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Environmental Impact Study of a Modular Building Kit Destined for Export



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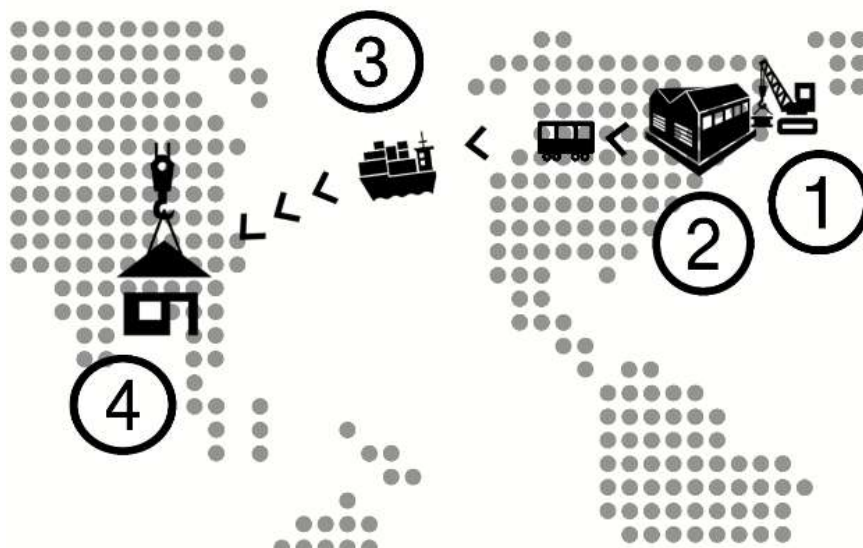
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EXECUTIVE SUMMARY

This report presents the results of an analysis of greenhouse gas (GHG) emissions generated by a modular building kit for prefabricated wooden structures. Manufactured in Quebec by American Structures Inc., the kits are then assembled in Dalian, China. The goal of this study is to complete an analysis of the prefabricated system using a “cradle-to-gate” approach; from the extraction of the raw materials to the construction itself, including the impact of international transport and assembly.

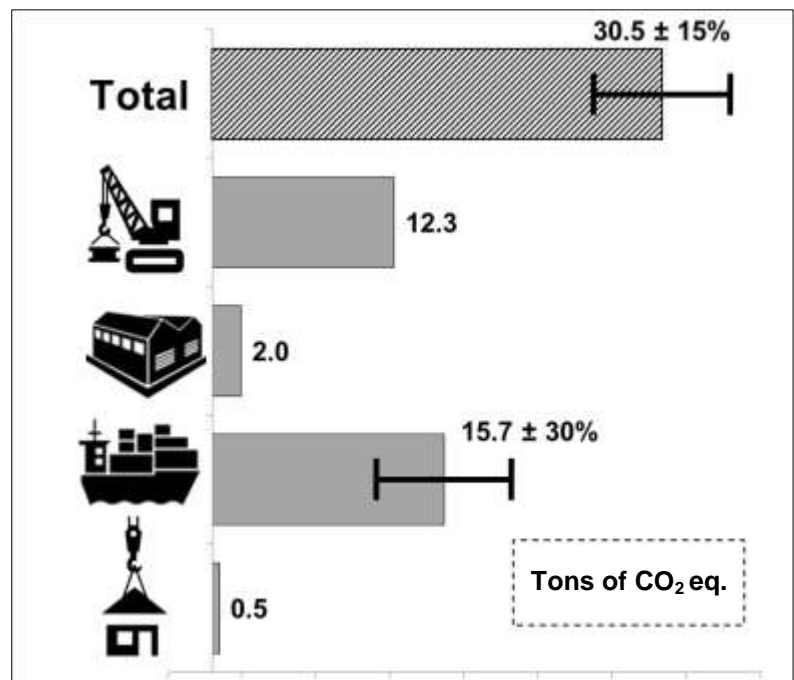
The object of the study is a four-bedroom, single-family home with a surface area of 240 m² (2580 ft²). The structure is designed to account for the significant seismic activity in the Dalian region.



The life phases under examination are:

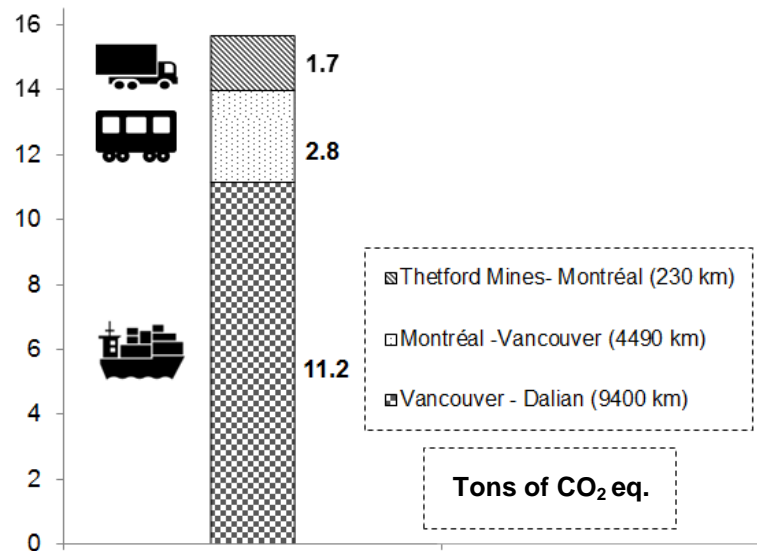
- (1) the extraction of raw materials and the production of the building materials,
- (2) manufacturing,
- (3) transportation of the construction kit and
- (4) the assembly of the kit.

The results of the GHG emissions inventory are as follows:

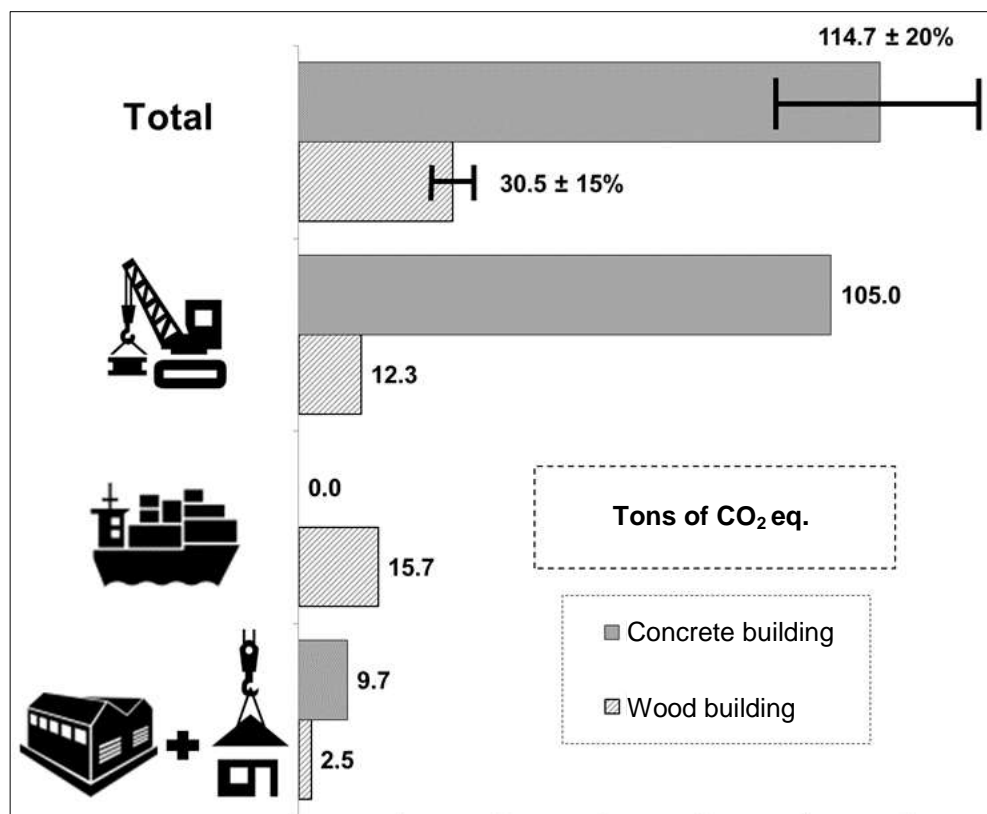


The emissions that result from the transportation of the prefabricated modules account for a substantial portion of the total GHG emissions (51%). Other significant sources of emissions are a result of the extraction of the raw materials and the production of the kits (40%).

The breakdown of the emissions that result from the transportation of the modules is the following:



In order to put the environmental impacts of the prefabricated building into perspective, a comparative GHG analysis of the modular kit was prepared; the GHG emissions of the prefabricated structure were compared to those of an equivalent concrete structure with identical structural and energy performance:



It is important to note that the framing was oversized in order to account for the high seismic activity in the Dalian area. When compared to an area without seismic activity, the oversizing adds 35% GHG emissions in the case of a concrete building, and only 1% additional emissions in the case of a wood building. This is due to the lighter weight and the inherently lower material inputs in wood frame construction.

Despite the fact that the transportation of the prefabricated modules adds an important share to the GHG emissions of the modular kit, this option remains a viable option from an environmental standpoint. In fact, even if built directly on site, **an equivalent concrete structure would generate close to four times the amount of GHG emissions** as compared to the prefabricated modular system – and this amount includes the transportation from the factory in Thetford Mines, Quebec to the building site.

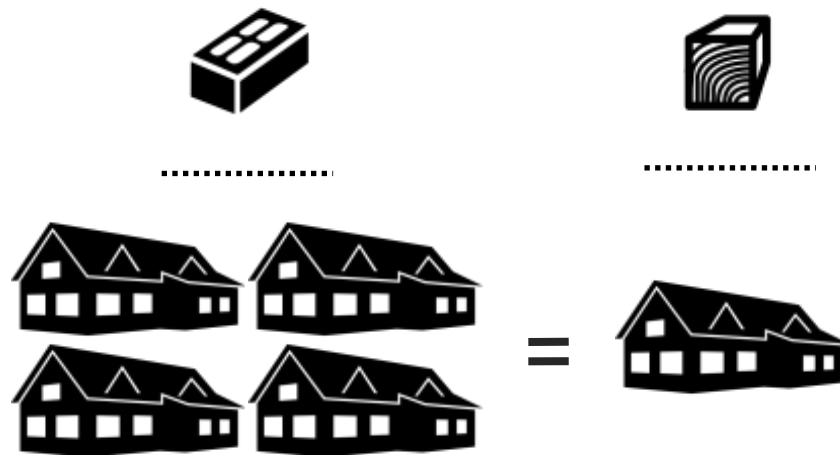


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1. INTRODUCTION

Building industry professionals are constantly reconsidering their options: the design parameters are numerous and there is a vast range of technical solutions. Reducing the carbon footprint of the industry is yet another challenge: how to minimize the environmental impact of construction while striving to improve techniques that can yield increasingly durable, comfortable and economically viable buildings?

Operating within this context, American Structures Inc. specializes in the design and construction of prefabricated floor joists, trusses, walls, roofs and floors. Based in Thetford Mines, Quebec, the company has recently diversified its target market by exporting its expertise in prefabricated construction to clients internationally, most notably in China. The Chinese government affirms a strong desire to support the emergence of new building methods, particularly wood-based building techniques, for which Canada is internationally renowned.

In an effort to document the environmental impact of wooden structures when compared to other building techniques, the Quebec Wood Export Bureau (QWEB) mandated Écohabitation, a multidisciplinary specialist in the field of sustainable building, to produce a life cycle analysis of prefabricated buildings made from wood sourced in Quebec.

This report presents the analysis of the greenhouse gas emissions (GHG) of a sample product made by American Structures according to a “cradle-to-gate” approach: from the extraction of the raw materials right up to the assembly, including the international transport of the kit to its destination. Because a study requires a reference point in order to provide a comparison, this report also includes a comparative analysis of the GHG emissions of a wood structure to that of an equivalent building built with a concrete structure. The structural and energy performance of the two analyzed buildings are identical.

2. GREENHOUSE GAS EMISSION ANALYSIS OF THE PREFABRICATED BUILDING

2.1.GENERAL INFORMATION AND SCOPE OF THE STUDY

2.1.1. PRODUCT ANALYZED: MODULAR BUILDING KIT

The subject of the analysis is a 240 m² (2580 ft²), single family home with 4 bedrooms – 2 on the ground floor and 2 on the upper level. Based on an average usage pattern, this house should be able to accommodate 5 people over a minimum lifespan of 50 years. The house is built according to the projected dimensions noted on the building plans of the B-2 Type Villa (number 11-196, 17 May 2011), provided by Prefab Solutions Inc.

This modular building kit is prefabricated at the American Structures factory located in Thetford Mines, Quebec, Canada. The components of the house are then shipped to its construction site in Dalian, China. It is estimated that these kits will travel 9 400 km by boat, 4 490 km by train and 230 km by truck before arriving at the final location of assembly. The foundation walls, the foundation itself and the interior finishing materials are provided locally and therefore are not included in the study.

It is worthy of noting that Dalian is located in a zone of high seismic activity. This was taken into consideration in the study, in order to account for the additional materials that are required in the building design to enable earthquake resistance up to 7.5 on the Richter scale.



Here is a summary of the components of the prefabricated building that was analyzed:

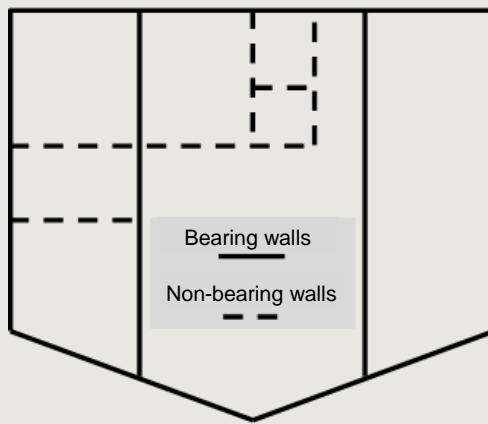
Component: Exterior Walls				
Orientation of the wall	South	North	East	West
Surface are of the wall	81 m ² (866 sq ft)	84 m ² (909 sq ft)	27 m ² (287 sq ft)	27 m ² (287 sq ft)
Detail of the wall assembly	Torrefied wood pine exterior cladding 25 x 76 mm (1 x 3") furring Air barrier membrane Oriented strand panels (OSB) 11 mm (7/16") 51 x 152 mm (2 x 6") studs at 406 mm (16") Fiberglass batting insulation 152 mm (6") RSI 3.52 (R-20) Polyethylene 6 mil 25 x 76 mm (1 x 3") furring 12.7 mm (1/2") plasterboard panels			

Component: Doors and windows (41% of surface)				
Orientation of the wall	South	North	East	West
Surface area of doors	-	1x 1.7 m ² (1x 18.7 sqft)	-	-
Surface area of windows	47 m ² (503 sq ft)	35 m ² (376 sq ft)	8.5 m ² (92 sq ft)	1.5 m ² (16 sq ft)
Window details	PVC framed, double-paned windows, LowE and argon gas			

Component: Floors	
Surface area of floors	60 m ² (643 sq ft)
Detail of the typical assembly	15.5 mm (5/8") plywood 355.6 mm (14") open web floor joists at 406 mm (16") 12.7 mm (1/2") plasterboard

Component: Roof	
Surface area of the roof	297 m ² (3192 pi ²)
Detail of the typical assembly	Asphalt shingle exterior roofing 15.5 mm (5/8") plywood 279 mm (11") fiberglass batt insulation - RSI of 7.04 (R-40) 762 mm (2' 6") open web roof joists at 610 mm (24") 12.7 mm (1/2") plasterboard

Component: Interior walls	
Load-bearing walls	
Surface area	255 m ² (2745 sq ft)
Doors	3 x 1.7 m ² (3 x 18.7 sq ft)
Assembly details	
Oriented strand board panels (OSB) 11 mm (7/16")	
51 x 152 mm (2 x 6") studs at 406 mm (16")	
12.7 mm (1/2") plasterboard	
Non-load bearing walls	
Surface area	130 m ² (1400 sq ft)
Doors	9 x 1.7 m ² (9 x 18.7 sq ft)
Assembly details	
12.7 mm (1/2") plasterboard	
51 x 92 mm (2 x 4") studs at 406 mm (16")	
12.7 mm (1/2") plasterboard	



2.1.1. FUNCTIONAL UNIT OF THE ANALYSIS

For the purposes of the *comparative study*, the unit of comparison between the various construction techniques must be fixed/standardized. The structures analyzed must be buildings able to host an average of 5 people according to the average usage conditions, to withstand the seismic activity experienced in Dalian (China), have an estimated energy consumption of 27 068 kWh of electricity and to have a minimal lifespan of 50 years.

2.1.1. DETAILS OF THE ANALYSIS AND CALCULATION METHODOLOGY

This life-cycle analysis was done using Impact Estimator for Buildings, version 5.0 software, developed by the Athena Sustainable Materials Institute. The evaluation methodology for calculating the environmental impacts of the product is based on ISO 14040:2006 and ISO 14044:2006 which are internationally recognized standards.

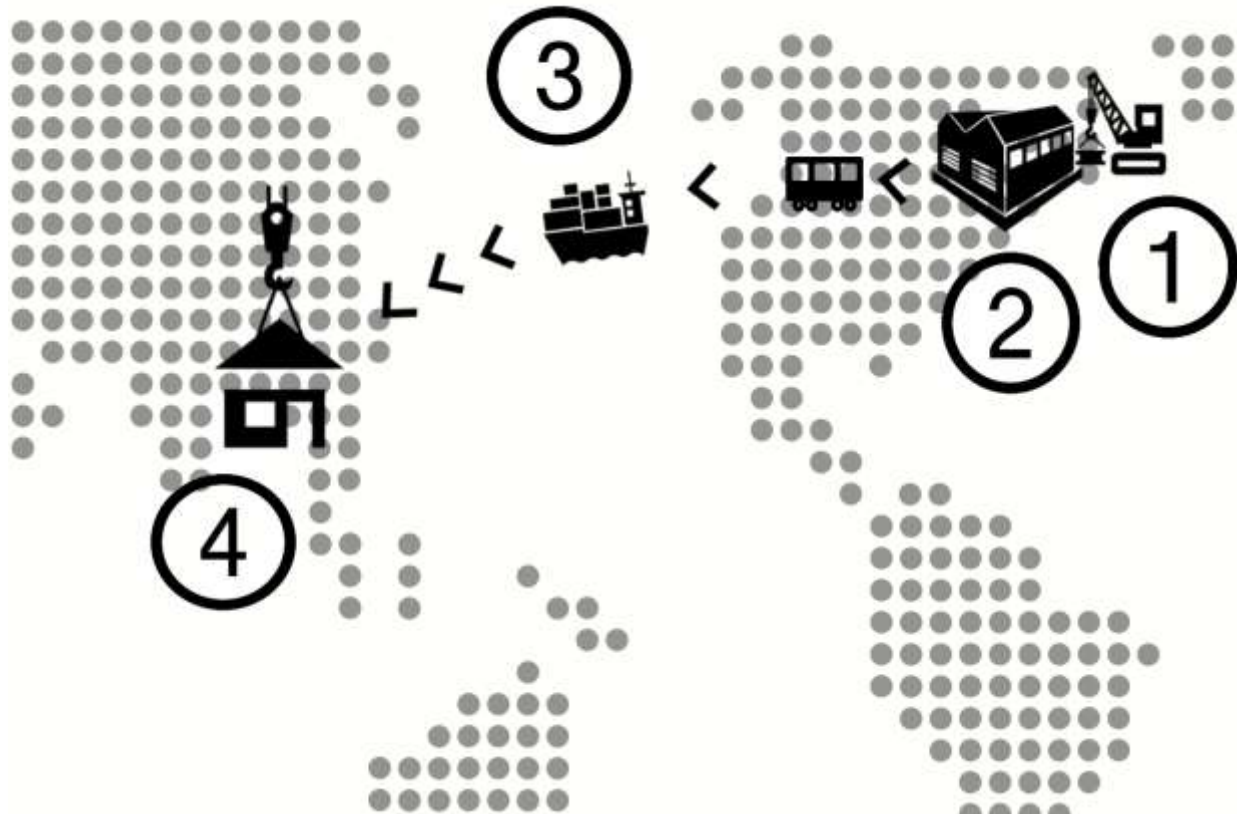
This report focuses primarily on the product's life cycle impact with regards to climate change, that is to say the assessment of the greenhouse gas (GHG) emissions. In addition to carbon dioxide CO₂, nine primary GHGs were studied and their contribution to climate change was brought down to CO₂ equivalents: methane (CH₄), nitrous oxide (N₂O), CFC-11, CFC-12, HCFC-22, HCFC-141b, HCFC-142b, HFC-134a and sulfur hexafluoride (SF₆).

In view of the goal of the study and the nature of the product under scrutiny (which is destined for export), the approach undertaken is the cradle-to-gate, meaning that the analysis ends after the assembly of the construction kit and before the use of the product.

2.1.BOUNDARIES OF THE SYSTEM

2.1.1. LIFE CYCLE OF THE BUILDING

From the extraction of the raw materials to the final construction, the inventory of the life cycle covers the following phases:



①

Extraction of raw materials and production of the materials

This phase includes the extraction of the raw materials as well as the production of the construction materials. The phase of extraction of the raw materials includes activities such as reforestation or restoration of certain materials. The production phase is generally the step that uses the most energy and has the highest environmental impact. This phase begins with the transport of the raw materials to the factory and ends at the factory, after processing when the product is ready to be shipped.

②

Manufacturing

This phase includes the transport of various products, as well as the production of the prefabricated modules at the Thetford Mines factory. The transportation phase includes shipping the products from their production factories to the distributors, as well as from the distributors to Thetford Mines. This step includes the use of shop tools and machines, their energy consumption, waste management as well as the heating and ventilation of the shop during production.

3**Transportation of the construction kit**

This phase includes all the transport needed for the prefabricated modules to reach their destination: from the shop in Thetford-Mines in Québec to the construction site in Dalian, China.

4**Assembly and construction**

This phase includes equipment necessary for the on-site assembly of the prefabricated modules, waste management on site as well as the finishing and adjustments made on site.

2.1.2. NOT WITHIN THE SCOPE OF THE STUDY

The analyzed product is a prefabricated modular building intended for export. For this type of product, the cradle-to-gate approach is better suited, due to the significant uncertainty surrounding the life cycle phases of the product upon which the manufacturer has no direct control. The justification for excluded items is as follows:

- Foundation and foundation walls: while the environmental impacts of foundations are significant (abundant use of concrete and insulating materials that contain blowing agents), they are not part of the analyzed product since they are entirely built on site before the manufactured components arrive. American Structures provides recommendations for the foundations and supervises the work site. However there remains much uncertainty with regards to their environmental impact due to the lack of information about the source of the materials used at each building site as well as the dimensions of foundations, which may vary from site to site, depending on their geological conditions. For these reasons and in order to simplify the study's results, these components are excluded from the scope of the analysis.
- Finishing materials: Most interior finishing materials are not delivered with American Structures' modular building kit. As well, these materials can vary greatly, depending on the choices made by the eventual occupants of the house and the building site. This study focuses on the structure of the building, so other than the plaster, the finishing materials have been excluded from the scope of the study (coatings, paint, flooring materials, kitchen and bathroom furnishings etc.)
- Occupancy: The service life is responsible for the majority of the environmental impact of the building over its life cycle. This includes the usage, the maintenance, and replacement of the building systems. It also includes the impacts of providing energy and water to the occupants of the building. However, even if the design choices have an important impact on the service life, the impacts are in a large part determined by the consumption of the occupants depending on their varying habits. This phase is therefore excluded from the study, but a cursory estimation is provided in the *Energy Efficiency Analysis*.
- End of life: the end of life phase includes the deconstruction or demolition of the building, the transportation of the waste materials to the location where they are to be treated, the treatment of the materials themselves as well as their disposal at the end of life. This phase is excluded, as it depends on the disposal techniques applied by the contractor responsible for the end of life phase.

2.2. QUALITY OF DATA

The ideal situation would be to be able to very precisely quantify the real characteristics of the assembly kit and to be able to deduct the exact amount of associated GHG emissions. However, certain limits to the precision of the data collection exist within the context of this study.

The quantities of materials were extracted from the information and plans provided by American Structures. For each construction component, the dimensions of the assemblies were analyzed according to their composition and structural capacity. Standard quantities of materials were assigned to each type of assembly. Thus, it is possible that the real quantities of materials used in the shop differ from the standard amounts of materials (finishing details, design of window and door frames, labor etc.) In order to guarantee the most precision possible, the results of the list of materials (App. 7.1) were counter-verified with American Structures Inc.'s order forms.

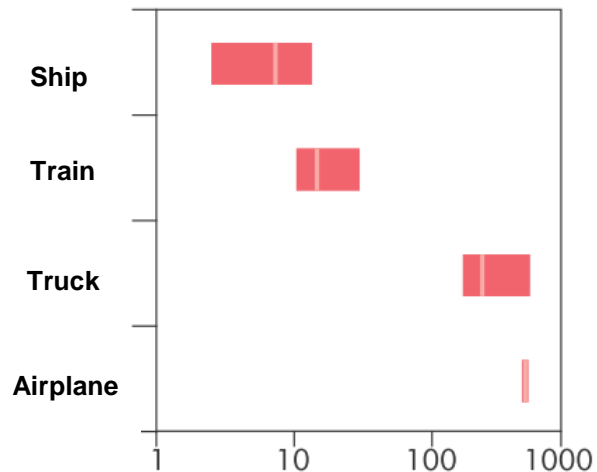
The database used for the characterization of the mid-point impacts of the surveyed materials is TRACI, developed by the American EPA. This database is the reference standard in North America for life cycle analyses. Version 2.1 was used, which came out in 2012. Some of the allocation factors for the major GHG emissions contributing to global climate change were updated with the most recent data communicated by the IPCC in June 2014.

Finally, with regards to the shipping of the assembly kit, other assumptions were made concerning the distances traveled and the impact of the transport types. First, the distance traveled by the assembly kit is based on estimates that take into account the shortest path to the destination. For example, 230 km is the distance that separates Thetford-Mines from Montreal by road, but it's certainly possible that the assembly would travel a less direct route to the Port of Montreal. The same uncertainty applies to the distance traveled by train or boat: a detour while en route would allow the train or boat to unload or load up before getting back on track to its destination.

The allocation of the GHG emissions resulting from transportation was established based on emission factors laid out by the GHJG Protocol and the US EPA. Their information is identical and is summarized in the below table:

<i>GHG emissions by transport mode (gCO₂ eq./ton-km)</i>	
Truck	185
Train	16
Boat	30

These values were compared to those from the IAE (International Energy Agency). In the graph to the right, the pale line represents the world average by transport mode, while the bar demonstrates the variation that can exist. With regards to the average value for train and truck transport, it comes close to the EPA value. However, the impact of transport by boat seems much less significant, with an average value of 9 g CO₂ eq. versus 30 g CO₂ eq.

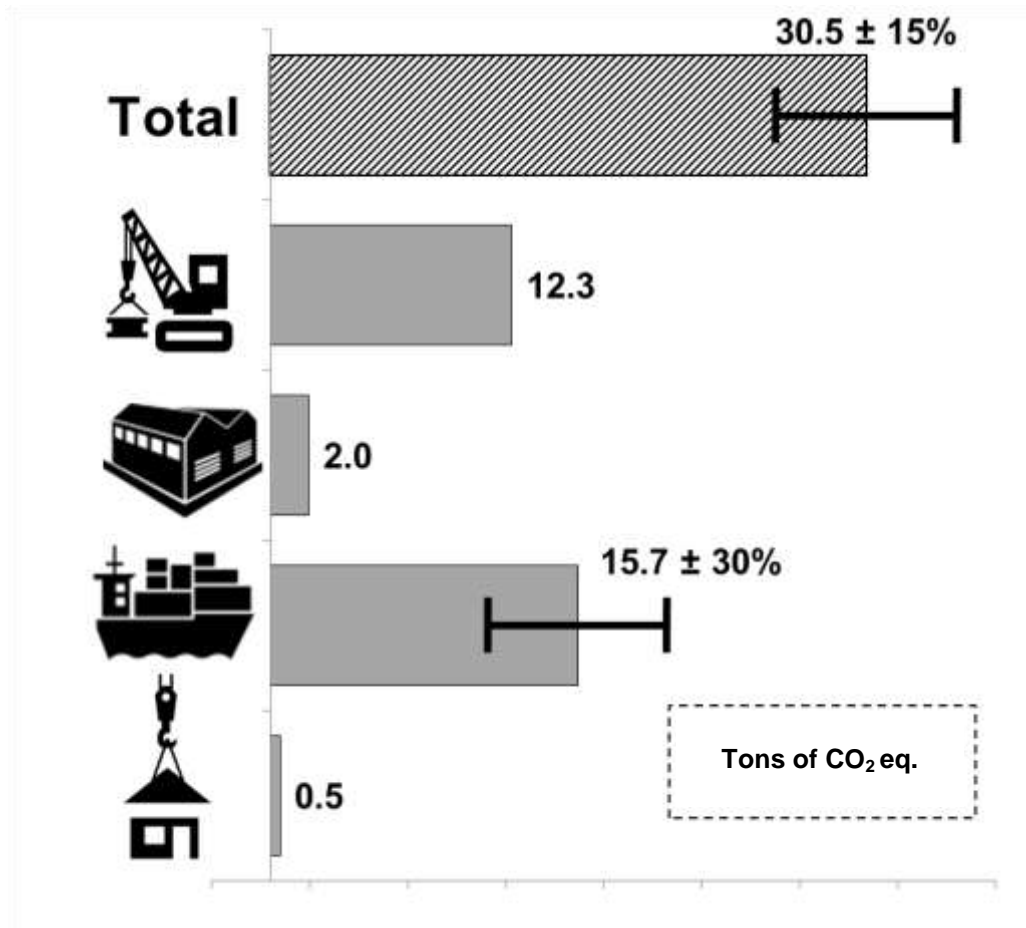


Thus, even if we use the values offered by the GHG Protocol for the needs of our analysis, it appears that they correspond to an average, even unfavorable scenario. According to the calculation results, the margin of error for the emissions linked to transport is estimated at 30%.

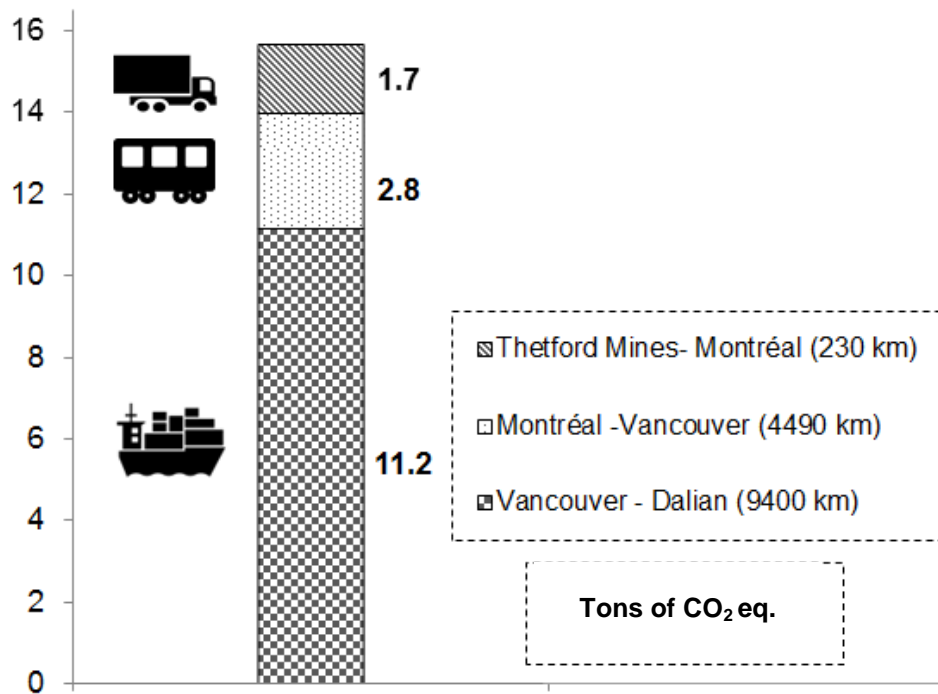
2.1.RESULTS OF THE GHG EMISSIONS INVENTORY

The complete list of materials by analyzed unit is detailed in Appendix 7.1.

The total inventory of the greenhouse gas emissions for the analyzed product is summarized in the following figure:



The following graph details the GHG emissions generated by the transportation of the modular construction kit:



The majority of the GHG emissions for this type of construction occur at the extraction of the raw materials and the production of the construction materials. This phase represents 40% of the GHG emissions of the analyzed product, while the manufacturing and assembly phases have a much more moderate impact (7% and 2% respectively of the total GHG emissions).

These emissions are low which is mostly due to the use of a wooden structure with a small environmental impact, as well as the use of Quebec's abundant hydro-sourced electricity, which is relatively low in carbon emissions (see ref.).

The most important share of the total GHG emissions of the analyzed product is the transportation from the place of manufacturing to Dalian, accounting for a total of 51% of GHG emissions of the product.

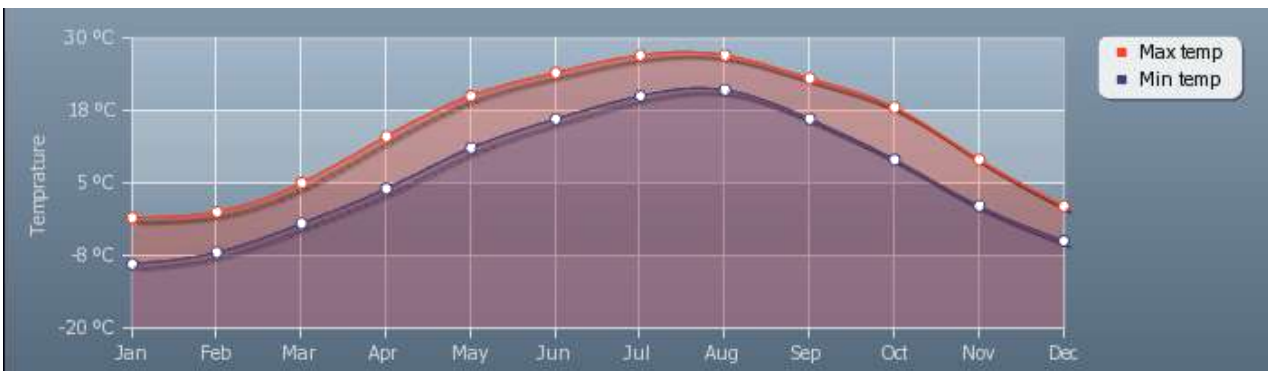
Among the GHG emissions from transportation, those related to maritime transport are the largest, due to the large distance traveled (71% of the transport-related GHG emissions are from marine transport).

3. ENERGY EFFICIENCY ANALYSIS

In order to be able to compare the building detailed above to an equivalent, fictional building, built using different techniques, it is necessary to analyze its energy performance to be able to ensure that the two buildings will operate with identical energy efficiency.

This analysis was completed through REM/Rate software, an American product used for residential energy ratings (used for Energy Star and LEED® for Homes programs). The details of the analysis can be found in Appendix 7.4 of this report.

The city of Dalian is located in a heating dominated climate zone. Over the past three years, the average degree-days were 3108 HDD (of heating at 18°C) and 730 CDD (of cooling at 18°C). The graph below illustrates the variations in temperature that occurred in 2013 in the city of Dalian. (World Weather and Climate Information, 2013):



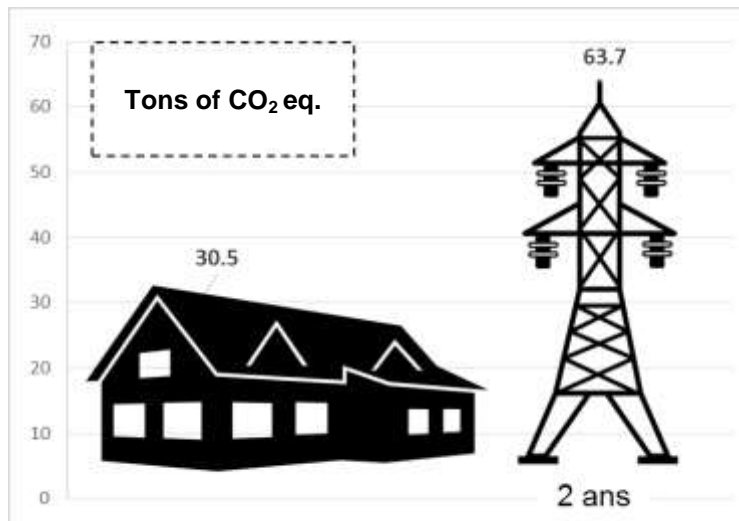
The climate data used for the purposes for the energy study is the set for the city of Beijing, the city with the closest climatic averages, given the available data.

Taking into account the foundation insulation recommended on the plans, the detailed assemblies of the envelope noted on the previous page, an electric air-to-air heat pump system to ensure good heating and cooling, as well as an electric hot water heater for the heating of domestic hot water: the overall energy consumption of the building is estimated at 27 068 kWh/year. (Appendix 7.3).

It is important to note that a significant portion of the environmental impacts over the life cycle of the building are linked to its service life. Even though these impacts are not included in the cradle to gate approach, it is interesting to be able to quantify them in order to put them in perspective. To do so, we are interested solely in the energy consumption of the building, which is by far the most polluting portion of the service life. The intensity of GHG emissions from the consumption of electricity (heating and cooling with a heat pump) is estimated at 1.177 kg of CO₂ eq./electric kWh (GHG Protocol, 2014)¹.

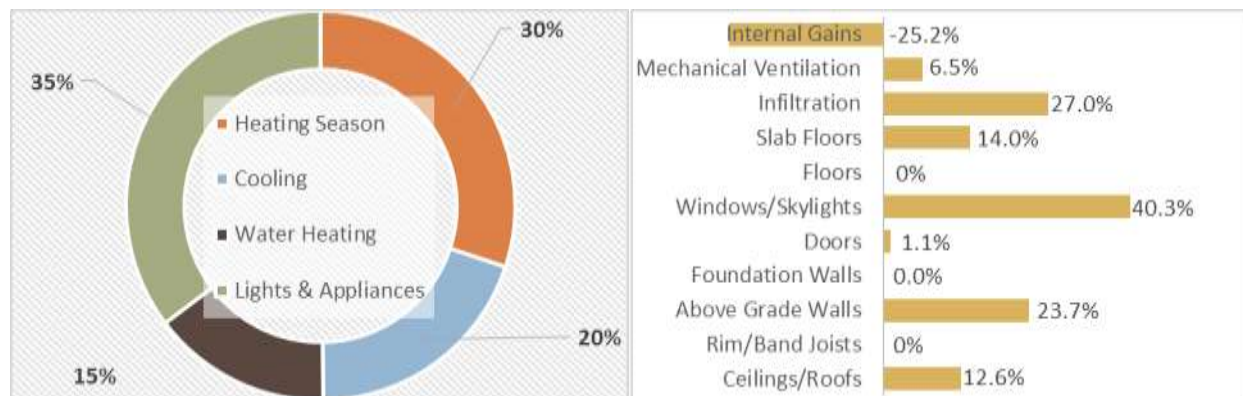
¹ The intensity of GHG emissions in Dalian is primarily due to the use of electricity that comes from coal-fired plants. Put in perspective: the GHG emission intensity of Quebec-produced electricity is estimated at

The following figure demonstrates a comparison between the calculated impacts of the construction of the modular kit, as compared to those during the 2 years of service life (solely electric consumption):



We notice that the GHG emissions linked to the use of electricity are very significant: each year, they are approximately equivalent to the total to the GHG emissions that resulted from the construction and transportation of the prefabricated modular building.

The breakdown of the estimated energy consumption and losses are detailed on the following graph:



The building's heating needs are estimated at 65 kWh/m²-yr, while cooling needs are estimated at 42 kWh/m²-yr and the total energy needs at 215 kWh/m²-yr.

0.002 and 0.008 kg of CO₂_{éq.} /kWh, thanks to the use of hydroelectric source of electricity (Statistics Canada, 2011).

4. COMPARATIVE ANALYSIS WITH A CONCRETE BUILDING

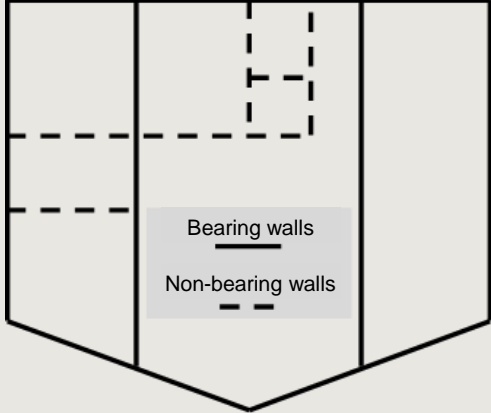
4.1.PRODUCT ANALYZED FOR THE COMPARATIVE ANALYSIS

In order to compare the environmental impacts of the prefabricated house from Quebec, a reference house composed from materials widely used in China must be analyzed. It is estimated that the comparative base would correspond to a building with a concrete structure with identical architecture, the same seismic performances as well as the same energy efficiency.

This fictitious house, for the purposes of comparison, is entirely built on site in Dalian and its exterior walls, columns as well as the floor are all concrete:

<i>Component:</i> Exterior walls	
Detail of the wall assembly	Torrefied wood pine exterior cladding 25 x 76 mm (1 x 3") furring Air barrier membrane 88 mm (3.5") rigid foam insulation – expanded polystyrene (EPS Type 2) 203 mm (8") concrete walls of 4000 psi 25 x 76 mm (1 x 3") furring 12.7 mm (1/2") plasterboard

<i>Component:</i> Floors	
Detail of the floor assembly	Floating concrete slab of 4000 psi 12.7 mm (1/2") plasterboard

<i>Component:</i> Interior walls	
Assembly details: load bearing walls	
Concrete blocks with #5 steel reinforcement 25 x 76 mm (1 x 3") furring 12.7 mm (1/2") plasterboard	
Assembly details: non-load bearing walls	
12.7 mm (1/2") plasterboard 51 x 92 mm (2 x 4") studs at 406 mm (16") 12.7 mm (1/2") plasterboard	

4.1.QUALITY OF THE DATA

There are a number of calculation uncertainties with regards to the hypothetical concrete building used as a reference. First, the construction techniques are assumptions and there could be variants. Other possibilities could be the replacement of the concrete structure with insulated concrete forms, the use of other insulation types (extruded polystyrene for example) or a steel structure. However, after a thorough review of the available information on the matter and given the location of the work site, the technique retained was deemed to be the most “conventional”.

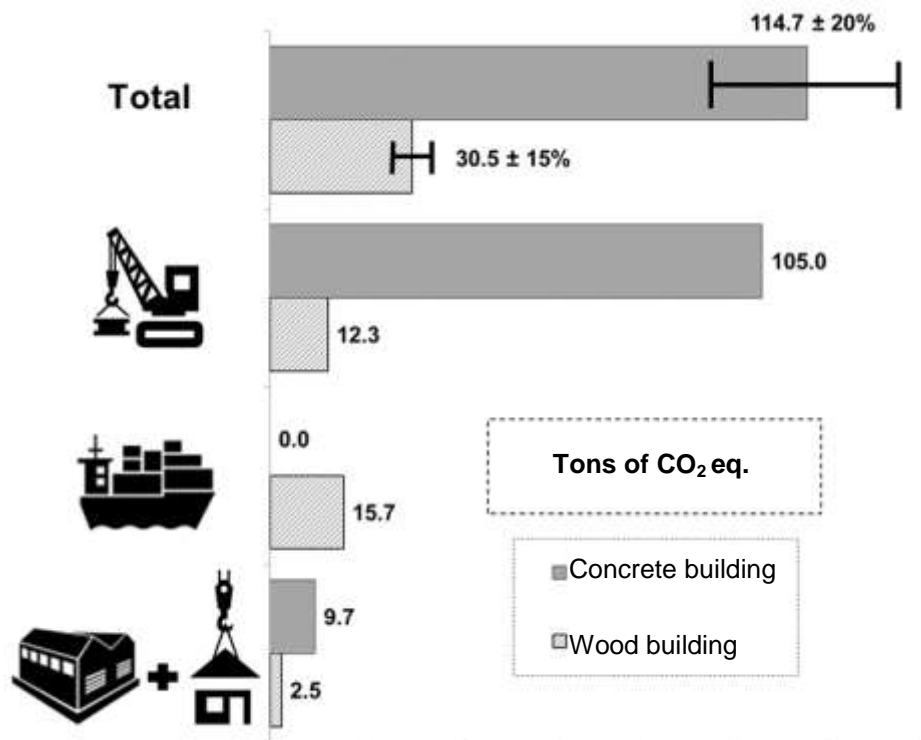
There are also uncertainties with regards to the environmental impacts of the materials most commonly used on work sites in Dalian. Indeed, their origin and composition is uncertain such that this report analyzes the most *probable* impacts, as determined by the generic North American data available in the TRACI database and adapted to the Chinese context. However, the precautionary principle has guided all hypotheses and weightings upon which this analysis relies, such that the results offer the most probable situation possible and the hypotheses do not skew the results of the comparative analysis.

Furthermore, it was no easy feat to find precise GHG emission factors for the Chinese context; we based our work on the figures available from the GHG Protocol’s database and the factors of potential climate change (21 for CH₄, 310 for N₂O) in order to establish the intensity of GHG emissions that result from electricity use within the Liaoning province in Dalian. This intensity was calculated at 1.177 kg CO₂ eq. / kWh of electricity. This value was used to adjust the hypotheses of our calculations.

4.1.RESULTS OF THE COMPARATIVE ANALYSIS

The complete list of materials by unit of analysis is detailed in *Appendix 7.2*.

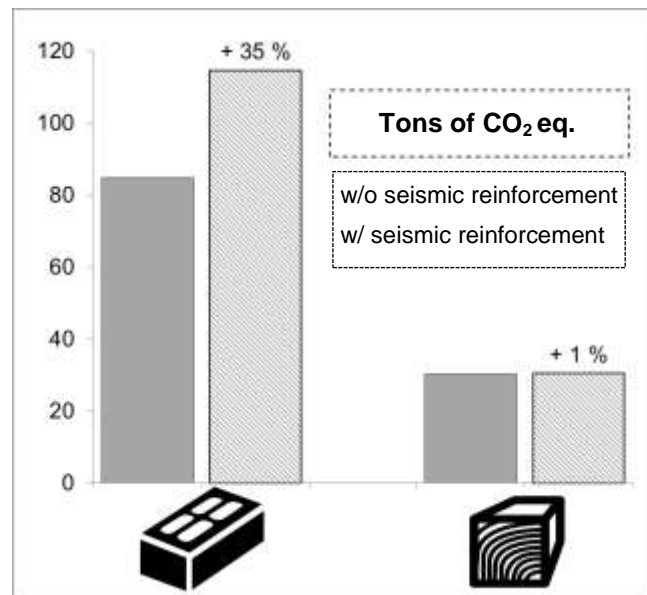
The total inventory of the greenhouse gas emissions of the analyzed product is summarized in the figure as follows:



The emissions that result from the use of concrete are much more substantial than those resulting from the use of wood. This is in great part due to the main ingredient of concrete, the Portland cement, which is one of the primary contributors to global climate change (roughly 800 to 1 000 kg of CO₂ equivalents are generated for each ton of cement). Furthermore, the use of concrete as a structural material means a reduced adaptability of the structure when compared with those built of wood and therefore calls upon higher material inputs in order to bolster structural performance. Petroleum-based rigid insulation is generally what is found on concrete structures.

Furthermore, the seismic activity of Dalian calls for oversized structural elements, which further compounds the GHG emissions generated from the use of steel and concrete when compared to equivalent wooden frames.

The additional GHG emissions are summarized in the following graph:



The oversized structural components generate higher GHG emissions in the case of concrete (+ 35%) than in the case of wood (1%). This can be explained by the fact that wooden structures have much lower mass than concrete structures, lowering the dynamic forces transferred to the wood frame in the event of an earthquake.

The low environmental impact of wood is in a large part due to the fact that it is considered virtually carbon neutral over its life cycle (when one excludes the impacts that are the outcome of the industry itself). Indeed, trees absorb CO₂ for their growth, essentially sequestering carbon thanks to the process of photosynthesis until they release this carbon through decomposition at the end of their life cycle. It is estimated that close to 900 kg of CO₂ equivalents are sequestered for each m³ of wood.

Thus, despite the fact that the transport of prefabricated modules boosts the GHG emissions of the modular construction kit, opting for a building made of wood will minimize its environmental impact. In fact, even if built on-site, an equivalent concrete structure would generate close to 4 times the GHG emissions of the prefabricated modular structure, including its transport from Thetford Mines to China.

5. CONCLUSIONS AND NOTEWORTHY FACTS

- For this type of building, the majority of the GHG emissions result from the extraction of raw materials and the production of construction materials. This phase represents 40% of the GHG emissions of the analyzed product, while the manufacturing and assembly phases have a significantly more modest impact (7% and 2% respectively of the total GHG emissions).
- The most substantial part of the total GHG emissions of the analyzed product come from shipping between where it is manufactured in Thetford Mines (Quebec, Canada) to Dalian (China) where it is assembled. Transportation is responsible for 51% of the total GHG emissions of the product.
- It is interesting to note that the service life, which was excluded from the scope of this “cradle-to-gate” analysis, would represent a large portion of the impact if we would pursue a “cradle-to-grave” analysis. In the city of Dalian in the Liaoning province, the annual electric consumption of the occupants generate nearly the same amount of GHG emissions as those generated by the building itself.
- The seismic activity in the Dalian area calls for oversized structural elements, which further compounds the GHG emissions generated from the use of steel and concrete (+ 35%) when compared to equivalent wooden frames (+ 1%).
- Despite the fact that the transport of the prefabricated modules adds a significant share of the total GHG emissions of the modular building kit, this type of structure remains nonetheless an environmentally viable alternative. Even if built directly on-site, an equivalent concrete structure would generate close to 4 times the GHG emissions of the prefabricated modular structure.

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« Cargo ship with containers », « Roof holding of a crane on prefabricated », « Industrial Building », « Truck of big size side view », « Construction tool vehicle with crane lifting », « Power line with four insulators », « House Building », « Board Wood », « Brick », par Freepik, sous license CC by 3.0

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7. APPENDIXES

7.1.MATERIAL LIST- MODULAR PREFABRICATED BUILDING

Material	Unit	Total quantity	Columns and beams	Floors	Ceilings	Walls	Extra materials	Mass	Units
1/2" Regular Gypsum Board	m^2	1050.10	0	65.6694	326.15	658.28	0	8.46	Tons
6 mil Polyethylene	m^2	492.50	0	0	314.53	132.44	45.53	0.07	Tons
Air Barrier	m^2	132.44	0	0	0	132.44	0	0.01	Tons
Double Glazed Hard Coated Argon	m^2	131.36	0	0	0	131.36	0	2.13	Tons
FG Batt R20	m^2 (ép. 25 mm)	772.77	0	0	0.00	772.77	0	0.21	Tons
FG Batt R40	m^2 (ép. 25 mm)	6117.50	0	0	6117.50	0	0	1.37	Tons
GAF Everguard© white TPO membrane 60 mil	m^2	827.79	0	0	827.79	0	0	1.22	Tons
Galvanized Sheet	Tons	0.23	0	0.0754	0.15	0	0	0.23	Tons
Joint Compound	Tons	1.05	0	0.0655	0.33	0.66	0	1.05	Tons
Laminated Veneer Lumber	m^3	1.67	1.67	0	0	0	0	0.91	Tons
Nails	Tons	0.18	0	0.0068	0.05	0.09	0.03	0.18	Tons
Oriented Strand Board	m^2 (ép. 9 mm)	345.16	0	0	0.00	345.16	0	2.08	Tons
Paper Tape	Tonnes	0.01	0	0.0008	0.004	0.008	0	0.01	Tons
Pine Wood Shiplap Siding	m^2	372.87	0	0	0	274.67	98.21	3.03	Tons
PVC Window Frame	kg	1174.46	0	0	0	1174.46	0	1.17	Tons
Roofing Asphalt	kg	5790.52	0	0	5790.52	0	0	5.79	Tons
Screws Nuts & Bolts	Tons	0.11	0	0	0	0	0.11	0.11	Tons
Small Dimension Softwood Lumber, kiln-dried	m^3	19.41	0	1.5684	8.28	8.99	0.57	8.64	Tons
Softwood Plywood	m^2 (ép. 9 mm)	590.55	0	98.9763	491.57	0	0	2.79	Tons
Water Based Latex Paint	L	158.23	0	0	0	158.23	0	0.12	Tons

7.1.MATERIAL LIST- EQUIVALENT CONCRETE CONSTRUCTION

Material	Unit	Total quantity	Columns and beams	Floors	Ceilings	Walls	Extra materials	Mass	Units
1/2" Regular Gypsum Board	m ²	1050.10	0.00	65.6694	326.15	658.28	0.00	8.46	Tons
6 mil Polyethylene	m ²	492.50	0.00	0	314.53	132.44	45.53	0.07	Tons
8" Concrete Block	Blocks	1556.48	0.00	0	0	1556.48	0.00	29.57	Tons
Air Barrier	m ²	132.44	0.00	0	0	132.44	0.00	0.01	Tons
Concrete 30 MPa (flyash av)	m ³	49.13	8.61	14.384	0	26.127	0.00	114.22	Tons
Double Glazed Hard Coated Argon	m ²	131.36	0.00	0	0	131.36	0.00	2.13	Tons
Expanded Polystyrene	m ² (ép. 25 mm)	452.87	0.00	0	0	452.87	0.00	0.33	Tons
FG Batt R40	m ² (ép. 25 mm)	6117.50	0.00	0	6117.50	0	0.00	1.37	Tons
GAF Everguard© white TPO membrane 60 mil	m ²	827.79	0.00	0	827.79	0	0.00	1.22	Tons
Galvanized Sheet	Tons	0.15	0.00	0	0.15	0	0.00	0.15	Tons
Joint Compound	Tons	1.05	0.00	0.0655	0.33	0.657	0.00	1.05	Tons
Laminated Veneer Lumber	m ³	1.33	1.33	0	0	0	0.00	0.73	Tons
Mortar	m ³	29.80	0.00	0	0	29.80	0.00	38.15	Tons
Nails	Tons	0.11	0.00	0.0006	0.05	0.0587	0.00	0.11	Tons
Paper Tape	Tons	0.01	0.00	0.0008	0.004	0.0075	0.00	0.01	Tons
Pine Wood Shiplap Siding	m ²	372.87	0.00	0	0	274.67	98.21	3.03	Tons
PVC Window Frame	kg	1174.46	0.00	0	0	1174.46	0.00	1.17	Tons
Rebar, Rod, Light Sections	Tons	19.24	4.43	0.7284	0	14.082	0.00	19.24	Tons
Roofing Asphalt	kg	5790.52	0.00	0	5790.52	0	0.00	5.79	Tons
Small Dimension Softwood Lumber, kiln-dried	m ³	10.08	0.00	0	8.2838	1.7977	0.00	4.49	Tons
Softwood Plywood	m ² (ép. 9mm)	491.57	0.00	0	491.57	0	0.00	2.32	Tons
Water Based Latex Paint	L	158.23	0.00	0	0	158.229	0.00	0.12	Tons

7.1.ENERGY MODELING DETAILS

The details of the analysis of the various elements of the assembly are as follows:

Assembly: Slab on grade				
Components	Thickness (mm)	RSI _o	RSI _c	RSI
		0%	100%	
Floor finishing	-	-	-	-
Concrete slab 102 mm (4")	102	0.04	0.04	0.04
Polyethylene 6 mil	-	-	-	-
Rigid insulation 51 mm (2") Extruded polystyrene XPS	51	1.68	1.68	1.68
Drainage Gravel	-	-	-	-
<u>Thermal resistance of the assembly</u>			Total	Effective
RSI (m ² ·°C/W) :			1.72	1.72
R (hr·sq ft·°F/Btu) :			9.8	9.8
U (Btu/hr·sq ft·°F) :			0.1023	0.1023

Assembly: Foundation wall with 300 kPa [4000 psi] capacity (average depth of 1.37 m [4'-6"])				
Components	Thickness (mm)	RSI _o	RSI _c	RSI
		0%	100%	
Exterior environment / French drain system	-	-	-	-
Rigid insulation 51 mm (2") Extruded polystyrene XPS	51	1.68	1.68	1.68
Concrete foundation 203 mm (8")	203	0.08	0.08	0.08
Drainage Gravel	-	-	-	-
<u>Thermal resistance of the assembly</u>			Total	Effective
RSI (m ² ·°C/W) :			1.76	1.76
R (hr·sq ft·°F/Btu) :			10.0	10.0
U (Btu/hr·sq ft·°F) :			0.1000	0.1000

Assembly: Exterior wall				
Components	Thickness (mm)	RSI _o	RSI _c	RSI
		23%	77%	
Torrefied wood pine exterior cladding	-	-	-	-
Furrings 25 x 76 mm (1 x 3")	-	0.12	0.12	0.12
Air barrier membrane	-	-	-	-
Oriented strand board panels (OSB) 11 mm (7/16")	11	0.11	0.11	0.11
Studs 51 x 152 mm (2 x 6") aux 406 mm (16")	139.7	1.19	3.52	2.42
Fiberglass batting insulation 152 mm (6") RSI 3.52 (R-20)	-	-	-	-
Polyethylene 6 mil	-	-	-	-
Furrings 25 x 76 mm (1 x 3")	-	0.18	0.18	0.18
Plasterboard 12.7 mm (1/2")	12.7	0.08	0.08	0.08
Interior air film	-	0.12	0.12	0.12
<u>Thermal resistance of the assembly</u>			Total	Effective
RSI (m ² ·°C/W) :			4.13	3.03
R (hr·sq ft·°F/Btu) :			23.4	17.2
U (Btu/hr·sq ft·°F) :			0.0427	0.0581

Assemblage : Roof				
Components	Thickness (mm)	RSI _o	RSI _c	RSI
		6%	94%	
Asphalt shingle exterior cladding	-	-	-	-
Plywood 15.5 mm (5/8")	-	-	-	-
Ventilated air space	-	0.16	0.16	0.16
Open web roof joists of 762 mm (2' 6") at 610 mm c/c (24") Fiberglass batting insulation 279 mm (11") RSI 7.04 (R-40)	749.3	6.37	7.04	7.00
Plasterboard 12.7 mm (1/2")	12.7	0.08	0.08	0.08
Exterior air film	-	0.11	0.11	0.11
<u>Thermal resistance of the assembly</u>			Total	Effective
RSI (m ² ·°C/W) :			7.28	7.24
R (hr·sq ft·°F/Btu) :			41.3	41.1
U (Btu/hr·sq ft·°F) :			0.0242	0.0243

For the purposes of the comparative analysis, the selected wall is as described in the table below and represents an energy performance that is equivalent to that of the wall of the wooden structure:

Assembly: Exterior wall – Equivalent concrete structure 4000 psi with #5 steel armature				
Components	Thickness (mm)	RSI _o	RSI _c	RSI
		0%	100%	
Torrefied wood pine exterior cladding	-	-	-	-
Furrings 25 x 76 mm (1 x 3")	-	0.12	0.12	0.12
Air barrier membrane	-	-	-	-
Rigid insulation 88 mm (3.5") Expanded polystyrene EPS Type2	87.5	2.45	2.45	2.45
Concrete walls 203.2 mm (8")	203.2	0.08	0.08	0.08
Furrings of 25 x 76 mm (1 x 3")	-	0.18	0.18	0.18
Plasterboard of 12.7 mm (1/2")	12.7	0.08	0.08	0.08
Interior air film	-	0.12	0.12	0.12
<u>Thermal resistance of the assembly</u>			Total	Effective
RSI (m ² ·°C/W) :			3.03	3.03
R (hr·sq ft·°F/Btu) :			17.2	17.2
U (Btu/hr·sq ft·°F) :			0.0581	0.0581

The specifics of the hypothetical data used for the modeling are noted below:

Climatic reference used:	Beijing, China
Heating and cooling system:	Air to air heat pump , 8.5 HSPF , 14 SEER
Secondary heating source:	Electric baseboard heaters
Heating – cooling thermostats setpoints:	20 °C (68 °F) - 25.5 °C (78 °F)
Hot water system:	Electric water heater (efficiency of 92 %)
Air tightness:	3.5 ACH @ 50 Pa
Ventilation system:	Heat Recovery Ventilation Efficiency of 62 % , 96 cfm , 87 W