved March 1, 2024

Table 14: Solar panels embodied carbon in $KgCO_2e$ over the lifespan of the building

Component	A1-A3	A4	A5	Emissions due to solar panel replacement
Racking System	626	250	0	2,063
Battery	53	18	0.29	146
Solar Panels	7,944	1,610	0	21,105
Total	8,623	1,878	0.29	23,315

Table 15: Estimated operational and embodied carbon emissions at years 1 and 60

Description	Unit	Year 1	Year 60
Operational emissions	kg CO_2e	18,980	1,138,820
Embodied emissions	kg CO_2e	107,200	130,516
Avoided emissions from solar panels	kg CO_2e	5,340	320,400

6. Embodied Carbon Payback

This report section evaluates how many years the building needs to pay back the amount of embodied carbon emitted by using the avoided carbon emissions obtained from using solar panels. Results show that solar panels offset 5% of the embodied carbon (expanded scope) annually.

Since the operational carbon emissions are significantly higher than the avoided emissions from solar panels, the panels will never offset the whole life carbon. However, when looking at only the embodied carbon payback, Figure 2 shows it will take 13 years for the solar panels to offset the embodied carbon emitted for the core scope, 20 years for the expanded scope, 37 years to offset all embodied carbon emissions, including replacing all solar panels after 25 years of operation.

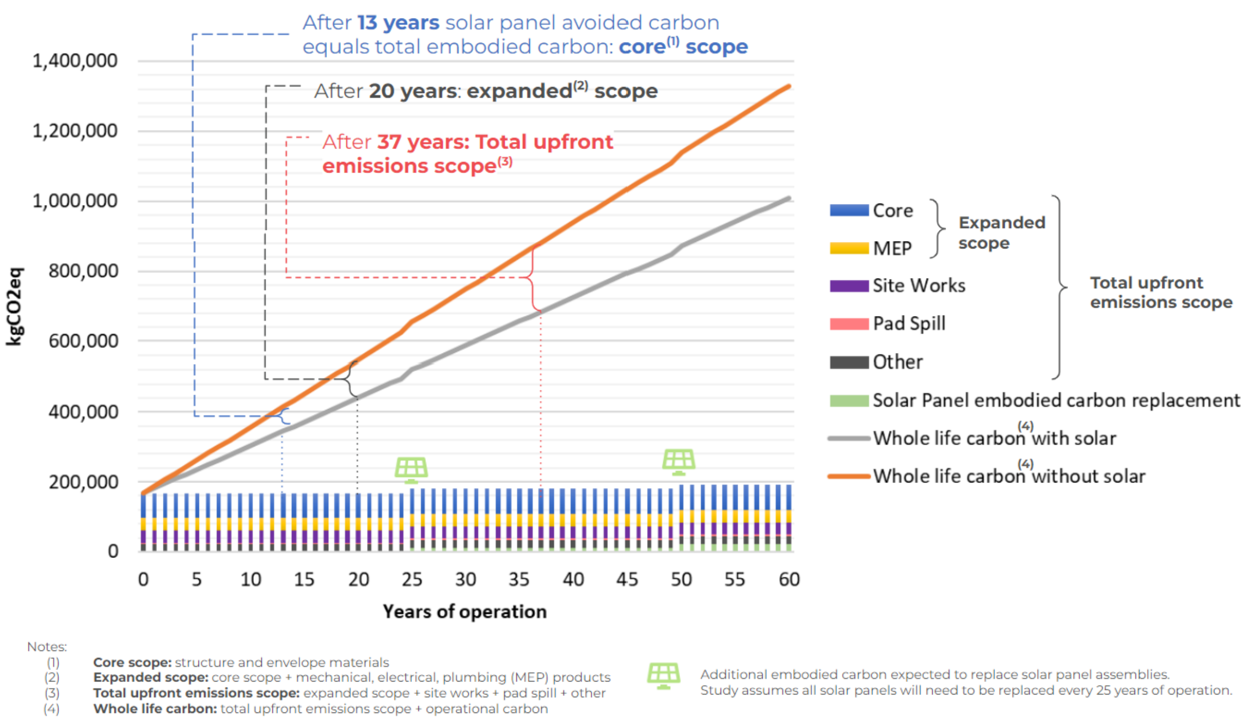


Figure 2: Carbon payback from installed solar panels over the building roof

7. Carbon Offset and Removal Options

7.1. Carbon capture, utilization, and storage (CCUS)

This section of the report addresses potential Arctic carbon offset and removal options. Information presented herein provides a general overview of considerations requiring further investigation to confirm its feasibility. As such, this section provides general guidance in carbon capture, utilization, and storage and illustrates case studies presenting similar climatic conditions currently present in Cambridge Bay. Similarly, an evaluation of Indigenous Clean Energy (ICE) collaboration opportunities and carbon removal options via funding opportunities is also explored.

Carbon emissions ("CO2") can be stored in deep geological formations, copying the natural trapping of oil and gas underground over millions of years. Various reservoirs, including deep saline formations and depleted oil and gas reservoirs, offer substantial CO2 storage capacity.

Global geological analyses suggest abundant CO2 storage capacity, estimated between 8,000 Gt and 55,000 Gt, significantly surpassing the 220 Gt of CO2 storage projected for 2020-2070 in the IEA Sustainable Development Scenario.[26] While most of this capacity is onshore, there is also considerable offshore capacity. However, factors such as land use, public acceptance, and geological considerations will determine the development of CO2 storage sites. As such, the following case studies provide a general overview of potential applications that Cambridge Bay could further evaluate for its implementation.

Case studies

- **Project Orca (Iceland):** A collaboration between Carbfix and Climeworks.[27] This initiative utilizes Direct Air Capture (DAC) technology to extract CO2 directly from the atmosphere. Direct Air Capture offers a unique advantage by offsetting emissions from industries like agriculture, which are challenging to capture using other methods.
- **CCS Project (Norway):** The project involves capturing CO2 from industrial sources in the Oslo region, including the cement plant of HeidelbergCement and the waste-to-energy plant of Fortum Oslo Varme. The captured CO2 is liquefied, pressurized, and transported to an onshore terminal before being piped to a North Sea subsea well for injection into a geological storage complex. Additionally, the Northern Lights CCS Project plans to explore direct air capture using Climeworks' technology to mitigate emissions further.
- **Hellisheidi Geothermal Power Plant (Iceland):** Carbfix has developed a solution called Carbon Capture & Mineralization (CCM).[28] The project captures CO2 at the source and injects it into basalt rock formations. The carbonated water reacts with elements like calcium, magnesium, and iron, forming stable mineral deposits within two years. This process enables the permanent storage of CO2.

[26] International Energy Agency IEA, CCUS in Clean Energy Transition, September 2020, Retrieved March 2024
[27] Climworks, Orca: the first large-scale planet, Retrieved March 2024
[28] Carbfix, Up-scaling Geothermal Operations: Hellisheioi & Nesjavellir, Retrieved March 2024

7.2. Indigenous Clean Energy (ICE) collaboration opportunities

The Canadian Climate Institute produced the 2019 Indigenous Clean Energy Waves of Change Report.[29] The report suggests that Indigenous clean energy initiatives could qualify for carbon offsets or renewable energy credits under specific circumstances. These projects should be mandated to safeguard ancestral Indigenous territories, encompassing sacred areas and crucial ecological habitats vital for traditional practices like sustainable fishing, wildlife preservation, and medicinal plant harvesting.

A key strategy is constructing microgrids that integrate renewable power generation with battery storage and control systems to link with local power plants. This approach takes advantage of cost-effective renewable power generation and storage and digital innovations that simplify the integration of diverse electricity sources. From the perspective of First Nations, Métis, and Inuit communities nationwide, the primary areas for Indigenous leadership and action include:

1. Combining power generation and energy storage.
2. Harnessing the potential of hydropower to enable direct-to-market renewable electricity.
3. Decreasing diesel dependency in remote Indigenous communities.
4. Adjusting electricity demand to an appropriate scale through behavioral change[30] in energy consumption.
5. Actively seeking out renewable power procurement.
6. Implementing clean energy projects at a community level.
7. Backing Indigenous entrepreneurship focused on achieving net-zero emissions.

7.3. Carbon removal options: Funding programs

The Federation of Canadian Municipalities (FCM) recently increased the impact and flexibility of the Green Municipal Fund (GMF). The fund, endowed with $1.65 billion from the Government of Canada, offers funding streams to support low-carbon initiatives:

1. Sustainable Municipal Buildings: Funding for energy-efficient new construction and retrofits of municipal and community buildings.
2. Community Energy Systems: Support for renewable energy solutions aligned with a net-zero future.
3. Municipal Fleet Electrification: Funding to electrify municipal and transit fleets, reducing transportation emissions.
4. Organic Waste to Energy: Support generating renewable energy from organic waste or landfill gas.
5. Local Net-Zero Transformation: Funding for innovative projects with significant greenhouse gas reduction benefits.

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[29] The Canadian Climate Institute, Indigenous Clean Energy Waves of Change Report, 2022

[30] Behavioural change: actions that consumers can take to reduce or eliminate unnecessary or wasteful energy consumption in a building.

The FCM states that First-time indigenous community applicants can receive funding covering 100 percent of their plans, studies, and pilot projects.

8. Future Recommendations

The following recommendations are intended to reduce embodied carbon on future building projects. The recommendations shown in Table 16 consist of three stages. The first is the material stage, which aims to procure low-carbon materials. Second, the transportation stage aims to use low-carbon fuel vehicles and minimize travel distance. The third construction stage aims to electrify site works through machinery and on-site energy and reduce site waste.

Table 16: Low-carbon recommendations for the A1-A3 product stages

Product Assembly Stage (A1-A3)	
1	Develop an end-of-life plan for wood materials. Wood products provide carbon sequestration by storing carbon emissions inside them. However, they must be responsibly sourced from certified sources and should not be burned at end-of-life but rather reused in some long-lived application.
2	Increase the use of bio-based materials. For example, sheep wool can be used for insulation, and bio-based gypsum boards can be used instead of regular products.
3	Increase the use of recycled materials or products with recycled content to reduce virgin material procurement.
4	Compare material alternatives' embodied carbon with environmental product declarations (EPDs). An EPD is a third-party verified document that transparently communicates any product or material's environmental performance or impact over its lifetime. EPDs offer the opportunity to compare alternative products and select lower-carbon alternatives
5	Look for low-embodied carbon solar panels. Solar panels have high embodied emissions through materials extraction, manufacturing, transporting, construction, and end-of-life. Comparing solar panels with high EPDs can help select a lower embodied carbon alternative.

Table 17: Low-carbon recommendations for the A4 transportation stage

Transportation Stage (A4)	
1	Reduce the number of materials that require assembly on-site or in transportation modes with a high carbon intensity. The transportation of wood studs contributed the most carbon emissions due to the number of trucks required to ship the materials.
2	Minimize workers' flights to the site and maximize the incorporation of the local workforce instead of moving the project-skilled workforce and engineers from other provinces. Air travel emissions significantly contributed to the project (17% of the total building emissions: expanded scope).
3	Consider the product's carbon footprint (A1-A3) and transportation (A4) in the procurement stage. In some instances, local materials might not be preferred if they have a high carbon footprint during manufacturing.
4	Move away from fossil fuels-based transportation methods and promote biofuels and electricity-based ones.
5	Conduct a carbon assessment study for different transportation alternatives for flights, roads, ships, railways, etc.

Table 18: Low-carbon recommendations for the A5 construction stage

Construction Stage (A5)	
1	Utilize low-carbon energy for construction site operations. This can be done by using renewable electricity and reducing the need for diesel. Additionally, biofuels are a viable alternative option.
2	Transition from fossil-fuel-based equipment to renewable electrical equipment. Project managers should utilize highly efficient equipment and reduce idling time if obtaining electrical equipment is challenging.
3	Minimize the amount of on-site product waste and non-reusable shipping containers.

9. Key items to track during construction

Lastly, to effectively manage the carbon emissions of a project, high quality and accuracy of data is vital, this section of the report summarizes the required items that need to be tracked during construction to properly conduct a high-quality life cycle assessment of a project in the Arctic and obtain embodied carbon results.

Table 19: Key items to track during construction to perform an LCA in the Arctic

Item no.	Item name	Phase	Reporting
1	Building Materials	A1-A3	Existing materials, additional materials/ replacements. Quantities and descriptions.
2	Other Materials	A1-A3	Materials that are not part of the building but are required for site work
3.	Material Transportation	A4	Place of origin, method of transportation, distance
4.	Site Energy Usage	A5	Electricity, diesel for portable heaters, and propane tanks
5.	Machinery and Equipment	A5	Type, diesel for construction machinery, and hourly usage
6.	Staff	-	Working days and hours
7.	Team Transportation	-	Methods, locations, and distances

10. Conclusion

While net-zero carbon targets are increasingly being referenced in the building industry in southern Canada, there are significant barriers to achieving these same goals in the North. These can be seen in the selection of materials that can be chosen to minimize carbon footprint, affordability, transportation feasibility, and suitability for Arctic winter. Demands imposed from current and projected climate projections, such as dealing with 24-hour daylight environments, climate change resiliency, ease of installation, maintenance repair, and replacement, are prioritized before the embodied carbon lens.

Local contractors and builders emphasize that energy efficiency and low-carbon lenses must be balanced with longevity and ease of replacement and reflect the capacity of the local workforce conducting the work. Cambridge Bay is currently powered by diesel generators, fueling a grid that cannot handle large amounts of renewable energy. Supporting projects in the Arctic financially through increased levels of building efficiency and renewable energy systems will minimize diesel dependency.

This report benchmarks embodied carbon and can provide a target for future energy-efficient buildings in the Arctic to beat. It also brings greater awareness of embodied carbon accounting and management to the Arctic and the Inuit Nunavut community in general across the construction and energy sectors.

We, as Mantle and PI/KHS hope this study helps educate funders, academics, and industry professionals about the realities of low-carbon construction in the North.

APPENDIX A: Kuugalak materials and LCA model selection: expanded scope

Material Name	LCA Model selection	Qty	Unit	GWPi (kgCO_2e/m2)	% of total impact
Studs for ZS2 panels	Softwood lumber, kiln-dried and planed (American Wood Council, Canadian Wood Council)	145.86	m3	249.61	26.14%
Screw Jacks[31]	Various (hollow and hot-rolled structural steel)	1.02	m3	123.5	12.93%
Solar Panel	Photovoltaic monocrystalline panel, per m2, 14.5 kg/m2, 224 Wp (One Click LCA)	30.6	m2	84.23	12.61%
Solar Panel (Racking System)	Galvanized steel mounting systems for photovoltaic panels, 43.3 kg/m2 (Donnee Environnementale Generique Par Defaut)	1413	kg	7.79	
Solar Panel (Battery Pack)	Basic lighting and power system for very small building, standard performance per m2 (196m2)	196	m2	28.38	
EPS Insulation	EPS insulation – USA-based OLC in-house data	106.21	m3	78.17	8.19%
Boiler	Hot water boiler (Johnson Controls Hitachi)	292.57	kg	52.32	5.48%
Heater	Electric air heater (Donnee Environnementale Generique Par Defaut)	73.94	kg	51.89	5.43%
Cementitious siding (ZS2 Panels)	Fibre cement boards (81.16 lbs/ft3)	1.86	m3	23.83	2.50%
Fiberglass Windows	Fiberglass windows (Inline)	0.57	m3	19.34	2.03%
Plumbing	Various (Copper, PEX, PVC pipes)	842.09	m	18.88	1.98%
ZS2 Tech Board	Sandwich panel with EPS core and double cement board siding for walls and roofs (ZS2 Technologies)	16.92	m3	18.68	1.96%
HVAC Ducts	Galvanized steel ventilation duct, rectangular	40.03	m	10.69	1.12%
	Galvanized steel ventilation duct, circular	83.67	kg	5.61	0.59%
Membrane	SBS polymer-modified bitumen membrane roofing, self-adhered (Soprema)	0.76	m3	14.84	1.55%
Steel Doors	Float glass, single pane, generic (156 lbs/ft3)	0.43	m3	14.07	1.47%

31 Steel Screw Jacks used for the foundation have been mapped to the hollow and hot-rolled structural steel. There was no equivalent material for the screw jacks to be mapped to in the software. Therefore, it might be underestimated due to the material mapped didn't account for the manufacturing process from steel to the screw jack product itself.

Underfloor heating system	Underfloor heating system for office area per m2	58.42	m2	13.48	1.41%
Gypsum Board	Gypsum plasterboard, fire resistant (Gypsum Association)	4.18	m3	13.47	1.41%
Pressured Treated Structural Lumber	Softwood lumber, kiln-dried and planed (American Wood Council, Canadian Wood Council)	11.33	m3	11.94	1.25%
Self-Adhesive Vapour Barrier	Self-adhesive air/vapour barrier membrane (Soprema)	0.33	m3	9.55	1.70%
Conduit	Glass wool insulation for pipes, unfaced, per meter (One Click LCA)	110.48	m	9.52	1.00%
Tank	Various (water storage and water tank)	66.81	kg	9.19	0.96%
Tile flooring	Vinyl tile flooring, luxury and solid	0.23	m3	8.07	0.85%
Seam Metal Roofing	Steel roof and floor deck, 22-16 gauge (Steel Deck Institute)	0.45	m3	7.84	0.82%
Wooden Door	Wood door leaf with mineral core (Masonite Architectural)	0.3	m3	7.65	0.80%
Ventilation	Various (air intake and heat recovery)	76	kg	7.52	0.79%
Heating Fixture	Various (horizontal and vertical radiant panels)	8	unit	7.27	0.76%
Epoxy Flooring Adhesive	Epoxy flooring adhesive	0.1	m3	6.82	0.71%
Domestic Water Heater	Electric water heater (water cylinder) (Sofath)	35.38	kg	3.63	0.38%
Structural Lumber	Softwood lumber, kiln-dried and planed (American Wood Council, Canadian Wood Council)	3.58	m3	3.6	0.38%
HVAC Heater	Electric heating coil (Donnee Environnementale Generique Par Defaut)	7.67	kg	3.35	0.35%
Decking	Planned redwood decking (One Click LCA)	2.51	m3	3.17	0.33%
Plumbing Fixture	Various (bathroom and kitchen sink, toilet)	81.51	kg	2.58	0.27%
Railings	Aluminium handrails, 7.38 kg/m (Construction Specialties (CS))	0.06	m3	2.37	0.25%
Aluminum Flashing	Anodized aluminum extrusions (Aluminum Extruders Council (AEC))	0.01	m3	2.35	0.25%
Lighting Fixtures	Various (Battery, emergency light, sensor)	15.81	kg	2.24	0.23%

Glazed Door Windows	Float glass, single pane, generic	0.02	m3	2.17	0.23%
MEP Insulation	Glass wool insulation for pipes, 50% recycled glass content (One Click LCA)	40.7	m	2.16	0.23%
Plywood	Softwood lumber, kiln-dried and planed (American Wood Council, Canadian Wood Council)	1.89	m3	1.99	0.21%
Acoustic Insulation	Acoustic rock wool insulation, fire resistant (Rockwool North America)	1.52	m3	1.14	0.12%
Waterproofing Membrane	Waterproofing sealants, 7.68 kg/m2, rapidguardtm Cartridge, rapidguardtm Sausage (Sto)	0.04	m3	0.91	0.10%
Vapour Barrier	Polyethylene vapour barrier membrane, 0.15 mm, 0.14 kg/m2 (One Click LCA)	0.02	m3	0.91	0.10%
Pump	Various (circulating and water pump)	12.44	kg	0.51	0.05%
Receptacles	Outlet cover for sockets and switches, 0.0163 kg/unit (One Click LCA)	3.77	kg	0.45	0.05%
Security Fixtures	Outdoor camera, motion activated, 1.764 kg/unit (Legrand)	4.8	kg	0.44	0.05%
Fire Extinguisher Fixture	ABC powder for fire extinguisher (One Click LCA)	4.8	kg	0.14	0.01%
			TOTAL	**954.91 kgCO2e / m2**	**100%**

APPENDIX B: Operational Emissions

Annual Operational Energy & Carbon for Kuugalak building

	Fuel Load Distribution (kWh)		Description
	Base Case	Actual Case	
Electricity Grid	16,679	12,744.90	Carbon Factor[32] 0.840 kgCO2/kWh
Fuel - Diesel	71,574	32,706	Carbon Factor[33] 0.253 kgCO2/kWh
Total Energy	54,895	45,451	in kWh
CO_2e (Tonne)	32.1	18.98	Net equivalent mass of carbon dioxide emission

[32] The Government of Canada, Emission Factors and Reference Values - Retrieved March 1, 2024

[33] The Government of Canada, Provincial and Territorial Energy Profiles - Retrieved March 1, 2024

Renewable Source Generated Energy (kWh)

	Base Case	Actual Case	Description
Solar (kWh)	0	6,717	On-site electricity generation by 18 solar panel
CO_2e (Tonne)	0	5.34	Net equivalent saving mass of CO_2e

Net total carbon emissions

	Base Case	Actual Case	Description
Total (kWh)	88,253.30	45,450.90	Annual Net Total Energy in Fuels Consumption
EUI (kWh/m2)	795.07	409.46	Annual Energy Use Intensity
CO_2e (Tonne)	32.1	13.6	Net equivalent mass of CO_2e