Super:Lightness

Lightweight High Performance Northern Architecture

by
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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Architecture

Waterloo, Ontario, Canada, 2024
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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Super:Lightness proposes lightweighting as a means of providing high performance residential architecture in the Canadian North. The North faces severe challenges relating to buildings and infrastructure, as goods and fuel resupply must be shipped at great expense from southern Canada. These challenges compound each other, as the climate of the region and the cost of resupply necessitates highly efficient buildings, while the construction of these projects is complicated by the remoteness and lack of infrastructure. Lightweighting presents a means of moving through these problems, simplifying transportation and construction in remote communities, allowing for the construction of high performance architecture.

Through study of the challenges in the North, from climatic to socioeconomic, and studying past and current building practices in the region, three key elements of transportability, constructability, and building energy performance are identified, with lightweighting as an important means of addressing these. Considering this, precedents from alternative disciplines, and architecture in other settings, are studied as they relate to lightweightness and these key elements, informing building design in the North.

Drawing on research of the northern context and the study of precedents, two prototypes of lightweight high performance residential architecture are proposed, *Super:Light Architecture* and *Northern Lightweight Architecture*. These proposals improve on key elements of transportability, constructability, and energy performance, addressing the needs of the North through lightweight design. The design process of these proposals is highly analytical, quantifying component weights and modelling energy consumption to develop an optimized design. This process can inform architecture at large, as the challenges of the North become relevant worldwide due to climate change, fossil fuel depletion, and economic limitations, making lightweight high performance architecture an increasingly impactful design methodology.

Acknowledgements

Thank you to my advisor, John Straube, for your enthusiasm for this work, the incredible expertise you shared with me, and for the insight you provided along the way, critically examining practices often taken for granted, embracing the spirit of *Super:Lightness*.

Thank you to my mother, Cynthia Chaplin, for your love and patience throughout this process and to my father, Adam Gordon, for the same support, and whose documentation of the North provided valuable context for my research.

Thank you to my friend Lara Sedele and all my friends who made my time working on this thesis an enjoyable experience, and who may or may not have come to share my appreciation of lightness.

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Chapter 1
Introduction

The Canadian North faces a range of challenges from socioeconomic to climatic, with issues of limited infrastructure and remoteness being particularly acute and shared across the region. These challenges limit the availability of high quality, energy efficient homes in the North, while these same challenges demand efficient buildings due to the cold climate and the cost of resupply in remote communities..

Objective

The objective of this thesis is to develop high performance northern architecture which can meet the demands of the climate and reduce energy consumption, while also meeting the challenges of transportation and construction in the North.

Scope

This thesis focuses on northern residential buildings, with a particular focus on the eastern Arctic, as this represents the most extreme condition, relying on intermittent transportation and resupply via air cargo and sealift, while also placing the highest demands on building performance.

Approach

The pursuit of high performance northern architecture is accomplished through lightweighting, allowing for the incorporation of a high performance building enclosure, while simultaneously reducing transportation and construction costs and complexity.

This thesis will describe the northern context, including the challenges for general life in the North and specific issues for architecture, particularly those affecting residential buildings. These include climatic, cultural, infrastructural, and economic challenges. This thesis then explores current and past standard practices of northern buildings, and studies best practices developed by contemporary building science research and precedents in the region. Through the course of this research, three key elements of northern building design are identified: transportability, constructability, and energy performance, and the application of lightweighting is identified as an impactful means of accomplishing these key elements. With this in mind, precedents which address these key elements are studied, including alternative disciplines of outdoor recreation, racing vehicle design, and space travel, along with architecture from other settings which share challenges of the North, all of which can inform future architectural design in the North.

Drawing on this rigorous study of the northern context and precedents, two designs of lightweight high performance northern architecture are presented, *Super:Light Architecture* and *Northern Lightweight Architecture*. These prototypical residential designs address key aspects of transportability, constructability, and energy performance, exceeding the demands of the North, and providing high quality buildings and homes to the people of the region. The process of their design is intended to be highly analytical and transparent, quantifying material and component weights and modelling energy consumption, both compared to a baseline project, to develop an optimized design. The results of these proposals, both in terms of weight and energy consumption, are analyzed to provide insight for future architectural work in the North, and to the practice of architecture at large.

Relevance

The North is in need of high quality energy efficient housing that can be effectively provided by the limited transport and construction infrastructure available. These challenges have a wider relevance as ongoing climate change and environmental degradation, caused by human fossil fuel consumption and resource extraction, drive the need to reduce energy and material consumption, lightweightness arises as a means of addressing these enormous challenges. The built environment comprises a large portion of this consumption, in the shipping and construction processes and in its operation, and thus lightweighting as it applies to architecture becomes a vital consideration. These challenges are not new to the North, and the practices that are successful in this context, and novel proposals which address these challenges, provide valuable insight for architecture in all settings.



figure 1-01: Baker Laker, NU.
source: author



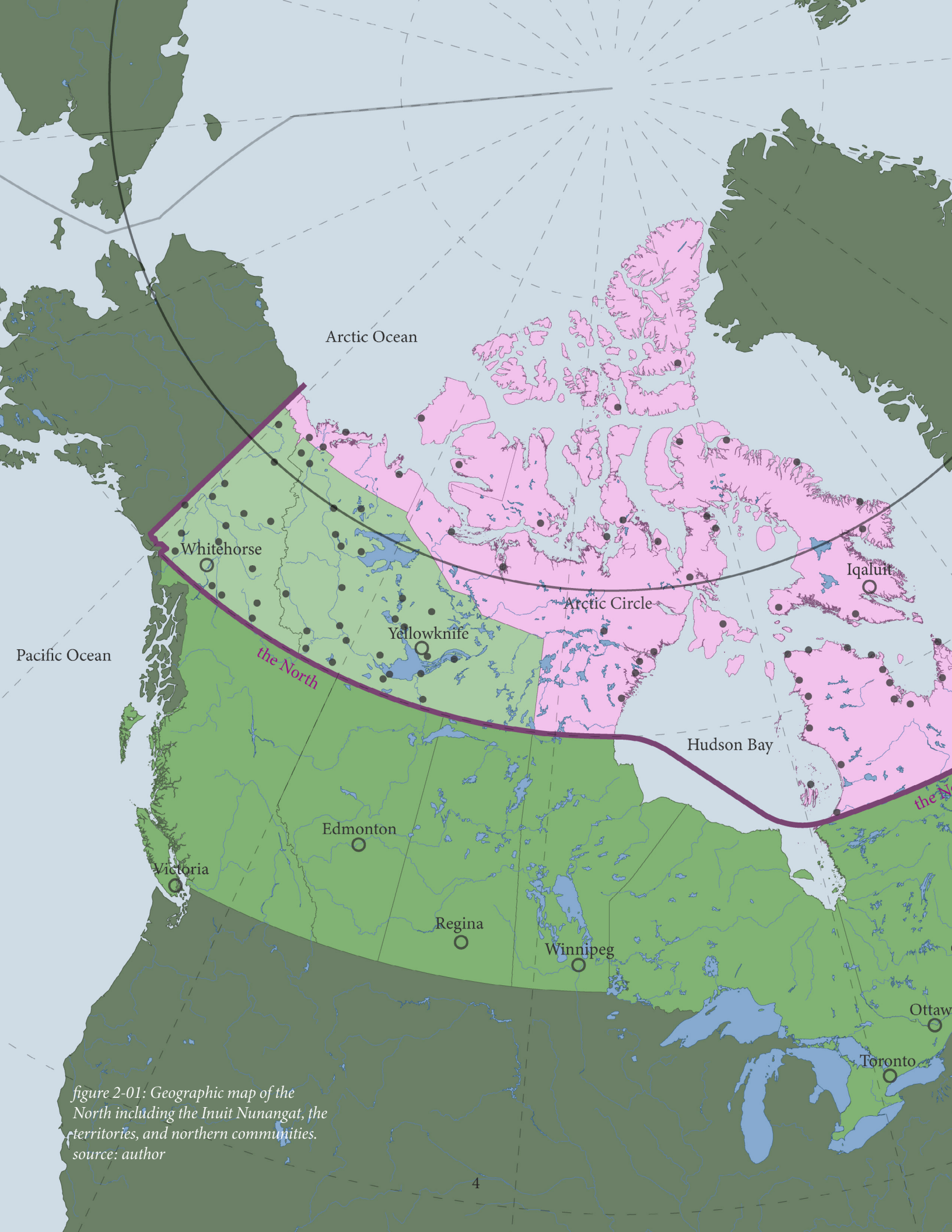


figure 2-01: Geographic map of the North including the Inuit Nunangat, the territories, and northern communities. source: author



Chapter 2
The Northern Context

2.1 - Introduction and Context

The North is a vast region of Canada that faces enormous challenges, particularly affecting architecture and infrastructure, limiting the availability of high quality shelter for the people of the North. These challenges, ranging from geographic and climatic to socioeconomic, vary across the region, but the difficulties of transportation, construction, and infrastructure are shared. These issues have led to a crisis of housing shortages, a lack of affordability, and failures of existing housing stock that are pressing and need to be addressed. However, building in the North is complicated and requires an understanding of the northern context and its challenges, and an understanding of how architecture can address the needs of the people in the North. This chapter describes the northern context and its challenges for users and architects in the region.

Geographic Context

In this thesis the North refers to the territories of Canada, the Yukon, Northwest Territories, and Nunavut, as well as the remainder of the Inuit Nunangat, Nunavik and Nunatsiavut in northern Quebec and Labrador (see figure 2-01). With a population of 135,000 people spread over more than 4.5 million km^2, the population density is just 0.03 people per km^2, a key issue for people living in the region.[1] The North is a very cold climate, as shown in the 10°C isotherm, which is delineated by a warmest monthly average temperature of 10°C. This isotherm area also roughly coincides with the Inuit Nunangat which is formally recognized as Inuit-owned land in agreements with the Canadian government.[2] This thesis focuses on the eastern arctic and the Inuit Nunangat, as the issues of transportation and construction are especially pronounced in this region and there is greater need for high quality buildings, especially housing.

1 Statistics Canada, "Census Profile, 2021 Census of Population," Catalogue no. 98-316-X2021001. Ottawa, Statistics Canada, 2022. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/index.cfm?Lang=E

2 "Inuit Nunangat," Indigenous Peoples Atlas of Canada, Canadian Geographic. Accessed May 2, 2023. https://indigenouspeoplesatlasofcanada.ca/article/inuit-nunangat/

Challenges of the North

A defining challenge of the North is its cold climate. It is colder in the Canadian North than the northern regions of Europe or Asia, and there are also issues of high winds, snowdrifts, and permafrost, all of which vary across the region, complicating building in the North. Other northern regions experience shared climatic challenges, however these tend to be more accessible and more populated.[3] The small population of the North makes infrastructure and services difficult to provide across the region.[4]

The North is diverse in climate and culture, and these affect architecture across the region, necessitating locally sensitive design. However, many of the challenges of building are shared throughout, making this thesis work relevant in a range of northern contexts.

An important and unique consideration of the Canadian North is the Inuit and First Nations communities, the largest demographic of the region. These groups have been historically mistreated by the Canadian government, making interaction with the government an important consideration as it affects a variety of issues in the North, particularly housing and health services. (see Chapter 2.3 - Inuit and First Nations Cultural Context)

Transportation and construction are complicated and difficult due in part to the climate, labour shortages, and limited infrastructure available in the North. This is compounded by political and economic issues. These challenges have contributed to housing shortages, affordability issues, and a failing housing stock in dire need of repairs and replacement.

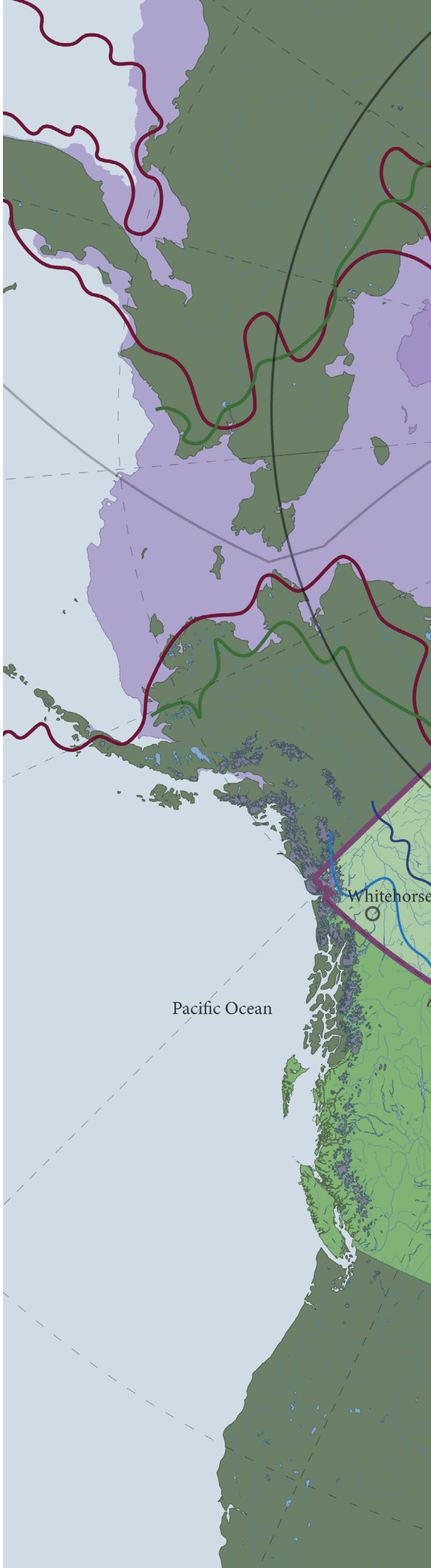


figure 2-02: Climate map of the North including sea ice extents, the treeline, permafrost zones, and other climate features. source: author

3 Heather Exner-Pirot, "The Rural and Remote Arctic." *Overcoming Remoteness: Innovation to Support Economic Development, Critical Minerals, and Security in the Arctic* (Ottawa: Macdonald-Laurier Institute, 2023), 10. http://www.jstor.org/stable/resrep52112.5

4 Lola Sheppard and Mason White, *Many Norths: Spatial Practice in a Polar Territory* (New York: Actar Publishers, 2017), 26.


Arctic Ocean
Arctic Circle
Yellowknife
Iqaluit
Hudson Bay
Atlantic Ocean
the North
the North
Line of the North
Glaciers
Sea Ice Extents 2022/23
Treeline
10°C Isotherm
Dis/Continuous Permafrost



figure 2-03: Baker Lake, NU, note the high wind exposure landscape and the snow fence visible to the north of town.
source: author



figure 2-04: Permafrost melting, causing landslides and collapses.
source: Katie Orlinsky,

2.2 - Climate

The North is an incredibly cold place. Through the winter, -30°C to -40°C is a common occurrence across the North, along with other climatic challenges of high winds, snowdrifting, and permafrost. Climate change is another concern, increasing wind and snow loads, and destabilizing permafrost, further challenging buildings and infrastructure in the North. (see figure 2-02)

Climate of the North



figure 2-05: Twilight midnight in Iqaluit with Inuksuk High School in foreground. source: Adam Gordon, 2022

The 10°C isotherm area covers the Canadian Arctic Archipelago and much of mainland Nunavut and Nunavik, indicating cool summers. While inland communities in Yukon and Northwest Territories experience warmer summers, they experience similarly freezing winters to communities farther north. Inland communities in the North can experience large daily temperature swings due to their continental climate. Winter low temperatures are -40°C across the North, and many communities spend months below 0°C.

Because of the open landscape, high winds are another major concern in the North. High winds can also cause enormous snowdrifts as snow collects on any raised structure and does not melt for many months, posing a serious challenge. In some communities a significant investment has been made into building snowdrift fences to ameliorate this issue. (see figure 2-03)

Permafrost is another important aspect of the northern environment. Permafrost describes the condition where the soil remains frozen throughout the year. Upper layers of the soil may thaw seasonally, described as the active layer, while lower layers are permanently frozen. Permafrost areas are affected by climate change which is causing the continuous permafrost line to shift and disrupting the more variable active layer.[5, 6] Saline water content also weakens permafrost, affecting coastal communities in the North. (see figure 2-04)

At such a high latitude, communities experience a wide range of daylight conditions. Summer days are very long and the winters are extremely dark. During the summer the sun often does not fully set and communities experience a twilight nighttime during the summer. Many communities are far north of the Arctic Circle and can experience months of 24 hour daylight during the summer, and months-long darkness in the winter. (see figure 2-05)

5 Melody Schreiber, "The Housing Crisis in the Arctic, Caused by Melting Permafrost," *Bloomberg.Com*, May 10, 2018. https://www.bloomberg.com/news/articles/2018-05-10/melting-permafrost-and-the-housing-crisis-in-the-arctic

6 John Streicker, *Yukon Climate Change Indicators and Key Findings 2015* (Whitehorse: Yukon University, 2015), 9-10.

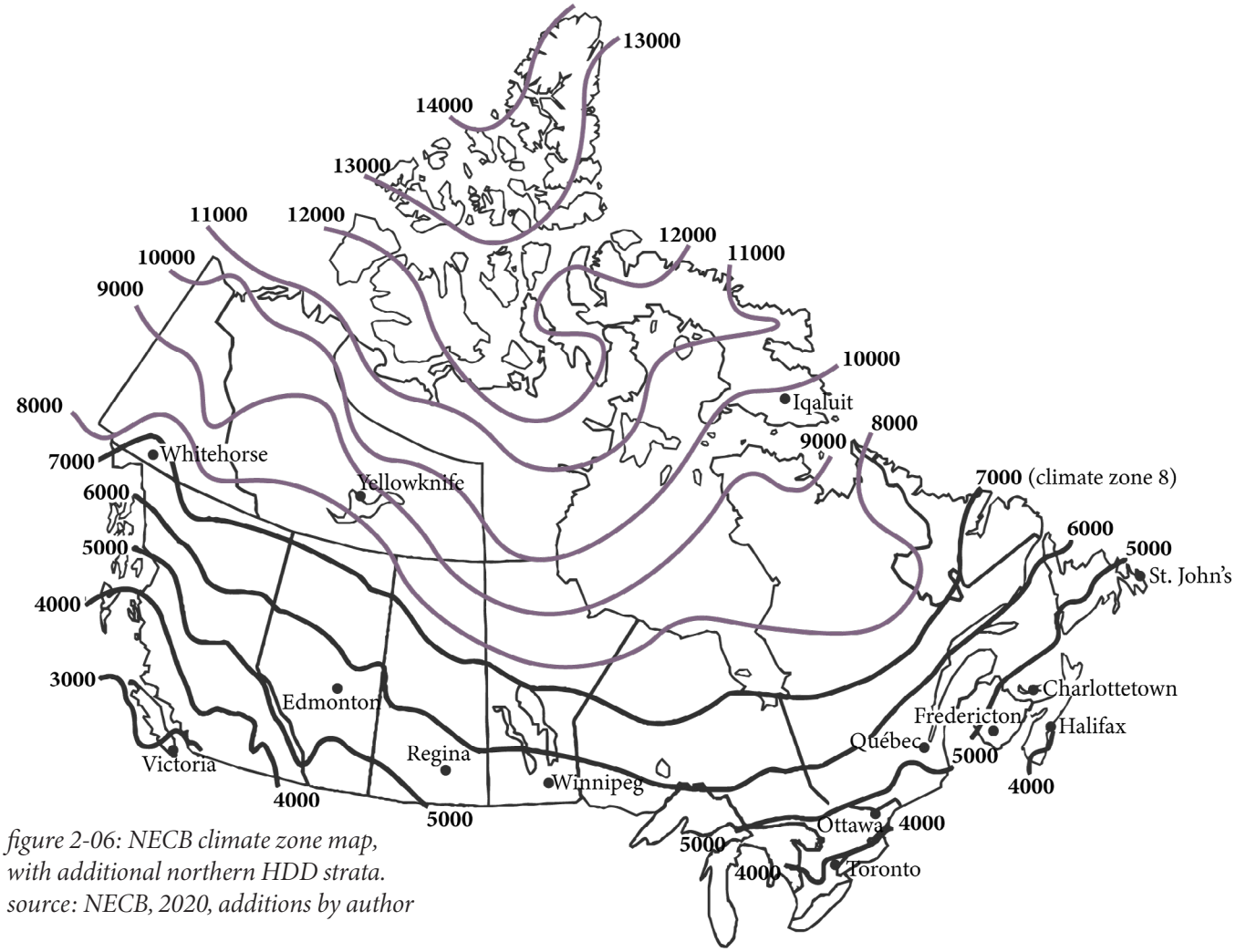


figure 2-06: NECB climate zone map, with additional northern HDD strata. source: NECB, 2020, additions by author

The effects of climate change on the climate of the North are important to understand as well. The average temperature of the world has increased by 0.8°C since 1948, and the change is twice that in Canada, an increase of 1.7°C.[7] These effects are even more dramatic in the North, which has seen a 2.3°C average temperature increase in the same time period, an effect called Arctic amplification.[8]

Climate Challenges for Buildings

The climate of the North poses a range of challenges for buildings in the North. The cold, high winds, snowdrifts, permafrost, and daylighting all need to be addressed. Climate change is also affecting buildings in the North, causing permafrost instability and forest fires, particularly in the Yukon and Northwest Territories.

The National Energy Code of Canada for Buildings (NECB) design low temperatures are around -45°C across the North.[9] The North is largely within the NECB and ASHRAE climate zone 8, experiencing 7,000 or more heating degree days (HDD), but most communities experience significantly more than this. This requires excellent building enclosure design, particularly insulation and airtightness, as well as larger heating equipment relative to southern climates. (see figure 2-06)

While the cold is the most immediate challenge in the North, it tends to be the most straightforward to address with high performance building design, but it is still an ever-present concern. Homes must be highly resilient to contend with the deep cold when building equipment fails, even temporarily.

7 E. Bush, et al, *Canada's Changing Climate Report* (Ottawa: Government of Canada, 2019), 125-127.

8 Judah Cohen, et al, "Recent Arctic Amplification and Extreme Mid-Latitude Weather," *Nature Geoscience* 7, no. 9 (Aug. 17, 2014): 627-637. https://doi.org/10.1038/ngeo2234

9 Canadian Commission on Building and Fire Codes, *National Energy Code of Canada for Buildings 2020*, 5th ed. (Ottawa: National Research Council of Canada, 2020), "Table C-1," 270.



figure 2-07: Snowdrifting on buildings in Baker Lake, March 24, 2024.
source: user m0useg1rl on reddit, 2024



figure 2-08: Foundation damage due to settlement and frost heave.
source: David Michael Lamb, 2017

In addition to the cold, the open landscape creates high winds which can damage buildings and critical services. Buildings need to be able to handle high winds consistently as failures in the winter are particularly dangerous and difficult to repair. Climate change is exacerbating this issue as sea ice reduces and temperatures shift, causing higher winds in coastal communities.[10]

Related to the issue of high winds is snowdrifting. Snow fences are built to shelter from the prevailing winds, however snowdrifts from other directions still need to be accounted for in building design and community planning. Climate change is also increasing precipitation, leading to more snow. This is compounded by increased rainfall, making snow heavier and prone to freezing, requiring robust building structure and enclosure.[11] (see figure 2-07)

Permafrost poses an enormous challenge for the foundations of buildings, making the ground movement of a site unpredictable. In cases where the building leaks heat to the ground it may cause the permafrost to melt, destabilizing the foundations and damaging buildings.[12] To avoid this, buildings in the North are typically raised off the ground, which leads to issues for building enclosure. This permafrost instability also increases the risk of landslides and disrupts infrastructure. Permafrost is a critical issue for buildings in the North, making foundation design an important consideration. (see Chapter 3.3 - Structure) (see figure 2-08)

The long days and nights are another difficulty, making glazing and lighting an important design element, both for reducing daylighting in summer, and providing ample light in the dark winters. Making the best use of available daylight is highly desirable for users in the North.

Some of the climatic challenges described here are more severe than others but small problems can compound quickly in such a harsh climate far from support services. This is the reality of life in the North: there is little room for error. Architecture must perform well in the face of the North's many challenges, and must be prepared for when systems fail.

10 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part G, section 4.2, 106.

11 John Streicker, *Yukon Climate Change Indicators and Key Findings 2015* (Whitehorse: Yukon University, 2015), 4.

12 "Permafrost Foundations," Cold Climate Housing Research Center, November 13, 2019. https://cchrc.org/permafrost-foundations/

2.3 - Inuit and First Nations Cultural Context

The majority population in the North is Inuit, First Nations, or Métis, making up about 75,000 people or 56% of the population of the North.[13] This is made up of 50,000 Inuit living predominantly in the Inuit Nunangat, and 21,000 First Nations living across 14 First Nations groups in the Yukon and 27 in the Northwest Territories. There are also 4,000 Métis, mainly in the Yukon and Northwest Territories. Understanding the relationship between these groups and the Canadian government is an important element of understanding the conditions in the North. There are examples of mistreatment of First Nations and Inuit throughout colonialism and contemporary politics. Two examples are highlighted here, the residential school program and the High Arctic Relocation Program.

The residential school program in Canada was a cultural genocide of Inuit, First Nations, and Métis groups across Canada. Children were taken from their families to attend Canadian schools away from home for months at a time.[14] Residential schools excluded important First Nations' and Inuit cultural teachings such as history, language, and dress, and these were usually prohibited at school. Residential school survivors recall losing their language, a critical means of learning from their elders and family, further isolating them. (see figure 2-09, figure 2-11)

The High Arctic Relocation Program was a forced relocation of 92 Inuit people enacted by the Canadian government in 1953. This forced relocation from Quebec to Resolute and Grise Fiord in the far North made hunting and food security nearly impossible for residents and families were not provided homes as they were promised. In 1996 a Reconciliation Agreement was settled, paying restitution to the families, and in 2010 the Canadian government fully admitted wrongdoing and apologized.[15] (see figure 2-10)

Even today, promises for support are frequently unmet. In his 2015 campaign "[Justin] Trudeau had promised: to conduct a comprehensive review of federal laws for compliance with the Section 35 Aboriginal and treaty rights; he promised to completely remove the cap on funding for First Nations social programs; and he promised to address the water crisis on



figure 2-09: The Last Goodbye, carved by Inuit sculptor Abraham Anghik Ruben, recalling his siblings being taken away from his family to attend a school in Aklavik. Ruben would later be sent to Grollier Hall and Inuvik Federal School. source: Abraham Anghik Ruben, 2001



figure 2-10: Rynee Flaherty, right, is the eldest survivor of the Grise Fiord Exiles. The sculpture is in Grise Fiord, in honour of the Inuit families subjected to the High Arctic Relocation Program in 1953. source: Gabriel Zaráte, 2010

13 Statistics Canada, "Census Profile, 2021 Census of Population," Statistics Canada, 2022.

14 Crystal Gail Fraser, "Inuit Experiences at Residential School," The Canadian Encyclopedia, Apr. 29, 2020, https://www.thecanadianencyclopedia.ca/en/article/inuit-experiences-at-residential-school

15 "Inuit get federal apology for forced relocation," *CBC News*, Aug. 18, 2010. https://www.cbc.ca/news/canada/north/inuit-get-federal-apology-for-forced-relocation-1.897468



figure 2-11: Inuvik Federal School.
source: Anglican Church of Canada, c. 1959

reserves – none of which he completed in his first term."[16] Failure of these goals, in addition to pipeline negotiations and other environmental concerns, are representative of Inuit and First Nations groups' strained relationship with the federal government.

The legacy of the Canadian government's residential schools have made community engagement with public services difficult for many Inuit and First Nations groups, especially health and education. The strained historical and contemporary relationship between the North and the Canadian government means that architecture for communities in the North is complicated, and work to contend with issues both technical and social, is an important aspect of architects' work in the North.

Inuit and First Nations groups are tight-knit and resilient, however they face extensive challenges due to the northern context and economic and political issues. Improving housing is a critical step in strengthening these communities, reducing health issues from unsuitable housing and overcrowding, increasing economic stability, and providing spaces for families and groups to gather to share their traditions and culture.

16 Pam Palmater, "Enough with the broken promises. Will Trudeau do better for First Nations this time?" *The Globe and Mail*, Oct. 25, 2019. https://www.theglobeandmail.com/opinion/article-enough-with-the-broken-promises-will-trudeau-do-better-for-indigenous/

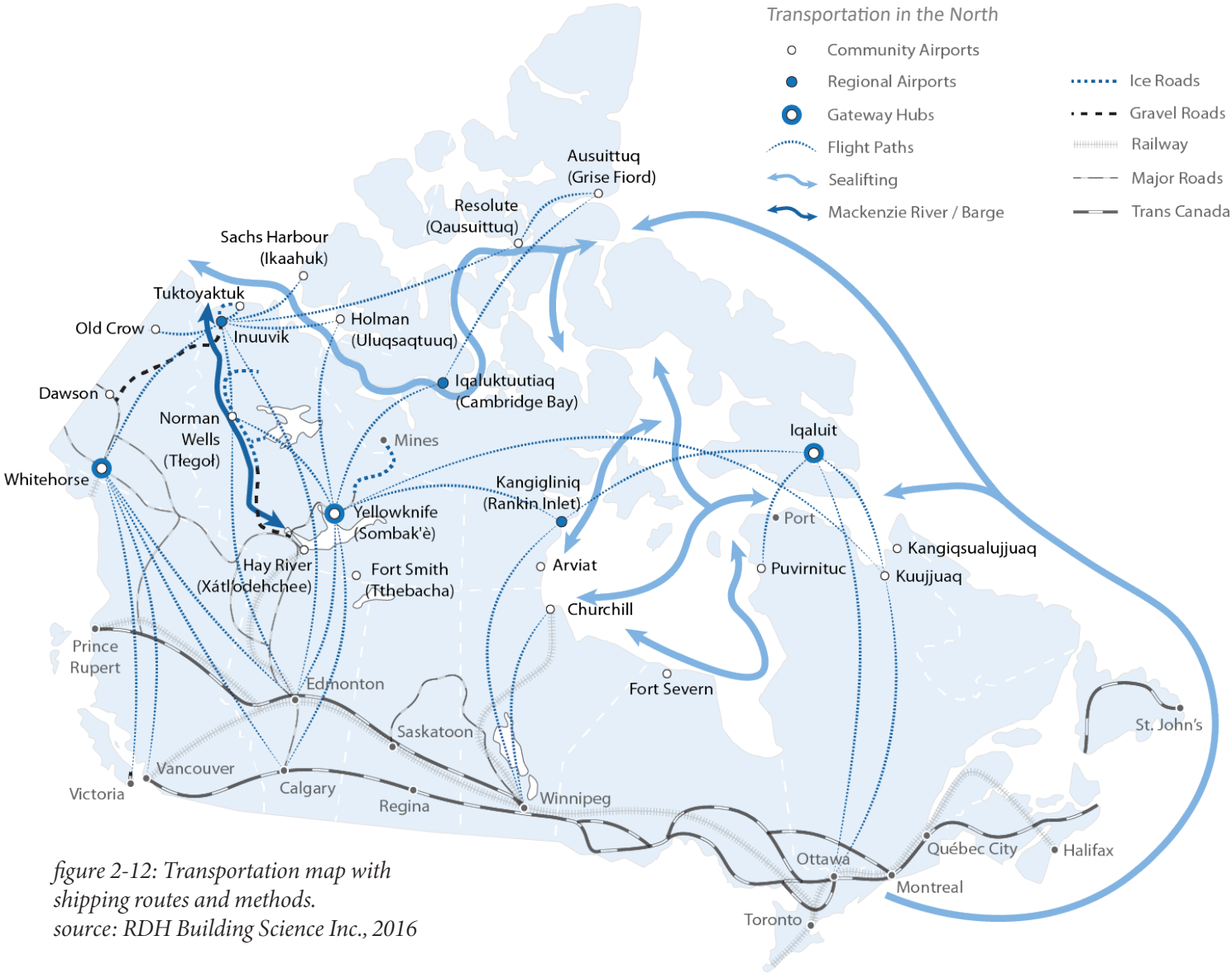


figure 2-12: Transportation map with shipping routes and methods.
source: RDH Building Science Inc., 2016

2.4 - Transportation and Infrastructure

To transport anything to the North is a difficult process. There are three typical modes: road, air, or ship. Each mode has its limitations, and can work in conjunction for projects in the North. There are also alternative options available depending on location. The seasonal availability of each shipping method, along with its capacity and cost is important for designers to consider.

Utility infrastructure in the North is also lacking, and communities often rely on trucks to distribute water and fuel, and to collect wastewater. Electricity is typically generated by diesel which needs to be shipped from the south. These systems leave users vulnerable to water and fuel shortages, and power outages, which can lead to even more severe problems in the North due to the harsh climate, and the difficulty of repairs. (see figure 2-12)

Transportation Process and Challenges

There are no roads to Nunavut, Nunavik, and Nunatsiavut. The only highway to Yellowknife is a 1,400 km journey from Edmonton and only unpaved roads continue north from there. Even winter roads do not reach the more remote communities on the coast of the Arctic Ocean. Trucks also have limits on size and weight that need to be accounted for. Increasing precipitation and permafrost instability have also made the few highways unusable in places. Winter roads offer an additional means of transport,

however these have a limited weight capacity, and climate change has made routes unreliable, forming later and thawing earlier.[17] (see figure 2-13)

The most frequently available shipping method for consumer items is by plane. Flights depart from southern cities, stopping in communities across the North, with smaller regional flights connecting distant communities. Air transit and cargo are available year round, making it the only option for transporting perishable foods to communities without truck access.

The cost of shipping by air is extremely high however, and subsidies are needed to make these necessities attainable.[18] Given the cost of air transport, this shipping method is uncommon for building supplies, but where materials are needed quickly, such as winter repairs, air cargo is the only option, and should be a concern in the design of northern projects. (see figure 2-14)

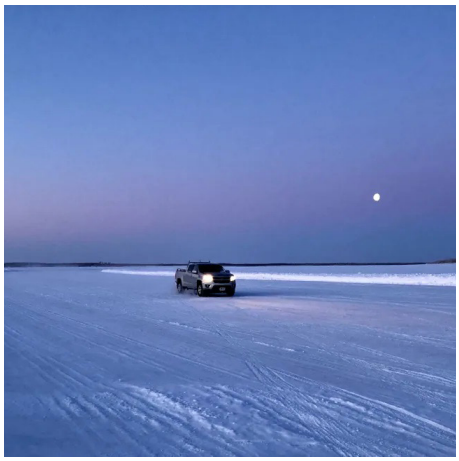


figure 2-13: Aklavik to Inuvik ice road, which opened late in the season and only to vehicles under 5,000 kg.
source: Andrew Pacey, 2023



figure 2-14: A Canadian North flight is loaded and fuelled in Clyde River, NU.
source: Adam Gordon, 2022

The typical method of shipping building materials to the North is by sealift, which also supplies fuel for these remote communities. This is not a simple process either as the sea ice clears for a short period of the summer, just two weeks in some places, and communities can only afford to purchase and store a limited amount of goods at one time. (see figure 2-02, figure 2-12)

Unloading in these remote communities is difficult, as most do not have a large dock system with machinery. Barges are typically beached and unloaded by hand or with a front loader.[19] In 2022 Iqaluit completed a deep sea port, increasing shipping capacity to the North.[20] Sealift is the most affordable option, and has the largest capacity, but is limited by the infrastructure and machinery available for unloading. It is also expensive compared to other sea cargo due to the short shipping season and smaller ships. The sealift also supplies fuel for vehicles and power plants, totalling 237,000 m^3 of petroleum products in 2022.[21] Given the higher capacity and lower cost, sealift is the first option to consider for shipping building supplies. (see figure 2-17)

17 Dylan G. Clark, et al, *Due North: Facing the Costs of Climate Change for Northern Infrastructure* (Ottawa: Canadian Climate Institute, 2022) 35.

18 Tracey Galloway, "Is the Nutrition North Canada Retail Subsidy Program Meeting the Goal of Making Nutritious and Perishable Food More Accessible and Affordable in the North?" *Canadian Journal of Public Health* 105, no. 5 (September/October 2014): 395. https://www.jstor.org/stable/canajpublheal.105.5.e395

19 Denis Calnan, "Northern hamlet enjoys Christmas in September," *Toronto Star,* Sep. 6, 2011. https://www.thestar.com/news/canada/2011/09/06/northern_hamlet_enjoys_christmas_in_september.html

20 "Iqaluit Deep Sea Port Project Milestone Achieved." Government of Nunavut, Nov. 14, 2022. https://www.gov.nu.ca/en/newsroom/iqaluit-deep-sea-port-project-milestone-achieved-2022-11-14

21 "Dry Cargo Re-Supply Programme, Activity Summary Shipping Year 2020," Government of Nunavut, June, 2021.

Alternative transportation options also exist, such as trains and barges, although these are quite limited. There are three train lines to northern Canada, with terminals in Moosonee, ON, Churchill, MB, and Hay River, NWT. In Moosonee and Churchill, goods shipped by train can be loaded onto boats which can then travel north around Hudson Bay. (see figure 2-15)

In Hay River, NWT, goods and fuel are unloaded from train lines onto tugboats and barges operated by Marine Transportation Services (MTS) which ship throughout Northwest Territories and into Nunavut from this point.[22] These barges can also be loaded from trucks driving from southern Alberta, and are a good option for communities along the accessible waterways such as the Mackenzie River.

A shipping method that has been proposed for the North is helium filled airships which "could play a part in easing the housing crisis in hard-to-reach regions like northern Quebec [including Nunavik]."[23] Airships could support greater loads than airplanes, and are less affected by bulky cargo, making them more appropriate for transporting building materials while seaways are frozen. While these airships have not been proven yet, they have seen interest from mining companies for similar challenges to community resupply, demonstrating their applicability.[24] (see figure 2-16)

It is key to understand the seasonality of these transportation methods as the climate controls much of the shipping and building season. Consideration must be given to the benefits and limitations of each method when transporting materials to the North, such as speed, cost, and availability. The impact of climate change will also be felt in the coming decades as infrastructure becomes less reliable. Issues of seasonality, size and weight limits, lead times, and handling need to be accounted for as transport is a large component of northern architecture logistics and costs. (see figure 2-18)



figure 2-15: Moosonee train station, goods are trucked through town and loaded on boats bound for Hudson Bay. source: author



figure 2-16: Airship proposed for year round cargo to the North. source: Lockheed Martin

22 "Marine Transportation Services," Government of Northwest Territories. Accessed May 2, 2023. https://www.inf.gov.nt.ca/en/MTS

23 Frédéric Tomesco, "Flying Whales poised to lift off in Montreal thanks to Quebec investment," *Montreal Gazette*, June 18, 2019. https://montrealgazette.com/business/flying-whales-poised-to-lift-off-in-montreal-thanks-to-quebec-investment

24 Heather Exner-Pirot, "Airships," *Overcoming Remoteness: Innovation to Support Economic Development, Critical Minerals, and Security in the Arctic* (Ottawa, Macdonald-Laurier Institute, 2023), 33. http://www.jstor.org/stable/resrep52112.11

figure 2-17: The beach in Baker Lake. A wharf was built, but many communities use the beach to unload sealifts.
source: author



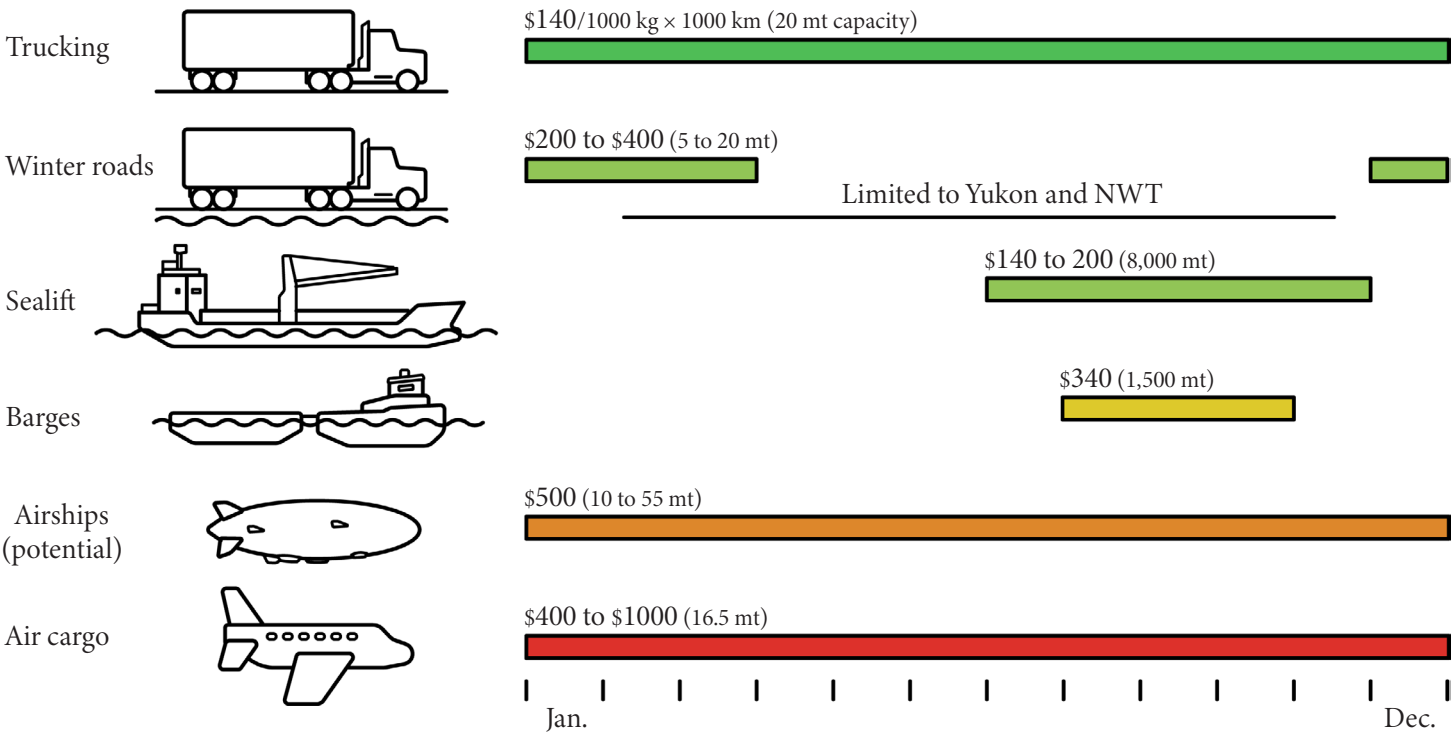


figure 2-18: Transportation diagram for northern building materials.
source: author

Utilities Infrastructure Challenges

In addition to the limited transportation infrastructure, the utilities infrastructure to support buildings in the North is lacking. Water supply, sewage, electricity, and heating fuel are fragile systems across the North, often relying on trucked deliveries. In areas with permafrost, infrastructure that is usually buried must use other methods, often more costly and vulnerable.

Water supply and sewage are most commonly distributed and collected by truck. Out of 51 Inuit communities in the North, 41 rely on a trucked system.[25] This leads to high costs for users, making water conservation important. Water supply systems are also vulnerable to contamination, affecting entire communities, requiring bottled water delivered by air cargo at enormous cost.[26] (see Chapter 3.5 - Systems) (see figure 2-19)



figure 2-19: A water truck in Iqaluit is filled by a member of the Canadian Armed Forces.
source: Dustin Patar, 2021

Electricity in the North is generated by diesel plants in most communities, supplied by sealift. Some communities in Northwest Territories and the Yukon have hydroelectric power, reducing emissions, and there is viability for this in Iqaluit. Wind turbines are a promising option, given the high winds in the North and a windmill is being built in Sanikiluaq, Nunavut "which is expected to produce [1 MW,] enough power to cut the community's reliance on diesel fuel by half."[27] Winds are strongest during the winter, when energy demands are highest. Solar is also being tested, but dark winters limit its use. Inuit and northern residents support the development of renewable energy sources due to the pollution from diesel generators and because renewable sources could reduce costs.[28] (see figure 2-20)



figure 2-20: Wind turbines at Raglan Mine in Nunavik, QC, across the Hudson Strait from Ellesmere Island.
source: Justin Bulota/Tugliq Energy

Heating systems most commonly use oil or diesel furnaces and boilers, with tanked storage, requiring truck deliveries. Similar issues of cost and maintenance for water supply also apply to fuel. Oil or diesel costs are greater than for natural gas, used by most Canadians, and tanked systems for houses and communities lead to risk of environmental contamination from leaks. Alternative systems using biomass or wood are practical in Northwest Territories and the Yukon where wood is available, but are more labour intensive, and are unviable north of the treeline.

25 "Access to Drinking Water in Inuit Nunangat," *ITK Quarterly Research Briefing*, no. 2 (2020), 4. https://www.itk.ca/wp-content/uploads/2020/12/ITK_Water_English_07.pdf

26 Avery Zingel, "An old fuel tank and 'the void' contaminated Iqaluit's water, experts say," *CBC News*, May 06, 2022. https://www.cbc.ca/news/canada/north/iqaluit-water-contamination-may-2022-1.6443273

27 Nick Murray, "Sanikiluaq wind project represents major Nunavut renewable energy policy shift," *CBC News*, Sep. 20, 2023. https://www.cbc.ca/news/canada/north/sanikiluaq-wind-project-anuriqjuak-nukkiksautiit-1.6968052

28 Nicole C. McDonald and Joshua M. Pearce, "Community Voices: Perspectives on Renewable Energy in Nunavut." *Arctic* 66, no. 1 (2013), 100. http://www.jstor.org/stable/23594610

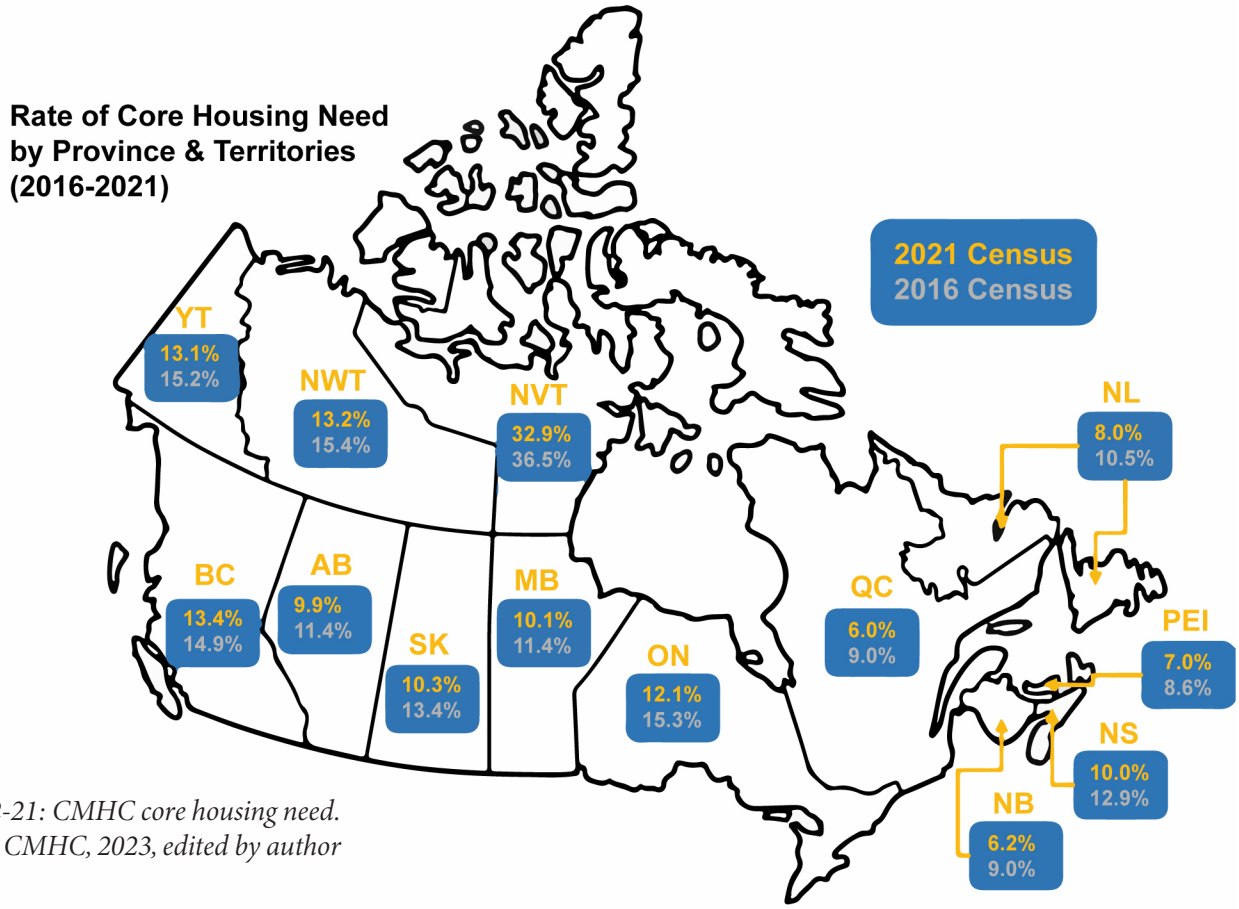


figure 2-21: CMHC core housing need.
source: CMHC, 2023, edited by author

2.5 - Deficiencies of Northern Housing

Housing need across the North is "both uniquely acute and longstanding," as described by the Inuit Tapiriit Kanatami, the body representing Inuit concerns across Canada.[29] Housing shortages and unaffordability are important problems, and the limited and substandard existing supply mean that new builds are critically needed, but these represent an enormous investment that is unavailable at the moment. (see figure 2-21)

Housing Shortage and Unaffordability

CMHC census data from 2021 puts core housing need at 33% in Nunavut, more than three times the national average of 10%. "Core housing need" is defined as inadequate, unsuitable, or unaffordable housing.[30] In the Yukon and Northwest Territories, core housing need is 13% however this housing need is particularly concentrated in the Inuit and First Nations populations. This crisis is especially concerning in the North, as the consequences are more severe due to fewer services for the unhoused and a harsher climate.

These issues arise partly from the cost and difficulty of building in the North. In 2016, the Nunavut Housing Corporation (NHC) appeared before the Standing Senate Committee on Aboriginal Peoples, and the headline statistics were dire: 52% of Nunavummiut live in social housing, with 38% of these tenants living in overcrowded conditions, and in some communities, as many as 72% of tenants in overcrowded homes.[31] These issues are seen across the North, not just Nunavut, with some 53% of Inuit

29 Inuit Tapiriit Kanatami, *Inuit Tapiriit Kanatami Pre-Budget Submission 2022* (Ottawa: Inuit Tapiriit Kanatami, 2021). https://www.itk.ca/wp-content/uploads/2021/11/ITK-pre-budget-submission-2022-FINAL.pdf

30 "Housing in Canada online: Definitions of variables." Canada Mortgage and Housing Corporation. http://cmhc.beyond2020.com/HiCODefinitions_EN.html

31 Nunavut Housing Corporation, "Nunavut is facing a severe housing crisis," *Nunavut Housing Corporation's Appearance before the Standing Senate Committee on Aboriginal Peoples*, Mar. 23, 2016. https://assembly.nu.ca/sites/default/files/TD%20158-4(3)%20EN%20Nunavut%20is%20Facing%20a%20Severe%20Housing%20Crisis.pdf

in the Inuit Nunangat, and 30% of First Nations in Northwest Territories living in overcrowded homes.[32] Another concern raised by the NHC was that more consistent investment, rather than unpredictable funding injections, would improve outcomes as long term planning would be more clear.[33]

This housing need has been an issue since before Nunavut was established in 1999, but as of 2022 there are some plans in place to address the need. As reported by Nunatsiaq News, a northern newspaper, "in October [2022], the Government of Nunavut and the Nunavut Housing Corporation announced Nunavut 3000 [also called Igluliuqatigiingniq], a plan to build 3,000 new housing units across the territory by the year 2030 at an estimated cost of $2.6 billion" or $866,000 per unit.[34]

Building Deficiencies and Failures

Compounding the issues of housing shortages and unaffordability, is the serious deficiencies of the existing housing stock. Issues with existing northern housing are relevant to study in identifying common challenges that arise once buildings are completed. Poor construction quality, enclosure design, and services design are sources of failure that need to be addressed with new builds and require retrofit solutions when possible. Lori Idlout, the Nunavut MP, has made housing issues a top priority, saying "housing was definitely the biggest issue, not just to increase housing, but to address the mould crisis, to make sure that we're renovating the old houses that were built many years ago, and to also make sure that we keep our elders in our communities. It's a huge concern."[35] (see figure 2-22)

Building enclosure failures or poor enclosure design compromises building safety and comfort for occupants, and can lead to more serious problems. Leaks or condensation due to damage or poor design, allows warmth to escape more by air leakage or damaged insulation, increasing energy costs. Mould is a prevalent issue in the North, resulting from moisture or condensation on surfaces and within the enclosure. The issue of fire safety



figure 2-22: These photos are part of former MP Mumilaaq Qaqqaq's report "Sick of Waiting" documenting the conditions of northern housing. source: Mumilaaq Qaqqaq, 2021

32 "Housing conditions among First Nations people, Métis and Inuit in Canada from the 2021 Census," Ottawa, Statistics Canada, 2022. https://www12.statcan.gc.ca/census-recensement/2021/as-sa/98-200-X/2021007/98-200-X2021007-eng.cfm

33 The Honourable Lillian Eva Dyck, et al, "We Can Do Better: Housing in Inuit Nunangat," *Report of the Standing Senate Committee on Aboriginal Peoples*. (Ottawa: Senate of Canada, Mar. 2017) https://sencanada.ca/content/sen/committee/421/APPA/Reports/Housing_e.pdf

34 "Ambitious plan to create 3,000 homes announced in Nunavut," *CBC News*, Oct. 18, 2022. https://www.cbc.ca/news/canada/north/10-year-housing-plan-nunavut3000-1.6619839

35 "New Nunavut MP Lori Idlout wants to shift territory's relationship with federal government," *CBC Radio*, Sep. 22, 2021. https://www.cbc.ca/radio/asithappens/new-nunavut-mp-lori-idlout-wants-to-shift-territory-s-relationship-with-federal-government-1.6185424

is also present when structural components are put at risk, such as damage to drywall exposing wood studs. These issues were documented extensively in former MP Mumilaaq Qaqqaq's report Sick of Waiting, in 2020.[36]

Another common point of failure is building foundations, especially surface foundations. Settlement due to permafrost variation is common and can cause many building issues including structural weakness, sloping or tilting, and damage to the building enclosure when building components are pulled apart, leading to the issues highlighted previously.[37] Foundation structural issues are a major concern as the work to repair them is much more involved and the safety issues are more critical. (see Chapter 3.3 - Structure)

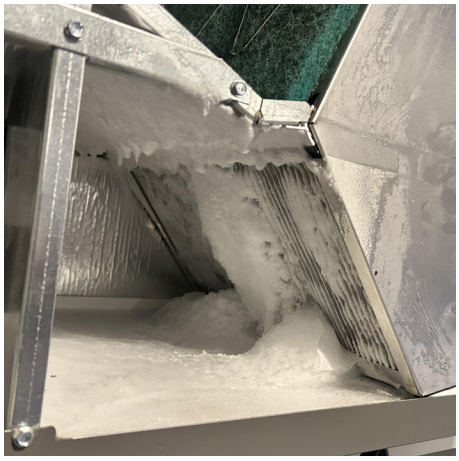


figure 2-23: HRV covered with frost due to condensation on the unit.
source: reddit user stovebolt6, 2024

Building systems are critical for life in the North, and when failures arise they can cause serious health and safety effects for users, and can be difficult to repair or operate, making them a key point of concern. Ventilation in particular is an important but poorly understood system, and is a frequent source of issues. Failures or misuse can lead to moisture problems, and its proper operation is important to ameliorate these ill effects. (see figure 2-23)

These issues with the existing housing stock, combined with housing shortages and unaffordability, demonstrate the need for more funding to construct new builds, and to repair existing buildings. Common sources of failure also indicate points of focus for future proposals in the North. The climate causes significant challenges for buildings, particularly the cold and permafrost, however improved enclosure and foundation design can help address these issues. Building systems are another important consideration and improved maintenance and operation will improve outcomes, leading to more efficient and durable buildings. New housing builds have been shown to have a significant positive effect for their users, both for mental and physical health, demonstrating the important downstream effects of high quality housing.[38]

36 Mumilaaq Qaqqaq, *Sick of Waiting - A Report on Nunavut's Housing Crisis* (Iqaluit: Member of Parliament for Nunavut, Mar. 25, 2021)

37 Jason McMillan and Lola Sheppard, "Unsettling Ground: Arctic Urbanism on Fluid Geology," *Études Inuit Studies* 44, no. 1/2 (2020): 191. https://www.jstor.org/stable/27078829

38 Mylène Riva, et al, "Relocating to a New or Pre-Existing Social Housing Unit: Significant Health Improvements for Inuit Adults in Nunavik and Nunavut," *Canadian Journal of Public Health* 111, no. 1 (2020), 26. https://www.jstor.org/stable/27181111



figure 2-24: Baker Lake construction yard including trucks and frontloaders, as well as a Quonset hut garage. source: author

2.6 - Construction and Life Cycle

In addition to the shipping and transportation considerations, the lack of infrastructure also causes challenges for the construction process in the North. There is limited construction equipment and labour, and the cost of transportation for workers can be prohibitive, making construction very expensive. Similar challenges are faced in the maintenance and end of life of buildings. Labour and materials are expensive making even minor repairs costly, causing issues to go unresolved until failures arise. Demolition is also expensive and wastes potentially recyclable materials. (see figure 2-24)



figure 2-25: Midnight Sun Mosque on a barge to Inuvik via the Mackenzie River. source: Wahleed Ahmed, 2011

Construction Challenges

Construction and trades labour in the North is expensive due to the limited workforce and the high cost of flights.[39] There are also issues with finding specialized labour for building services, requiring these workers to be flown to site, increasing costs. It is also important to consider the weather conditions that workers in the North need to contend with, which causes the building season in the North to be much shorter and work days to be more unpredictable due to the harsh climate.

In some communities with more infrastructure, prefabrication is a viable process as it reduces the need for expensive on site labour. Most communities in the North are unable to take as much advantage of prefabricated buildings, as they tend to be relatively inefficient to ship given their bulk, and communities often lack the necessary lifting equipment on site. Prefabrication allows for specialized labour to work in a controlled setting and complete work that would be difficult on site, making it useful when it is available. (see figure 2-25)

The construction vehicles that are available in the North are often not perfectly suited to the job at hand as they may be too large or too small for a given job. Working around the limitations of the available equipment is a necessity. Front loaders with various tools are typically available, even in remote communities, as these are also used for unloading ships. Trucks are extremely common civilian vehicles which could supplement the limited construction equipment as they can carry building supplies and tow trailers to transport building materials.

39 "Contractor shortage stalls Nunavut housing repairs," *CBC News*, Feb. 26, 2014. https://www.cbc.ca/news/canada/north/contractor-shortage-stalls-nunavut-housing-repairs-1.2551792

Due to the permafrost, drilling foundations and moving earth is difficult and requires larger machines than might be needed for unfrozen sites. For pile foundations, air-track drills are typically available in larger communities. (see Chapter 3.3 - Structure) (see figure 2-26)

Given the costs and challenges associated with the transportation of equipment and labour to the North, buildings that can be built with local equipment and labour are preferred, as it increases the productivity of the limited building season. This also serves to stimulate the local economy, and allows for input from people who are familiar with the local setting. Due to the varying availability of labour and machinery across the North, determining viable construction processes early is important.



figure 2-26: Airtrack drill in Nunavut and front loader for pile installation. source: Canadrill Limited

Maintenance Challenges

The North challenges buildings and services, thus ensuring that buildings are durable, and repairable when they do fail, is critical. If upkeep requires specialized labour or parts, it is expensive or may be entirely impossible at times. This operation and maintenance is a critical consideration to ensure a successful project over its life cycle.

The building enclosure is critical to keep users comfortable, as well as protect the structure from the environment. Because of this, maintaining the building enclosure is important, as it reduces the risk to critical components such as the structure and services. This repair process must be made simple and economical, to avoid the necessary maintenance being postponed. (see Chapter 2.5 - Deficiencies of Northern Housing) (see figure 2-27)



figure 2-27: Damage to roofing due to a wind storm in Iqaluit. source: Beth Brown, 2018

Repairs on destabilized foundations, if adjustment is not built into the foundation system, can be extremely expensive and may require heavy equipment. Some foundation types simplify this issue, making releveling a process homeowners can undertake, but this requires people to work outside and to understand the process, requiring more work on the part of residents.[40]

Building systems are important, but can be vulnerable and are more complicated to repair, making them a particular concern. Ventilation systems and heating systems are critical services that require upkeep, such as clearing frost on HRVs or repairing fuel tank stands. Greater attention is required from users due to the cold, and improperly installed or protected equipment can cause major environmental and safety problems.[41] Building systems do not

40 Isenegger, J.A. *Final Report to CMHC of the Multi-Point Space Frame Foundation Monitoring and Analysis*, report for Canada Mortgage and Housing Corporation (Winnipeg: Reid Crowther & Partners Limited, Mar. 1989). https://publications.gc.ca/collections/collection_2022/schl-cmhc/NH17-280-1989-eng.pdf

41 John Last, "How an Iqaluit homeowner's leaky tank cost her $250K," *CBC News*, June 14, 2019. https://www.cbc.ca/news/canada/north/iqaluit-leaky-tank-costly-1.5174545

have the infrastructure in place for proper upkeep, and users may not fully understand their operation, meaning issues commonly go unreported until the problem is already severe.[42] Keeping equipment accessible so that repairs are convenient is necessary to ensuring long term performance.

Maintenance in the North can be complicated, particularly when specialized labour is needed. Because of this, maintenance needs often go ignored, increasing life cycle costs compared to routine maintenance. Making repairs economical and convenient will dramatically improve the longevity of buildings, and will improve building energy performance, making repairability an important consideration for architecture in the North.



figure 2-28: A house in N'Dilo, NWT which caught fire in 2017 has not been cleared as there is nowhere to put the waste except for the local landfill. The fire started due to a faulty wood stove. source: Adam Gordon, 2019

Waste and Recycling

Shipping goods to the North is very expensive, and the same is true of return trips, meaning that shipping garbage or recyclable materials to be processed is unviable. From an environmental and economic perspective this is not ideal, as many materials that could be recycled or reused at their end of life are put into landfill and burned, releasing harmful chemicals when products such as insulation and membranes are burned. Derelict or damaged buildings that have not been removed can also pose serious safety risks with highly flammable materials, gas leaks, and structural failures. Simplifying disassembly to reduce waste and, more generally, to account for this end of life process, are worth considering for improving the environmental impact of northern architecture. (see figure 2-28)

42 John Hockman, *Survey of HRV/ERV Performance Issues in Canada's Near North and Far North: Final Report*, report for Canada Mortgaga and Housing Corporation (Winnipeg, JL Hockman Consulting inc., 2016). https://yukon.ca/sites/yukon.ca/files/yhc/yhc-hrv-erv-performance-issues-canadas-north-report.pdf

2.7 - Conclusion

The challenges of the North are varied and severe. The climate is one of the harshest on earth, with some of the coldest temperatures in the northern hemisphere, and high winds and snowdrifts. Government promises for support are unmet, and a legacy of poor treatment for Inuit and First Nations in the North has led to economic and political difficulties. There is extremely limited infrastructure for transportation and shipping, often just a few plane trips each month, and a few sealifts each year leading to high costs for goods and services from southern Canada. Utilities infrastructure for building services is also limited, leaving users vulnerable to water, electricity, and fuel shortages. When building is possible, the process is complicated due to the difficulty of transporting materials, limited labour, and the lack of machinery. These challenges have led to housing shortages, and a failing existing building stock that desperately needs new builds and extensive repairs. Buildings in the North must be high performance, while remaining economical to construct, operate, and maintain. There are many well-documented best practices, and an understanding of these is critical for architects, especially for those proposing novel solutions. The people of the North rely on their homes for shelter in a fundamental way. To serve them, architects must fully understand the compounding challenges of the northern context and how they affect the practice of architecture in the North.



figure 2-29: View of Iqaluit, looking south to Koojesse Inlet. source: Adam Gordon, 2022




204
206



figure 3-01: Brightly clad houses in Inuvik, NWT. source: John Straube

Chapter 3
Practices and Guidelines for Building in the North

3.1 - Introduction

As described in Chapter 2, the North challenges architecture in unique ways and an understanding of established practice in addressing these challenges is critical to developing improved design methods. Buildings can be divided into three general elements, structure, enclosure, and systems, all of which are affected by the northern context. While codes and guidelines necessarily lag behind the most contemporary research, and new building materials and practices are promising, established methods are critical to understand as they have a track record of success. This reliability is paramount for buildings in the North.

3.2 - Codes and Guidelines

The building code governing the North is generally the National Building Code of Canada (NBCC). The three territories, and Labrador which includes Nunatsiavut, enforce the NBCC, while Nunavik follows the Quebec Construction Code (RBQ).[43] The National Energy Code of Canada for Buildings (NECB) is an energy code intended to improve energy efficiency with requirements based on climate. While the NECB does not legally govern architecture in the North, it is useful to consider for environmental and building science information. Each of the territories also publish extensive building guidelines updated approximately alongside the NBCC. These guidelines are not legally binding, but are intended to detail the many concerns for northern architecture and provide best practice recommendations. The guidelines also include social and economic considerations, encouraging the use of local labour and user serviceable maintenance, which are especially important in the North.

It is important to note that building codes and guidelines are not the full requirements of a high performance building. Instead they are simplified and enforceable requirements, and are often the minimum standard, especially in cases such as the extreme climate of the North. Primary attention must be paid to the needs of a project, rather than code prescriptions. (see figure 3-02)

43 "Model Code Adoption across Canada," National Research Council of Canada, October 24, 2022. https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada/model-code-adoption-across-canada



figure 3-02: Northern building guidelines. source: Governments of Nunavut, Northwest Territories, and the Yukon

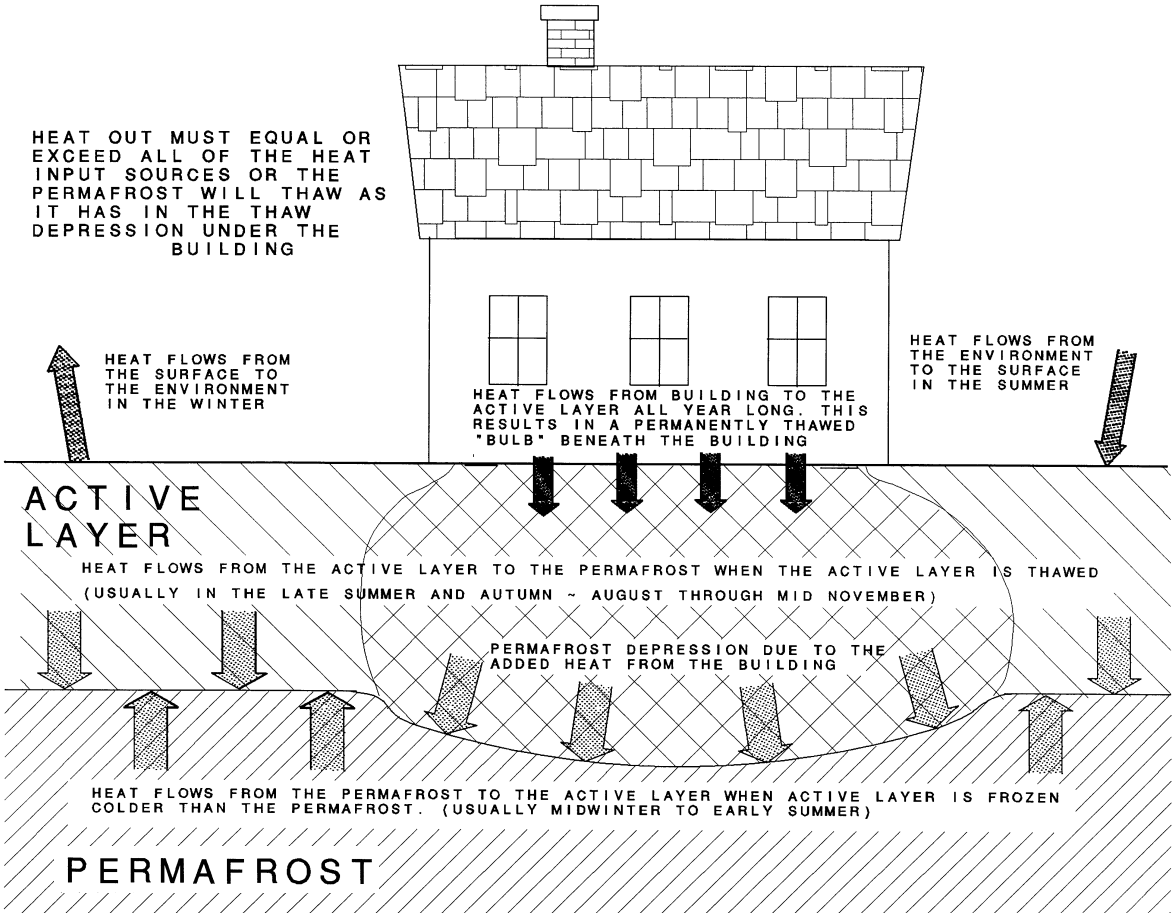


figure 3-03: Diagram of permafrost foundation design considerations. source: CCHRC, 2000

3.3 - Structure

To succeed in the North, the building structure must be able to accommodate the many challenges of the North while remaining economical in materials, transport, and construction costs. The structural system of a building is a large component of its weight and thus greatly affects transportation costs and constructability. Foundations in particular are complicated by permafrost, requiring greater consideration and expertise.[44] For the building superstructure, light wood framing is common, especially for residential and other small projects, given that it is economical in materials and transportation, and is well understood by available labour. However, consideration for building energy performance and longevity may make other options more appropriate such as steel, mass timber, or engineered wood products. The effects of climate change are also increasing the demands placed on the structure of buildings in the North, as snow and wind loads increase and permafrost becomes unstable.

Foundations

Permafrost and seasonally frozen ground complicates foundation construction across the North. Many issues taken for granted in southern Canada with respect to building substructure, underfloor building enclosure, and building services need to be reconsidered. On permafrost, care must be taken to avoid thawing the ground underneath the building, causing settlement. This is accomplished by thermally isolating the building from the ground, usually on raised foundations. Permafrost is also changing due to climate change, damaging foundations and challenging future design.[45] (see figure 3-03)

Surface foundations are commonly used for projects in the North, as they are economical to construct and are structurally sufficient. Typical surface foundation systems include: post and pad, pad and wedge, and space frame or multipoint systems in steel or aluminium.[46] Surface foundations are designed to be adjustable to accommodate the inevitable shifting that occurs in permafrost ground, and building guidelines recommend a minimum of

44 Canadian Commission on Building and Fire Codes, *National Building Code of Canada 2020*, Vol. 1 (Ottawa: National Research Council of Canada, 2020) Div B, Part 4, section 4.2.4.10, 85.

45 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part E, section 3.1, 64.

46 J.A. Isenegger, *Final Report to CMHC of the Multi-Point Space Frame Foundation Monitoring and Analysis*, report for Canada Mortgage and Housing Corporation (Winnipeg: Reid Crowther & Partners Ltd., Mar. 1989), 3. https://publications.gc.ca/collections/collection_2022/schl-cmhc/NH17-280-1989-eng.pdf

100 mm of adjustability.[47] For projects such as fire halls and garages which are typically unheated, a slab on grade is an acceptable option, but in general concrete is unviable for the North, due to the weight and labour required. (see figure 3-05)

Pile foundations are becoming the preferred foundation system in the North, especially for large buildings, as they are less susceptible to settlement due to permafrost shifting. However, piles are more difficult to construct due to the limited machinery and the difficulty of drilling into frozen ground. Pile types used in the North are usually rock socketed piles or adfreeze piles. Driven or helical piles may be appropriate in non-permafrost and warm permafrost regions, but are likely unviable in solid permafrost.[48] Adfreeze piles are a unique option for the North when socketing to bedrock is not possible in which the pile is inserted into a water saturated slurry, freezing into the permafrost. Adjustable pile caps are still recommended for adfreeze piles to accomodate permafrost settlement. (see figure 3-06)

Actively cooled foundations, which keep the permafrost frozen, are another option for northern foundations, especially in places where climate change is affecting the permafrost layer. Thermosyphon slabs and thermopiles make use of a thermosyphon system to cool the ground, improving permafrost stability.[49] For all permafrost foundations, performance monitoring is recommended, as well as the sharing of this data to improve the information available for future designers.[50] (see figure 3-04)

The challenges of permafrost and seasonally frozen ground make foundation design complicated and often unstable. The ability for foundation systems to adjust to ground instability is critical for long term performance in the North as enclosure or structural failures are a common result of foundation issues. Foundations are an important component of any building structure, especially in the North, and these complicated issues for foundation design need to be considered early in a project's life cycle.



figure 3-04: Adfreeze piles with thermosyphons improve permafrost stability in vulnerable soil, seen here at the Trans-Alaska pipeline.
source: John Straube

47 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part E, section 3.3.7, 71.
48 Ibid, 66.
49 Christine Harries "The Future of Building Foundations in the Canadian North." *Building Tomorrow's Society* (Fredericton: Canadian Society for Civil Engineering, 2018), 5.
50 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part E, section 3.3.1, 69.

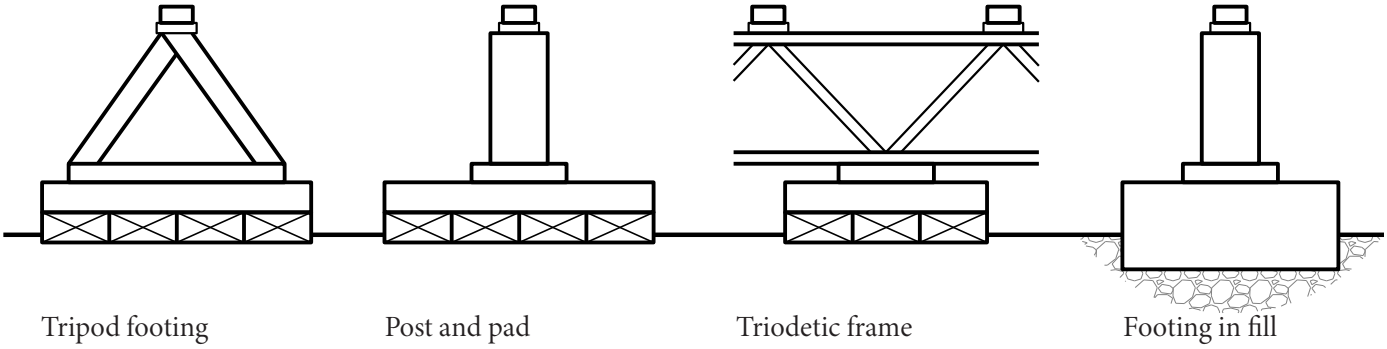


figure 3-05: Common surface foundations.
source: author

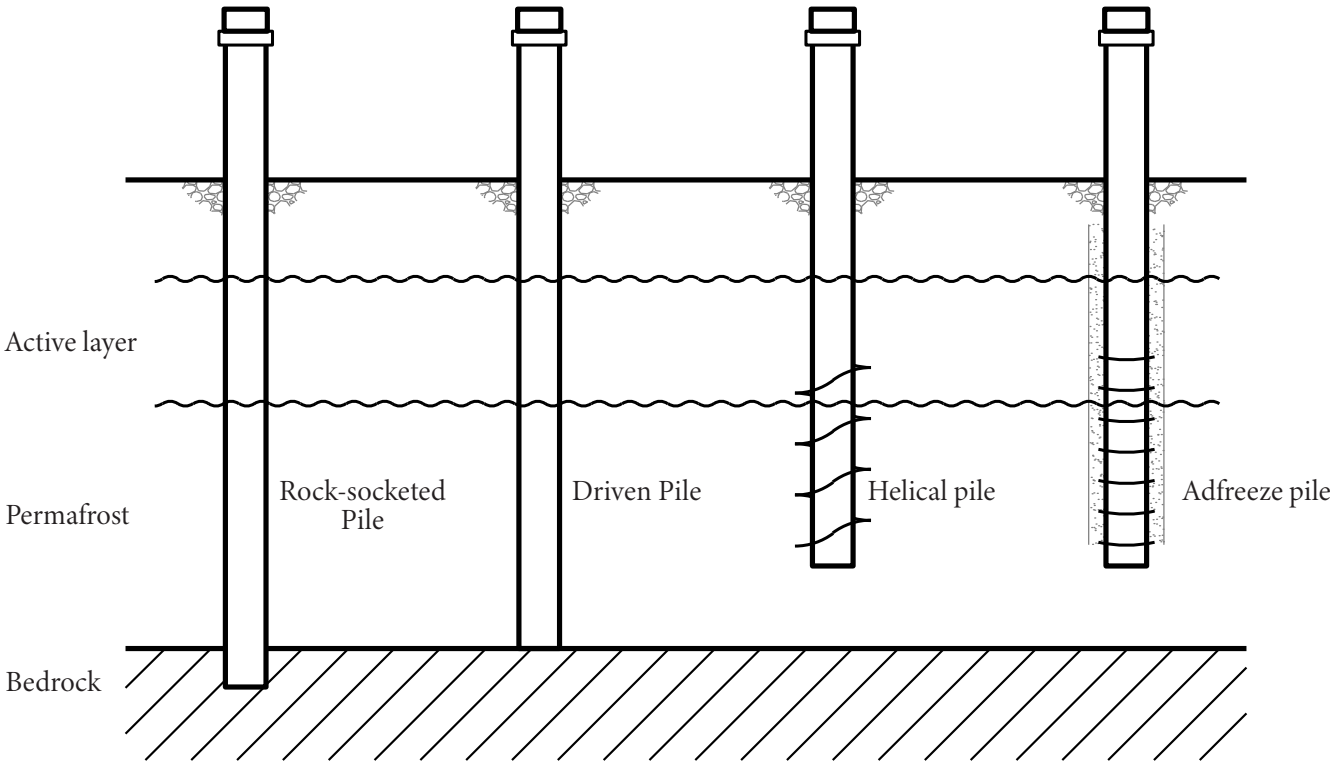


figure 3-06: Common pile foundations.
source: author

Walls

The winds and snowdrifts in the North can place high lateral loads on walls, in addition to increased vertical loading due to roof snow loads. Exterior walls also require careful coordination with the building enclosure and building systems as poorly insulated areas can lead to vulnerabilities such as condensation and can weaken energy performance.

Conventional wood framing is ubiquitous in the North given its versatility, suitable strength, and economy in transportation, construction, and materials. Wood structures can be constructed rapidly by the labour available in communities of the North.[51] Limitations on structural capacity, damage from moisture, and warping are potential issues of wood framing that should be addressed. Wood is less conductive than steel structures, however studs create thermal bridges, thus exterior insulation is recommended. (see figure 3-07)



figure 3-07: Wood framing is common in the North as it is simple and economical, the lightweightness of wood framing reducing shipping costs.
source: John Straube

Structural insulated panels (SIPs) are useful as infill panels or as a structural system for the North. SIPs are composed of a foam core, typically a polystyrene or polyurethane foam, which is sandwiched between sheathing, usually OSB. These panels can have excellent thermal and airtightness performance due to this foam core, however joints between panels are a key point of concern, and this is where the majority of quality control is needed for this system.[52] Fire safety is also a concern with SIPs due to their combustible structural foam core. Although SIPs have been a promising system for the North since 1960, they have not become a widespread solution.

Steel construction is a reasonably common option for larger buildings in the North, however it is necessary for designers to consider the machinery and labour available in communities before using a steel structure. The increased weight of steel structures also incurs additional shipping costs. Steel stud framing is acceptable, however increased thermal conductivity and limited local labour knowledge necessitates more detailed consideration. With building enclosure best practices, thermal bridging can be addressed, making steel studs an acceptable option.[53] (see figure 3-08)



figure 3-08: Canadian High Arctic Research Station under construction, built in a steel frame.
source: user CambridgeBayWeather on wikipedia

51 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part G, section 6, 107.
52 "Structural Insulated Panels in Alaska," Cold Climate Housing Research Center, Mar. 2015, 24. https://cchrc.org/media/SIPs_Report.pdf
53 *Good Building Practices Guidelines*, 3rd ed. (Iqaluit: Government of Nunavut, 2020), Part S, section 5, S-9.



figure 3-09: Nunavut legislative assembly, with glulam and timber structure.
source: Adam Gordon, 2022

Mass timber structures are acknowledged by the northern building guidelines as a good option, especially for spans and loads that cannot be easily handled by light wood framing.[54, 55] Timber frame structures with non-structural walls, such as SIPs or framed infill, are another option that can offer performance improvements. While the materials tend to be more expensive and heavier, potential performance improvements and construction savings, and greater structural capacity make this system a good option in some circumstances. (see figure 3-09)

Concrete is uncommon in the North due to its weight and the difficulty of its production in most communities. Concrete masonry units, prefabricated panels, and tilt up panels are possible but they are expensive to ship, and difficult to work with due to their weight.

Roofs

Roofs are also expected to contend with high winds and snow loads, and while long spans are uncommon in the North, large structural members come with difficulties in transportation and construction, meaning that lighter, more efficient, structural systems are needed. Building enclosure design for the roof is also a common point of difficulty as water ingress must be avoided, and roofing design with "perfect enclosure" principles is not well understood by builders.

Wood structures are also common for roofs, including low slope roofs, due to the advantages of wood framing in the North. Prefabricated or site fabricated wood trusses can offer structural efficiencies, making them a good option for roof structures as they are reasonably lightweight and the

54 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part G, section 6.4, 108.
55 *Good Building Practices Guidelines*, 3rd ed. (Iqaluit: Government of Nunavut, 2020), Part S, section 4, pg S-8.

materials are inexpensive.[56] Engineered wood joists or rafters can offer greater strength, and more resistance to moisture or warping, than typical lumber, and are recommended by all northern building guidelines due to these advantages, particularly for the strength to weight ratio as this saves shipping costs and simplifies construction.[57, 58, 59] (see figure 3-10)

SIPs are also an option for roofs as they can support large spans and can form an effective air and thermal control layer. Construction detailing at panel joints is particularly important for SIPs roofs as they are more vulnerable to condensation issues than other methods. Additional exterior insulation is useful to avoid condensation issues caused by imperfect interior sealing.

Steel roof structures are another viable option, but similar to walls, consideration should be given to the labour and machinery needed. Open web steel joists (OSWJ) are an effective structural component for roofs given their strength to weight ratio, allowing for a lightweight component with long spans. (see figure 3-11)

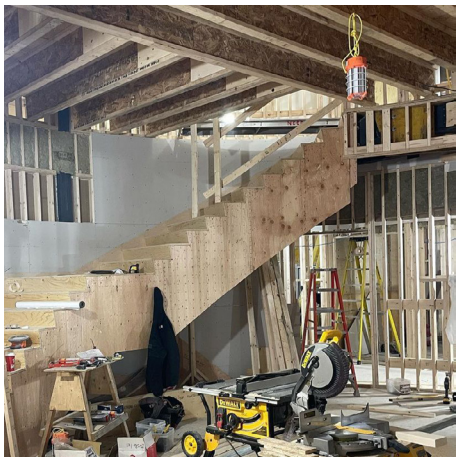


figure 3-10: Engineered wood joists are a good option for roofs and interior or exterior floors as they have greater strength to weight than lumber, reducing weight, saving transportation costs. source: Lateral Office, 2022



figure 3-11: Open web steel joists make a lightweight roof or floor structure, and are a good option but increased conductivity is a concern and continuous exterior insulation is recommended. source: Groupe Canam

Floors

For floors, coordination between structure, building enclosure, and building services is critical, due to the need for raised foundations, and the exposure that comes as a result. Foundation points also complicate floor structures as there are only a limited number of solid points to connect to, rather than typical foundations in southern communities which provide a line of support. Longer floor spans are useful in the North as this reduces the number of footings or piles, simplifying construction and maintenance, with fewer points to level over time as foundation settlement occurs.

Typical wood framing is common for floors, however engineered wood joists and trusses offer greater strength to weight, allowing for lighter members and longer spans.

SIPs are particularly appropriate for floor structures, as they allow for long spans due to the high bending resistance for their weight, and can provide strong insulation. The lack of voids within the floor can complicate plumbing or duct integration, requiring an additional false floor. Longer spans, reducing foundation points, and issues of floor flex are solved with a deeper foam core, which also improves insulation. (see figure 3-12)

56 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part G, section 6.3, 108.
57 Ibid, 110.
58 *Good Building Practices Guidelines*, 3rd ed. (Iqaluit: Government of Nunavut, 2020), Part S, section 4.1.1, S-8.
59 *2022 Design Requirements and Technical Standards*, 2nd ed. (Whitehorse: Government of Yukon, 2022), Part 3, section 3.1, 94.

Steel floor structures are a good option for larger buildings, as they can accommodate long spans and increased structural requirements, however transportation and construction may be more expensive due to increased weight. Fluted steel sheets and OWSJ are an effective structural system for floors, as the long spans permit fewer foundation points. Because of the high conductivity of steel, exterior insulation is required to avoid thermal bridging.



figure 3-12: UW Architecture design-build course in 2023 made use of SIPs, allowing the team of students to construct the tiny house simply and rapidly, the floor structure taking just one day. source: author

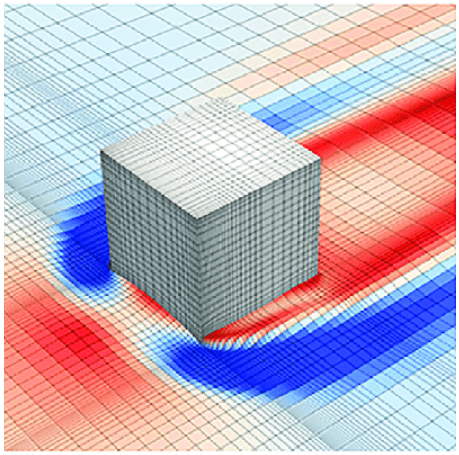


figure 3-13: Snow distribution due to building aerodynamics, red areas indicating largest snow pileup. source: C. Xiaoxiao, Z. Yu, 2022

Wind and Snow Loads

Buildings in the North must be designed to contend with the high winds and snowdrifts that can build up on buildings and exert significant loads that must be accommodated by the building enclosure. Aerodynamics of buildings in the North is an important consideration for wind loads and especially for snowdrifting.[60] Shallower roof slopes reduce rain and wet snow shedding, however they allow for wind sweeping of dry snow pileup on the roof, more common in the North. Low slope roofs also present a smaller frontal area to winds, reducing wind loads, as well as reducing snow pileup on the leeward side of the building. Raised foundations also improve aerodynamics and wind sweeping by allowing wind to flow under the building, reducing snow buildup.[61] (see figure 3-13)

Climate change is increasing the wind and snow loads in the North, due to the warming of the Arctic. Increasing temperatures are increasing the precipitation overall, and particularly increasing the severity of rain and snowstorms.[62] Increased snowfall will also tend to be wetter, increasing the loads exerted on roof structures, as well as loads exerted by snowdrifts.

The harsh climate of the North challenges building structures with high winds, snow loads, and permafrost. Compounding these challenges is the difficulty of transportation and construction in the North, making lightweight solutions preferable. Climate change is increasing wind and snow loads, and disrupting permafrost, further challenging structures in the North. Architects and engineers must understand established best practices, as well as promising novel systems and materials, to develop appropriate solutions to address the many challenges for structural design in the North.

60 Lola Sheppard and Mason White, "Arctic Architecture: Standards, Experiments, and Consensus," chapter in *Canadian Modern Architecture: 1967 to the Present* (New York: Princeton Architectural Press, 2019), 365.

61 *Housing Construction in Nunavik - Guide to Good Practices*, 1st ed. (Quebec: Société d'habitation du Québec, 2017), Section 3.3.1, pg 12

62 John E. Walsh, et al, "Ongoing Climate Change in the Arctic," *Ambio* 40 (2011), 6. http://www.jstor.org/stable/41418322

3.4 - Enclosure

The building codes and guidelines of the North naturally deal extensively with the building enclosure given the demands placed on its performance, and the harsh environment it must contend with. Insulation is a key consideration, however recent building science research has put greater attention on issues of airtightness, detailing, and preventing condensation to improve the performance of northern buildings. In addition to the necessary enclosure functions, important considerations for the North are durability and maintenance, as well as transportability and constructability. Given the difficulty of building in the North and the challenges of such a harsh climate, these become vital concerns for architecture.

Perfect Enclosure System

The methodology of building enclosure design promoted by the building guidelines and codes is referred to as the "perfect wall system" or "perfect enclosure system." The perfect enclosure is a design aid in which required functions of the building enclosure are conceptualized as distinct layers which fully enclose the building and its structure. A proposed building enclosure is required to detail how it will fulfill the necessary functions to form a continuous system, protecting both the occupants and the building itself from environmental damage.

The control layers of the building enclosure can include many different functions, but the most common perfect enclosure system "has the rainwater control layer, the air control layer, the vapor control layer and the thermal control layer on the exterior of the structure."[63] Fire is also a priority but is not commonly thought of as a control layer within the building enclosure and is seen as part of the overall construction, however treating fire control as a distinct layer is useful as it ensures there is continuous fire protection. Finish functions fulfill the aesthetic requirements for users, with cladding often serving additional control purposes such as UV and physical damage protection, while also delivering the finish function. (see figure 3-14)

Building enclosures in the North need to perform well in the harsh climate, keeping users comfortable, and protecting the building itself. The "perfect enclosure system" is used to ensure the necessary functions of the building enclosure are met, and maintains a focus on ensuring continuity of the control functions and simplifying communication between designers and builders regarding this key building element.

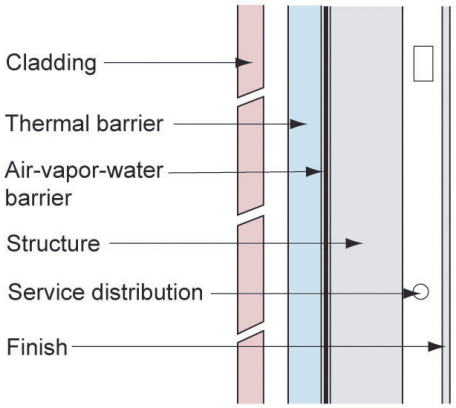


figure 3-14: "Perfect Enclosure" design, showing enclosure components including control layers, structure, and finishes. source: John Straube, 2012



figure 3-15: Project in BC with wood framing and exterior insulation. source: Patrick Walshe, 2013

63 Joseph Lstiburek, "Building Science Insight 001: The Perfect Wall," BuildingScience.com Corporation, July 15, 2010, https://buildingscience.com/documents/insights/bsi-001-the-perfect-wall

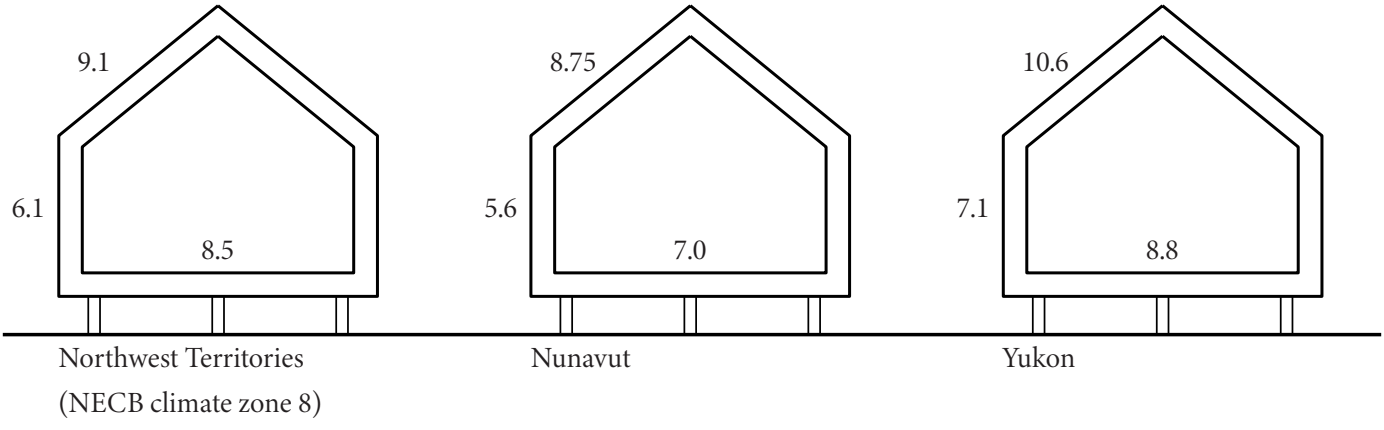


figure 3-16: Insulation requirements under building codes and guidelines. source: author

Thermal Control

Warmth is the most immediate concern for architecture in the North. Building equipment can provide plenty of heating but thermal control is critical for comfort, efficiency, and resiliency. The need to avoid thermal bridging is becoming better understood, but is often not fully executed. The "perfect enclosure system" highlights the need for thermal control continuity, which can significantly improve overall performance. These performance gains are possible without the need for specialized labour or large cost increases, making them necessary considerations for enclosure design in the North.

The NECB and northern building guidelines prescribe minimum thermal control requirements for building assemblies. NBCC 2020 takes thermal bridging into account and also sets minimum effective thermal performance values.[64] The GNWT building guidelines refer to the NECB for insulation requirements.[65] The Nunavut and Yukon building guidelines differ from the NECB and GNWT guidelines, with the Yukon guidelines setting the highest minimum baseline. It is important to note that these standards are based on nominal insulation and are a minimum, requiring energy modelling for a more optimized enclosure design to fit the specific climate of a project. (see figure 3-16)

The specific choice of insulation will depend on factors such as the structural system, other functions such as fire or sound control, and economics, including weight which affects shipping costs. While historically uncommon in southern regions, externally insulated wood frame buildings are becoming more common in the North due to the improved performance and relative affordability. This avoids thermal bridging through studs, which causes condensation, especially in the North where the temperature differences between interior and exterior are much greater. (see figure 3-15)

64 Canadian Commission on Building and Fire Codes, *National Building Code of Canada 2020*, Vol. 1 (Ottawa: National Research Council of Canada, 2020), Div. B, Table 9.36.2.6.-A, 9-241.

65 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part H, section 1.2.1, 131.

A specific consideration for roof insulation is the use of an unvented roof assembly or a ventilated attic system. Insulated attics, a more typical construction method, uses attic space for insulation, with air and vapour control at the interior ceiling, and water control on the exterior face of the roof. Air and vapour sealing is often inadequate leading to moist air in the attic which condenses on the cold roof, leading to rot and mould. In southern regions, this can be easily ventilated, however in the North ventilation allows snow ingress and so is not recommended.[66] Insulated, unventilated roof assemblies are constructed similarly to walls with insulation, and air, vapour, and water control all performed in the same compact assembly. Insulated roof assemblies, especially exterior insulated assemblies, reduce the need for ventilation and simplify overall enclosure continuity.

Raised foundations require floors to fulfill the same enclosure functions required of walls and roofs, thus more insulation is required than with typical foundations due to the increased exposure.

Building codes across Canada are being updated to incorporate current building science knowledge and real-world thermal performance. To this end, continuous exterior insulation is strongly recommended across the North, in accordance with "perfect enclosure" principles. All of the northern building guidelines also make extensive recommendations with respect to the placement and assembly of insulation, minimizing thermal bridging and the risk of condensation and improving energy performance.



figure 3-17: Tyvek housewrap in progress on a project in Cambridge Bay. source: Jane George, 2010



figure 3-18: Ventilated rainscreen installation on a project in Iqaluit. source: John Straube, 2019

Water Control

While the North is mostly a dry climate with little precipitation, the precipitation tends to fall as snow, changing the nature of water control in northern building enclosures. Any water ingress that does occur can freeze within the wall assembly, causing issues for energy performance. The northern building guidelines focus on wind driven moisture, as rain or snow, and the issue of draining snowmelt within the enclosure.

Northern building guidelines recommend Pressure Equalized Rainscreens (PER) or Pressure Equalized Rainscreen Insulated Structure (PERSIST) which make use of compartmented air spaces behind the cladding to mitigate exterior wind pressure across the cladding and allow any water that penetrates the cladding to drain out. Most importantly, PERSIST systems have continuous exterior insulation and a waterproof drainage layer. Climate change is increasing these drainage and water resistance demands as

66 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part H, section 1.1.7, 130.

precipitation and meltoff increase.[67] It is likely that ventilated rainscreens are a more effective solution as they are better understood by labour, and allow for larger wall cladding panels such as sheet metal, offering economic benefits and simplifying labour. (see figure 3-17, figure 3-18)

Roofs are the primary place for water ingress failures as they are subjected to high winds and snow pileup. Due to the need for windsweeping and lightweight structures, wood framed low slope roofs are more common than in southern regions. Much like wall assemblies, exterior insulation dramatically improves performance and thus should be incorporated into roof designs, both for low slope and pitched roofs. (see figure 3-19)



figure 3-19: Low slope roof that has rotted due to moisture ingress caused by a failed roof membrane water barrier.
source: Thomas W. Hutchinson, 2017



figure 3-20: Construction in Yellowknife using a tape sealed sheathing product as the primary air barrier.
source: Adam Gordon, 2018

Air Control

The importance of the air control layer in the building enclosure is widely recognized as "the energy impact of air leakage is significant and must be considered."[68] However across the North and Canada at large, requirements for airtightness vary significantly and the building science is not perfectly understood by labour. The application of NECB and NBCC requirements vary between the territories and the measurement method also varies, complicating comparison. Further, actual building construction often does not meet these standards and testing is relatively uncommon, making air control a particularly important consideration for improving energy performance in the North. Smaller tests using infrared cameras or smoke tracer observation may be simpler to incorporate on challenging sites.

The NECB specifies maximum assembly and building-wide leakage rates, however the NECB airtightness requirement of 1.5 L/(s×m^2)@75 Pa, is likely not stringent enough for the North. Smaller buildings have a greater surface area to volume ratio compared to larger buildings, meaning that for the same air leakage rate per square metre of enclosure, a smaller project will lose proportionally more air, and thus heat energy, making this minimum requirement a relatively weak standard for smaller projects. Across the North, exterior insulation and exterior air and vapour barriers are recommended as this improves thermal performance and reduces condensation within the building structure.[69] (see figure 3-20)

67 *2022 Design Requirements and Technical Standards*, 2nd ed. (Whitehorse: Government of Yukon, 2022), Part 3, section 2.1.2, 53.
68 John F. Straube and Eric F.P. Burnett, *Building Science for Building Enclosures* (Westford, MA: Building Science Press, 2005), 205.
69 *Good Building Practices Guidelines*, 3rd ed. (Iqaluit: Government of Nunavut, 2020), Part A, section 3.6.3.(1), A-21.

Vapour Control

The vapour control layer tends to tolerate larger gaps than air control without causing significant performance or durability issues. In the North, due to the extreme temperature and vapour pressure differential, vapour diffusion is of greater concern than in southern Canada. Vapour issues can be especially problematic as condensation can cause mould which has been an issue for users in the North, though most of these issues are a result of poor air control, rather than vapour diffusion.

The NBCC requires a vapour barrier, and recommends placing it on "the warm side" of the enclosure, most commonly the interior so as to avoid condensation.[70] Colder climates tend to simplify this issue of placement because the vapour pressure differential is nearly always from the interior to the exterior, whereas it tends to change during the summer in more temperate climates. The northern building guidelines reference the NBCC with regards to vapour control and its installation.[71] (see figure 3-22)



figure 3-21: A home in Qikiqtarjuaq, Nunavut with a small window to wall ratio and inset door to protect from snow. source: Sarah Kokseak, 2018

Fire Control

Fire safety is a major concern in the North, as there is limited firefighting infrastructure, and repairs to damaged homes can take a long time given the limited shipping infrastructure. Building guidelines across the North highlight issues of protecting combustible material. Another concern is the issue of firefighting in the extreme cold. Systems such as sprinklers and fire hoses need to be protected from freezing and products that are susceptible to freezing should be avoided, even for indoor settings. Climate change is leading to greater issues of forest fires, thus fire resistant building enclosures are beneficial in areas at risk, such as the Yukon and Northwest Territories. (see figure 3-23)

Openings

The weakest part of the building enclosure tends to be windows and doors, and their connection to the rest of the building enclosure, and poor construction can lead to significant energy losses. In the North these construction difficulties and enclosure weaknesses are compounded, making them a key point to address. (see figure 3-21)

The northern building guidelines set performance requirements for windows and doors but are particularly concerned with issues of durability,

70 Canadian Commission on Building and Fire Codes, *National Building Code of Canada 2020*, Vol. 1 (Ottawa: National Research Council of Canada, 2020) Div B, Part 9, section 9.25.4.3, 168.

71 *Good Building Practices Guidelines*, 3rd ed. (Iqaluit: Government of Nunavut, 2020), Part A, section 3.1.6.(3), A-8.

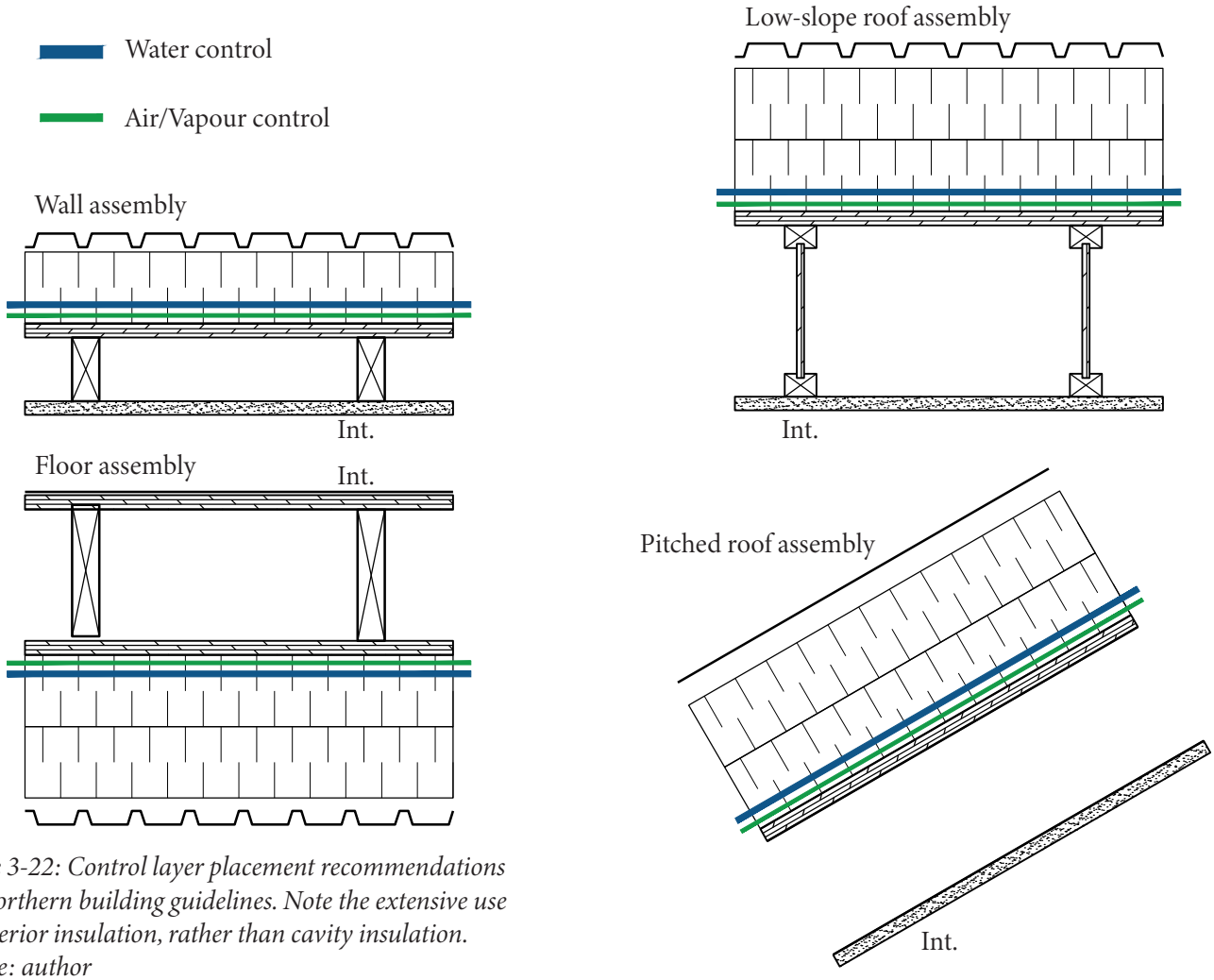


figure 3-22: Control layer placement recommendations per northern building guidelines. Note the extensive use of exterior insulation, rather than cavity insulation. source: author



figure 3-23: RDH testing on cladding resistance to forest fires, 20 minute test. source: RDH Building Science, 2024

transport and buildability. Issues of vandalism and forced-entry are a major concern, and the durability to deal with this is a key consideration.[72] Consistent sizing and smaller windows are frequently suggested across the building guidelines as this reduces the cost and simplifies initial construction and potential replacement.

Cladding and Finishes

Cladding should be selected to work well with the rest of the enclosure system, while also addressing the challenges of the North. Lightweightness is important to reduce shipping costs and construction effort, and durability and repairability are useful as cladding can be damaged by wind, snow, vehicles, and UV exposure. Lower portions of buildings are more vulnerable to impacts and GNWT guidelines recommend more durable finishes at the lower 1.2 m of a project.[73] Cladding patterns, fasteners, joints, and penetrations are points of complication that should be simplified to ensure quality installation and repairability. In most of the North sheet metal cladding is considered a good option, as it is durable, economical, and simple to patch or replace.[74] (see figure 3-24)



figure 3-24: Steel cladding at the Iqaluit Aquatic Centre, completed in 2017, designed by Stantec.
source: Jeff Pelletier, 2023

Wood cladding is another common option for northern projects, due to its economy and sufficient durability. Wood cladding requires more maintenance than other options, but is more impact resistant and the installation is simple, making it a good option.[75] Other possible cladding systems include fibre reinforced cement or plastic panels, metal composite panels, or Insulated Metal Panels (IMPs). (see figure 3-25, figure 3-26)

Cladding choices for roofs are relatively limited, and low-slope roof membranes are often left exposed. Lapped steel sheet metal roofing in 24 ga is considered best practice for pitched roofs by northern building guidelines. IMPs are also viable, offering a lightweight high performance roof system, however IMPs tend to be more expensive than other options.

Interior finishes are similar to southern climates, but consideration should be given to ease of installation and maintenance. Interior floor finishes in particular prioritize durability and sheet flooring is generally considered best practice in most settings, often linoleum or vinyl, as these are economical, simple to install, and reasonably durable.

72 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part H, section 2.1.1, 149.
73 Ibid, 138.
74 *Good Building Practices Guidelines*, 3rd ed. (Iqaluit: Government of Nunavut, 2020), Part A, section 3.5.2, A-19.
75 Ibid, A-18.

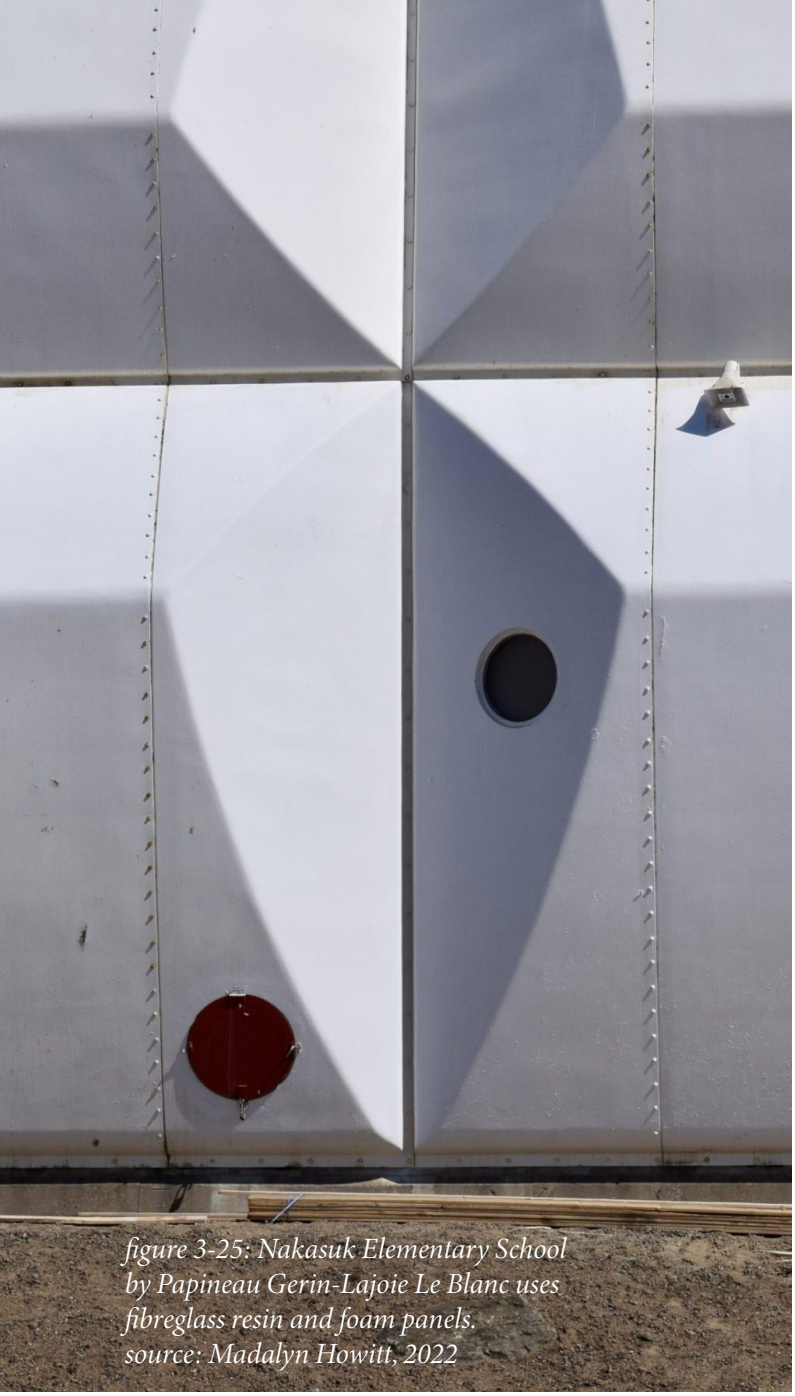


figure 3-25: Nakasuk Elementary School by Papineau Gerin-Lajoie Le Blanc uses fibreglass resin and foam panels.
source: Madalyn Howitt, 2022



figure 3-26: K'alemi Dene School in N'Dilo, NWT by Taylor Architecture Group, with replaceable fibre cement panels.
source: Ihor Pona, 2010

Building enclosure design principles are not fully understood or executed by the building industry and are a key point of consideration for improving building energy performance in the North. The "perfect enclosure system" is a useful tool for designers, as well as for communicating with builders to highlight the importance of continuity for performance and protecting the building. Insulation and airtightness are of primary concern for warmth, however other issues such as moisture ingress and condensation can create major issues for building safety and performance. In such a harsh climate, high performance buildings are a necessity, keeping users warm and dry. What qualifies as a high performance enclosure or building in southern Canada, is often the minimum standard for projects in the North. The needed performance and durability must also be balanced with construction and repair processes that can be accomplished economically and with labour and machinery available in these remote communities. Compounding these challenges, shipping building materials to the North is extremely expensive, thus size and weight considerations are critical for costs and to simplify the transportation and construction process.

3.5 - Systems

In the cold climate of the North, building services are a necessity, but the high cost of shipping fuel and generating electricity make these services expensive. Efficiency is important for reducing operational costs for users and reducing greenhouse emissions generally. This also reduces the fuel transportation and storage required. GNWT guidelines highlight the tradeoff between modern high efficiency systems and their increased specialization, which adds complexity and thus repair costs. More critical than efficiency is reliability, due to the enormous demands placed on the building services, and the difficulty of repairs or replacement. "For this reason, 'simple and reliable' mechanical systems are desirable in all buildings."[76] Additionally, monitoring systems are a critical means of identifying issues with building services. (see Chapter 2.4 - Transportation and Infrastructure)



figure 3-27: Domestic fuel tank, protected by large stones, in Iqaluit.
source: Adam Gordon, 2022



figure 3-28: NRC testing of dual core HRV in a house in the North, intended to reduce frost within the HRV.
source: NRC, 2019

Heating

Heating is a critical system for buildings in the North given the extreme cold. The reliability of the heating system is the primary concern, even at the expense of efficiency. However, fuel costs are high due to the transportation required, making fuel efficient systems important for the entire supply chain, from its transport to the North to on site storage.

Because of the need to reduce fossil fuel usage, for cost and environmental reasons, alternative heating systems such as biomass or wood pellets are acceptable, however they are unviable in much of the Inuit Nunangat due to the lack of trees and the inefficiency of shipping wood pellets.[77] Electrical resistance heating systems are expensive, due to the cost of power generation in remote communities. Electrical heat pumps are capable of high efficiency in warmer temperatures, but cold climate versions are being developed, making them viable for high performance northern buildings.[78] If there is sufficient renewable power opportunities locally, electric heating systems may be a good solution. Current northern building guidelines do not make recommendations for electrical heating. Hydronic heating systems can make use of efficient air-to-water heat pumps or diesel boilers, and can also supply domestic hot water.[79]

76 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part J, 194.
77 Ibid, 254.
78 *Energy Efficient Housing Guidelines for Whitehorse, YT: Energy Optimized House* (Canada: RDH, Nov. 24, 2016), 7.
79 Doug Picklyk, "Net Zero in Nunavut," *HPACMag*, Aug. 23, 2023. https://www.hpacmag.com/features/net-zero-in-nunavut/

Fuel Supply

Fuel for space heating and hot water must be stored in tanks at each home, making them important to consider for operating costs and building safety. Fuel is typically trucked to each house, increasing costs, making system efficiency important. Fuel tanks are usually stored outside on a tank stand, although these are vulnerable and have often failed, resulting in fire risk and environmental damage. Generally a one week supply is required, thus energy efficiency gains lead to compound savings, reducing the needed fuel delivery, allowing supply trucks to take fewer trips, and saving significant costs.[80] (see figure 3-27)

Indoor Air Quality

Indoor air quality (IAQ) is a vital consideration for building systems design in the North, as issues due to poor design, lack of maintenance, and misuse of building systems have been a major problem for users in the North (see Chapter 2.5 - Deficiencies of Northern Housing). Ventilation in particular is important in the North as airtightness is critical for enclosure performance, and contaminants such as mould, dust, and general pollutants need to be actively removed. Ventilation is critical to prevent the development of mould and to ameliorate its effects when it does occur. While Heat Recovery Ventilators (HRVs) and Enthalpy Recovery Ventilators (ERVs) are beneficial for their energy savings, the difficulty of their maintenance and operation in the North complicates their use.[81] (see figure 3-28)

Indoor air quality has been an ongoing issue for northern homes, making system design, and proper user understanding important. While the extreme climate places high demands on the systems, and efficiency is important, simple and reliable functioning is critical, both to reduce life cycle costs, and result in better comfort and health for users in the North.

Electrical

Diesel power plants are expensive to operate and are vulnerable to outages from weather or fuel shortages. Due to the cost of shipping fuel to the North, storing it, and running diesel generators, electrical efficiency is critical for projects in the North. As of 2024, government residential electricity rates

80 *Good Building Practices Guidelines*, 3rd ed. (Iqaluit: Government of Nunavut, 2020), Part M, section 6.3.3.(2), M-37.

81 John Hockman, *Survey of HRV/ERV Performance Issues in Canada's Near North and Far North: Final Report*, report for Canada Mortgage and Housing Corporation (Winnipeg, JL Hockman Consulting inc., 2016), 53. https://yukon.ca/sites/yukon.ca/files/yhc/yhc-hrv-erv-performance-issues-canadas-north-report.pdf

are 93.39 ¢/kWh.[82] For comparison, in Ontario, on-peak rates are 18.2 ¢/kWh. While modern building systems can conserve power, overly complicated operation will lead to greater life cycle costs and poor user experience. Lighting demand during the winter is particularly high, and timers, motion detectors, and dimmers are all simple systems that can offer power savings. On site renewable power generation could reduce costs and environmental impact.[83, 84]

Water and Plumbing

Plumbing systems in the North are a challenge, due to the limited utilities infrastructure and the cold environment. Public water and sewage pipes cannot be maintained in permafrost, meaning most communities rely on trucks to supply water and remove wastewater for each home. These costs are high, making efficiency for this system extremely important. Low flow fixtures and efficient appliances are likely to recoup their costs quickly, and generally do not bring excessive maintenance costs, making them a good choice. Tanks are required to store 90 L per person, per day, typically for a week between deliveries, taking up a large amount of space.[85] Tanks must also be kept in a conditioned space to avoid freezing or algae growth.[86] Service crawlspaces for water and sewage tanks are a reasonably common system, especially in semi-detached housing where services for multiple units can be consolidated.

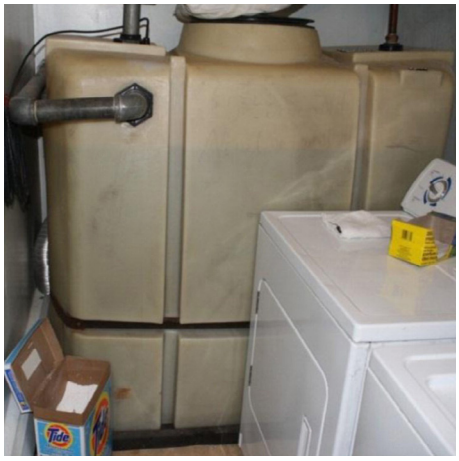


figure 3-29: Water tank in a home in Coral Harbour, NU.
source: Kiley Daley, 2014

Buildings systems are required to keep occupants safe and healthy in the North, but come with challenges. Storing water, wastewater, and fuel on site leads to high costs and potential dangers, making efficient building systems important. Reliability is likely more important than efficiency, and complex systems can lead to user error and greater costs, despite energy savings. Overall building efficiency is important to consider, and a high performance building enclosure is more impactful than an efficient heating system. Best practices for building enclosure should be applied first, before more advanced systems are considered, to ensure an economically sustainable project.

82 "Customer Rates," Qulliq Energy Corporation, Oct. 1, 2022. https://www.qec.nu.ca/sites/default/files/rate_schedule_-_effective_october_1_2022_-_final_approved_all_languages.pdf
83 *Good Building Practices Guidelines*, 3rd ed. (Iqaluit: Government of Nunavut, 2020), Part N, section 1.1.3, N-3.
84 *Good Building Practice for Northern Facilities*, 4th ed. (Yellowknife: Government of Northwest Territories, 2021), Part K, section 4.3.1, 325.
85 Ibid, 211.
86 Ibid, 213.

3.6 - Standard and Good Practices

The North is one of the most demanding settings in the world, extremely cold and remote, making housing construction important, and yet existing housing is quite poor. Current construction practices in the North have improved, however there are still significant building science advancements that are not implemented, especially as they relate to issues of thermal performance and causes of condensation. There are a few common assemblies that are useful to understand as they are well understood by local labour, lending an insight into the practices of the existing construction industry in the North. Novel building practices will require an education investment, but designing with existing practices in mind can simplify this process.

Walls

Walls are an important enclosure and structural element, providing separation from the exterior and contending with wind and snow loads. As well, openings and building systems need to be properly coordinated and installed, ensuring an effective overall building enclosure.

Table 3-01: NHC "wrap and strap" wall assembly (2008)[87, 88]

Component	Dimension	Weight	Notes
13 mm Gypsum	12.7 mm	6.11 kg/m²	FR
2x2 Strapping @ 600 mm OC	38 mm	1.18 kg/m²	
RSI 1.3 Mineral wool insulation	38 mm	2.66 kg/m²	RSI eff: 0.9
6 mil Polyethylene		0.14 kg/m²	A/VB
2x6 Lumber studs @ 400 mm OC	140 mm	14.00 kg/m²	
RSI 3.9 Mineral wool insulation	140 mm	4.48 kg/m²	RSI eff: 2.5
Housewrap		0.06 kg/m²	WB
Structural siding	12.7 mm	8.38 kg/m²	
Total	**200 mm**	**33.9 kg/m²**	**RSI 3.6**

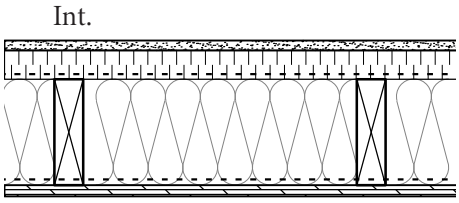


figure 3-30: NHC "wrap and strap" wall assembly with interior strapping space. source: author

This wall assembly was developed by the NHC and was used in many housing projects in Nunavut, although is now outdated. This system is also used in Northwest Territories and the Yukon, sometimes referred to as a "wrap and strap" system.[89] The wall system makes use of an interior 1 ½" strapping insulation space and 5 ½" cavity insulation for greater insulation depth and to reduce thermal bridging. The polyethylene air and vapour

87 M.Z. Rousseau, et al, "Report Task 4 - Review of Work Plan & Selection of Wall Assemblies," *PERD 079 Project* (Ottawa: National Research Council of Canada, May, 2008), 7.

88 *Optimal Northern Wall Design Guidelines*, report for Canada Mortgage and Housing Corporation (Vancouver: RDH Building Engineering Ltd. May 26, 2016), 7.

89 M.Z. Rousseau, et al, "Report Task 4 - Review of Work Plan & Selection of Wall Assemblies," *PERD 079 Project* (Ottawa: National Research Council of Canada, May, 2008), 7.

barrier is buried in this system, complicating repairs, however this makes it less vulnerable to damage and reduces penetrations during construction which need to be sealed. The structural siding system combines sheathing and cladding products, saving weight and thus transportation costs, and accelerating construction. However, siding in this assembly is not attached with an air gap which reduces ventilation and drying.[90]

Table 3-02: Current standard practice wall assembly (2020)[91]

Component	Dimension	Weight	Notes
13 mm Gypsum	12.7 mm	6.11 kg/m²	FR
6 mil Polyethylene		0.14 kg/m²	A/VB
2x6 Lumber studs @ 400 mm OC	140 mm	14.0 kg/m²	
RSI 3.4 Fibreglass insulation	140 mm	1.87 kg/m²	RSI eff. 2.5
13 mm OSB sheathing	12.7 mm	8.38 kg/m²	
RSI 1.0 Mineral wool insulation	38 mm	2.66 kg/m²	RSI eff. 1.0
2x2 Strapping @ 600 mm OC	38 mm	1.18 kg/m²	
Housewrap		0.06 kg/m²	WB
Engineered wood siding	9 mm	6.21 kg/m²	
Total	**212 mm**	**40.6 kg/m²**	**RSI 3.5**

In discussions with a northern architect, this wall assembly came up as a standard detail for residential architecture in Nunavut.[92] Sheathing is only used where it is structurally necessary, and rigid exterior insulation is used over the entire enclosure to create a stiff surface to which housewrap can be fastened. The exterior insulation, although a limited depth, reduces thermal bridging, improving energy performance. This system lacks a ventilated drainage space however, reducing natural drying of the assembly.

Table 3-03: Northern building guidelines wall assembly (2021)

Component	Dimension	Weight	Notes
13 mm Gypsum	12.7 mm	6.11 kg/m²	FR
2x4 Lumber studs @ 400 mm OC	89 mm	11.1 kg/m²	
RSI 2.1 Fibreglass insulation	89 mm	1.13 kg/m²	RSI eff. 2.0
13 mm OSB sheathing	12.7 mm	8.38 kg/m²	A/VB
Housewrap		0.06 kg/m²	WB
RSI 4.4 XPS insulation	125 mm	2.66 kg/m²	RSI eff. 4.4
1x2 Strapping @ 600 mm OC	19 mm	0.59 kg/m²	
Engineered wood siding	9 mm	6.21 kg/m²	
Total	**258 mm**	**36.2 kg/m²**	**RSI 6.4**

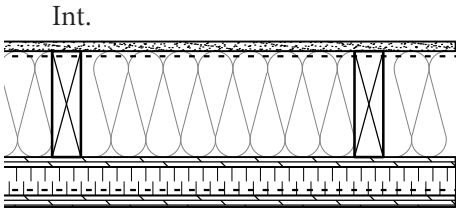


figure 3-31: Current standard practice wall assembly.
source: author

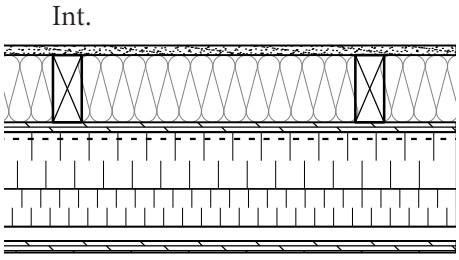


figure 3-32: Northern building guidelines wall assembly.
source: author

90 John F. Straube and Graham Finch. "Ventilated Wall Claddings: Review, Field Performance, and Hygrothermal Modeling." Research report, Building Science Press, 2009, 1.

91 Discussion with architect in Nunavut and from the northern building guidelines

92 Discussion with architect in Nunavut

Best practice enclosure design locates the air, water, and vapour control at the exterior of the wall structure, with a large proportion of the insulation to the exterior of these control layers. This protects the structure from the environment, and avoids thermal bridging through the structure. This assembly serves to simplify air and vapour barrier construction as it does not need to be wrapped around the interior structure or openings. This assembly requires additional labour for exterior insulation, due to the rigid boards rather than batts, however it is still practical for local labour. Depending on the depth of the exterior insulation, cladding attachments can be complicated, however at less than 150 mm, long screws with strapping are an effective and economical method.

Roofs

High wind loads, snowdrifting, and cold temperatures make roof construction an important consideration for buildings. With attics, extensive insulation is simple to include however issues of ventilation can arise and thus construction needs to be high quality to ensure a robust building.

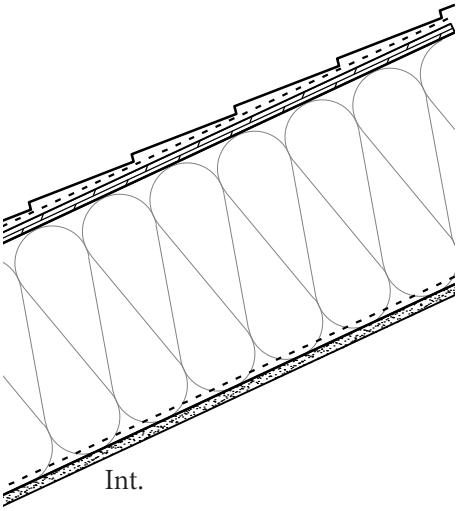


figure 3-33: Standard practice roof assembly.
source: author

Table 3-04: Standard practice roof assembly (2020)[93]

Component	Dimension	Weight	Notes
13 mm Gypsum	12.7 mm	6.11 kg/m^2	FR
6 mil Polyethylene		0.14 kg/m^2	A/VB
302 mm I joist @ 400 mm OC	302 mm	9.51 kg/m^2	
RSI 7.4 Fibreglass insulation	300 mm	4.27 kg/m^2	RSI eff. 6.8
13 mm OSB sheathing	12.7 mm	8.38 kg/m^2	
Housewrap		0.06 kg/m^2	WB
Asphalt shingles	6 mm	10.8 kg/m^2	
Total	**327 mm**	**39.3 kg/m^2**	**RSI 6.8**

This design is a standard roof detail in Nunavut for housing, and improves on the outdated unvented attic roof construction. The roof joists act as a thermal bridge to the exterior which weakens thermal performance, although additional exterior insulation can reduce this problem.

93 Discussion with architect in Nunavut and from the northern building guidelines

Table 3-05: RDH Energy Efficient Proposal roof assembly (2016)[94]

Component	Dimension	Weight	Notes
13 mm Gypsum	12.7 mm	6.11 kg/m^2	FR
1x4 Strapping @ 600 mm OC	19 mm	1.41 kg/m^2	
6 mil Polyethylene		0.14 kg/m^2	A/VB
Raised heel truss @ 600 mm OC	530 mm	12.0 kg/m^2	
RSI 19.4 Fibreglass insulation	760 mm	6.5 kg/m^2	RSI 19.4
13 mm OSB sheathing	12.7 mm	8.38 kg/m^2	
Housewrap		0.06 kg/m^2	WB
24 ga Steel roofing	24 ga	4.88 kg/m^2	
Total	**574 mm**	**39.5 kg/m^2**	**RSI 19.4**

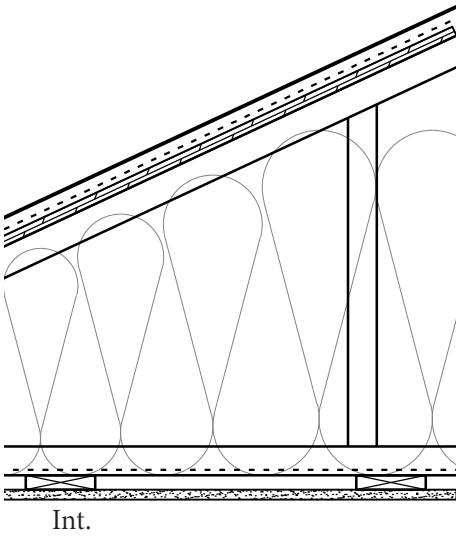


figure 3-34: RDH Energy Efficient Proposal roof assembly.
source: author

This roof assembly is part of the "Energy Optimized House" designed for Whitehorse, Yukon.[95] RDH has conducted extensive building science research, particularly for enclosures, and have developed several options to improve northern enclosure design. The raised heel trusses are constructed similarly to standard trusses, but allow for enormous insulation depth and improved insulation at the eaves, improving energy performance, however air leakages need to be accounted for and the polyethylene air and vapour barrier requires a quality installation to avoid condensation in the roof, and a ventilated attic is important for this assembly.

Table 3-06: Northern building guidelines roof assembly (2021)

Component	Dimension	Weight	Notes
13 mm Gypsum	12.7 mm	6.11 kg/m^2	FR
1x2 strapping @ 400 mm OC	19 mm	0.89 kg/m^2	
240 mm I joist @ 400 mm OC	241 mm	8.42 kg/m^2	
RSI 3.3 Fibreglass insulation	229 mm	2.67 kg/m^2	RSI eff. 3.3
13 mm OSB sheathing	12.7 mm	8.38 kg/m^2	VB
Housewrap		0.06 kg/m^2	A/WB
RSI 5.8 XPS rigid insulation	165 mm	3.47 kg/m^2	RSI eff. 5.8
2x3 Strapping @ 600 mm OC	64 mm	1.98 kg/m^2	
24 ga Steel roofing	24 ga	4.88 kg/m^2	
Total	**514 mm**	**36.9 kg/m^2**	**RSI 9.1**

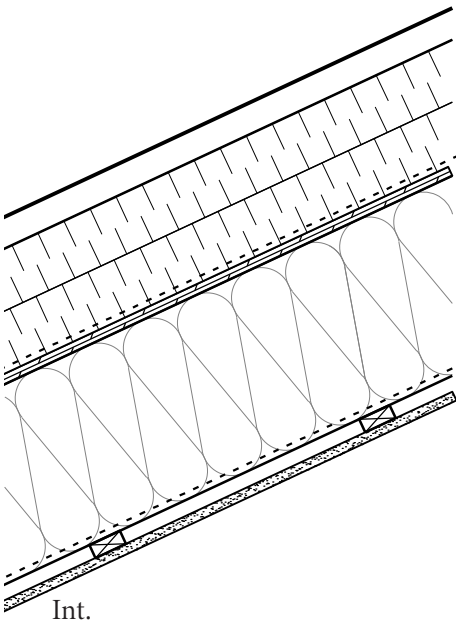


figure 3-35: Northern building guidelines roof assembly.
source: author

This assembly follows best practices as laid out in the northern building guidelines and comports with contemporary building science research. Thermal bridging is eliminated with the use of continuous exterior insulation. Engineered wood I-joists reduce the weight of roof joists, compared to large lumber members. The large proportion of insulation located at the exterior also reduces the risk of condensation due to air leakage into the assembly.

94 *Energy Efficient Housing Guidelines for Whitehorse, YT: Energy Optimized House*, report for Natural Resource Canada (Canada: RDH, Nov. 24, 2016), 18.
95 Ibid, 18.

Floors

Floors in the North are complicated by the need to elevate buildings off the permafrost, thus exposing the underside of floors to the environment. The need for high quality enclosure design is necessary at building floors, just as it is for walls and roofs.

Int.

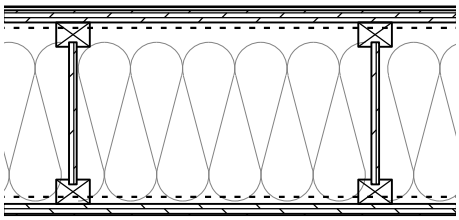


figure 3-36: Standard practice floor assembly.
source: author

Table 3-07: Standard practice floor assembly (2020)[96, 97]

Component	Dimension	Weight	Notes
Flooring	3.2 mm	2.60 kg/m²	FR
16 mm OSB sheathing	15.9 mm	10.5 kg/m²	
6 mil Polyethylene		0.14 kg/m²	A/VB
302 mm I joist @ 400 mm OC	302 mm	9.51 kg/m²	
RSI 7.4 Fibreglass insulation	300 mm	4.27 kg/m²	RSI eff: 6.8
Housewrap		0.06 kg/m²	WB
Engineered wood siding	9 mm	6.21 kg/m²	
Total	**330 mm**	**33.3 kg/m²**	**RSI 5.0**

This floor assembly is typical of northern construction, as it is simple and economical to construct, and has reasonable insulation depth due to the deep floor joists. Floors are not a significant source of failure, failures at floors are usually a result of foundation problems, however insulation and airtightness continuity are important for building efficiency, which this assembly lacks. This system also does not meet minimum insulation values for the North. Exterior insulation can be added to bring this assembly in line with current requirements, and is a reasonably economical retrofit for existing construction. Fully exterior insulation would be better from a building science perspective, however this results in an extremely deep floor assembly. With fully exterior insulation, building services could be run between floor joists, avoiding the risk of freezing or heat loss.

The building assemblies described above are designed to be economical in materials and construction, and to offer a reasonable performance standard for life in the North. However, current building science has improved upon these designs and with similar material and labour costs, higher performance construction is possible. Building enclosure priorities are centred on continuous insulation and airtightness, which these typical assemblies tend to lack. These assemblies are well understood and are used in existing construction making them important to understand in proposing new designs, as well as developing retrofit proposals for existing homes.

96 *Energy Efficient Housing Guidelines for Whitehorse, YT: Energy Optimized House*, report for Natural Resources Canada (Canada: RDH, Nov. 24, 2016), 5.
97 Discussion with architect in Nunavut and from consultation of the northern building guidelines

3.7 - Conclusion

The many challenges of the North, from the harsh climate to the sparse population and infrastructure, make high performance buildings important for their users, but also difficult to execute. People in the North rely on their homes for shelter, and poor design or improper construction can have serious consequences. This chapter has discussed standard and best practices of northern construction and highlighted the limitations of current solutions. Despite their limitations, existing solutions are useful to study as their successes and failures can inform future design in the North, addressing the issues identified in past work.

Existing practices of the North highlight the need for building enclosure improvements, while at the same improving constructability and ensuring that detailed design of building enclosures can be easily executed on site. Simple and reliable designs are preferred as these allow for the simplification of labour both for construction and for later repairs or replacement. Despite this, established solutions do not perform to the desired standard, with most projects failing to meet the northern building guidelines recommendations for insulation, leading to poor performance and higher operating costs.



figure 3-37: K'alemi Dene School in N'Dilo, NWT, by Taylor Architecture Group, 2009. source: Ihor Pona, 2011





figure 4-01: Man constructing an igloo, the traditional winter shelter of the Inuit.
source: Frank E. Kleinschmidt, 1924



figure 4-02: The DEW Line was a series of radar bases across the North. source: Paul Kelley, c. 1960

Chapter 4
Northern Architecture Precedents

4.1 - Introduction

Shelter in the North has always been a challenge for its people, and this will continue to be true, given the nature of the climate and remoteness. However, improvements in transportability, constructability, and energy performance can meaningfully address these issues, and provide high quality homes and buildings in the North. Understanding historical and contemporary precedents lends an insight into successful aspects that should be implemented in future. These precedents also offer warnings, given the unforgiving context. Shelter must contend with the varied challenges of the North, and the means of overcoming these, in the traditional shelters carried by sled and modern projects airlifted by plane, can inform future projects in the North.

4.2 - Inuit and First Nations Shelter

Traditional forms of shelter for the Inuit and Dene First Nations of the North are valuable to study as they mediate issues of climate, transport, and culture. Inuit and Dene people were traditionally nomadic, using temporary portable shelters as they travelled around their lands. Inuit used igloos during the winter, as they could contend with the harsh weather. Following contact with settlers and the establishment of trading posts, Dene in the North began to use permanent winter shelters.[98] While no longer nomadic, the utility of lightweightness, transportability, simple construction, and protection from the climate are still important elements of contemporary buildings, making traditional shelters that addressed these challenges valuable to study.

98 "Our History," Dene Tha' First Nation, https://denetha.ca/history/ accessed Nov. 30, 2023.

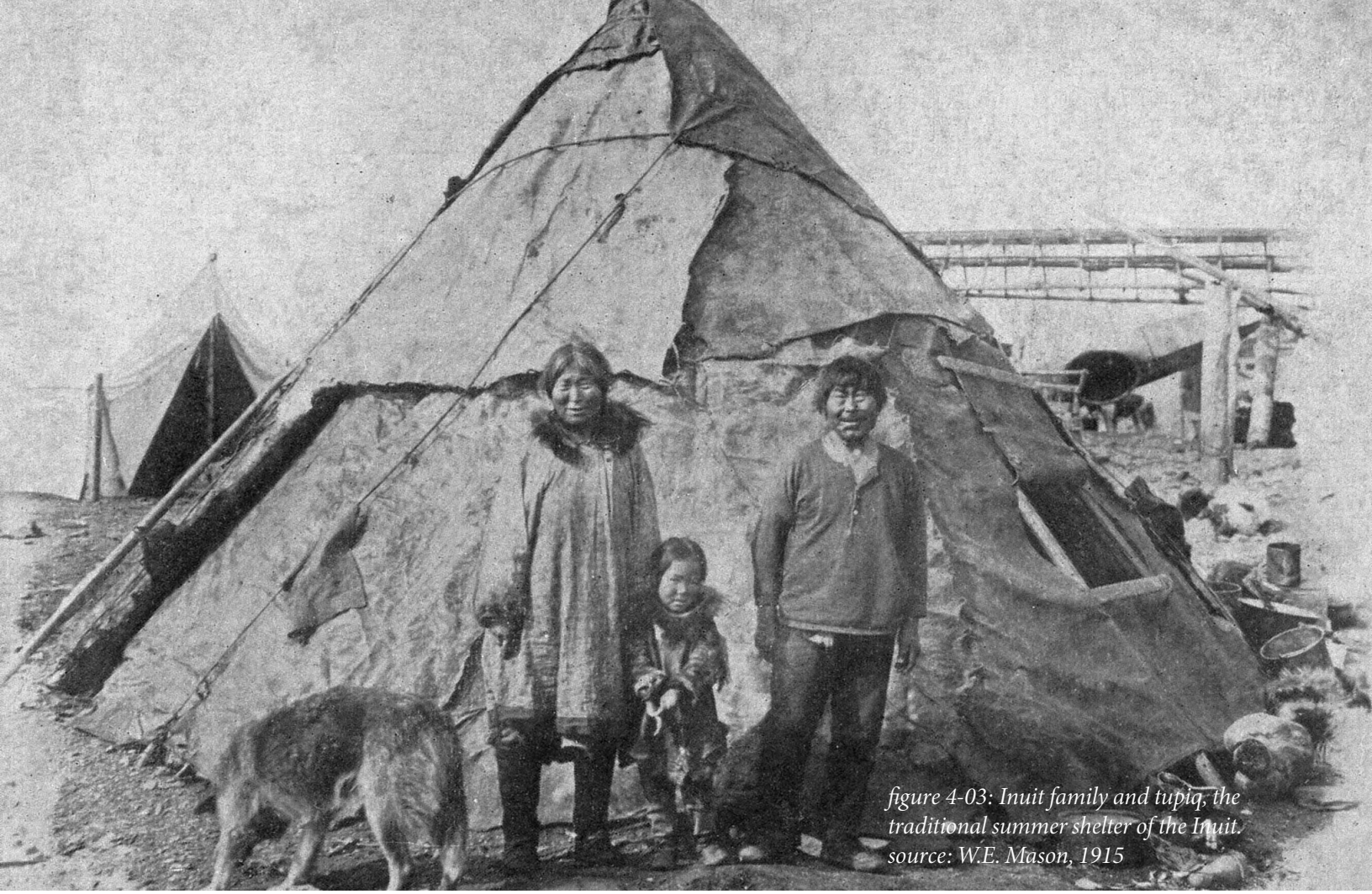


figure 4-03: Inuit family and tupiq, the traditional summer shelter of the Inuit. source: W.E. Mason, 1915

The Inuit tent is a tupiq, and the Dene tent is the tipi. The inuit also used tents called qarmaqs in the shoulder season.[99] These tents were an important shelter typology, allowing them to carry their shelter following game and fish during the summer and shoulder seasons. Tupiit are constructed from whale bones and animal skins, such as caribou or seal.[100] They are conical in shape and can be closed at the top to keep warmth inside. Oil lamps, called qulliqs, fuelled by whale or seal blubber, were used to cook some of their food and provide light and warmth. Qarmat were a more insulated tent, constructed from bones or wood, and could be covered with animal skins, sod, or snow for insulation.[101] (see figure 4-03, figure 4-04)

Tipis of the Dene are also constructed in a conical shape, from wood poles and animal skins, with an open chimney.[102] Much of the Dene lands in the North are below the treeline, so a fireplace in the centre of the tent was common. The conical shape of the tupiit and tipis offered a few critical utility benefits. The primary benefit was the rapid constructability afforded by its shape, allowing it to be constructed from the ground. The materials are also relatively lightweight, allowing for transportability and rapid construction. The conical shape is volumetrically efficient, reducing heat loss and the materials needed. Another climatic benefit is the aerodynamic shape, reducing the wind loads and snowdrifting across the sparsely treed areas of the North. (see figure 4-05)

99 Edward Mills and Harold D. Kalman, "Tupiq," The Canadian Encyclopedia, Apr. 30, 2020. https://www.thecanadianencyclopedia.ca/en/article/tupiq

100 Beth Brown, "Nunavut seamstresses reviving skin tent tradition," *Nunatsiaq* News, July 12, 2017. https://nunatsiaq.com/stories/article/65674nunavut_seamstresses_reviving_skin_tent_tradition/

101 Edward Mills and Harold D. Kalman, "Architectural History of Indigenous Peoples in Canada," The Canadian Encyclopedia, Sep. 30, 2007. https://www.thecanadianencyclopedia.ca/en/article/architectural-history-early-first-nations

102 Michael I. Asch, "Dene," The Canadian Encyclopedia, May 15, 2017. https://www.thecanadianencyclopedia.ca/en/article/dene



figure 4-04: Qarmaq frame reconstruction near Resolute, NU, the frame would be covered with skins, dirt, and snow for the enclosure.
source: Ansgar Walk, 1997



figure 4-05: Chipewyan-Dene camp at Fort Smith, NWT.
source: Library and Archives Canada

The winter shelters of the Inuit and Dene were less mobile, as there was less need to move during the winter and the weather favoured more durable shelters. The traditional winter shelter of the Inuit is the igloo, an iconic shelter typology that has many relevant aspects to study for contemporary architecture. Igloos are constructed from blocks of snow built into a dome shape. Qulliqs provided some light and warmth, however temperatures were often just above 0 °C inside, an increase of 30 °C or more over exterior temperatures.[103] Snow insulates to approximately RSI 3.5 in a 50 cm thick igloo wall. Interior shelves covered with furs are constructed for sitting and sleeping, lifting the occupants off the floor. The entranceway is also lowered to act as a cold sink, keeping warm air inside and the dome shape of an igloo is volumetrically efficient. The ability to construct a shelter with the limited materials available in the North allowed the Inuit to weather the harsh winters, and to hunt on the sea ice, constructing igloos as they went, not needing to carry building materials with them. (see figure 4-01)

Winter shelters of the Dene people varied across the region, however pit houses and lodges were common.[104] Pit houses are constructed partially below grade, with a domed roof and an entrance from a central hole in the roof, which also serves for ventilation.[105] This typology affords similar benefits as the igloo, however can be more permanent and is simpler to insulate with earth. Lodges are more tentlike and are generally constructed from a wood frame covered with skins. Following contact with settlers, more permanent houses were constructed, generally log cabins which could be used for many winters.

The traditional summer shelters of the Inuit and Dene First Nations are lightweight constructions, affording transportability and constructability for the nomadic groups.Even the summers in the North are quite cold in many regions and these shelters kept occupants warm with the limited heating available. The winter shelters are not portable, but are constructed from local materials which reduces the need to transport them. The transportability, constructability, and warmth of these traditional shelters are still highly relevant for northern buildings, and these successful shelter typologies have valuable lessons for contemporary architects working in the North.

103 René R. Gadacz, "Igloo," The Canadian Encyclopedia, Dec. 19, 2006. https://www.thecanadianencyclopedia.ca/en/article/igloo
104 Michael I. Asch, "Dene," The Canadian Encyclopedia, May 15, 2017. https://www.thecanadianencyclopedia.ca/en/article/dene
105 Edward Mills and Harold D. Kalman, "Pit House," The Canadian Encyclopedia, Apr. 28, 2020. https://www.thecanadianencyclopedia.ca/en/article/pit-house

4.3 - Northern Housing Research

Housing has been an issue in the North for decades, and many efforts have been made to improve key aspects of building performance, transportability, and constructability, as well as critical problems of affordability. Work from the Canada Mortgage and Housing Corporation (CMHC), National Research Council (NRC), and RDH Building Science, among others, is valuable to study as they have extensively researched these issues and have proposed solutions to address the housing needs in the North.



figure 4-06: Arctic Hut Mk. 3 at Donjek Glacier, Yukon, under NRC testing. source: Directorate of Engineer Development, Canadian Army, 1950



figure 4-07: Arctic Hut Mk. 3 interior. source: Directorate of Engineer Development, Canadian Army, 1950

4.3.1 - Past NRC and CMHC Work

In the 1950s, following greater Canadian attention on Arctic sovereignty, improving construction in the North became a large field of research. NRC work from 1960 is some of the earliest Canadian work in this field. Today, NRC work includes valuable research on building performance and construction, especially for developing building codes. Similarly, CMHC work has been a reference for architects across Canada in housing construction for decades, and this is true of work in the North as well.

In 1960, the NRC published a report on improving northern housing, in particular by improving transportability and constructability via lightweighting and prefabrication. The report identifies key difficulties for northern buildings such as shipping and construction costs, building foundations, and performance issues. The designs are now dated but the issues remain relevant, as "a major portion of northern building difficulties and costs is and will long be attributable to transportation."[106] Lightweighting as a means of improving these aspects is highlighted, "economic problems rather than technical favour new materials and systems in northern housing. Certain lightweight prefabrication systems can effect considerable reductions in northern costs."[107] The options include lumber stressed skin panels, SIPs, and prefabricated Quonset Huts (see Chapter 5.4.5 - Quonset Huts). The report recommends stressed skin panels, given their transportation cost saving and rapid construction. The report also supports the use of SIPs, and advancements in SIPs since then has brought down the cost and improved joint details, making them a strong option. (see figure 4-08)

106 R.E.Platts, *Prefabrication in Northern Housing*. (Ottawa: National Research Council of Canada Division of Building Research, Nov. 01, 1960), 2. https://doi.org/10.4224/20375947

107 R.E.Platts, *Prefabrication in Northern Housing*. (Ottawa: National Research Council of Canada Division of Building Research, Nov. 01, 1960), 1. https://doi.org/10.4224/20375947

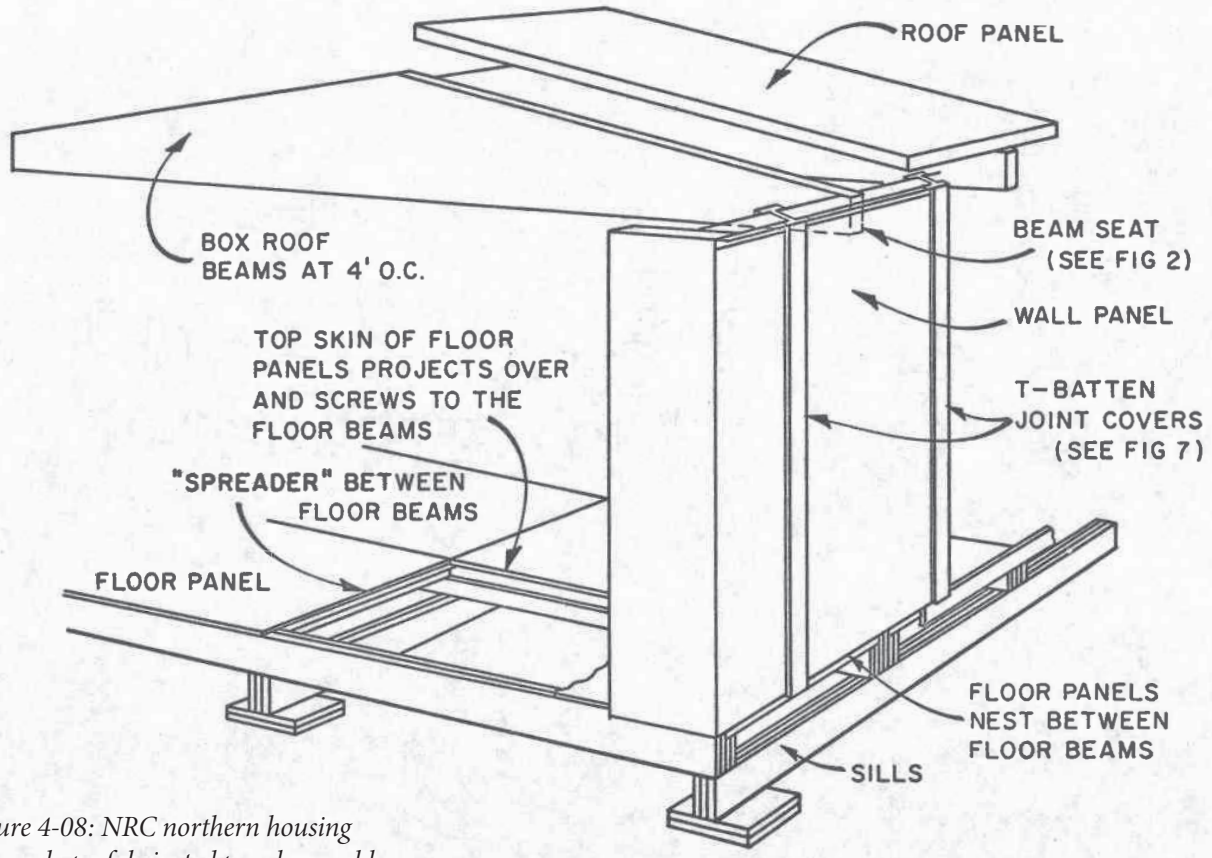


figure 4-08: NRC northern housing research, prefabricated panel assembly. source: R.E. Platts, 1960

CMHC research in prefabrication and rapid construction for housing, published in 1960, included options for northern housing.[108] The earliest prefabricated designs for northern housing date to the 1950s. One example is the Arctic Hut Mk. #3, a barracks developed for the Canadian military in 1950. The shelter was 13 m by 5.5 m, composed of prefabricated plywood and lumber panels, with insulation and vapour control, which could be rapidly connected by aluminium splines.[109] The roof and floor were supported by aluminium girders. NRC research from 1958 into the operation of these huts found that they were reasonably comfortable with either wood or diesel heating. An installation at Donjek Glacier in the Yukon found that heating was adequate, but that temperatures at the ceiling were too high for comfort, likely indicating insufficient ventilation. The NRC research also notes that there was likely some degradation of the permafrost below the hut, which could lead to settlement over time.[110] (see figure 4-06, figure 4-07)

Past research on improving northern housing has identified many challenges that architecture in the North still faces today including transportability, constructability, and building performance, while also meeting the need for affordability. Methods of improving these aspects have included a focus on lightweighting and prefabrication, which can allow for less expensive shipping, simpler on site labour, and rapid construction.

108 *Catalogue of House Building Construction Systems* (Ottawa: Central Mortgage and Housing Corporation, 1960)
109 A.D. Kent, *Arctic hut heating and ventilation trials* (Ottawa: National Research Council, Apr. 01, 1958), 1-2. https://doi.org/10.4224/20386704
110 A.D. Kent, *Arctic hut heating and ventilation trials* (Ottawa: National Research Council, Apr. 01, 1958), 49. https://doi.org/10.4224/20386704

4.3.2 - Current NRC and CMHC Work

Current NRC research is involved in construction and design best practices, especially as it pertains to developing building codes. NRC work determines many of the building codes across Canada, including the northern building guidelines Currently, CMHC provides funding for northern housing projects and continues to research economical means of providing and operating housing in the North.[111] CMHC work includes built projects such as the Northern Sustainable House projects, which are valuable precedents for architects and builders in the North.

The Program of Energy Research and Development 079 (PERD 079) is an extensive research project by the NRC, which is focused on developing energy efficient northern buildings. Much of this research appears in the current building guidelines of the North. PERD 079 includes options for northern housing assemblies including CMHC designs, SIPs construction, engineered wood framing options, and double stud walls. These designs are intended to improve building performance, while remaining transportable and constructable. (see figure 4-09)

Some conclusions from the PERD 079 literature review are that "structural insulated panel systems have performed well in Northern Canada when properly installed. These panels improve the energy performance of building envelopes and reduce timber use... A panel's weight is about 35% less than the same size of wood frame construction. Panel construction is faster than wood-frame construction."[112] PERD 079 research pertaining to construction practices, enclosure detailing, and building systems have generally been incorporated into the current northern building guidelines.

Current CMHC work in the North includes user group engagement and issues of economic sustainability. CMHC work with Inuit groups in developing culturally sensitive floor plans is particularly useful for architects.[113] CMHC has also developed prototype houses called "Northern Sustainable Houses" (NSH). The NSH E/2 Houses, located in Dawson and Arviat, are designed to use half of the energy of a typical building based on the 1997 Model National Energy Code for Houses (MNECH 1997).

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111 "Canada supports 21 rapid housing units in Nunavut." Canada Mortgage and Housing Corporation, Oct. 03, 2023. https://www.cmhc-schl.gc.ca/media-newsroom/news-releases/2023/canada-supports-21-rapid-housing-units-in-nunavut

112 M.N. Said, "Task 2: Literature Review: Building Envelope, Heating, and Ventilating Practices and Technologies for Extreme Climates," *PERD 079 Project* (Ottawa: National Research Council of Canada, Dec. 08, 2006), 91. https://doi.org/10.4224/20377640

113 Dr. Peter C. Dawson, *An Examination of the Use of Domestic Space by Inuit Families Living in Arviat, Nunavut* (Ottawa: Canada Mortgage and Housing Corporation, Oct. 10, 2003), 75-77. publications.gc.ca/pub?id=9.569993&sl=0

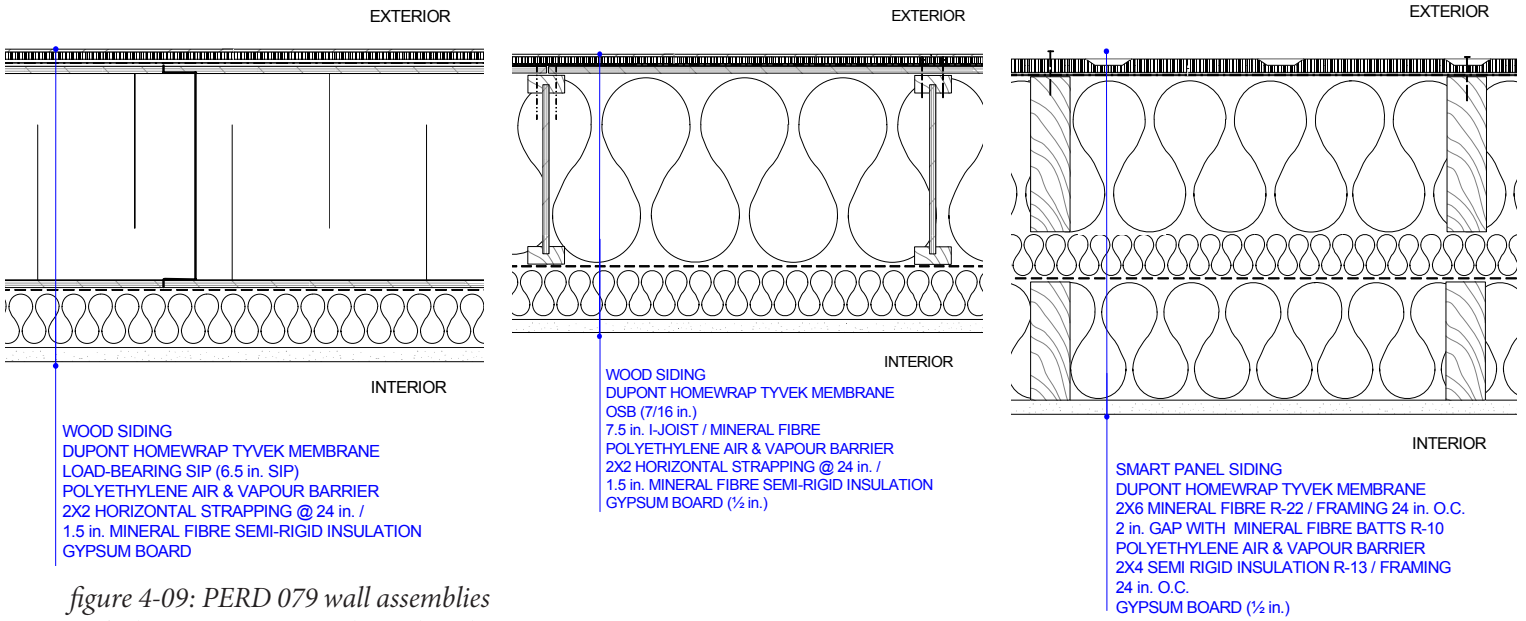


figure 4-09: PERD 079 wall assemblies including SIPs, engineered wood stud, and double stud wall options.
source: National Research Council, 2008

The Dawson E/2 House is a more typical construction method, and is similar to the "wrap and strap" system (see Chapter 3.6 - Standard and Good Practices). The Arviat E/2 House and E/2 SIP house are designed with the same 50% energy reduction goals. The Arviat E/2 House uses a double stud wall with an additional gap for insulation depth. The insulation values for the E/2 House are RSI 6.3, RSI 10.7, RSI 8.6 for the walls, roof, and floor respectively. Airtightness of the framed house was measured at 1.4 ACH, meeting Nunavut guidelines, however airtightness of the E/2 SIP House was not measured. Insulation values for the E/2 SIP House are RSI 7.8, RSI 12.7, RSI 7.8. The total annual energy consumption of the E/2 House was 69,000 kWh, including heating oil and electricity. Energy consumption of the E/2 SIP House was 58,000 kWh.[114] The E/2 House had 10 occupants, and the E/2 SIP House had seven occupants, making comparison difficult. These projects would consume significantly less energy with fewer occupants. Overall, "the occupants appeared to be generally satisfied with the layout and performance of the house."[115] Considering the insulation values and the measured electricity consumption of approximately 10,000 kWh, it seems likely that hot water heating was a major component of the energy consumption, including a hydronic heat loop for the exterior sewage tank. (see figure 4-10)

The Dawson E/9 House is designed to use just 11% of the heating energy of a house under MNECH 1997. The Dawson E/9 House is a duplex and uses SIPs walls with additional interior insulation, a raised heel truss roof with attic insulation, and a lumber framed floor. The building was designed with nominal RSI 8.4 walls, an RSI 14.1 roof, and RSI 7.8 floor, although the roof and floor suffer from thermal bridging due to a lack of exterior insulation. The project also includes an HRV, with heat traces to avoid frosting.

114 "Arviat E/2 Northern Sustainable House Energy Consumption Performance Assessment." (Ottawa: Canada Mortgage and Housing Corporation, Apr. 2016), 2-3. publications.gc.ca/pub?id=9.824418&sl=0

115 "Arviat E/2 Northern Sustainable House Energy Consumption Performance Assessment." (Ottawa: Canada Mortgage and Housing Corporation, Apr. 2016), 4. publications.gc.ca/pub?id=9.824418&sl=0





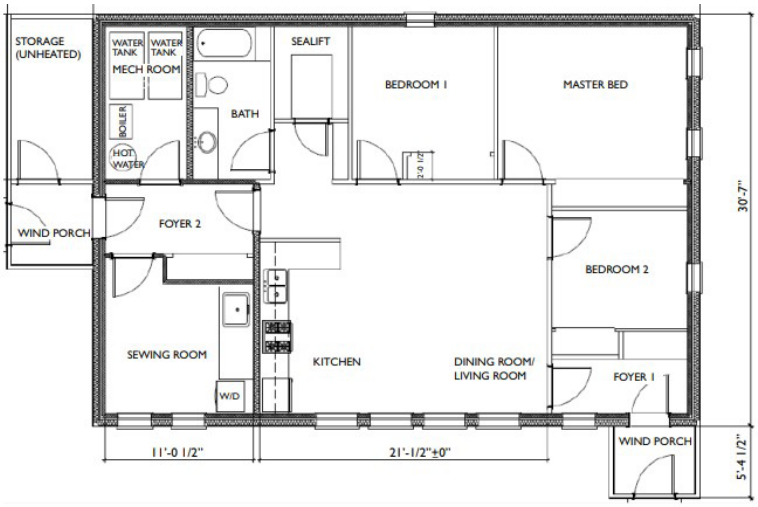


figure 4-10: Arviat E/2 House.
source: CMHC, 2015

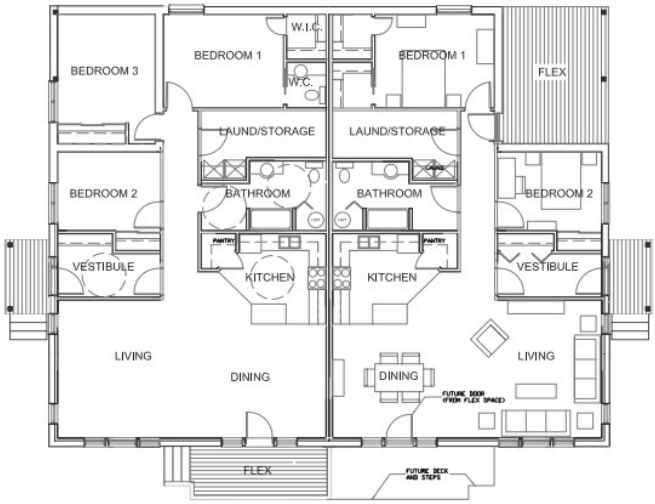


figure 4-11: Dawson E/9 House.
source: CMHC, 2012

Given the building enclosure improvement, it was decided that electric baseboard heaters would meet the heating need. These are less expensive to supply and maintain than fuel fired systems. "The E/9 project demonstrated the full extent to which the energy performance of a northern house could be optimized within a limited budget while also addressing the cultural and lifestyle needs of the [Tr'ondek Hwech'in Han First Nations] occupants."[116] This project did not meet its energy goals, and measured energy consumption of the E/9 House showed a 60% decrease in space heating energy compared to energy modelling of an MNECH project. The E/9 House consumed 21,000 kWh/yr, demonstrating a reasonably efficient design, with a 20% reduction in space heating energy consumption compared to conventional northern homes, although hot water energy and domestic electrical usage were nearly twice as much.[117] Electrical costs are high, meaning electrical heating for northern projects should be carefully considered to ensure economic feasibility. These CMHC projects also highlight the impact of proper systems operation, as misuse can result in significant energy costs.[118] (see figure 4-11)

116 "Design and Construction of the Northern Sustainable House E/9 Project – Dawson City, Yukon." (Ottawa: Canada Mortgage and Housing Corporation, July 2012), 5. publications.gc.ca/pub?id=9.620421&sl=0

117 "Dawson E/9 Northern Sustainable House Energy Performance Assessment." (Ottawa: Canada Mortgage and Housing Corporation, Mar. 2015), 2-3. publications.gc.ca/pub?id=9.803526&sl=0

118 "Arviat E/2 Northern Sustainable House Energy Consumption Performance Assessment." (Ottawa: Canada Mortgage and Housing Corporation, Apr. 2016), 4. publications.gc.ca/pub?id=9.824418&sl=0

4.3.3 - RDH Building Science Inc. Research

John Straube, the advisor to this thesis, is a principal at RDH Building Science Incorporated, which has conducted extensive building science research, particularly for building enclosures and RDH work is extremely valuable in identifying concerns with detailing and building assemblies. RDH has partnered with northern housing groups and other public organizations to develop best practices for new builds and retrofits in the North.[119] A particularly relevant study is the "Optimal Northern Wall Design Guidelines" developed by RDH for CMHC in 2016.

The general conclusion of the Optimal Northern Wall Design Guidelines is that the optimal wall assembly for most of the North is a 2x4 framed wall with 150 mm to 200 mm of exterior insulation, with optional batt insulation between studs.[120] This wall assembly "meets the required hygrothermal performance, is readily buildable by local contractors without any specialized trades or skillsets, and optimizes Northern Canadian material costs with labour costs."[121] Other tested options, such as double stud walls and 2x6 walls with split insulation, did not meet cost or enclosure performance standards. Current building practice in the North frequently uses additional interior cavity insulation, such as the "wrap and strap" system, however "the wall is inherently susceptible to durability concerns caused by air leakage condensation... does not adequately address thermal bridging concerns, and is structurally inefficient by using up floor space." (see figure 4-12)

The report also includes research on shipping and labour costs of these assemblies and this research is particularly relevant for more remote sites. Of the best options, a split insulated wall or fully exterior insulated wall with XPS insulation and fibreglass batts was the most economical to ship. While SIPs were the lightest assembly, their bulk increased shipping costs.[122] The quickest wall assembly was SIPs and the next quickest was split or exterior insulated framed walls, creating a tradeoff between transportation and labour costs. While the report focuses on walls, these designs are relevant for roofs and floors as well. (see figure 4-13)

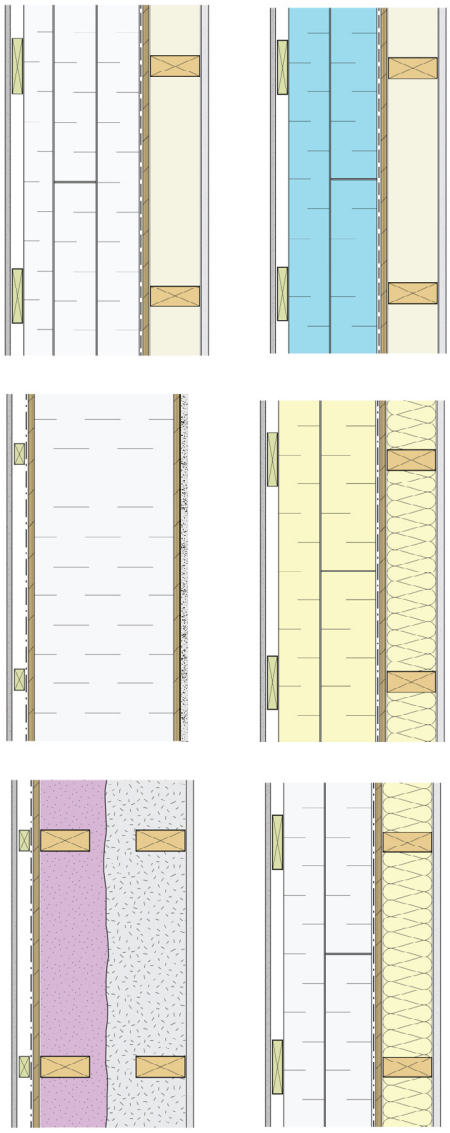


figure 4-12: RDH optimal wall designs for the North including exterior and split insulated wood framing, SIPs, and double stud walls.
source: RDH Building Science Inc. 2016

119 Graham Finch, et al, *Energy Efficient Housing Retrofit Guide for Yukon* (Vancouver: RDH Building Science Inc., Dec. 2021)
120 *Optimal Northern Wall Design Guidelines*, report for Canada Mortgage and Housing Corporation (Vancouver: RDH Building Engineering Ltd. May 26, 2016), 4.
121 *Optimal Northern Wall Design Guidelines*, report for Canada Mortgage and Housing Corporation (Vancouver: RDH Building Engineering Ltd. May 26, 2016), 4.
122 *Optimal Northern Wall Design Guidelines*, report for Canada Mortgage and Housing Corporation (Vancouver: RDH Building Engineering Ltd. May 26, 2016), 35.

Wall ID	Hygrothermal Assessment	Effective R-value at -20˚C	Thermal Efficiency	Constructability	Cost	Score
D-CFI	Fail	41	7	Moderate (5)	6	18
D-FG	Fail	42	7	Moderate (6)	10	23
D-ocSPF	Pass	40	7	Poor (4)	4	15
D-ccSPF	Pass	40	6	Poor (3)	5	14
SIPS	Pass	40	10	Moderate (5)	5	20
S4-EPS	Pass	43	9	Excellent (9)	8	26
S4-XPS	Pass	43	9	Excellent (10)	7	26
S4-MFI	Pass	43	9	Excellent (9)	6	24
S4-PIC	Pass	42	6	Good (7)	6	19
S6-EPS	*Pass*	*66*	*5*	*Good (8)*	*6*	*19*
S6-XPS	*Pass*	*67*	*5*	*Good (8)*	*4*	*17*
S6-MFI	*Pass*	*66*	*6*	*Good (8)*	*2*	*16*
S6-PIC	*Pass*	*67*	*1*	*Good (8)*	*2*	*10*
X-EPS	Pass	41	10	Good (7)	7	24
X-XPS	Pass	42	10	Good (7)	6	23
X-MFI	Pass	41	10	Good (7)	5	22
X-PIC	Pass	41	6	Good (7)	4	17

figure 4-13: RDH wall performance summary chart. source: RDH Building Science Inc. 2016

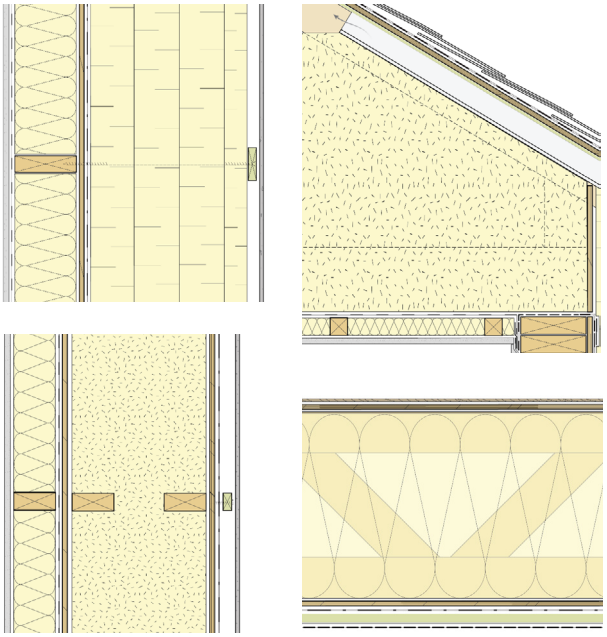


figure 4-14: Near net-zero wall, roof, and floor. source: RDH Building Science Inc. 2019

Another report by RDH for the CMHC was a feasibility study on net-zero housing in the North. The proposed assemblies are similar to the previous recommendations but with more insulation, however the key takeaways of the report have more to do with overall building design. "Form factor is a critical design consideration when combining energy efficiency and cost effectiveness... Achieving near-net zero or Passive House levels of thermal performance may only be feasible in compact larger multi-family housing types."[123] Another key takeaway was that "improved enclosure measures allow downsizing the heating system, which can result in a mechanical equipment cost savings."[124] (see figure 4-14)

RDH research supports the use of "perfect enclosure" principles, with exterior insulation and a ventilated rainscreen, in conjunction with efficient building forms. These elements allow for high performance architecture for the North that will be economical to transport and can be constructed by available labour.

The issue of operating costs is important and there is a strong economic case for high performance buildings, despite the additional upfront cost. Energy modelling such as HOT2000 and performance monitoring of existing projects are critical to guide planning and enclosure design decisions. Project funding, such as from the CMHC, often incentivizes improved building performance, helping to reduce the upfront costs. This research in building construction consistently highlights the need for transportability and constructability in northern buildings, commonly supported by lightweighting, while also contending with the challenge of the northern climate, demanding high performance and reliable buildings.

123 *Near-Net Zero Buildings in the North: Final Report*, report for Canada Mortgage and Housing Corporation (Vancouver: RDH Building Science Inc. June 24, 2019), 191.

124 *Near-Net Zero Buildings in the North: Final Report*, report for Canada Mortgage and Housing Corporation (Vancouver: RDH Building Science Inc. June 24, 2019), 191.

4.4 - Northern Housing Precedents

Contemporary building science research is valuable to study, but its implementation is often complicated. This is especially true in the North, where projects must also mediate labour issues, economics, and politics. Built examples of northern housing provide examples of successes and warnings to learn from for future projects. Government programs house a large population in the North, and thus the projects they have built, and those built in collaboration with private companies, are useful precedents.

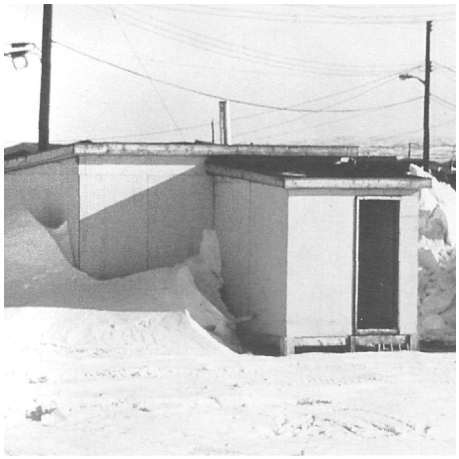


figure 4-15: Matchbox house.
source: Richard Bushell, NWTHC

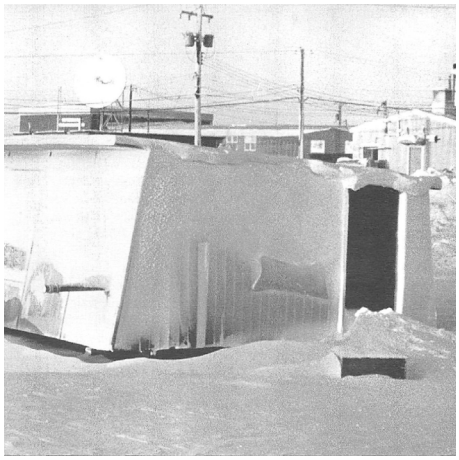


figure 4-16: An 'Anarak' house in Cambridge Bay.
source: Richard Bushell, NWTHC

4.4.1 - Public Housing

Public housing programs manage a large portion of the housing in the North. Nunavut Housing Corporation (NHC) houses around 60% of Nunavut.[125, 126] The Nunavik social housing body, Kativik Municipal Housing Bureau (KMHB) houses 98% of Nunavik, and Northwest Territories Housing Corporation (NWTHC) operates 2,400 units, approximately a quarter of dwellings in the territory.[127] The Yukon is less reliant on public housing, however Yukon Housing Corporation (YHC) subsidizes rent for many tenants.

The earliest public housing options in the North were the matchbox and "512" houses in the 1950s. The matchbox houses were tiny, 288 ft^2, while the "512" houses were slightly larger at 512 ft^2.[128] These houses performed poorly, and were overcrowded with the extended families in the North.[129] (see figure 4-15, figure 4-16)

Social housing in Nunavik is particularly relevant for study as KMHB houses 98% of the population. EVOQ is a Canadian architecture firm that has been hired on many occasions to develop high performance, economical, and culturally sensitive housing. EVOQ and KMHB's work in community consultation is valuable in the development of culturally relevant space planning, which can help strengthen communities and improve building

125 David Venn, "Our Home: The high cost, low return of public housing," *Nunatsiaq News*, Mar. 14, 2023. https://nunatsiaq.com/stories/article/our-home-the-high-cost-low-return-of-public-housing/

126 *2022-2023 Annual Report* (Iqaluit: Nunavut Housing Corporation, 2023), 19. https://www.nunavuthousing.ca/publications

127 "Did you know? 98% of Nunavik's population is housed by the KMHB," Kativik Municipal Housing Bureau, accessed Dec. 10, 2023. https://www.omhkativikmhb.qc.ca/en/all-news/390-kmhb-housing-population-nunavik

128 Jane George, "Tiny homes could cure western Nunavut town's growing pains," *Nunatsiaq News*, Sep. 20, 2016. https://nunatsiaq.com/stories/article/65674tiny_homes_could_cure_western_nunavut_towns_growing_pains/

129 Lola Sheppard and Mason White, "Arctic Architecture: Standards, Experiments, and Consensus," *Canadian Modern Architecture: 1967 to the Present* (Princeton Architectural Press: New York, NY, 2019), 354.



figure 4-17: Social housing in Nunavik by EVOQ Architecture.
source: EVOQ Architecture

efficiency. Nunavik social housing has developed a generally appropriate plan which features a large front room, typically combining the living room, dining room, and kitchen. This allows for a flexible space for large families and community members when hosting gatherings.[130] Several typologies for Nunavik public housing have been developed including one and two-storey duplexes, and rowhouses. While there are some cost drawbacks of multi-storey buildings, increased density can improve energy performance of each unit. (see figure 4-17)

4.4.2 - Public-Private Collaboration

NHC, NWTHC, and KMHB frequently partner with other public and private groups, and these projects are useful to study. Private companies have developed successful northern housing designs for public entities that are able to be more prototypical than the general housing stock managed by the public housing groups.

In 2011, NHC and Cold Climate Building Inc. partnered to develop a SIPs duplex in Iqaluit and this project has several useful elements to study.[131] The Iqaluit SIPs duplex is constructed from SIPs for the walls and floors, and a lightweight wood truss roof structure. The foundation is a Multipoint space frame, which allows for a rapidly constructable and rigid substructure with adjustability to accommodate permafrost settlement. The roof uses an unvented insulated attic design, and remote humidity sensors are used to ensure that problems can be identified quickly and addressed. The advantage of attic insulation is that an insulation depth of 450 mm is possible. The project includes several useful building systems elements such as a shared mechanical room between units, simplifying maintenance for NHC staff, and allowing each boiler to heat the whole project in the case of failure. Heating is provided by hydronic heating loops, using radiant floor panels. It also has a conditioned crawlspace below the mechanical room to keep water tanks warm. (see figure 4-18, figure 4-19)

130 *Housing Construction in Nunavik - Guide to Good Practices*, 1st ed (Quebec: Société d'habitation du Québec, 2017) http://www.habitation.gouv.qc.ca/fileadmin/internet/documents/English/logement__nunavik_2014.pdf

131 "Iqaluit Duplex," Cold Climate Building, 2011, accessed Jan. 20, 2024. https://coldclimatebuilding.ca/portfolio-items/iqaluit-duplex/

There are tectonic elements that could lead to problems with the most impactful being the stepped roof which can cause snow pileup. The joint between the wall face and lower roof is a weak point, and weather sealing at this joint is extremely important. A more general issue is that the upper level requires additional structural members, adding shipping costs and complicating construction.



figure 4-18: Iqaluit SIPs duplex by Cold Climate Building and NHC.
source: Cold Climate Building



figure 4-19: Space frame foundation for SIPs duplex.
source: Cold Climate Building

Another project by Cold Climate Building is a multi-use resource centre in Sanikiluaq, Nunavut. The building was designed by architect Richard White, for the Arctic Eider Society, an Inuit conservationist group. It is a relatively large project, at 460 m^2, and is heated with in-floor hydronic heating loops and a forced-air system. This project is designed to be net-zero, using an electric heating system with solar panels and future wind turbines to offset the emissions from diesel generation. The hydronic loops are heated by electric air-to-water heat pumps. Cameron Haines, P.Eng., of Southface Engineering who worked on the project stated "there's a lot of wind up there, so that's why the model was so positive towards net zero," and notes that "[heat pumps are] one of the best systems to use because of the size of the heating area so you need very low temperatures which allows the heat pumps to operate at a very high efficiency."[132] The heat pumps also preheat the domestic hot water, in addition to an electric boiler, improving the efficiency of the water heating which is an energy intensive system. (see figure 4-20)

4.4.3 - Northern Housing Independence

Given the high costs of shipping to the North, and the issue of economic leakage to southern firms, there have been efforts to improve housing independence in the North. A few northern companies have been founded in an effort to offset some of the need for transported material, and to provide economic opportunities in the North.

First Kaska Construction Limited Partnership is a construction firm owned by Liard First Nation in the Yukon which purchased Heartland Timber Homes and relocated operations to Watson Lake, Yukon.[133] The homes are a timber post and beam construction, and use solid timber infill walls, with up to 200 mm of exterior insulation, to create durable and

132 Doug Picklyk, "Net Zero in Nunavut," *HPAC Magazine*, Aug. 23, 2023. https://www.hpacmag.com/features/net-zero-in-nunavut/

133 Jim Elliot, "Log home construction kit business moving to Watson Lake, operated by First Kaska," *Yukon News*, Mar. 02, 2023. https://www.yukon-news.com/local-news/log-home-construction-kit-business-moving-to-watson-lake-operated-by-first-kaska-7004276

comfortable homes.[134] Watson Lake is below the treeline, making timber construction reasonably economical for local communities. These timber frames could also be shipped to other northern regions and used with framed or SIPs infill walls to reduce shipping weight and bulk. The company also supplies kits for people building their own homes, empowering communities and users to take greater ownership and to support housing self-sufficiency in the North. (see figure 4-21, figure 4-22)

Another northern building company is Sakku Innovative Building Solutions which is currently constructing a modular home factory in Arviat, Nunavut.[135] Arviat is on Hudson Bay, giving it sealift access to other northern communities, and is the third largest community in Nunavut with around 2,800 people. The project is jointly funded by Sakku Investments Corporation, the government of Nunavut, and the federal government, totalling a $50 million investment. Sakku Investments is partnered with RG Solutions, a Quebec based modular home builder which completed two pilot project five-plexes in Arviat in 2022. Factory production for the units took approximately two months, and on-site construction was completed in eight, dramatically reducing the time needed to construct homes in the North.[136] The ability to work indoors allows for prefabrication during the winter, and to then ship further North as soon as the ice clears.[137] The prefabricated homes are built from wood framing, and while information on enclosure and insulation is unavailable, prefabrication can offer better quality control which is particularly important for airtightness and waterproofing, although the construction of these on site still requires special attention. (see figure 4-23)

Northern housing must address the many compounding challenges of life in the North. The climate is an ever-present concern, demanding high performance buildings, while economics and politics make it difficult to access funding. Transportability and constructability efficiencies, particularly by lightweighting and prefabrication, can help streamline projects and deliver successful high performance buildings.



figure 4-20: Resource centre in Sanikiluaq, NU.
source: HPAC Magazine



figure 4-21: Timber home wall construction.
source: Heartland Timber Homes

134 Katie Todd, " 'A paradigm shift': Liard First Nation tackles housing crisis with timber home kits, new production plant," *CBC News*, Oct. 07, 2023. https://www.cbc.ca/news/canada/north/liard-first-nation-lego-timber-homes-1.6986397

135 Jeff Pelletier, "Construction begins on Arviat modular home factory," *Nunatsiaq News*, Sep. 11, 2023. https://nunatsiaq.com/stories/article/construction-begins-on-arviat-modular-home-factory/

136 Don Procter, "Nunavut modular home factory changing lives in the Far North," *Journal of Commerce*, Sep. 22, 2023. https://canada.constructconnect.com/joc/news/technology/2023/09/nunavut-modular-home-factory-changing-lives-in-the-far-north

137 "SIBS sells 22 modular housing units to NHC, aims to 'change the landscape of the construction industry in Nunavut'," Northern News Services Limited, June 14, 2023. https://www.nnsl.com/news/sibs-sells-22-modular-housing-units-to-nhc-aims-to-change-the-landscape-of-the-construction-industry-in-nunavut-7273983



figure 4-22: Heartland Timber Home near Dawson Creek, BC.
source: Heartland Timber Homes, 2021



figure 4-23: Modular home in Arviat, NU, part of the Kivalliq Pilot Project.
source: Fred Lum, 2022



figure 4-24: Aerial view of DEW Line station in Tuktoyaktuk, NWT. source: unknown author, c. 1960

4.5 - DEW Line

The Distant Early Warning Line (DEW Line), was a series of radar bases established in the 1950s by the USA and Canada. The bases were built in Alaska, Yukon, Northwest Territories, and mainland Nunavut, as well as on Baffin Island and Greenland. The DEW Line was built to detect bombers flying over the arctic from the USSR, with construction beginning in 1954 and operational in the summer of 1957. The bases had to contend with many of the difficulties of the North, particularly transportation and construction. The DEW Line cost approximately $350 million in 1952, $4 billion in 2023 USD, and is one of the largest projects ever undertaken in the North, making it a valuable precedent.[138] (see figure 4-24)

The bases themselves vary somewhat but a common typology at the larger stations was to have two long buildings, with housing units, recreation, and technical equipment, and an enclosed bridge connecting them. This form allowed the buildings to be oriented parallel to the prevailing winds, reducing snowdrifts around the buildings. "For stations at the western end of the line... prefabricated panels, fully insulated, were put together to form modular building units 28 feet long, 16 feet wide and 10 feet high. These modules were put on sleds and drawn to station sites hundreds of miles away by powerful tractors."[139] The DEW Line made use of preassembled buildings, modular assemblies, and Quonset Huts. A focus on transportability and constructability, making extensive use of prefabrication

138 Thomas W. Ray, "A History of the DEW Line 1946-1964," *Air Defense Command Historical Study* no. 31 (United States Northern Command, June 1965), 8.

139 P. Whitney Lackenbauer, Ph.D. et al, *The Distant Early Warning (DEW) Line: A Bibliography and Documentary Resource List* (Calgary: Arctic Institute of North America, University of Calgary, Oct. 2005), 12.

and lightweighting, allowed for the rapid construction of the DEW Line, despite the harsh conditions and limited infrastructure.

The bases themselves were not high performance, requiring diesel to be supplied by the millions of gallons, however the logistics to construct the DEW Line are useful to study. Transporting materials and workers, 416,000 tonnes, and 25,000 people total, was an enormous undertaking.[140] With no infrastructure in place, runways for airlift required extensive manual labour. "The delivery of the initial supplies and personnel amounted to the largest commercial airlift ever assembled. 136,000 tonnes of supplies were carried in 45,000 flights using hundreds of aircraft—everything from four-engine cargo carriers to single engine bush planes."[141] (see figure 4-25)



figure 4-25: DEW Line air cargo in Kaktovik, Alaska.
source: unknown author, Canadian Centre for Architecture, c. 1960

The iconic radomes of the DEW Line are a fascinating construction, and one that has useful lessons for contemporary construction in the North. They were quite large, 17 m in diameter and mounted on towers to see over the landscape, leaving them exposed to high winds, snowdrifting, and extreme temperatures.[142] A rigid geodesic dome was developed in collaboration with Buckminster Fuller (see Chapter 5.3.1 - Buckminster Fuller - Dymaxion and Geodesics). Fuller's early designs used a textile stretched over an aluminium space frame, but fibreglass panels were thought to be more durable. Using repeatable elements and fibreglass-reinforced plastic cladding panels, the radomes were simply and rapidly assembled on site. Contemporary radomes make use of inflatable and textile structures in even the most demanding environments. This allows for significant lightweighting and constructability improvements, simplifying installation in extremely remote areas.[143] The modern version of the DEW Line, the North Warning System, uses textile claddings over a metal geodesic frame simplifying constructability with lightweighting and compact transportability. (see figure 4-26, figure 4-27)



figure 4-26: Textile radome covering for the North Warning System.
source: SHM Canada

140 P. Whitney Lackenbauer, Ph.D. et al, *The Distant Early Warning (DEW) Line: A Bibliography and Documentary Resource List* (Calgary: Arctic Institute of North America, University of Calgary, Oct. 2005), 9-10.

141 Mark Wolverton, "The DEW Line," *Invention & Technology* 22, vol. 4 (Spring 2007). https://www.inventionandtech.com/content/dew-line-0

142 F. Robert Naka and William W. Ward, "Distant Early Warning Line Radars: The Quest for Automatic Signal Detection," *Lincoln Laboratory Journal* 12, no. 2 (2000), 200.

143 "Inflatable Radomes to Protect Satellites on Ships During Testing," *Cruise Industry News*, Sep. 03, 2023. https://cruiseindustrynews.com/cruise-news/2023/09/inflatable-radomes-to-protect-satellites-on-ships-during-testing/



figure 4-27: Fibreglass radome, 1,200 kg.
source: Estate of Buckminster Fuller



figure 4-28: DEW Line in Tuktoyaktuk.
source: unknown author, c. 1960

After the development of ICBMs, the DEW Line was rendered obsolete, with the clean-up effort costing $575 million, completed in 2014.[144] Demolition in the North is just as challenging as construction, and the "DEW line sites cleanup is the biggest environmental project ever undertaken by the Government of Canada."[145, 146] The ability to deconstruct buildings and greater environmental sensitivity are needed in the North, due to the difficulty of removal and remediation in these remote sites.

The DEW Line was a huge project and the logistics to undertake it were an enormous feat, made possible by the scale of the American military. Even given the capacity of the military, transportability and constructability were primary concerns. Every component that could be lightweighted and streamlined was made so. From preassembled huts and modular building components, to the lightweight radomes that could stand up to the harsh environment, the difficulty of building in the North necessitated lightweight construction, a difficulty that still exists for people in the North, necessitating these same considerations.

144 "DND announces DEW Line clean-up completed," *CBC News*, Mar. 07, 2014. https://www.cbc.ca/news/canada/north/dnd-announces-dew-line-clean-up-completed-1.2564735

145 "Massive DEW line cleanup in Arctic to finish this summer," *CBC News*, May 29, 2013. https://www.cbc.ca/news/canada/north/massive-dew-line-cleanup-in-arctic-to-finish-this-summer-1.1350330

146 "The Distant Early Warning Line: An Environmental Legacy Project," Government of Canada, Nov. 28, 2013. https://www.canada.ca/en/department-national-defence/corporate/video/other/distant-early-warning-line-an-environmental-legacy-project.html

figure 4-29: Aqsarniit Hotel.
source: Dustin Patar, 2020



4.6 - Aqsarniit Hotel

Iqaluit is the largest city in Nunavut and the capital, and has seen a significant growth since Nunavut was created. To accommodate the economic and governmental functions, the Aqsarniit Hotel and conference centre was built in 2020. The hotel is owned by Qikiqtaaluk Corporation, an Inuit company, and was built by Bird Construction, a Canadian company who specialize in modular buildings. (see figure 4-29)

The building, other than the ground floor, was prefabricated in China, imported and sent by sealift to Iqaluit, and assembled on site.[147] Each modular unit was stacked by crane without the need for a superstructure. Once assembled on site, the building was wrapped to waterproof the joints between units, and insulated at the exterior. In total the fabrication took six months and the construction took 24 months, although it was delayed by covid, with the project costing $70 million. "Based on [Qikiqtaaluk Corporation's] evaluation and assessment, we found the best way was to proceed and build this in modular units... we would reduce our completion date by a year. And also at a cost saving of about $6 million."[148] (see figure 4-30, figure 4-31)

147 Jane George, "COVID-19 slows launch of Iqaluit's new Aqsarniit hotel, conference centre." *Nunatsiaq News*, Sep. 14, 2020. https://nunatsiaq.com/stories/article/covid-19-slows-launch-of-iqaluits-new-aqsarniit-hotel-conference-centre/

148 Emma Tranter, "From Shanghai to Iqaluit: New hotel ships pre-assembled rooms across international waters, " *Nunatsiaq News*, July 23, 2019. https://nunatsiaq.com/stories/article/from-shanghai-to-iqaluit-new-hotel-ships-pre-assembled-rooms-across-international-waters/

This project benefits from the construction infrastructure in Iqaluit, allowing for the cranes and heavy machinery required to assemble the large prefabricated modules. While this project was successful, there is little interest at the governmental level to construct public housing this way due to the lack of employment opportunities for Inuit in this process. On a smaller, and more constructable scale for remote communities, specific building elements such as building services, mechanical room assemblies, washrooms, and kitchens may be able to take advantage of prefabricated modules.

Prefabricated enclosure panels, incorporating insulation, waterproofing, and cladding are an option that has been explored in the past, allowing for expedited construction and potentially higher quality enclosures. Papineau Gérin-Lajoie Le Blanc architectes (PGL) developed several lightweight prefabricated cladding designs in the 1970s and onwards. Inuksuk High School, formerly Gordon Roberston Educational Centre, built in 1971 and Nakasuk Elementary School built in 1973, make extensive use of fibreglass reinforced resin panels with polyurethane foam insulation. The panels were lightweight, reducing the need for machinery and making use of local labour force.[149] (see figure 4-32, figure 4-33, figure 4-34)

Prefabricated buildings are useful for northern architecture as they reduce the need for on site labour, particularly relevant due to the limited labour available. Modular buildings can also allow for better quality control, as workers are in a controlled environment, simplifying detailing and a high performance enclosure. Prefabrication generally requires larger machinery due to greater size and weight, however it can significantly expedite construction making it a strong option for buildings in some parts of the North.



figure 4-30: Prefabricated hotel units. source: Stack Modular, 2021



figure 4-31: Units on sealift barge. source: Stack Modular, 2021

149 Lola Sheppard and Mason White, "Arctic Architecture: Standards, Experiments, and Consensus," *Canadian Modern Architecture: 1967 to the Present* (Princeton Architectural Press: New York, NY, 2019), 371-372.





figure 4-32: (top, left) The prefabrictated panels are lightweight to simplify labour.
source: Guy Gerin-Lajoie, 1970

figure 4-33: (top, right) Inuksuk High School by PGL, 1971.
source: Guy Gerin-Lajoie, 1971

figure 4-34: Nakasuk Elementary School, built in 1973 by PGL.
source: Adam Gordon, 2022

4.7 - Conclusion

Throughout the history of architecture in the North, from traditional Inuit and First Nations shelters to military megaprojects, the enormous challenges of transportation, construction, and climate are constant, necessitating buildings that can be easily brought to site and constructed with the labour and equipment available. Reliability is another crucial consideration, as repairs and maintenance can be impossible, and failures endanger users. This reliability is an extension of high performance and constructable projects, where simple and robust designs lead to higher quality construction and greater resilience when systems do fail. It is these challenges of transportability and constructability that require lightweighting, such that high performance buildings are made simple and economical to construct. In one of the harshest and most remote environments on earth, these considerations are paramount. The people of the North need lightweight high performance architecture.



figure 4-35: Igloo interior on King William Island, near Gjoa Haven. source: Fram Museum





figure 5-01: UltraTNT tarp.
source: Microdose Gear, 2023

figure 5-02: Halley VI Station.
source: B. Newham, 2010



Chapter 5
Precedents to Address Key Elements

5.1 - Introduction

This thesis proposes three key elements to improving buildings in the North: transportability, constructability, and building energy performance. These elements address critical issues of economic sustainability and high quality housing. For economic sustainability, shipping and labour costs are a significant portion, requiring transportable and constructable projects, and due to the limited infrastructure, operating costs are high, necessitating excellent energy performance. High quality housing is supported by high performance buildings, keeping users warm and healthy, and improved constructability allows users or local labour to undertake maintenance and repairs, improving longevity and further reducing life cycle costs.

Given these key elements of transportability, constructability, and building performance, lightweighting arises as an enormously impactful design methodology. Lightweighting directly addresses transportation costs, and improves constructability by reducing the need for heavy equipment and simplifying manual labour. These benefits to transportation and construction allow for high performance buildings to be more easily built in the North.

This chapter studies alternative disciplines in which lightweightness is a design priority, taking insight from the methodologies developed in them to inform northern architecture. Following this, precedents are studied which address the key elements of transportability, constructability, and building performance.

5.2 - Philosophy of Lightweightness

5.2.1 - Purpose of Lightweightness

Lightweighting is not often undertaken by architects, meaning there is no established methodology for lightweighting in architecture. In other disciplines where lightweighting is a major consideration, there is a more clearly articulated and analytical design methodology that can lend valuable insight for architects. This section investigates existing lightweighting in buildings, and alternative precedents of tents, racing vehicles, and space travel where lightweightness is a design priority, and which can provide insights for lightweighting in architecture.



figure 5-03: Wood framing, a lighter form of building than traditional brick homes. source: John Straube

5.2.2 - Material Optimization

Current building practices are reasonably optimized, occasionally for lightweighting, but more commonly in the pursuit of material reduction. The overall balance of these demands is constantly tested by the building industry, and many innovations have taken place historically, allowing for the lighter and more economical buildings available today.[150] An example of this optimization is low rise residential construction, which has evolved from solid brick walls and large beams to lightweight lumber framing, and in some cases to advanced framing.[151] Within a lumber framing system, components such as beams and joists have been optimized through material development, such as engineered wood products, reducing weight. At a meta level, the increased adoption of BIM and energy modelling serves to lightweight buildings by improving planning, reducing wastage and construction allowances. This is particularly important for the North as wasted materials and unused spare materials represent a significant cost. (see figure 5-03, figure 5-04)



figure 5-04: Topology optimized concrete slabs, enabled by 3d printing, can allow for lightweighting of a traditionally massive building component. source: Texas Society of Architects, 2020

In typical building practice, lightweighting beyond what is currently practiced offers limited economic savings. In the North however, this optimization is highly relevant, due to the high cost of transporting materials, and the limited machinery available on site. Material cost, shipping cost, and the cost of construction must all be balanced to design the optimal building, and as lightweighting reduces costs, super high performance buildings become more attainable in the challenging context of the North.

150 Brian Potter, "How Valuable Are Building Methods That Use Fewer Materials?" Construction Physics, Feb. 06, 2024. https://www.construction-physics.com/p/how-valuable-are-building-methods

151 Joseph Lstiburek, "BSI-030: Advanced Framing," Building Science Corporation, Mar. 10, 2010. https://buildingscience.com/documents/insights/bsi-030-advanced-framing

5.2.3 - Tent Typology

The tent has been an important part of human shelter for millenia, serving as a lightweight and rapidly constructable home for people across the world. Today tents are used in a wide variety of settings from refugee shelters to recreation, serving a demanding set of uses. The lightweightness and versatility of the tent typology has made them appropriate for these disparate uses, and these examples provide designs and a methodology that can lend insight for lightweight architecture.



figure 5-05: Inuit family and tupiq. source: William H. Grant, 1922

Traditional Tents

Traditionally, the tent served as a portable shelter for Inuit and northern First Nations groups during the summer hunting season, allowing them to follow animals over the course of days or weeks. The ability to pack up camp and carry it was necessary, so minimizing weight allowed them to travel unencumbered (see Chapter 4.2 - Inuit and First Nations Shelter). The versatility of the tent typology and the specialization of its design allows it to be successful in this incredibly challenging context. (see figure 5-05)



figure 5-06: Refugee tent shelter proposal. source: Jason Child, 2013

Refugee shelter

The versatility of the tent also makes them appropriate for refugee shelters, where the ability to transport many shelters at once, and to easily construct them, is critical to housing people displaced by disaster or wars. A previous University of Waterloo thesis by Jason Child studies refugee tent shelters, and proposes a new example which highlights a key value of the tent typology, which is its adaptability. Child uses an analytical and clearly articulated decision making methodology that balances several key metrics to design an optimized shelter.[152] Among these metrics is lightweightness, simplicity of construction, repairability, and long term use, all key design considerations shared by northern architecture. (see figure 5-06)

Recreation

Some of the most demanding uses of tents come from recreational fields such as hiking and mountaineering where shelters must contend with harsh environments but where weight is paramount as everything must be carried on one's person. Backpacking equipment makers are constantly experimenting with new materials and designs to develop high performance lightweight equipment. Tents are a large component of a hiker's equipment weight, making them an important consideration in lightweighting for hikers.

152 Jason Child, *Beyond the Minimum: A Durable Emergency Shelter* (thesis, University of Waterloo, 2013), 93. http://hdl.handle.net/10012/7402

Bill Moss and Buckminster Fuller

Many aspects of modern tent design can be traced to Bill Moss, a tentmaker and artist who worked from the 1950s to the 90s, founding Moss Tent Works in 1975.[153] Moss pioneered the dome tent in 1955 with the Pop-Tent which made use of fibreglass poles with a synthetic fabric, rather than the traditional A-frame tents being used.[154] The Pop-Tent was faster to erect and was considerably lighter as it used flexible poles and an efficient dome shape. Moss Tent Works was a major force in developing the modern tent, creating highly resilient but lightweight shelters. (see figure 5-07)

In 1975 The North Face produced the first geodesic dome tent, the Oval Intention, inspired by Buckminster Fuller's work, and some employees met with him.[155] The Oval tent and the geodesic design is still in use today for some of the most extreme settings, such as base camps and arctic expeditions, where wind and snow loads are a major consideration. The geodesic structure affords high strength as well as volumetric efficiency, reducing material weight and improving energy performance, keeping users warm in harsh conditions (see Chapter 5.3.1 - Buckminster Fuller). (see figure 5-09)



figure 5-07: Moss Tent Works Starlet, 2,776 g, still in use since 1985. source: author

Thru Hiking

Thru-hikers are likely the most demanding users on the weight of their equipment out of any discipline, often at the expense of durability and certainly comfort. Thru-hikers hike thousands of kilometres, making the weight of their equipment enormously impactful. "Ultralight" is the term often given to thru-hikers and their equipment, indicating a base weight of less than 10 lbs (4.54 kg). A crucial element of "ultralight" is the quantitative analysis of equipment, which means weighing absolutely everything. This avoids redundancy and "default" choices, developing an understanding of the real weight cost of each component. (see figure 5-08)



figure 5-08: Hiking backpack by author, constructed from XPac VX07/VX21, a sailcloth material with a polyester reinforcing grid to create a lightweight, high strength textile. Weight: 363 grams. source: author

For thru-hiking, small dome tents or trekking pole supported tents are the most common choice. Trekking pole tents allow trekking poles to serve as the structure of the shelter, making multiple uses of an item and saving weight. Two important tentmakers in the thru-hiking space are Joe Valesko who founded Zpacks in 2005, based in Florida, and Dan Durston who founded Durston Gear in 2018, based in British Columbia. These tentmakers produce some of the most popular tents for thru-hiking, owing to their highly functional design and incredible lightweightness.

153 "Bill Moss: Fabric Artist & Designer by Marilyn Moss," Bill Moss Tents, 2014. https://www.billmosstents.com/about

154 Marilyn Moss, *Bill Moss: Fabric Artist & Designer* (USA: Chawezi, 2013), 36.

155 "The Dome Tent," The North Face Journal, Jan. 23, 2017. https://thenorthfacejournal.tumblr.com/post/156273811924/the-dome-tent-from-buckminster-fuller-to-the-top



figure 5-09: TNF GeoDome and Starp.
source: The North Face, 2018

Zpacks

Zpacks is a major force in thru-hiking equipment design, producing some of the most popular tents and backpacks, as well as clothing and other equipment.[156, 157] Zpacks is most famous for bringing Dyneema Composite Fabric (DCF) to the wider market, previously called Cuben Fiber, a composite fabric formed from a sheet of Ultra High Molecular Weight Polyethylene (UHMWPE) sandwiched by polyester, originally popularized by racing yacht sails (see Chapter 5.2.4 - Racing Vehicles). DCF is an ideal material for tents due to its high strength to weight ratio, allowing it to be pitched taut and to resist snow, rain, and wind loads, while remaining completely waterproof. Zpacks produces "hands down the lightest fully enclosed two person tent in the world" with their Duplex Lite, released in 2024, weighing 423 g.[158] The Duplex Lite features 0.55 oz (19 g/m^2) DCF for the main tent, and 0.75 oz (25 g/m^2) DCF for the floor. The tent is 1.14 m to 1.02 m wide, just barely letting two people sleep side by side, compromising comfort for weight savings. (see figure 5-10)

Zpacks epitomizes ultralight hiking: using high tech materials, with exorbitant prices to match, to achieve high performance and lightweightness. In general, Zpacks' equipment is austere, focused on lightweightness rather than durability or comfort. The highly analytical design process of Zpacks, carefully weighing each component to understand the weight cost of thicker fabric or stronger guylines, is also useful to consider in the North.

Durston Gear

Dan Durston, an accomplished hiker himself, is active in the online thru-hiking communities and has written extensively about his design process. Prior to founding his own company, Durston was one of the first tentmakers to use DCF, developing a tent with the material in 2009, and since then Dyneema has become the optimal material for the highest performance and lightest shelters in thru-hiking.

156 Tyler Fox, "The Pacific Crest Trail Gear Guide (2023 Survey)," Halfway Anywhere, Jan. 24, 2024. https://www.halfwayanywhere.com/trails/pacific-crest-trail/pct-gear-guide-2023/#notes-on-the-gear

157 Kate Richard, "Top Tents and Shelters on the Appalachian Trail: 2023 Thru-Hiker Survey," The Trek, Jan. 11, 2024. https://thetrek.co/appalachian-trail/top-tents-and-shelters-on-the-appalachian-trail-2023-thru-hiker-survey/

158 "Duplex Lite Tent," Zpacks, Feb. 2024. https://zpacks.com/products/duplex-lite



figure 5-10: ZPacks Duplex, a popular ultralight tent, 507 g. source: Backcountry Emily, 2017



figure 5-11: Durston X-Mid Pro 2, made from Dyneema, 509 g. source: Durston Gear, 2023

Durston Gear's X-Mid has quickly become popular with the thru-hiking community and makes several key design choices that improve on past tent designs. The X-Mid uses a hiker's trekking poles, saving weight, and places the poles in an offset position, forming a strong pyramidal shape resisting wind and snow loads, and increasing interior space. The X-Mid has a rectangular footprint, with only four stakes needed, greatly simplifying the tent pitch.[159, 160] Another important consideration for ultralight hikers, is the excellent volumetric efficiency of the X-Mid, reducing material use and thus weight.[161] The X-Mid geometry was a major innovation in tent design, and is now patented by Durston. The X-Mid tent is also offered in different configurations, allowing for further optimization based on the specific application. (see figure 5-11)



figure 5-12: Black Diamond portaledge, weighing a total of 9.9 kg.
source: Black Diamond

Dan Durston's design process is highly analytical, and offers insight for architects, where many of the construction processes and materials are taken for granted. The design philosophy of optimizing form and material, and allowing these elements to inform each other, leads to highly successful outdoor equipment, and can inform architecture in the North.

Jessie Croll - Hybrid Bivouac

In mountain climbing every gram is critical as you ascend against gravity, meaning lightweightness leads directly to improved athletic performance. The portaledge is a form of tent that hangs from the side of a mountain, suspending its occupants over thousand foot drops and must stand up to violent winds, rain and snow, and cold. The demands on this shelter are extreme and it must accomplish this while weighing as little as possible. (see figure 5-12, figure 5-13)



figure 5-13: Jessie Croll Hybrid Bivouac, made from Dyneema and laminated UHMWPE strands, 480 g.
source: Jessie Croll, 2021

Jessie Croll's thesis, *Hybrid Bivouac*, at the University of Waterloo in 2021 develops a multifunctional tent, which can also serve as a hammock or portaledge. Croll's thesis "demonstrates how a design process that combines computational modelling tools and low-fidelity physical prototypes can be used to optimize the flexible composite membrane of an ultralight tensile structure... Modelling and fabrication methods from racing sail design... are adapted to simulate and fabricate an uncompromising and adaptive tent system."[162] Croll's particular innovation, which appears to be entirely novel

159 Dan Durston, "Long Term Review: Tarptent Stratospire 2." Into Cascadia, Nov. 30, 2015. https://intocascadia.com/2015/11/30/long-term-review-tarptent-stratospire-2/

160 Dan Durston, "Drop + Dan Durston X-Mid 1p Tent," comment on Drop.com forum, July 6, 2018. https://drop.com/buy/drop-dan-durston-x-mid-1p-tent/talk/2131238

161 Dan Durston, "The Volumetric Efficiency of Trekking Pole Shelters," Into Cascadia, Jan. 8, 2019. https://intocascadia.com/2019/01/08/the-volumetric-efficiency-of-trekking-pole-shelters/

162 Jessie Croll, *Hybrid Bivouac: High-Modulus Composite Membranes for Portable Shelters* (thesis, University of Waterloo, 2021), v.



figure 5-14: Jessie Croll Hybrid Bivouac, suspended form. source: Jessie Croll, 2021

in the hiking and climbing equipment space, is the use of strands of UHMWPE laminated to a DCF tent body to reinforce key structural points and axes, allowing for significant overall lightweighting.[163] This process is inspired by the reinforced textiles used for racing sails.[164] Jessie Croll's Hybrid Bivouac weighs just 368 g for the enclosure and 112 g for the carbon fibre ridge pole and connector, forming a 480 g shelter.[165] Croll's Hybrid Bivouac is capable of suspending its occupants as a hammock or portaledge, enabling a wide range of uses. The Hybrid Bivouac demonstrates the power of digital and physical simulation and modelling, as well as the material innovations of UHMWPE and carbon fibre. (see figure 5-14)

The tent typology has many relevant aspects to consider for northern buildings. A key element is specialization. Designs are optimized for their use, and architecture could incorporate this to a much greater extent. Related to this is the high level of analysis and engineering that goes into tent designs. Tentmakers must articulate the goals of their product, whether that be durability and storm-worthiness or absolute lightweightness, and design accordingly. Tents sacrifice the solid building enclosures people have come to expect, but these are not strictly necessary. Textile finishes are a compelling option to reduce transport volume, simplify construction, and save weight (see Chapter 5.3.3 - Frei Otto - Tensile Structures and Arctic City). Where tents have taken full advantage of cutting edge materials and design methods, buildings have been slower to incorporate these, and these could allow for more transportable and constructable high performance buildings, especially in the challenging context of the North. The quantitave approach, weighing each component is also useful to consider, to understand the real weight cost of each element, and thus find places to reduce weight.

163 Jessie Croll, *Hybrid Bivouac: High-Modulus Composite Membranes for Portable Shelters* (thesis, University of Waterloo, 2021), 24, 48.
164 Ibid., 24.
165 Ibid., 61.

5.2.4 - Racing Vehicles

"Simplify and add lightness" was the mantra that drove Colin Chapman and Team Lotus to seven Formula One Constructors' Championships and six Drivers' Championships in the 1960s and 70s. The cutting edge of lightweightness is racing, from the most expensive cars in Formula One to hobbyist runners. This philosophy drives innovation in these domains and there is plenty to learn from even the most exotic efforts at lightweighting. This section investigates motorsport, sail racing, and cycling for their extremely lightweight structures and the design methodology of these sports, which can inform lightweight architecture.



figure 5-15: Lotus 25, the first monocoque chassis, with a total weight of 450 kg, which won seven of 10 races in 1963. source: user Pexels on Pixabay, 2014



figure 5-16: Mclaren MP4/2, which used a carbon monocoque chassis. The MP4/2 won in 1984 and 1985. source: McLaren, 2023

Formula One

At its most elemental, acceleration is equal to force divided by mass, which is to say there are only two options: increase force, or decrease mass, and the balance of these is paramount in racing. In the case of motorsport, increasing power without weight is an engineering priority, and technologies such as forced induction have allowed for weight reductions and power increases. Aerodynamics and downforce also increase effective force and traction, without significantly increasing weight. Across the rest of the car, weight savings are critical and this is most noticeable with the monocoque chassis. First used in the 1962 Formula One season by Colin Chapman with the Lotus 25, the aluminium monocoque frame was lighter and stiffer than traditional tube frames and the Lotus 25 dominated the sport for two seasons, the car weighing just 450 kg. Today, Formula One cars are constructed using a carbon fibre composite monocoque chassis, incorporating a variety of materials such as kevlar, Nomex, aluminium, and recently Dyneema for structural and safety performance goals.[166] (see figure 5-15, figure 5-16)

While modern Formula One cars are actually heavier than they used to be, this is largely a result of safety improvements, more powerful engines, and aerodynamics tradeoffs, making them faster than ever. Formula One safety regulations require the ability to save the driver in a crash at 300 km/h and safe from the resultant fire. Puncture protection is required for the chassis and kevlar is used, also used in bulletproof vests. Fire resistance is another critical concern, and Nomex is a requirement in many cases. Nomex is a flame resistant and insulative fibre and is used in composite panels, protecting the driver from fires, and is used throughout drivers' clothing. (see figure 5-17)

166 Anna Duxbury, "History of safety devices in Formula 1: The halo, barriers & more," Autosport, Nov. 25, 2021. https://www.autosport.com/f1/news/history-of-safety-devices-in-formula-1-the-halo-barriers-more-4982360/4982360/

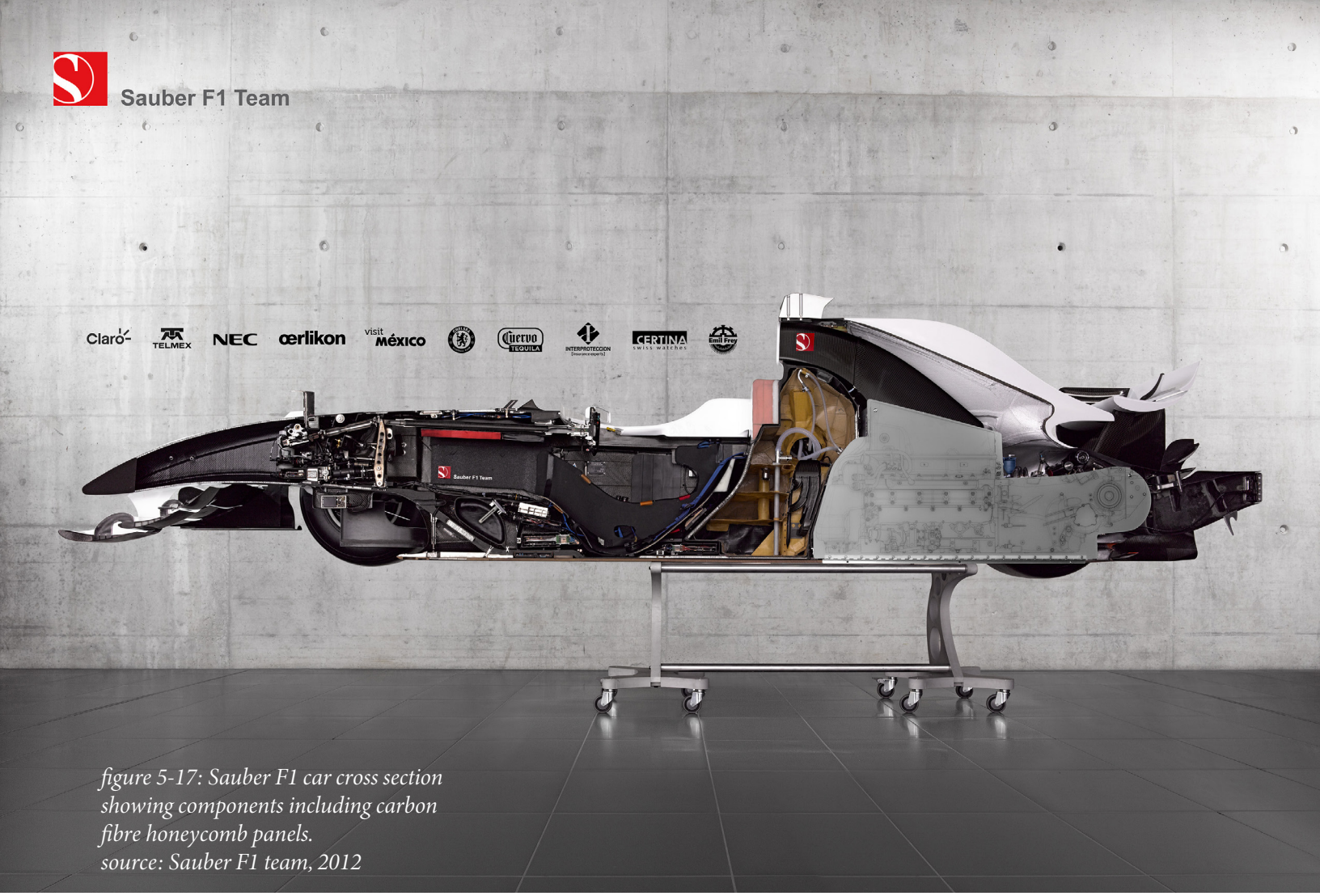


figure 5-17: Sauber F1 car cross section showing components including carbon fibre honeycomb panels.
source: Sauber F1 team, 2012

Lightweightness has led to dangerous safety tradeoffs in the past and people have died as a result, calling to attention critical considerations engineers and architects must also make in the built environment. In the documentary Grand Prix: The Killer Years (2011) Len Terry, the chief designer of Lotus from 1963 to 1965, highlights the dangers of the lightweighting that was taking place. "Right now everyone in this country was using the same engine, and so everybody basically had the same power. So the only way to beat the opposition was to add lightness, and that is what we tried to do. Colin most of the time carried it to extremes, and consequently his cars, although they were quick, were also very fragile, and tended to break."[167]

Many of the considerations of race car design are relevant to architecture. Determining the relevant dangers and making meaningful steps to ameliorate these is a necessity. The enormous difficulty of building in the North requires careful consideration of safety allowances, without making the project untenable through material and transport costs or construction difficulty. In Formula One, lightweighting improves acceleration and braking, critical elements of racing. However, lightweightness itself is just one component, albeit an important one, of creating a fast car. Similarly, lightweighting in the North simplifies transportation and construction, important challenges in the North, but does not itself create a high performance building, and compromises on weight to accomplish high quality northern buildings are important for architects in the North to consider.

167 *Grand Prix: The Killer Years* (United Kingdom: British Broadcasting Corporation, 2011), 8:00.



figure 5-18: AC40 class racing yachts of Emirates Team New Zealand. source: Armare Ropes, 2023

America's Cup

Sailboats make use of many of the same materials as Formula One, particularly carbon fibre composite structures, but have very different applications, developing interesting construction techniques and materials. An important aspect of sailboats is the sails themselves, requiring lightweight but incredibly high strength and durable textiles, giving them applicability in a variety of other fields, including architecture. Similar to Formula One, the highly analytical design methodology is relevant to architects, especially in challenging settings where the effects of an optimized design can have greater effect, such as in the North. (see figure 5-18)

Within sailboat racing, the most prestigious race is the America's Cup, a longstanding international competition that demands the highest performance and there is constant development to optimize the classic tradition of sailing. Eric Desjardins of McConaghy Boats, who build racing and luxury yachts, gave a presentation for the Royal Institution of Naval Architects in Australia and describes the importance of lightweightness. "The success of a race yacht is largely depending on how light it is... how light you want to do the structure, that still fits your purpose and will still let you finish a race. It's the same for planes, it's the same for a race car. The lighter you go, the faster usually you can go" and continues "the material of choice to achieve that these days, and the last few decades, is carbon fibre."[168] Lightweightness is critical to improving buoyancy and thus speed, as well as improving maneuverability. The current monohulls are constructed from carbon fibre composite structures, often a carbon and nomex honeycomb stressed

168 Eric Desjardins, "Construction of Advanced Composite Racing Yachts," *NSW Section & IMarEST ACT/NSW Technical Meeting* (Australia: Engineers Australia, 2021) https://www.youtube.com/watch?v=xWjSISr1h1M (8:00)

skin panel, similar to Formula One cars, designed to handle high forces while remaining lightweight. Novel systems such as foil cant arms and sail wings allow for higher performance, but require a weight tradeoff and thus testing to determine the overall superior system. (see figure 5-19)

The sails of America's Cup yachts are highly specialized, no longer traditional sails but 'wings' or 'soft wings', a rigid or semirigid structure designed to capture as much wind energy as possible. The wings also incorporate mechanized systems inside which control the shape throughout the height of the wing, allowing for optimized control and power transfer. With limits on the number of sails that may be constructed, detailed analysis is critical prior to construction.[169] More traditional high performance sailcloths, such as from Challenge Sailcloth, are constructed from UHMWPE laminated with polyester textiles and a film material, all of which work together to form a low stretch, durable, and lightweight sail. (see figure 5-20)

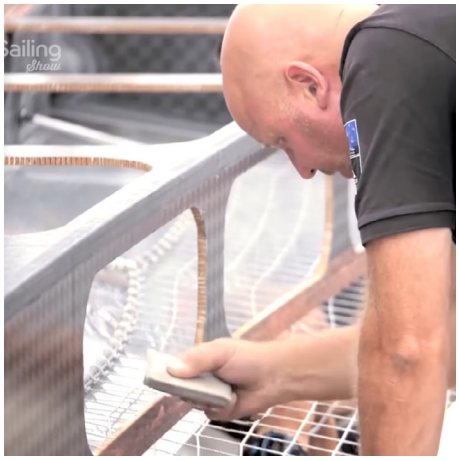


figure 5-19: AC50 Catamaran carbon fibre honeycomb structure with large cutouts for weight savings.
source: The Sailing Show, 2017

Another important element of yacht design in the America's Cup is the strict limitations on the number of components and boats allowed to be built. Each team may only construct one full AC75 boat, and limited parts to test performance, requiring a high level of analysis and design before the construction phase.[170] This practice is highly relevant to architecture, especially in demanding settings, where performance is often roughly estimated, and only recently have requirements been set for more detailed construction and energy modelling. Simulations of building aerodynamics, energy performance, snow loads, and many other elements are possible, and incorporation of this simulation would improve northern buildings.

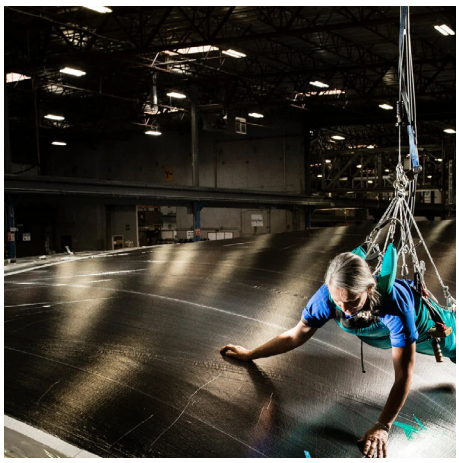


figure 5-20: North Sails 3Di technology manufacturing.
source: North Sails.

Tour de France

The bicycles at the highest level of cycling are highly engineered machines, optimized to take full advantage of an athlete's strength. In this pursuit, lightweightness is critical. The Tour de France is won and lost on its mountain stages, making the strength to weight ratio of each rider critical. Weight has long been a major focus of bike manufacturers and cyclists, and carbon fibre has become the material of choice. The highly modular nature of bikes also lends insight for architects. Each component and its weight is carefully considered. (see figure 5-21)

169 "Designer Spotlight: America's Cup Special Edition," North Sails, Apr. 5, 2021. https://www.northsails.com/blogs/north-sails-blog/designer-spotlight-americas-cup-special-edition-developing-softwing-technology-for-2021-ac

170 "The Technology," America's Cup. accessed Jan. 9, 2024. https://www.americascup.com/the-technology



figure 5-21: Jonas Vingegaard and Tadej Pogacar.
source: Zac Williams, SWpix.com, 2023

Carbon fibre bike frames have become highly optimized, and are incredibly lightweight and stiff, transferring power to the wheel as quickly as possible, providing better acceleration and efficiency. Carbon fibre allows for complex aerodynamic shapes which can support the load and power of a cyclist, making it an ideal material choice. Every year more components on a bike are made in carbon fibre, due to its versatility and strength.

As manufacturers can more easily hit the Union Cycliste Internationale (UCI) minimum weight of 6.8 kg, other optimizations have become more beneficial, most importantly aerodynamics. Aerodynamics, wider tires, hydraulic braking, and electronic shifting have all become priorities for bike manufacturers and racers, even at the expense of weight, and each component is measured and considered against its potential racing benefit. Hydraulic disc brakes are a recent example of this, as they add about 200 grams, but this is a worthwhile tradeoff when it makes a rider faster in cornering and descending. The last rim brake bike to win the Tour de France was in 2020, when Tadej Pogacar would swap between rim and disc brakes, opting for the lighter rim brakes on mountain stages.[171] Specialization has also become commonplace, where flatter, faster stages of the Tour de France will see riders using heavier aerodynamic bikes, and mountain stages will see riders using the lightest bike they can.[172]

171 Liam Cahill, "Tadej Pogacar's Tour de France-winning bike: a closer look at the Campagnolo parts that propelled him to victory," Road.cc, July 22, 2021. https://road.cc/content/feature/pogacars-all-italian-tdf-bike-focus-campagnolo-285041

172 Jessie-May Morgan, "Aerodynamics vs. Weight: What's the Tipping Point for Pro and Amateur Cyclists?" Bike Rumor, Mar. 24, 2023. https://bikerumor.com/aerodynamics-vs-weight-whats-more-important-tipping-point-pro-amateur-cyclists

Cycling has improved its performance analysis with wind tunnels, biometrics, and power estimations, and is optimizing in more impactful ways than weight reduction. However "weight weenies" are still common in the hobby, particularly in amateur hill climb races where there is almost no element more important than weight. In this discipline bikes can get truly silly, with users commonly taking extreme measures such as cutting parts down, carving holes into components, and altogether removing components. This weight consideration also extends to the cyclists themselves, as power to weight ratio includes body weight. This obsession can be detrimental however, and eating disorders are a serious issue in the sport.[173]

Cycling, like Formula One and the America's Cup, leverages cutting edge materials to build an optimized racing machine. Carbon fibre, aluminium, titanium, and specialized plastics are used to save weight in every feasible area. The UCI weight minimum means that instead of making the bike lighter, aerodynamic shapes, improved tires, hydraulic braking, and electronic shifting are able to be incorporated, and making these optimizations as light as possible allows more to be used with a smaller weight penalty. This component level analysis allows cyclists to understand the exact weight cost of additional features, and to consider their benefit against this. Cycling also demonstrates the importance of greater analysis and empirical study, where traditional practices are becoming outdated, and better testing and modelling improves performance. This is especially applicable to northern buildings where past practice is insufficient, and the highly analytical methodology of race vehicle design can afford significant optimization, leading to better homes for people in the North. (see figure 5-22, figure 5-23)

Racing equipment design demands every marginal advantage, and the engineering and design that goes into these projects is extensive. Important for designers to keep in mind is the actual goal, which is a high performance racing vehicle or equipment, where lightweightness is one element of this pursuit. Optimization and specialization is another key aspect of racing, and for northern buildings this is a valuable consideration. Whereas past buildings have made use of standard practices from the south, with relatively few context specific adaptations, contemporary designs must be measured against real energy performance and life cycle costs. There is a great deal of improvement possible for architecture in the North, and like racing vehicles, lightweighting is a key element of this optimization.



figure 5-22: Miguel Indurain's 1994 Pinarello, the last steel bike to win the Tour in 1994, weighing 9 kg.
source: unknown author, 1994



figure 5-23: Marco Pantani and his Bianchi Mega Pro XL Reparto Corse. This was the last aluminium bike to win the Tour in 1998, weighing 6.96 kg.
source: Bettini Photo, 1998

173 Sophie Smith, "Fat shaming and problem eating: The dark side of the Tour de France," *Telegraph*, June 29, 2022. https://www.telegraph.co.uk/cycling/2022/06/29/fat-shaming-problem-eating-dark-side-tour-de-france

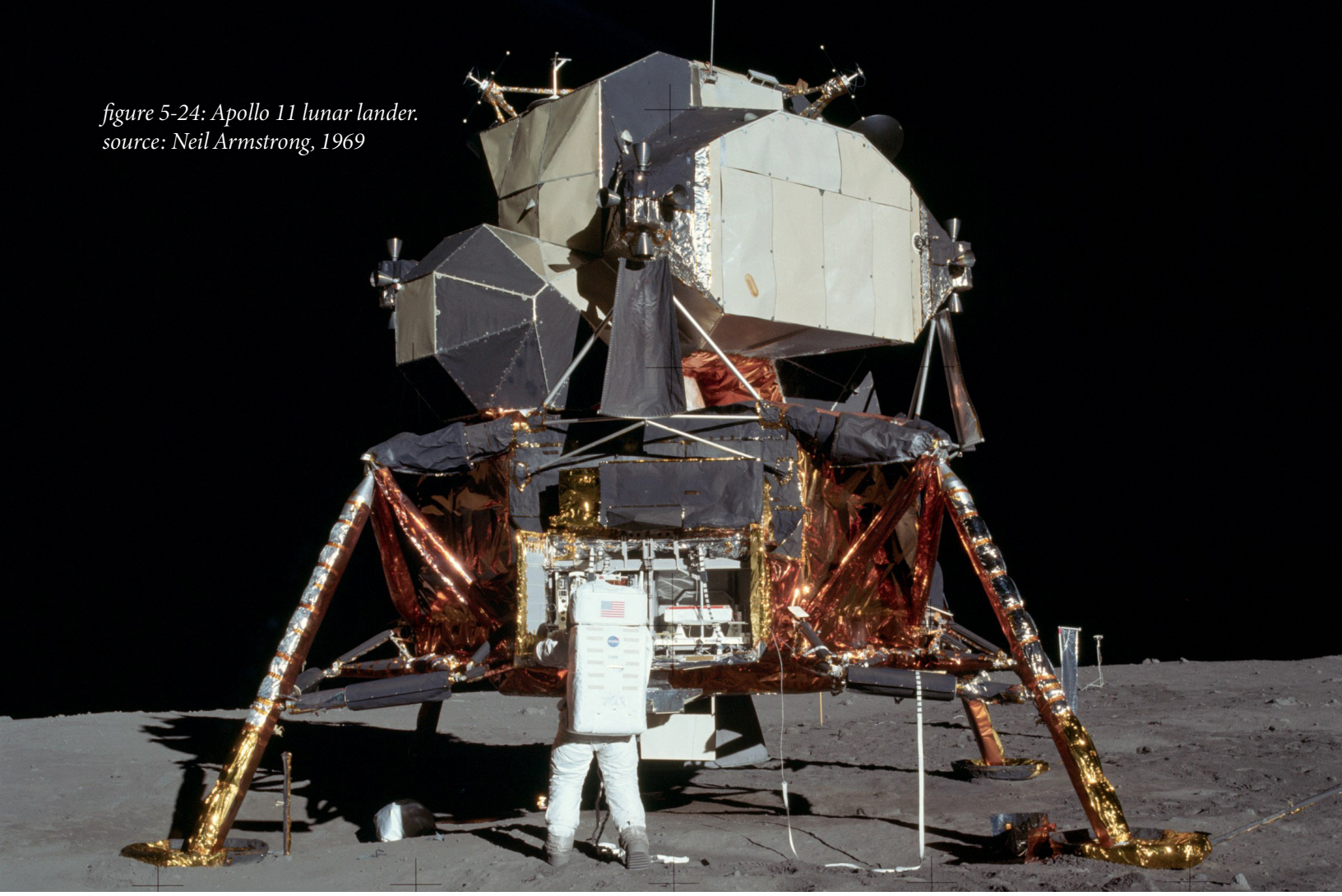


figure 5-24: Apollo 11 lunar lander. source: Neil Armstrong, 1969

5.2.5 - Space Travel

Space travel is a fascinating precedent of lightweight and compact design practices as the cost of carrying any payload to orbit is astronomical. Spacecraft and space stations must mediate the issues of transport to space, then contend with the environmental challenges of orbit and atmospheric reentry, while remaining lightweight. Future proposals for spacecraft and extraterrestrial settlements also take these key issues into account, while presenting novel ways of building, such as inflatable or 3D printed buildings.

Rocket Launches

The central issue of rocket launches is the fuel to payload ratio, called the "tyranny of the rocket equation" which "creates a vicious cycle where more fuel adds more weight, which in turn needs more fuel to lift. In practical terms, this means that for a typical single-stage rocket, approximately 90% of its initial launch mass must be propellant" demonstrating the critical need for lightweighting in space travel.[174] Similar to building in the North however, the need for lightweightness must be balanced with reliability as the cost of failure is greater than the cost of added weight to ensure a successful project.

The cost of transporting a payload to low earth orbit has been dramatically reduced since 2010 with the advent of the SpaceX Falcon 9, bringing the price down to $2,600 per kilogram.[175] The Falcon 9 is "the first orbital class rocket capable of reflight."[176] The high cost of the first stage, with

174 "The Tyranny of the Rocket Equation: An In-depth Examination," New Space Economy, May 28, 2023. https://newspaceeconomy.ca/2023/05/28/the-tyranny-of-the-rocket-equation-an-in-depth-examination/

175 Thomas G. Roberts, "Space Launch to Low Earth Orbit: How Much Does It Cost?" Aerospace Security, Sep. 01, 2022. https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost/

176 "Falcon 9," SpaceX, accessed Feb. 12, 2024. https://www.spacex.com/vehicles/falcon-9/

its nine Merlin rocket engines, can be recouped over the course of many launches due to its reusability. The landing legs are constructed from carbon fibre and aluminium honeycomb composite structure for its high strength to weight ratio, creating a lightweight landing system. SpaceX is currently developing Starship, "the most powerful launch vehicle ever developed" which is capable of carrying 150,000 kg to orbit, the Moon, Mars, or even further.[177] Even with its huge amount of fuel and launch power, it is only capable of carrying around 3% of its launch weight as payload, highlighting the critical need for lightweighting, despite the gigantic total weights. (see figure 5-25, figure 5-26)



figure 5-25: The Falcon 9 weighs approximately 30,000 kg, and launches with more than 500,000 kg of fuel and can carry 22,800 kg to low earth orbit. source: Getty Images, 2017



figure 5-26: Starship rocket. The booster is 200,000kg, the spacecraft is 100,000 kg, and with 4.6 million kg of fuel, it is capable of a 150,000 kg payload. source: SpaceX, 2021

Space Stations

Due to the enormous cost of getting payloads to space, satellites, such as space stations, must be made as lightweight as possible. The International Space Station (ISS) is 1,200 m^3 and 450,000 kg, comparable in size and weight to two four-bedroom houses including foundations.[178] Weight savings on the ISS are an engineering priority and there are a variety of solutions employed. A large portion of the ISS is covered with a Kevlar textile cladding and insulation, which protects the thin aluminium shell of the ISS from space debris, forming "a thermal vest as well as a bullet-proof one."[179] Another application of textiles for lightweighting is the use of inflatable shelters, such as the Bigelow Expandable Activity Module (BEAM) by Bigelow Aerospace, launched by SpaceX and attached to the ISS in 2016. BEAM weighs 1,413 kg and encloses 16 m^3.[180] (see figure 5-27, figure 5-28)

Lunar and Martian Bases

The environment on other planets and moons is inhospitable, especially in the slim atmosphere of our closest neighbours, the Moon and Mars. Future settlements must contend with the challenges of launch, including lightweightness and compactness, as well as stand up to the conditions at their destination. While no projects have been completed yet, NASA has funded ICON, a high tech construction firm, to develop Olympus, a laser 3D printing machine that could make use of dust on the Moon to form concrete-like buildings, making use of lunar regolith which avoids the need to

177 Trevor Sesnic, "Starbase Tour with Elon Musk," Everyday Astronaut, Aug. 11, 2021. https://everydayastronaut.com/starbase-tour-and-interview-with-elon-musk/

178 "ISS: International Space Station," European Space Agency. accessed Feb. 12, 2024. https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/International_Space_Station/ISS_International_Space_Station

179 Tim Radford, "Why is the space station covered in cloth?" *Guardian*, Aug. 16, 2007. https://www.theguardian.com/science/2007/aug/16/spaceexploration.timradford

180 "Bigelow Expandable Activity Module (BEAM)," NASA. accessed Feb. 14, 2024. https://www.nasa.gov/international-space-station/bigelow-expandable-activity-module-beam/

transport building materials.[181] The first implementation of Olympus will be to construct landing pads, simplifying the process of landing future machines and people on the Moon.[182] ICON has previously built 3D printed houses in Texas, including a community of 100 houses in collaboration with Bjarke Ingels Group.[183] (see figure 5-24)

Space travel and extraterrestrial settlements are a fascinating precedent for architecture here on Earth. The shelters must contend with the extremes of space, while remaining as lightweight as possible for the initial launch. Space vehicles and shelters leverage high performance materials such as carbon fibre and synthetic textiles to create habitations that can meet these demands. These challenges are, in some ways, an exaggeration of the challenges for buildings in the North, with difficult transportation and construction processes in an extreme environment, and as such, space travel can lend insight into design considerations and methodology for architecture in the North.

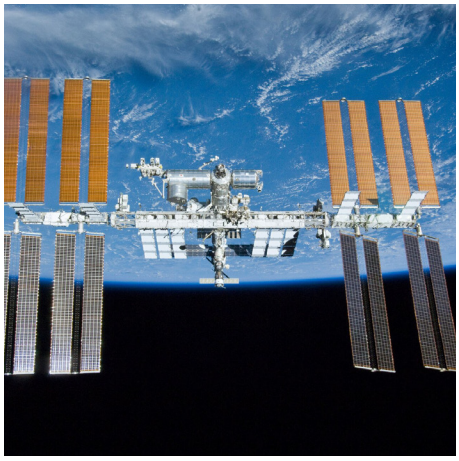


figure 5-27: The ISS weighs 450,000kg, is 108 m long, and encloses 1,200 m^3. source: NASA, 2018

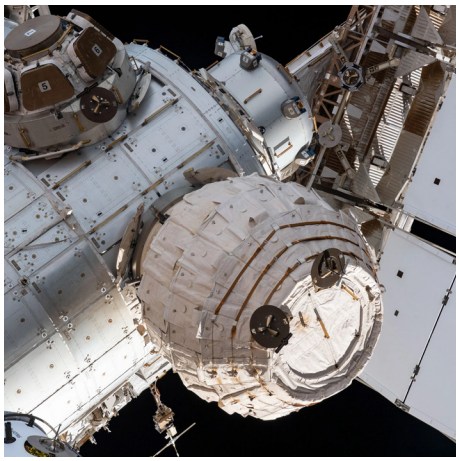


figure 5-28: BEAM, 1,400 kg, 16 m^3, made from Vectran fibre. source: NASA, 2022

5.2.6 - Conclusion

Throughout these alternative precedents, lightweighting is used to solve a variety of challenges, most commonly relating to performance, transportation, and ease of use. In architecture, lightweighting results in material reduction and simpler transportation and on site labour. Within these alternative disciplines, lightweightness is a design priority, however it is used in the pursuit of an overarching goal. In the North, this goal is that of transportable and constructable high performance buildings. Familiar building practices are relevant to consider, however lightweighting northern buildings requires a critical analysis of these established practices. The design methodologies of these alternative precedents can be balanced with the demands of the context, developing lightweight super high performance architecture for the North.

181 Brooke Bauguess, "ICON To Develop Lunar Surface Construction System With $57.2 Million NASA Award," Icon Build, Nov. 29, 2022. https://www.iconbuild.com/newsroom/icon-to-develop-lunar-surface-construction-system-with-57-2-million-nasa-award

182 Debra Kamin, "Maybe in Your Lifetime, People Will Live on the Moon and Then Mars," *New York Times*, Oct. 01, 2023. https://www.nytimes.com/2023/10/01/realestate/nasa-homes-moon-3-d-printing.html

183 Todd Woody, "The World's Largest 3D-Printed Neighborhood Is Here," *Bloomberg*, Feb 23, 2023. https://www.bloomberg.com/features/2023-3d-printed-houses-austin-texas



figure 5-29: Montrel Biosphere.
source: Peter Chaplin, 1967

5.3 - Lightweight Architecture

5.3.1 - Buckminster Fuller - Dymaxion and Geodesics

Buckminster Fuller famously asked "how much does your house weigh?"[184] Dymaxion house, the name a combination of dynamic, maximum, and tension, was an early example of a weight critical approach to architecture, with a strongly analytical design, reducing material consumption and expediting the construction process. Originally developed in 1927, the design was revitalized after WWII to respond to the growing issues of housing shortages and affordability, issues present now in the North. (see figure 5-29)

The Dymaxion House was 100 m^2 (1,076 ft^2), a comfortable single family home, and weighed 1,360 kg, excluding finishes and appliances.[185] The structure of the Dymaxion House uses a central mast which houses the building's services, upon which the rest of the building is hung in tension. The Dymaxion House was constructed largely from aluminium which has a high strength to weight ratio, allowing for the lightweight structure. The house was also designed with amenities such as adjustable natural ventilation, mechanical HVAC, high-tech shelves, and a prefabricated bathroom. The Wichita House is a built example of the Dymaxion House, developed from 1944 to 1946 by combining two of Buckminster Fuller's prototypes forming a two storey family home. The Wichita House

184 Matilda McQuaid, ed., *Envisioning Architecture: Drawings from The Museum of Modern Art* (New York: The Museum of Modern Art, 2002), 64-65.
185 "Dymaxion House," Buckminster Fuller Institute. accessed Aug. 03, 2023. https://www.bfi.org/about-fuller/big-ideas/dymaxion-house/



figure 5-30: Dymaxion Deployment Unit.
source: Marion Post Wolcott, 1941

was produced by Beech Aircraft Company, making use of industrial capacity following WWII, and of new production and material technologies. (see figure 5-30, figure 5-31, figure 5-32)

Buckminster Fuller's most famous constructions are his geodesic domes, which could enclose the maximum volume with the minimum material and surface area, allowing for lightweighting. The Montreal Biosphere was designed by Buckminster Fuller and built in 1967 for the USA pavilion at Expo 67. The Biosphere used a gigantic geodesic enclosure with acrylic panels, creating a comfortable microclimate.[186] Geodesic domes were also used to house radar assemblies, protecting them from the environment, with the componentized geodesic structure enabling them to be transported to remote sites such as the DEW Line across the North (see Chapter 4.5 - DEW Line).

The material and energy benefits, and simple construction of geodesic domes has led to their use in the North for a variety of purposes, including shelter, storage, and greenhouses. Green Iglu is a charity that helps build geodesic dome greenhouses and provides training to improve food security in the North. The domes can be built by a crew of two to three, and are constructed from lumber with bolted connections, and clad in polycarbonate.[187] Another example of geodesic domes in the North is the Weber Arctic company's Arctic Mobile Camps, which make use of geodesic dome tents to provide rapidly deployable and lightweight base camp facilities almost anywhere

186 I. Kalin, *Expo '67 Survey of Building Materials, Systems and Techniques* (Ottawa: Department of Industry, Trade, and Commerce, 1969), 223.

187 "Frequently Asked Questions," Green Iglu. accessed Jan. 12, 2024. https://www.greeniglu.com/faq

in the North.[188] The structural efficiency and energy performance of the sphere shape is highly relevant to buildings in the North, however they face challenges of furnishing and finishes on curved surfaces. They also cannot be connected to each other, so cannot benefit from shared walls for services. (see figure 5-33, figure 5-34)

The Dymaxion House and geodesic domes are early examples of lightweight architecture, and where lightweight is used as a means of meeting critical project needs, with many of these needs shared by the North today. For Buckminster Fuller, lightweighting through material and structural efficiency addressed material shortages and economic issues, and its compact transportability made it simple to distribute. These projects' lightweightness also simplified construction, allowing it to be erected quickly, meeting demand for wartime shelters and housing after WWII. These concerns are all highly relevant to the North and understanding Fuller's work, both for its novel design and construction methodology, can improve architecture in the North. Meeting the challenges of the North, particularly transportability, constructability, and building energy performance, requires a careful accounting of the demands and the means of addressing them. For the North, like for Buckminster Fuller, lightweightness arises as a means of addressing many of these issues.

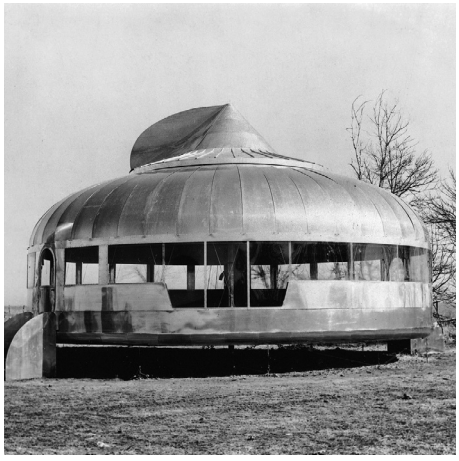


figure 5-31: The Dymaxion House was 100 m^2 and weighed 1,360 kg.
source: Estate of Buckminster Fuller

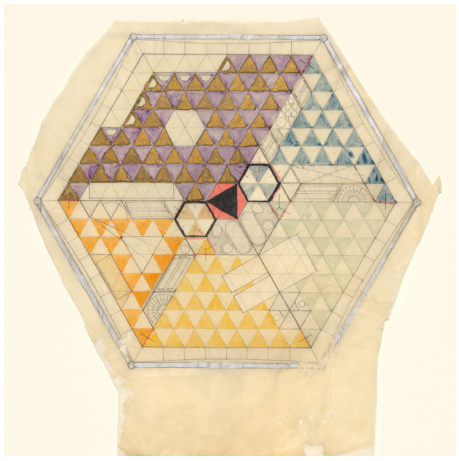


figure 5-32: Dymaxion House plan.
source: Buckminster Fuller, 1927

188 "Arctic Mobile Camps," Weber Arctic. accessed Feb. 27, 2024. https://weberarctic.com/locations/private-arctic-mobile-camps



figure 5-33: Green Iglu geodesic greenhouse.
source: Green Iglu



figure 5-34: Weber Arctic mobile camp, using geodesic tents from Pacific Domes.
source: Weber Arctic

5.3.2 - Kengo Kuma - Mêmu Meadows Experimental House

The Mêmu Meadows Experimental House was developed as a mediation between aboriginal Ainu architecture of Japan and contemporary building practices. The Ainu people are from the colder climates in the north of Japan, particularly Hokkaido. They live in villages with permanent homes, called Chise which are suited to the cold climate.[189] These traditional building practices inform the design of the Mêmu Meadows Experimental House by Kengo Kuma and associates. (see figure 5-37)

Traditional Chise are constructed from a lashed wood pole frame, with thatched roofs and low walls, up to a foot thick to provide warmth.[190] The roof is constructed on the ground and then lifted onto the home by a group.[191] Homes are composed of one or two rooms divided by a low partition, with a hearth in the centre for cooking and heating.[192] (see figure 5-35)

In the Mêmu Meadows Experimental House the same simple form is used, 80 m^2 made up of two rooms and a kitchen area, with a central hearth under a large pitched roof. The few partitions are low textile walls, allowing warmth from the hearth to distribute throughout the project.[193] The larch wood frame is a traditional material and is locally sourced, reducing transport costs and environmental impact. The frame is complemented with steel cross bracing, allowing for structural lightweighting creating the open interior. The deep eaves of traditional Chise are also used here, providing shade from warm summers and shedding rain and snow, while allowing for solar warming during winter. Speaking about traditional Chise houses, Kuma describes the inspiration for the mat flooring and floor radiant heating, as well as the textile cladding:

> "We also call [Chise] "earth houses" because residents lay cattail mats directly on the earth, which they warm by keeping a fire constantly burning in the hearth. The absorption of this radiant heat from the earth is the basic principle of Chise. Our design achieves the softness of a grass house through the membrane material used in the walls and ceiling. Soft as a stuffed animal, the structure sits directly on top of the earth."



figure 5-35: Chise home.
source: user Hno3 on Wikipedia. 2006

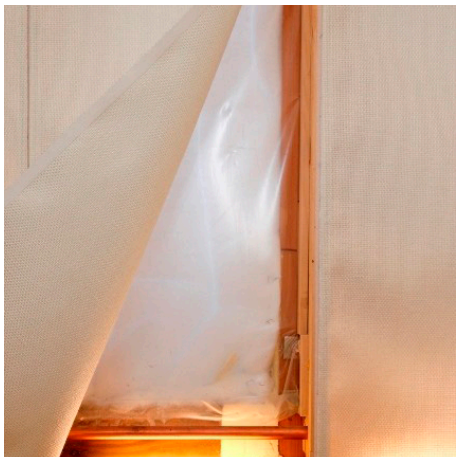


figure 5-36: Mêmu Meadows House wall assembly, showing PET insulation.
source: Kengo Kuma & Associates, 2011

189 David E. Young, Michiko Young, and Hong Yew. Tan, *Introduction to Japanese Architecture* (Singapore: Periplus, 2004), 24.
190 J. K. Goodrich, "Ainu Family Life and Religion," *Popular Science Monthly* 34 (Nov. 1888), 85.
191 J. K. Goodrich, "Ainu Houses and their Furnishing," *Popular Science Monthly* 33 (Aug.1888), 499.
192 Ibid., 503.
193 Phyllis Richardson, *Superlight: Rethinking How Our Homes Impact the Earth* (USA: Metropolis Books, 2014), 99.



figure 5-37: Mêmu Meadows House in Hokkaido, Japan, by Kengo Kuma. source: Shinkenkichu, 2013



figure 5-38: Mêmu Meadows House interior, note the low textile partitions, the central hearth, and bamboo mats. source: Shinkenkichu, 2017



figure 5-39: Mêmu Meadows House interior showing Larch frame, source: Shinkenkichu, 2017

Whereas traditional Chise were dark inside due to the few windows, the Mêmu Meadows Experimental House has a translucent building enclosure, allowing light into the house without requiring more windows. The enclosure is composed of an interior and exterior textile finish with insulation between. The building uses recycled polyester insulation, reducing the environmental impact and providing the translucent effect.[194] The building performance of this project is quite weak however, with limited insulation depth and significant thermal bridging at the timber frame. (see figure 5-36, figure 5-38)

As it relates to the Canadian North, there are several useful elements in the Mêmu Meadows Experimental House. The challenges of traditional Chise construction are relevant to the North, and lightweight structural frames that can be assembled by hand are beneficial. Timber frame construction could be faster than stick framing, maximizing the limited building season, provided the issue of large components is addressed. (see figure 5-39)

The finishes of the Mêmu Meadows Experimental House is the most interesting aspect to take away from the project. Textile exteriors could dramatically reduce cladding weight, and the acceptance or embrace of a flexible interior finish would also cut significant weight. Textile claddings have been used effectively in various settings, and can be plastic-coated to deal with environmental challenges like rain, snow, and UV, there are also concerns about impacts which are not addressed. Incorporation of textile claddings is especially viable in less vulnerable locations. (see fig. 5.3.2 - 10)

194 Ibid., 96.



figure 5-40: Dance Pavilion at the German Federal Gardens, 1957. source: Atelier Frei Otto Warmbronn

5.3.3 - Frei Otto - Tensile Structures and Arctic City

Frei Otto was an influential engineer and architect who worked extensively with tensile structures, and strove to create lightweight buildings, making economical use of materials. Otto became well known for his long spanning structures and enclosures, enabled by the efficiency and lightweightness of his work, often derived from physical experimentation. Frei Otto's work has had a lasting impact, both formal and pedagogical, and for this he was awarded the Pritzker Prize in 2015. An interesting theoretical project by Frei Otto is the Arctic City, developed in 1970 in collaboration with Kenzo Tange and Ove Arup. This project pushed the limits of what was technically feasible and demonstrates the possibilities Frei Otto saw for his work in the remote context of the North. (see figure 5-40)

Frei Otto first began experimenting with tensile structures and textile enclosures on the more manageable and experimentable scale of tents, optimizing form and utility through iteration.[195] In this pursuit, material and structural efficiency, and thus lightweightness, were as important as they are in tent design today. In post-war Germany, limited materials meant that Frei Otto's interest in efficient buildings was highly relevant and he gained popularity for his work on exhibition tents.[196] His exhibition tents included canopies for the German Federal Garden in 1955 to 1957, earning him national attention.[197] These works stood in deliberate opposition to the oppressive monumentality of Third Reich architecture,

195 Ludwig Glaeser, "The Work of Frei Otto" (New York: Museum of Modern Art, 1972) https://www.moma.org/calendar/exhibitions/2662
196 Anna Winston, "Frei Otto: a life in projects," *Dezeen*, Mar. 11, 2015. https://www.dezeen.com/2015/03/11/frei-otto-a-life-in-projects/
197 Ludwig Glaeser, "The Work of Frei Otto" (New York: Museum of Modern Art, 1972), 12. https://www.moma.org/calendar/exhibitions/2662

embracing a light and naturalistic form, Otto stating that "after the war, I liked to find a new way in the future to make a real revolution in architecture, remaking Germany as a peaceful country."[198] These pavilions were constructed from glass fibre textiles, permitting light through, and forming a tensioned fabric structure, creating a lightweight but expansive pavilion.[199] Frei Otto became the director the Institute for Lightweight Structures at Stuttgart University in 1964, and it was through this institute that he was commissioned for some of his most famous works, including the German Pavilion at Expo 67, and the Munich Olympiastadion in 1972.[200]

The German Pavilion at Expo 67 in Montreal, in collaboration with Rolf Gutbrod, was one of Frei Otto's largest projects and the first of its caliber for him, allowing him to test the possibilities of his tensile structures.[201] Like his contemporary Buckminster Fuller, Otto presented a pavilion which proposed that analytical design could generate a novel and improved form of architecture.[202] The pavilion was constructed from steel columns, between which a mesh of 50 mm steel cables acted in tension, carrying the roof canopy to the ground tension anchorage points, weighing 15 kg/m^2 plus the textile, approximately 2 kg/m^2.[203] The canopy was 8,000 m^2 of PVC coated polyester textile, creating a lightweight but expansive canopy. The structure and canopy was prefabricated in Germany and shipped to Montreal, then constructed in eight weeks including five weeks of gradual tensioning of the structure.[204] The pavilion also made use of a lightweight modular steel floor structure, allowing for an easily constructable, reconfigurable, and demountable interior spatial layout.[205] (see figure 5-41, figure 5-42)



figure 5-41: German pavilion interior. source: Atelier Frei Otto Warmbronn



figure 5-43: Munich Olympiastadion. source: Jorge Ryan, 2007

198 Tom Dyckhoff, "Tents - The Beginning of Architecture," BBC - The Culture Show, Sep. 2014. 12:50. https://www.bbc.co.uk/programmes/n3csw9sb

199 Jurgen W. Hennicke and Kazuo Ishii, *Membrane Designs and Structures in the World* (Tokyo: Shin Kenchikusha, 1999), 32.

200 https://www.pritzkerprize.com/laureates/frei-otto#laureate-page-1061

201 Frei Otto, *Tensile Structures*, vol. 2 (Cambridge: M.I.T. Press, 1974), 72.

202 David Langdon, "AD Classics: German Pavilion, Expo '67 / Frei Otto and Rolf Gutbrod," *ArchDaily*, Apr. 27, 2015. https://www.archdaily.com/623689/ad-classics-german-pavilion-expo-67-frei-otto-and-rolf-gutbrod

203 I. Kalin, *Expo '67 Survey of Building Materials, Systems and Techniques* (Ottawa: Department of Industry, Trade, and Commerce, 1969), 164.

204 Jurgen W. Hennicke and Kazuo Ishii, *Membrane Designs and Structures in the World* (Tokyo: Shin Kenchikusha, 1999), 124-125.

205 I. Kalin, *Expo '67 Survey of Building Materials, Systems and Techniques* (Ottawa: Department of Industry, Trade, and Commerce, 1969), 168.



figure 5-42: German pavilion, Expo 67
source: Atelier Frei Otto Warmbronn

Following Frei Otto's success at Expo 67, the Institute of Lightweight Structures was commissioned to assist with the design of the Munich Olympiastadion in 1972, in collaboration with architect Günther Behnisch. The enormous spans needed for the stadium could make use of Frei Otto's canopy system from Expo 67, expanding the scale dramatically.[206] While Frei Otto ended up taking a more minor role in the project, the Olympiastadion is a stunning example of tensile structure, covering 74,000 m^2 with a plexiglas canopy.[207] The project was constructed to be permanent, leading to enormous cost increase and a thematic division from the economy and temporary nature Frei Otto championed.[208] (see figure 5-43, figure 5-45)

206 Luke Fiederer, "AD Classics: Olympiastadion (Munich Olympic Stadium) / Behnisch and Partners & Frei Otto," *ArchDaily*, Feb. 11, 2011. https://www.archdaily.com/109136/ad-classics-munich-olympic-stadium-frei-otto-gunther-behnisch

207 Kay Schiller and Chris Young, *The 1972 Munich Olympics and the Making of Modern Germany* (Berkeley: University of California Press, 2010), 110.

208 Ibid., 108-110.

A highly theoretical and radical proposal by Frei Otto was the Arctic City in 1969. Developed in collaboration with Kenzo Tange and Ove Arup, Arctic City proposed to house 45,000 people under a 3 km^2 dome in the Arctic circle in a protected city, planned by Kenzo Tange.[209] Frei Otto also designed a pneumatic enclosure for an industrial complex in 1958, 750 m in diameter, and noted the applicability of this typology for colder climates.[210] The Arctic City's economy was centred on resource extraction, such as mining and fossil fuel drilling. The Arctic represented a fascinating and extreme condition, and was treated as a blank slate by modernist designers, giving them the liberty to propose such an ambitious project.[211] Arctic City is likely inappropriate for the Canadian North, however there are elements that address issues present today. While there is no desire for massive artificial ecologies in the North, the short building season is a major challenge, and a conditioned bubble to work in during winter months would have serious utility. The benefit of this typology is that it is extremely lightweight and packable, making transport and construction simple and quick. (see figure 5-44, figure 5-46)

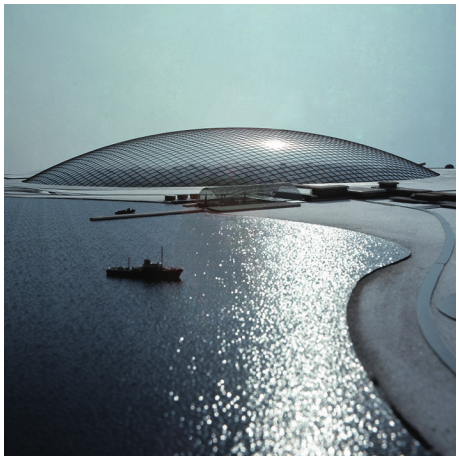


figure 5-44: Arctic City proposal by Frei Otto, Kenzo Tange, and Ove Arup. source: Atelier Frei Otto Warmbronn

Frei Otto's work centred on structural and material efficiency, resulting in lightweight buildings that could shelter large areas. While the development of his innovations have yielded impactful projects, Frei Otto's early works, highly concerned with limited materials and economy, are particularly relevant to the North. "Why should we build very large spaces when they are not necessary?" he asked in an interview in 2007, reflecting on his own and Buckminster Fuller's past proposals.[212] While it is worth considering these important architectural works, his smaller scale projects can directly inform northern buildings, both in form and design approach. It is Frei Otto's analytical and experimental methodology, and his desire to find lighter solutions for buildings, that can best inform architects in the North.

209 Thomas Herzog, *Pneumatic Structures: A Handbook of Inflatable Architecture* (New York: Oxford University Press, 1976), 115.
210 Frei Otto, *Tensile Structures*, vol. 1 (Cambridge: M.I.T. Press, 1967), 39-40.
211 Douglas Murphy, "Frei Otto's Arctic City," Icon Magazine, Apr. 09, 2014. https://www.iconeye.com/architecture/frei-otto-s-arctic-city
212 Justin McGuirk, "Frei Otto," Icon Magazine, May 2005. https://www.iconeye.com/back-issues/frei-otto-icon-023-may-2005



figure 5-45: Munich Olympiastadion.
source: Sandro Halank, 2022

figure 5-46: Author (baby) at the Millenium Dome by Buro Happold, frequent collaborators with Frei Otto. By volume, it is the world's largest tensile structure at 3 million m^3.
source: Cynthia Chaplin, 2001

5.4 - Rapidly Constructable Architecture

5.4.1 - Purpose of Rapid Construction

The ability to rapidly construct buildings is important as it allows for more to be built during the short building season, and by the limited labour available in the North. Conditions are often too harsh to work outdoors during the winter, and even in the spring and fall the cold, darkness, and wind can make work impossible. Rapidly constructable buildings also tend to make use of simple construction processes, enabling more unskilled labour to contribute to building. This reduces costs and strengthens the northern economy by employing local residents. Rapidly constructable buildings are often intended to be deployed at remote sites or in challenging conditions. These needs are often addressed by lightweighting, using innovative materials and construction systems to meet the challenges of their setting. Air supported structures, disaster relief architecture, prefabricated buildings, and tensioned fabric structures are designed specifically to contend with these challenges and are valuable precedents to study for the North.



figure 5-47: The Force Provider base, the arched shape is supported by "air-beams". source: US Army, 2011

5.4.2 - Air Supported Structures

The group perhaps most concerned with rapid housing deployment is the military, and there is a long history of this practice that is worth studying. Due to personnel availability, dangerous conditions, and limited on site infrastructure, the ability to construct a base quickly and with unspecialized labour is enormously important.

A particularly interesting product is the "Force Provider" system. Developed for the US military, this base can be set up in just a day and houses 600 people, as well as the necessary ancillary buildings. The key technology that allows for this fast installation is the use of "air-beams" which are an air supported arch structure. With two people, in just 10 minutes a 20' by 32' (6.1 m by 9.8 m, 60 m^2) tent can be inflated by a diesel air compressor and sealed.[213] They are also durable enough to withstand the desert conditions, "you can actually unroll the air-beam tent, put the four big stakes in the ground and blow it up in a sandstorm" allowing for simple, reliable, and rapid construction.[214] For a 60 m^2 "air-beam" tent, an entire package weighs approximately 320 kg and uses 1.90 m^3 of shipping volume.[215] (see figure 5-47)

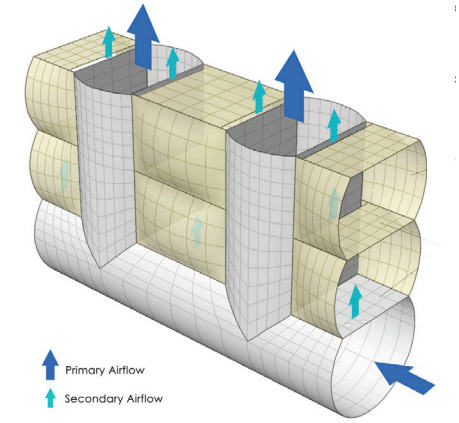


figure 5-48: Ontario Celebration Zone by Hariri Pontarini Architects, Blackwell Engineers, and Tectoniks UK. Diagram showing airflow into structure. source: Tectoniks UK, 2015

213 Bob Reinert, "Providing Shelter for Soldiers," US Army Newsroom, Oct. 11, 2011. https://www.army.mil/article/66467/providing_shelter_for_soldiers

214 Ibid.

215 "HDT Small Airbeam Shelters," HDT Global, 2019. https://www.hdtglobal.com/wp-content/uploads/2019/03/HDT_AirBeamShelters_15.pdf



figure 5-49: Ontario Celebration Zone.
source: Blackwell Engineers, 2015

This technology has also been used for large temporary installations such as The Ontario Celebration Zone in Toronto in 2015. Developed by Hariri Pontarini Architects, in collaboration with Tectoniks UK and Blackwell Structural Engineers, the inflatable structure covered 1,600 m^2, and was erected in 72 hours on Toronto's Harbourfront.[216] The project is built from air supported arch ribs, with inflated infill panels, creating a large transluscent covering. The fabric is a product from Serge Ferrari Group, who specialize in architectural textiles.[217] Tectoniks UK developed a detailed finite element analysis model to assess the performance of the structure, based on in house testing, enhancing the structural and visual lightweightness.[218] (see figure 5-48, figure 5-49)

Another application of this type of air supported structural system is "Tensairity" structures which make use of an inflatable pontoon to resist compressive forces, and transfer loads to the top and bottom chords to create a lightweight structural span. "Tensairity" has been used in bridges and roofs, to create lightweight and transportable long spans.[219] Modern plastic coatings and high strength fabrics allow for airtight and durable components, along with welded seams which create strong joints, typically the most vulnerable points. (see figure 5-50)

216 "Ontario's Celebration Zone Pavilion / Hariri Pontarini Architects," *ArchDaily*, 2015. https://www.archdaily.com/775880/ontario-celebration-zone-pavilion-tectoniks

217 "Flexlight Perform 502 S2 and 702 S2," Serge Ferrari Group. accessed Jan. 19, 2024. https://www.sergeferrari.com/us-en/productsflexlight-range/flexlight-perform-502-s2-and-702-s2

218 "Ontario's Celebration Zone," Hariri Pontarini Architects, 2015. https://hariripontarini.com/projects/ontario-celebration-zone/

219 "Tensairity Bridge," Tensairity Solutions, 2020. https://www.tensairitysolutions.com/project/tensairity-bridge/



figure 5-50: Pont de Val Cenis, by Philippe Barbeyer and Charpente Concepte, with a tensairity structure. source: Charpente Concept, 2005

These precedents have relevance to the North in both constructability and building energy performance aspects. The short building season in the North demands efficient construction processes, and the ability to raise a building enclosure quickly means that interior work can continue into the shoulder seasons. Insulation and airtightness is as important in the desert as the North, and improving building performance is also critical for the North for the same reasons of comfort and efficiency. An insulated blanket system can offer additional insulation, but without a large wall cavity the necessary insulation is difficult to incorporate.[220] Failure in the winter months would be dangerous, however given their lightweightness, shipping via air cargo would be more acceptable than for other construction systems. Air supported structures have incredibly rapid and simple construction making them useful in the North, and they are a promising option for semipermant shelters and similar building types.

220 "Energy Efficiency Kit," HDT Global, 2023. https://www.hdtglobal.com/wp-content/uploads/2023/01/HDT_Insulated-Liner_02.pdf



figure 5-51: Paper Log House, deployed in response to the 1999 Izmit earthquake. source: Shigeru Ban, 1999

5.4.3 - Shigeru Ban - Paper Structure Architecture

Disaster relief architecture has relevance for northern architecture, and Shigeru Ban's work is a valuable precedent. Ban uses cardboard, a seemingly trivial material, to create a lightweight shelter that can be easily constructed by those in need. His thoughtful work earned him the Pritzker Prize in 2014. Economics, lack of skilled labour, and challenging site conditions must be considered in disaster relief shelters, and must also be considered when building in the North.

The Paper Log House, developed in response to the 1995 Kobe earthquake in Japan, is constructed from cardboard tubes and sheets, and a mass produced kit of plywood joints, allowing these shelters to be easily assembled in two days by a small crew of locals.[221] The shelters make use of sand filled beer crates as a foundation, and a textile covering for the roof, using a tent material or recycled tarp, its lightweightness allowing it to be easily constructed. Simple demountability is another useful feature, allowing shelters to be removed when they are no longer needed, and to be reconstructed elsewhere or to be recycled.[222] (see figure 5-51)

In 1999, Türkiye was struck by an earthquake in the northwest, near Izmit. The Paper Log Houses were updated to make them appropriate for the setting, sheltering people displaced by the disaster. The cardboard tube wall structure was stuffed with newspaper to add insulation, and the floor plans were expanded to accommodate the larger families

221 Spoorthi Nagaraj, "Paper Log Houses by Shigeru Ban: Recyclable Materials and Architecture," Rethinking the Future, Aug. 18, 2021. https://www.re-thinkingthefuture.com/case-studies/a4922-paper-log-houses-by-shigeru-ban-recyclable-materials-and-architecture/

222 "Paper Log House - Kobe," Shigeru Ban Architects. accessed July 24, 2023. https://shigerubanarchitects.com/works/paper-tubes/paper-log-house-kobe/



figure 5-52: Disaster relief housing for the 2023 Türkiye-Syria earthquake. source: Shigeru Ban Architects, 2023



figure 5-53: Yakushima Takatsuka Lodge, a wilderness lodge by Shigeru Ban with paper log infill walls. source: Hiroyuki Hirai, 2013



figure 5-54: Tetraframe cast foam modular joint component. source: Jonathan Enns, 2015



figure 5-55: Yakushima Takatsuka Lodge interior, showing timber frame and translsucent effect of the paper log walls. source: Hiroyuki Hirai, 2013

in Türkiye.[223] In 2023, Paper Log Houses were again used in response to the Türkiye-Syria earthquake.[224] The roof panels feature cutouts so that people can more safely assemble the project from inside, rather than needing to climb on the roof. Northern architect Jonathan Enns' work on modular joinery is an interesting potential addition to these cardboard tube structures. He has developed a cast foam module that can act in the place of the pre-cut plywood elements, lightening the assembly and forming a more rigid system overall.[225] (see figure 5-52, figure 5-54)

Shigeru Ban has also used cardboard tubes in permanent projects such as the Yakushima Takatsuka Lodge, a wilderness hut on the island of Yakushima, south of Japan. Featured in *Superlight* by Phyllis Richardson, the project is a mountain shelter in a national park, necessitating a lightweight and easily transportable construction due to its remote site, and the desire for minimal environmental impact.[226] The project has a timber frame, with infill walls made from cardboard tubes coated in polyurethane for waterproofing. The cardboard tubes are designed to compress a plastic tube between them which allows for natural lighting and seals against drafts. This mountain refuge "represents an approach, in methods and materials, which the architect has employed in emergency shelters in the past, and could have real implications for models of urgent low-cost housing."[227] (see figure 5-53, figure 5-55)

Disaster relief architecture has many important aspects that are relevant to building in the North. For these shelters there is a need to construct them quickly, economically, and with limited skilled labour, often in challenging site conditions. Shigeru Ban's work with cardboard structures are a valuable precedent in packaging a housing system for ease of delivery, and using ordinary materials in novel ways to provide shelter to those most in need. The North is experiencing a dire housing crisis due to the cost and difficulty of building in the North, and the ability to leverage volunteer and unskilled labour allows for more housing to be built in the short summers, and gives users greater ownership over their homes, strengthening communities.

223 "Paper Log House - Turkey," Shigeru Ban Architects. accessed July 24, 2023. https://shigerubanarchitects.com/works/paper-tubes/paper-log-house-turkey/

224 Maria-Cristina Florian, "Shigeru Ban Unveils Updated Prototype for Temporary Housing in Response to the Turkey-Syria Earthquake," *ArchDaily*, Apr. 03, 2023. https://www.archdaily.com/998888/shigeru-ban-unveils-updated-prototype-for-temporary-housing-in-response-to-the-turkey-syria-earthquake

225 Enns, Jonathan. "1501C Tetraframe." Jonathan Enns, 2015. https://www.jonathanenns.com/1501C

226 "Takatsuka Lodge, Yakushima," Arquitectura Viva, Dec. 26, 2018. https://arquitecturaviva.com/works/cabana-takatsuka-9

227 Phyllis Richardson, *Superlight: Rethinking How Our Homes Impact the Earth* (USA: Metropolis Books, 2014), 244.

5.4.4 - Tensioned Fabric Structures

Tensioned fabric structures leverage the tensile strength of a fabric stretched over structural ribs to create a cohesive rigid enclosure. Like tent structures that have existed for millenia, these structures are designed to be highly constructable and demountable, as well as lightweight and transportable. Improved materials mean that these structures can span enormous spaces and achieve high building performance standards, while retaining the lightweight benefits of their historical precedent (see Chapter 5.2.3 - Tent Typology). Tensioned fabric structures have been used in a variety of settings from hotel installations in the Arctic to mining sheds in the desert, standing up to challenging conditions. (figure 5-58)

Sprung Structures is one of the largest companies in the field and has been in operation since 1887, constructing more than 12,000 buildings in 100 countries, giving serious credibility to their product. Sprung has many examples of permanent enclosed buildings and is unique in their use of aluminium ribs, rather than galvanized steel used by other companies. Aluminium affords a greater strength to weight ratio, rust resistance, malleability for profiling, and with bolted connections, demountability.[228, 229] The fabrics used by Sprung are coated with a variety of polymers, adding opacity, UV protection, waterproofness, fire retardancy, and strength to the base fabric.[230] These fabrics are approximately 800-850 g/m^2, much lighter than other claddings, and an interesting option provided the durability is proven.

The most extreme northern installation of tensioned fabric structures is the Arctic Watch Wilderness Lodge in Nunavut at 74° north, 800 km north of the Arctic circle. The project was constructed by Sprung Structures in 1992 on the north shore of Somerset Island. The lodge site is made up of several main huts which are fully insulated and enclosed, and have services such as kitchens, showers, and laundry to operate the hotel. There are also 16 private huts which are 3.7 m by 3.7 m, and are fully insulated and electrified.[231] While the lodge only operates in the summer, temperatures in June to September are frequently below zero meaning building performance is critical, proving its viability at a residential scale and its applicability for homes in the North. (see figure 5-56)



figure 5-56: Arctic Watch Hotel, located on Somerset Island, NU, by Sprung. source: Quark Expeditions, 2016



figure 5-57: Doyon Drilling warehouse, located in Alaska, a large insulated facility that could be used in other places in the North as a workspace for builders. source: Sprung Structures

228 "Aluminum Substructure," Sprung Structures. accessed Oct. 12, 2023. https://www.sprung.com/building-components/aluminum-substructure/

229 "Relocatable," Sprung Structures. accessed Oct. 12, 2023. https://www.sprung.com/sprung-advantage/relocatable/

230 "Architectural Membrane," Sprung Structures. accessed Oct. 12, 2023. https://www.sprung.com/building-components/performance-architectural-membrane/

231 "Arctic Watch - Hotel," Sprung Structures. accessed Oct. 12, 2023. https://www.sprung.com/projects/arctic-watch-hotel/

figure 5-58: Blue Origin headquarters, a tensioned fabric structure by Sprung. source: Sprung Structures, 2019



Another interesting project is in Alaska completed by Sprung for Doyon Drilling Incorporated, a land and ocean oil drilling company. This building is a fully insulated and heated warehouse and worksite, and is 24 m by 32 m, with an entirely open interior allowing for work on large drilling machines in the relative comfort of the indoors. The building was also able to be constructed in just 29 days. Built on permafrost, the project is insulated from the ground to reduce deformation, and is held down with Sprung earth anchors, resisting uplift from wind forces without requiring extensive drilling or concrete work.[232] This precedent could be deployed in the North for localized prefabrication plants, allowing complex work to continue in an indoor environment to then be quickly constructed on site even during the winter. (see figure 5-57)

Given the success in such harsh conditions, this technology is viable for incorporation into northern architectural practice. With a proven durability and ability to protect occupants from harsh winds and cold, the fabrics are useful to consider even for other applications. While thermal bridging from the aluminium structure is an enclosure issue to be addressed, the optimized structure reduces the number of members. The construction process may complicate its use in the North, but this will depend on how the rest of the project is constructed and may simplify the process overall. The lightweightness and constructability benefits of this system make this a compelling option for architecture in the North.

232 "Doyon Drilling," Sprung Structures. accessed Oct. 12, 2023. https://www.sprung.com/projects/doyon-drilling/

5.4.5 - Quonset Huts

Quonset huts are a prefabricated componentized building designed for the United States military for bases in the United Kingdom during WWII. The Quonset hut, named for Quonset Point where they were initially produced, was designed by a team at George A. Fuller Engineering under architect Otto Brandenberger. The Quonset Hut was an improvement over earlier designs, allowing for mass production, simpler construction, and improved energy performance. The adaptability of the huts allowed for a variety of specialties such as hospitals, barracks, and recreation, as well as suitability in a wide range of climates from the Philippines to Alaska.

The most common Quonset hut type was the Stran-Steel Quonset hut, finalized in 1941 by Otto Brandenberger and produced by Great Lakes Steel Corporation in Detroit.[233] As many as 153,000 units were produced for the US military during WWII.[234] The key benefit of this hut was the rapid buildability, taking 10 construction battalion members just one day to build the 20' by 48' (6 m by 14.6 m) hut. This was aided by Stran-Steel nailable framing that allowed the sheet metal structure and interior masonite to be quickly and easily attached. This insulated wall cavity was the key to improving building performance over the earlier Nissen hut, enabled by the novel technologies of Masonite and the Stran-Steel framing. The standard 20' by 48' hut kit weighed 3,175 kg and required approximately 8.5 m^3 of shipping volume.[235]

As a result of conflict in the Pacific with Japan, Alaska saw enormous investment from the United States military and an influx of military and civilian personnel. Following the war, housing in Alaska was stressed by the influx.[236] Alaska had 20,000 to 30,000 huts built for the war effort, and these presented a housing opportunity.[237] In 1945, Quonset huts, among other prefabricated hut types, were made available for people to purchase to be built for housing.[238] In 1946, Alaska Railroad established company housing on Government Hill in Anchorage, and would house 200 railway workers and families in Quonset Huts.[239] (see figure 5-61)



figure 5-59: Quonset Hut garage and grain bin (see Chapter 5.3.1). source: author, 2023



figure 5-60: Jamesway Hut in Antarctica. source: Antarctica New Zealand, c. 1985

233 Julie Decker and Chris Chiei, *Quonset Hut: Metal Living for a Modern Age* (New York: Princeton Architectural Press, 2005), 19.
234 Rogers, J. David, Ph.D. "Nissen and Quonset Huts." Missouri University of Science and Technology. accessed Nov. 03, 2023. 19. https://web.mst.edu/rogersda/umrcourses/ge342/quonset_huts-revised.pdf
235 Ibid.
236 Julie Decker and Chris Chiei, *Quonset Hut: Metal Living for a Modern Age* (New York: Princeton Architectural Press, 2005), 105.
237 Ibid., Steven Haycox, 34.
238 Ibid., Chris Chiei, 106-108.
239 Ibid., 110.



figure 5-61: Quonset Hut base in Alaska.
source: Capt. Lewis R. Devoe, 1943

The Jamesway hut used wooden ribs with an insulated "blanket" covering the building. The "blanket" was composed of fibreglass insulation batts between plastic-treated cotton that was fire resistant and waterproof which served as the interior and exterior finish. This hut type was 16' wide and constructed in 4' increments. A 16' by 16' (4.9 m by 4.9 m) unit weighed 544 kg and the wooden crating was reused as flooring.[240] The Jamesway Hut's use by the Army Air Corps meant that lightweightness was likely a requirement, allowing the huts to be flown to remote sites, including Antarctica, where it was used at the Amundsen-Scott South Pole Station (see figure 5-60, Chapter 5.5.3 - Antarctic Research Stations)

The key benefit of Quonset huts that allowed them to become so ubiquitous, even after the war, was their buildability, adaptability, and economy. In Alaska these benefits were critical due to the difficulty of transporting materials to site and the limited construction infrastructure, issues that also affect the Canadian North. Despite their utility and popularity, these huts were not ideal for homes. The 1960 NRC report on prefabrication for northern housing mentions Quonset huts but they were considered unviable, stating "the extensive insulation, blocking and finishing which must be added at the site for northern housing cancels cost and erection advantages, and also leads to performance problems."[241]

In terms of building performance, Quonset huts are difficult to bring up to modern standards. Interior spray foam insulation allows for a well insulated and airtight building but suffers from fire and damage vulnerability. In the case of the Jamesway hut, the use of modern textile claddings can help to improve durability and longevity, as well as lighten the hut, improving shipping and construction, making this hut style more viable. While the shape of the Quonset Hut is difficult to finish, the volumetric efficiency is an important element to consider, both for material economy, and energy efficiency. As well, the ability to demount and move the buildings is useful. To this day Quonset style huts are used for large unheated buildings across North America and are highly viable for a variety of projects in the North such as fire halls, storage facilities, and garages. (see figure 5-59, figure 2-24)

240 Ibid., Sheila Shanks and Clark Yerrington, 149.

241 R.E. Platts, *Prefabrication in Northern Housing* (Ottawa: National Research Council of Canada Division of Building Research, 1960), 8. https://doi.org/10.4224/20375947

5.5 - High Performance Architecture

5.5.1 - Purpose of High Performance

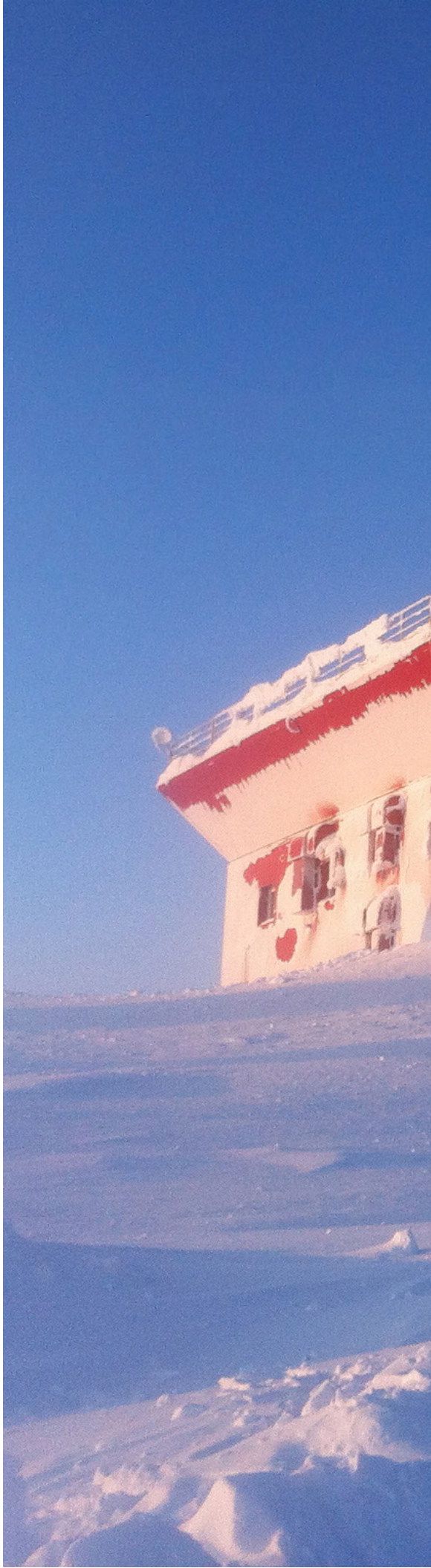
The cold climate of the North requires excellent energy performance to keep users warm and comfortable, and to reduce operating costs. High performance architecture refers to buildings with strong energy efficiency, through excellent enclosure design and construction, and efficient building systems. Economic sustainability is a critical consideration, and high performance buildings, even at greater initial cost, reduce life cycle costs dramatically. Resiliency is also critical as power or fuel shortages can make users unsafe or damage buildings, and interiors must be kept warm, even when systems fail. Reducing operating costs is critical for northern buildings and the precedents in this section, including Arctic and Antarctic research stations, and the CHIP House Solar Decathlon project, highlight important elements to accomplish this, particularly enclosure design and high efficiency building systems.

5.5.2 - Arctic Research Stations

Research stations located in the far North provide a valuable precedent for high performance buildings. The same challenges of a cold climate and remoteness are present, but budgets for these projects are higher, allowing for better optimized design. This optimization particularly focuses on high performance building enclosures, reducing operating costs and improving resiliency, important goals for all northern buildings.

PEARL

The Polar Environment Atmospheric Research Laboratory (PEARL) was built in 1992 to study the ozone layer. PEARL is 15 km from Eureka, Nunavut, on Ellesmere Island. The lab is extremely remote, and these conditions make it a useful precedent. Eureka's climate is the coldest inhabited place in Canada with more than 13,500 HDD, even more than Alert, Nunavut.[242] February, the coldest month, averages -32°C, with a July average of just 6°C, as well as high winds and four months of 24 hour daylight and darkness. (see figure 5-62)



242 Canadian Commission on Building and Fire Codes, *National Energy Code of Canada for Buildings 2020*, 5th ed. (Ottawa: National Research Council of Canada, 2020), Table C-1, Division B, C-18.



The Ridge Laboratory, the main building, is one storey, about 350 m^2, and houses laboratories, living quarters, and workshops.[243] The building appears to be constructed from lumber framing with cavity insulation, a polyethylene air and vapour barrier, and metal cladding.[244] There is likely also exterior insulation. While this is not the highest performance design, it is highly constructable and has been resilient enough to operate for the last 30 years. Other simple optimizations include small and uniform windows, consistent cladding, and simple finishes such as vinyl flooring, acoustic ceiling tile, gypsum board, and plastic wall panels. The building is elevated on a raised foundation, avoiding permafrost settlement. The building uses electric baseboard heating to avoid local pollution, and while it is not an efficient system when using diesel power generation, they are extremely simple to install and operate. (see figure 5-63)

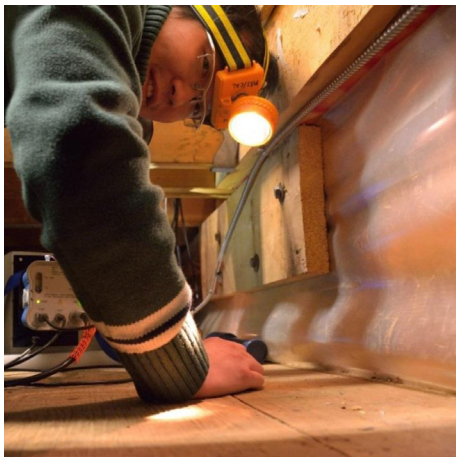


figure 5-63: PEARL wood framed structure and enclosure.
source: Dan Weaver, 2017

CHARS

The Canadian High Arctic Research Station (CHARS) is located in Cambridge Bay, Nunavut and is a major centre for Canadian northern research. Designed by EVOQ, who have extensive experience in the North, the project budget was $190 million CAD, and it is 4,800 m^2, completed in 2019.[245] "CHARS brings science and technology and traditional Inuit knowledge together under one roof," with both high tech facilities and traditional knowledge sharing spaces.[246] EVOQ describes the Inuit knowledge incorporated:

> "Both the process leading to the design and the design of the station itself are derived from a number of Inuit Qaujimajatuqangit principles "that which has always been known". The Inuit planning principle of free, open, interconnected spaces is used in the layout of the public spaces. The circular shaped qalgiq (traditional communal igloo) used inside and outside, takes on both a physical and symbolic presence. The exposed wood structure conveys the ingenuity of the many Inuit designed, stick built assemblies. The copper-coloured cladding is a nod to the Copper Inuit, the host community."[247]



figure 5-64: CHARS enclosure without cladding, showing exterior insulation.
source: Benson Steel, 2015

243 "Ridge Lab," CANDAC. accessed Feb. 03, 2024. https://www.candac.ca/candacweb/ridge-lab

244 Dan Weaver, "Polar Environment Atmospheric Research Lab: Virtual Tour." University of Toronto, July 2017. https://www.danweaver.ca/wp-content/uploads/2017/07/DanWeaver-PEARL-Virtual-Tour-Summer2017-v_online.pdf

245 Jane George, "Canadian High Arctic Research Station remains a big unknown to many," *Nunatsiaq News*, Oct. 30, 2019. https://nunatsiaq.com/stories/article/canadian-high-arctic-research-station-remains-a-big-unknown-to-many/

246 "Canadian High Arctic Research Station (CHARS)," EVOQ Architecture, 2019. http://evoqarchitecture.com/en/canadian-high-arctic-research-station-chars-cambridge-bay-3/

247 Ibid.



figure 5-65: CHARS, designed by EVOQ in Cambridge Bay, NU. source: Madalyn Howitt, 2023

Unlike the more remote northern research stations, CHARS is located within a community, making community engagement and a relationship with the local people a critical component of the project's goals.[248]

The structure of the public oriented spaces are constructed in glulam, while the laboratories are steel.[249] The knowledge sharing space in CHARS is modelled after a traditional Inuit tupiq, with glulam posts representing the whale bone or wooden posts. The building enclosure is steel stud infill walls with exterior mineral wool insulation and steel cladding shingles. The cladding is installed in an upward spiralling pattern, evoking the spiral construction of an igloo. The laboratory section of the building is clad with corrugated steel, a more economical product. The continuous exterior insulation and drained cladding system follow enclosure best practices for the North. CHARS also has several outbuildings, including a large tensioned fabric structure which is used as storage and a garage.

High performance enclosures and efficient building systems are demonstrated in these research stations, as greater initial captial allows these buildings to reduce their operating costs, yielding an economic savings in the long term. PEARL is more remote, and so is more optimized as a high performance building including a thick enclosure with small windows and deep insulation, volumetric efficiency, and simple building systems. CHARS is larger, and is more public facing, so compromises somewhat on building enclosure with its large windows, however the project still follows enclosure best practices with continuous exterior insulation and a ventilated cladding system. The importance of high quality building enclosures and efficient building systems are demonstrated in these projects, reducing operating costs, while also meeting challenging goals of northern scientific research and public facing functions. (see figure 5-64, figure 5-65)

248 "ANNEX C News Release of the Announcement on Location," Government of Canada, Aug. 24, 2010. https://web.archive.org/web/20140313030243/http://science.gc.ca/default.asp?lang=En&n=7642EB3A-1

249 Trevor Boddy, "High Arctic, High Design: Canadian High Arctic Research Station, Ikaluktutiak, Nunavut," Canadian Architect, June 10, 2019. https://www.canadianarchitect.com/high-arctic-high-design/

5.5.3 - Antarctic Research Stations

Antarctica is the coldest and most remote environment on Earth. The only inhabitants are scientists who live there primarily during the summer, when the weather is less inhospitable. The continent is thousands of kilometres from any other landmass, and many research stations are located further inland, requiring airlifts to transport people, equipment, and shelter to these sites. Because of the incredible demands on antarctic buildings, they are valuable to study for improving building energy performance in the North. Amundsen-Scott South Pole Station and Halley VI present fascinating shelter solutions for the extreme environment of Antarctica.



figure 5-66: Former South Pole Station, a large geodesic dome to provide shelter. source: Peter Rejcek, 2008

Amundsen-Scott South Pole Station

Amundsen-Scott South Pole Station is located at the South Pole, in the centre of Antarctica, an unbelievably remote and brutal setting. The highest temperature ever recorded there was -12.3°C on Christmas in 2011, and the coldest temperature ever recorded was -82.8°C in 1982, with an annual average temperature of -49°C.[250] These extreme temperatures require excellent building enclosure design, and the remote setting necessitates simple and rapid construction. The first base was established in 1957, and has been replaced twice, with the current building completed in 2008. The station is used for research in glaciology, geophysics, ocean and climate science, astrophysics, astronomy, and biology.[251] (see figure 5-68)



figure 5-67: New Amundsen-Scott South Pole Station, by Ferraro Choi and Associates built in 2008. source: Bill Henriksen, 2005

Despite the desert conditions with just 4 mm of precipitation per year, snowdrifting and snow accumulation is a huge concern. The original station is now buried under more than 10 metres of snow. The original station was constructed from prefabricated panels with tongue and groove connections for airtightness and continuous insulation, and was enclosed in a matter of months, with individual houses constructed in just two work days.[252] The second south pole station was a geodesic dome, 50 m wide, built with aluminium panels. It was designed to be lightweight, with no individual component weighing more than 23 kg, enabling airlift transportation, and workers to easily construct the base.[253] Buildings for inhabitation and research were constructed inside of the dome, sheltered from winds and snow. In 2009 it was disassembled and returned to the USA, the lightweight componentized

250 "Antarctic Weather," Ice Cube Neutrino Observatory. accessed Feb. 17, 2024. https://icecube.wisc.edu/pole/weather/

251 "Amundsen-Scott South Pole Station," US National Science Foundation, Oct. 12, 2006. https://www.nsf.gov/geo/opp/support/southp.jsp

252 Paul Siple, *90 South: the Story of the American South Pole Conquest* (New York: G.P. Putnam's Sons, 1959), 176.

253 Don L Richter, "Technical details, No single component in the dome weighed more than 50 pounds," *Antarctic Sun*, Oct. 09, 2007. https://antarcticsun.usap.gov/features/1988/



figure 5-68: Amundsen-Scott Station.
source: user CMichel67 on Wikipedia

construction simplifying the demolition and removal process. (figure 5-66)

The current Amundsen-Scott Station is 6,000 m^2 and was built at a cost of $174 million USD. Designed by Ferraro Choi and Associates, the base was built over the course of a decade, completed in 2008. All building materials were flown from McMurdo Station, Antarctica on ski-equipped aircraft, totalling 925 flights and approximately 11,000,000 kg of cargo.[254] (see figure 5-67)

To contend with the snowdrifting and the constantly rising snow level, the building is elevated 3 m above the ground and built upon hydraulic jacks, allowing the building to be permanently raised to avoid being buried as past bases have been. The volumetrics of the Amundsen-Scott Station are also designed to reduce snowdrifting and buildup. The lower portion of the leading face is chamfered, accelerating the wind and clearing snow from beneath the building. The aerodynamics of the Station were based on wind tunnel testing and computational fluid dynamics.[255]

The structure is a steel frame with SIPs infill walls, forming a relatively lightweight building, necessitated by the challenging transportation and construction setting. The building enclosure is composed of SIPs, providing approximately RSI 8.8 in the walls and RSI 12.3 in the roof.[256] SIPs are an ideal choice for this setting as they enable rapid installation. The cladding is metal panels for simple installation, and is a dark colour to encourage heat gain. The Station is composed of two buildings which are separated for fire and foundation settlement isolation, with a connecting walkway. This division also allows portions of

254 Peter West, "NSF dedicates New South Pole Station," US National Science Foundation, Jan. 15, 2008. https://nsf.gov/news/news_summ.jsp?cntn_id=110961

255 "Elevated Station Design for the South Pole Redevelopment Project at Amundsen-Scott South Pole Station," Ferraro Choi. accessed Nov. 01, 2023. https://ferrarochoi.com/publications/elevated-station-design/

256 Lisa Lounsbrough, "National Science Station Project: SIPs to the South Pole," Enercept, Jan. 22, 2018. https://www.enercept.com/blog/enercept-sips-to-the-national-science-station

the building to be entirely shut down for the winter to conserve energy. The walkway and the entrances to the building are shielded by textile windbreaks, which reduces snow buildup at these points, and reduces wind chill for people entering and exiting.

The Station is heated by waste heat from its power plant, reducing fuel consumption which in turn reduces the storage and transportation demands. During the peak season of the summer, up to 14% of power is provided by wind and solar, testing the viability of renewable power generation in extreme settings. Water is harvested from snow and ice, and must be extensively processed before and after consumption to ensure reduced local contamination. Due to this process, water conservation is critical and low flow fixtures and waterless toilets are used to reduce consumption. (see figure 5-69)

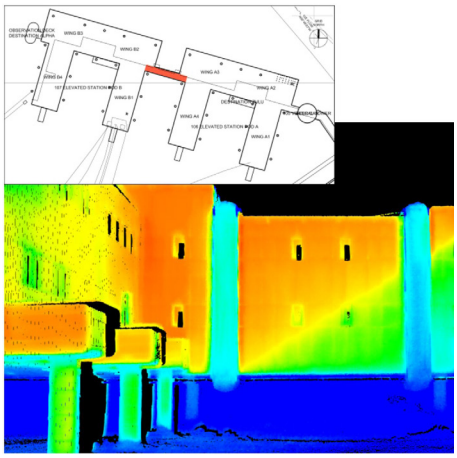


figure 5-69: Thermal imaging of the Amundsen-Scott Station central link. source: ERDC/CRREL 2018

While the effect of the Station on the expanse of snow is striking, the core building is a simple and high performance project. The Amundsen-Scott Station is constructed from well understood products, chosen for transportability, constructability, and excellent building performance, making it a valuable precedent for northern buildings. The building services of the Station, conserving water, fuel, and electricity, along with the passive energy savings, including aerodynamics and a high performance enclosure are also highly relevant to northern buildings.

Halley VI

The Halley VI Antarctic Research Station is fascinating precedent, more like a space station than a building, and has several features that are useful to study for northern architecture. It was built in 2013, designed by Hugh Broughton Architects, at a budget of $46 million.[257] Instead of being permanently installed, Halley VI is built on skis which allows it to be moved. The legs can also be individually raised to accomodate the rising snow level and to be moved to new locations, for safety and scientific purposes.[258] The base was relocated in 2016 due to a chasm forming in the ice shelf.[259] The summer temperatures at Halley VI are around -5° C and the winter temperatures are -30° C, requiring a high performance enclosure.



figure 5-70: Halley VI Antarctic Research Station, showing the linear module form. source: British Antarctic Survey, 2013

257 "Building the Halley VI Research Station in the Antarctic," DOZR, Dec. 02, 2021. https://dozr.com/blog/building-the-halley-vi-research-station

258 "Halley VI British Antarctic Research Station," Hugh Broughton Architects, 2015. https://hbarchitects.co.uk/halley-vi-british-antarctic-research-station/

259 "Halley Research Station relocation," British Antarctic Survey, 2018. https://www.bas.ac.uk/project/moving-halley/#about https://www.youtube.com/watch?v=QQvqaSWmVeo



figure 5-71: Halley VI central module.
source: Steve Colwell, 2010

The base is made up of eight modules, with dormitories, laboratories, and offices in the smaller modules, and a central 'mother ship' module with dining and recreation. Much of the base was prefabricated in South Africa, and then built over three summers in Antarctica. The weight of each module in the base is about 80,000 kg, with the substructure weighing around 9,000 kg, the limit that the sea ice could bear as it was towed to site. The modules are built from a steel structure and prefabricated enclosure panels.[260] The enclosure panels are composed of fibreglass reinforced plastic cladding with polyisocyanurate foam insulation, similar to the work of Papineau Gerin-Lajoie LeBlanc.[261] Like the Amundsen-Scott Station, Halley VI gets water from melting snow and ice, necessitating conservation, using waterless toilets and low flow fixtures.[262] Combined Heating and Power units, burning diesel, are used, and are supplemented with oil fired boilers during winters. (see figure 5-70, figure 5-71)

Many of the challenges of Antarctica are shared with the Canadian North, critically transportability, constructability, and building energy performance. High performance enclosures and efficient building systems reduce operating costs, and improve resiliency which are important in the North. Building volumetrics, both for reducing exterior surface area and for reducing snowdrifting are also important considerations. Lightweight designs simplify the difficult transportation proces and on site construction, making full use of the limited building season. These research stations operate in the harshest location on Earth, both in climate and remoteness, and the high performance design of these research stations should inform architecture in the North.

260 Ruth Slavid, "Halley VI Antarctic Research Station by Hugh Broughton Architects, Brunt Ice Shelf, Antarctica," *Architectural Review*, July 01, 2010. https://www.architectural-review.com/places/halley-vi-antarctic-research-station-by-hugh-broughton-architects-brunt-ice-shelf-antarctica

261 "British Antarctic Survey research station: secrets behind the design," Building.co.uk, Feb. 05, 2007. https://www.building.co.uk/british-antarctic-survey-research-station-secrets-behind-the-design/3080690.article

262 Mike, "Lifting the Lid on Antarctic Toilets," Ramblings to and from Antarctica, Feb. 19, 2012. https://esorekim.blogspot.com/2012/02/lifting-lid-on-antarctic-toilets.html

5.5.4 - CHIP House

The Compact Hyper-Insulated Prototype Solar House (CHIP House) is a project by SCI-Arc and Caltech which competed in the U.S. Department of Energy Solar Decathlon in 2011. Placing second in the engineering contest and sixth overall, the CHIP House is designed to run on its own solar power, including heating, cooling, and domestic hot water, requiring excellent energy performance.[263] The CHIP House makes a compelling design choice of placing the insulation within an exterior 'blanket' of batt insulation and a textile cladding, creating a continuous thermal control layer. (see figure 5-73)



figure 5-72: CHIP House interior. source: SCI-Arc, Caltech, 2011

The Solar Decathlon includes 10 contests and the winner is decided by a cumulative score. CHIP House placed third in the affordability contest, estimated at $262,000 USD to construct.[264] The energy balance contest measured power consumption and production during competition week and the CHIP House achieved a fully net-zero result. Passive energy efficient design was an important aspect of the CHIP House, as it allows for reduced energy consumption without adding significant costs. An impactful passive design strategy is the compactness of the project, at 65 m^2, and the angular shape which slopes upwards allowing for passive cooling, lighting, and ventilation, and optimal solar panel orientation.[265] (see figure 5-74)

Solar power for the house is generated by a 7.2 kW array on the roof which is capable of generating three times the consumed power.[266] The CHIP House also makes use of energy efficient appliances including a heat pump water heater. Motion sensors and a 3D tracking system were used to optimize lighting, reducing energy usage in empty parts of the house.[267]



figure 5-73: Exposed enclosure of the CHIP house, denim batt insulation. source: SCI-Arc, Caltech, 2011

The building structure is a mass timber frame with lumber framing infill walls, able to be constructed in part by the students themselves, and is left exposed on the interior reducing material consumption and creating an attractive wood interior, however this lacks fire resistance. (see figure 5-72)

The innovative building enclosure is a particularly interesting component of the CHIP House. The exterior insulation blanket allows for a large depth

263 "Solar Decathlon 2011 Final Results," US Department of Energy Solar Decathlon, 2011. https://www.solardecathlon.gov/past/2011/final_results.html

264 "Solar Decathlon 2011 Affordability Contest," US Department of Energy Solar Decathlon, 2011. https://www.solardecathlon.gov/past/2011/contest_affordability.html

265 Keya Lea, "Modernist Living in the Net-Zero CHIP House," Green Passive Solar Magazine, Dec. 09, 2011. https://greenpassivesolar.com/2011/12/modernist-living-net-zero-chip-house/

266 Sam Lubell, "SCI-Arc's CHIP House Takes A Bow In LA," *Architect's Newspaper*, Jan. 13, 2012. https://www.archpaper.com/2012/01/solar-decathlon-sci-arcs-chip-house-takes-a-bow-in-la/

267 "Solar Decathlon 2011," SCI-Arc, 2012. https://www.sciarc.edu/events/initiatives/solar-decathlon-2011



figure 5-74: CHIP House, by SCI-Arc and CalTech, in the 2011 Solar Decathlon. source: Jim Tetro, US DOE, 2011

of batt insulation, in this case recycled denim, to sit exterior of the structure, forming a continuous thermal control layer. Batt insulation is cheaper and lighter than rigid boards, reducing weight compared to traditional rigid exterior insulation and cladding, saving material, transportation, and labour costs. The insulation blanket is tufted, fixing the textile cladding and insulation to the structure while allowing the batt insulation to loft to its full thickness without a traditional structure to sit between. The cladding is a vinyl textile which is waterproof, UV resistant, and quite durable. A similar enclosure has been used in the extremes of the Arctic for a science storage facility in Greenland. Rubb, an engineered fabric building manufacturer, built the structure in 2016, carried to site by airplane and quickly erected and towed to site.[268] This enclosure allows for a lightweight and compact enclosure for transportation, and demonstrates the viability of textile enclosures in an incredibly harsh climate.

The CHIP House has several useful elements to consider for northern buildings: passive design through compact planning, solar orientation, and natural ventilation can be incorporated to save energy when weather permits; active systems such as heat capture, lighting optimization, and solar power are also worth considering; and the enclosure is particularly interesting for the northern context as the thick insulation is vital in the cold climate, and the lightweightness and compactness of batt insulation and textile cladding addresses the transportation challenges of the North. The CHIP House demonstrates how a relatively simple core building can be made highly energy efficient, as well as architecturally compelling, through innovative planning, enclosure design, and energy efficient building systems, making the CHIP House a valuable precedent for the North.

268 "A Rubb Arctic Adventure," Rubb USA, 2016. https://www.rubbusa.com/projects/rubb-arctic-adventure/

5.6 - Conclusion

The North is an extremely challenging context. Its remoteness and lack of infrastructure complicates transportation and construction, necessitating lightweight and highly constructable projects, while the climate demands high performance, resilient, and durable architecture. Chapter 5 has drawn on a variety of sources, both within architecture and from other disciplines, to investigate diverse approaches to the key elements of transportability, contructability, and high performance, particularly through lightweightness.

These precedents offer insight into lightweight design methodologies, such as those developed in athletics, racing, and space travel, as well as built examples, all of which highlight the importance of critical and analytical design, and the functional benefits of lightweightness. Rapid constructability is another key element of improving northern buildings and several useful precedents are studied, presenting options for improving the construction process, through simplifying the required labour, or making use of engineered technologies to expedite the process, often also making use of lightweightness. High performance architecture has also been explored, with projects from some of the most extreme places on Earth, which have used lightweighting to simplify transportation and construction, or projects designed to consume very little energy, both of which are useful to study for northern buildings as reducing operating costs and improving resiliency are important goals.

The compounding challenges of life in the North mean succesful projects must mediate the many demands from climatic to economic. These precedents studies have addressed specific elements of these challenges, making them valuable to learn from in developing a succesful project for the North.



figure 5-75: Stage 11 of the Vuelta Espana, 2021. A finishing gradient of 25% demands absolute lightweightness. source: Cxcling Creative Agency, 2021





figure 5-76: Prototype of Paper Temporary House for Korea. source: Shigeru Ban Architects, 2023

Chapter 6
Super:Lightness Proposals

6.1 - Introduction and Methodology

The previous chapters of this thesis have studied: the northern context and the needs of its users; standard and best practices for building in the North; precedents for northern architecture; and precedents which address the lightweightness and the key elements of transportability, constructability, and building energy performance. Chapter 6 presents two proposals for a novel northern architecture: *Super:Light Architecture*, and *Northern Lightweight Architecture*, informed by the rigorous study presented in previous chapters, and designed to exceed the demands of the North, providing high quality housing for users in the North.

Each proposal in this chapter will set out its measurable and conceptual performance and weight targets, along with its intended setting, then describe the design methodology, starting with lightweightness, and addressing key elements of transportability, constructability, and high performance.

6.2 - *Super:Light Architecture*

Super:Light Architecture is a superlightweight housing proposal intended for extremely remote communities in the North. It uses a tensioned fabric structure covered with a thick blanket of insulation, on a multipoint space frame foundation. This construction system allows for a lightweight building, reducing shipping costs and simplifying on site labour. The project is also rapidly constructable, allowing crews to build many units in a season.

Super:Light Architecture aims to cut weight in half compared to a baseline home constructed in more typical northern practice, a weight budget of approximately 6,500 kg, and to cut net heating demand in half, a limit of 7,000 kWh in Iqaluit.[269] The proposal is designed to use an air source heat pump in conjunction with hydronic floor heating, a highly efficient system that can take advantage of renewable energy sources and improve heating efficiency. This energy target allows for a significant proportion of heating demand to be met by internal heat gains from occupancy and use, and improves the viability of electric heating systems in the current context.



figure 6-01: Super:Light Architecture, set in Iqaluit.
source: author

269 *An Energy Standard for Homes in Iqaluit - A Business Case*, report for Department of Planning and Lands City of Iqaluit (Ottawa: Marbek Resource Consultants Ltd., Mar. 2005), 5.



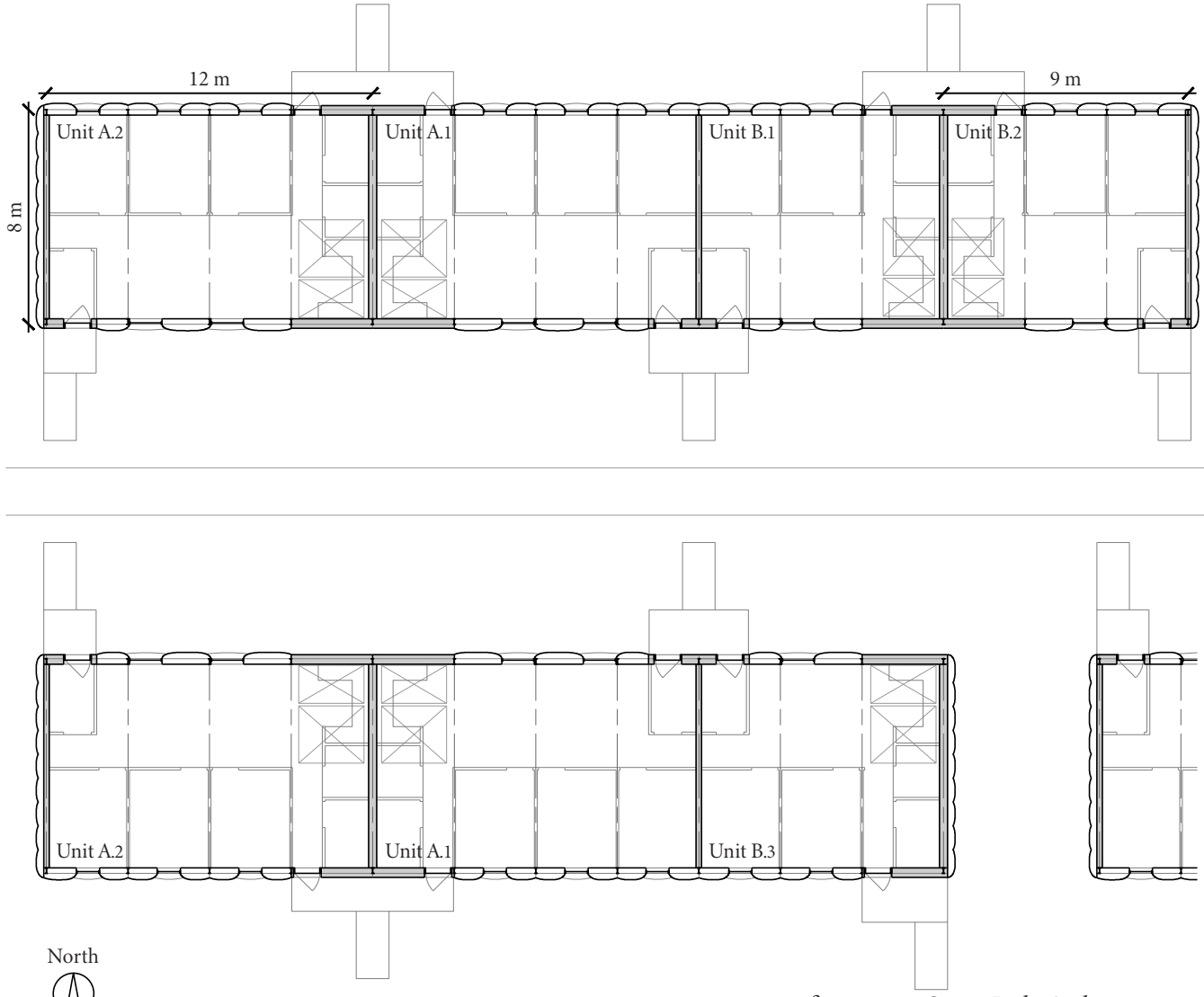


figure 6-02: Super:Light Architecture site plan showing unit configurations.

6.2.1 - Lightweighting

Form and Volumetrics

Optimizing the form and volumetrics of a project can have a major effect on lightweighting, and can offer energy performance advantages. Determining an optimal shape for these considerations, while remaining constructable is an important early step in developing a lightweight proposal for the North. Floor area to exterior enclosure area ratio, defined as enclosure area efficiency, is more important than volumetric efficiency. This is because excess vertical space is generally unusable and results in wasted enclosure area. (see figure 6-02, figure 6-03)

Spheres and cubes have good volumetric efficiency but poor enclosure area efficiency, due to excess vertical space. Hemispheres are an option which balances volumetric and enclosure area efficiency, and this is part of the reason igloos can be warm inside. Cylinder shapes, such as Quonset Huts or the Dymaxion House have good enclosure area efficiency, but are difficult to finish on the inside.

These options are less efficient than semi-detached or rowhouse units however, and forms that can be linearly connected result in a much greater enclosure area efficiency. *Super:Light Architecture* proposes a one-storey rowhouse typology, due to its excellent enclosure area efficiency, the ability to share building services, and its simpler constructability than a a two storey form.

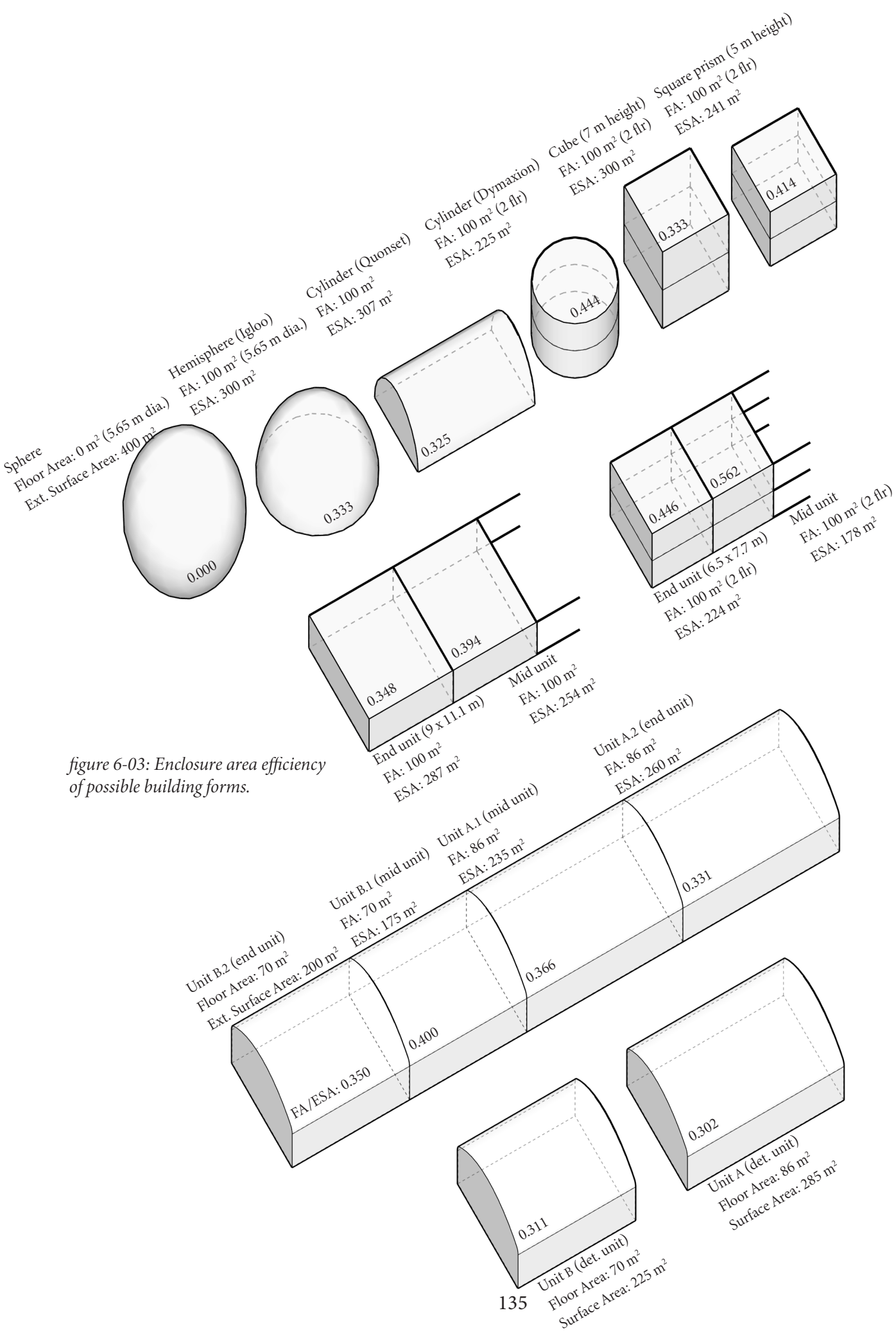


figure 6-03: Enclosure area efficiency of possible building forms.

Space Planning

The space planning of the project is based on a past co-design project between EVOQ and Inuit community members in Nunavik.[270] The floor plan of this proposal is designed to be flexible and in the future designs should be developed in collaboration with users in the North. In this case it features a large front room, allowing groups to gather, and to accomodate country food preparation and feasts. The bedrooms are sized for a queen bed or two single beds, accomodating a range of household types including larger families, multigenerational households, or cohabitating adults. (see figure 6-04)

There is a front door vestibule, reducing cold air and snow blowing into the home, and providing protected storage for outdoor clothing and equipment such as hunting equipment. There is also a rear door, providing additional egress in an emergency. Windows are intended to be generous, but not to add excessive heating load. (see figure 6-05)

The design is intended to provide high quality housing at an economically sustainable level, and to reduce energy consumption. The interior layout is flexible as the structure is provided by the tensioned fabric structure, allowing for more culturally specific design in different communities and allowing interior work to continue in winter. (see figure 6-06)



figure 6-04: Country food preparation and sharing is important for Inuit and northern culture. Space is provided for this in the living/dining room.
source: Acacia Johnson, 2019

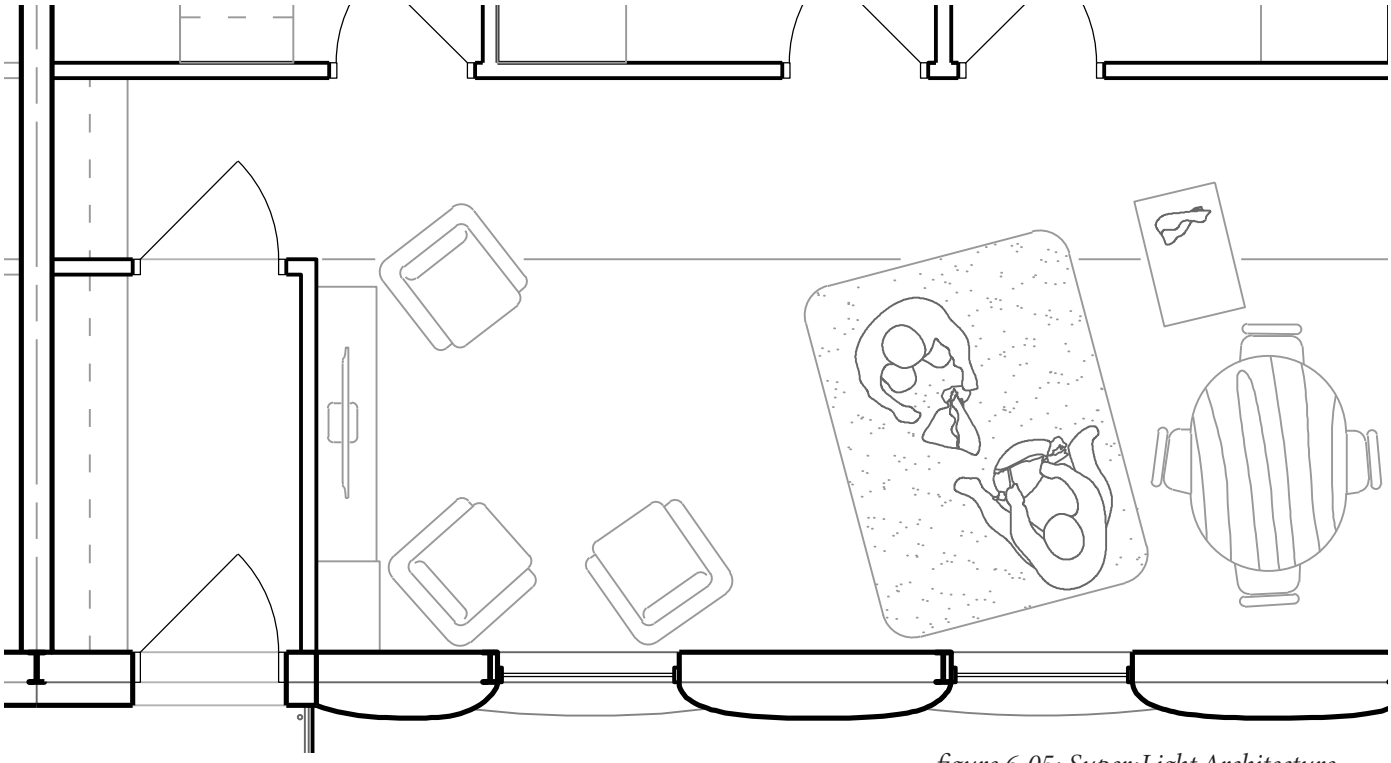


figure 6-05: Super:Light Architecture living/dining room space and vestibule.

270 Louise Atkins, "Case Study 4 - Inuit Housing," *Four Case Studies Exemplifying Best Practices in Architectural Co-design and Building with First Nations* (Ottawa: Royal Architectural Institute of Canada, 2018)

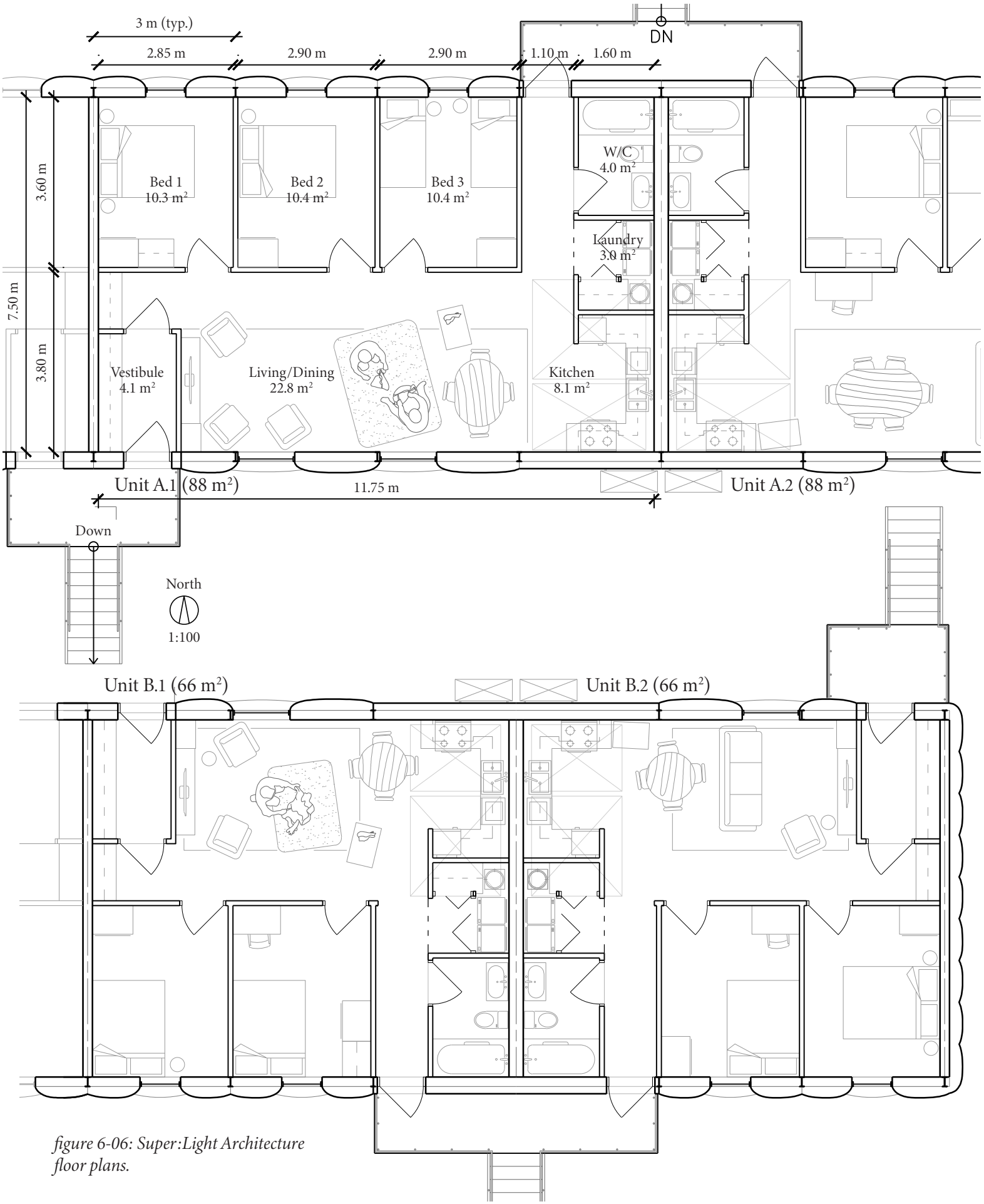


figure 6-06: Super:Light Architecture floor plans.

Construction System and Components

Super:Light Architecture is constructed from lightweight componentized aluminium ribs, structurally rigidified by a tensioned fabric. This construction system is extremely lightweight and rapid to construct, and can meet the structural demands of the North. The ribs are formed in an I-beam section which offers structural efficiency, further saving weight. (see figure 6-08)

The foundation structure is a multipoint foundation, constructed from aluminium and steel elements with bolted connections. The multipoint foundation is somewhat heavier than a post and pad system but is significantly more rigid, while remaining adjustable, improving repairability and building longevity. (see figure 6-09)

The building floor is constructed with SIPs, which are lightweight and rapidly constructable. SIPs are best suited for floors as they are strong in bending and by increasing the depth of the foam core, the floor becomes stronger and more insulating without adding significant weight.

The tufted textile cladding allows for the use of batt insulation as it holds the batts in place, rather than using heavier and bulkier rigid insulation. Material innovations have allowed for permanent fabric buildings, both for structure and for exterior finishes. Textiles save a large amount of weight and bulk over traditional solid finishes, making them a good option in this project. (see figure 6-07, figure 6-11)

The interior partitions and window and door openings are constructed in wood framing which is lightweight and easily constructable. The party walls between units are also constructed in wood framing, with additional sound and fire isolation to separate units.

An important element of this construction system is the use of a componentized kit of parts where each housing unit is a clear and constructable product, reducing material waste and the need for spare parts. Repeatable modules and consistent elements avoids unique components, simplifying construction and later repairs significantly as pieces are interchangeable, avoiding the need to ship specialized replacement parts.



figure 6-07: Super:Light Architecture uses a similar tufted textile cladding system to the CHIP House (see Chapter 5.5.5). source: SCI-Arc, 2011

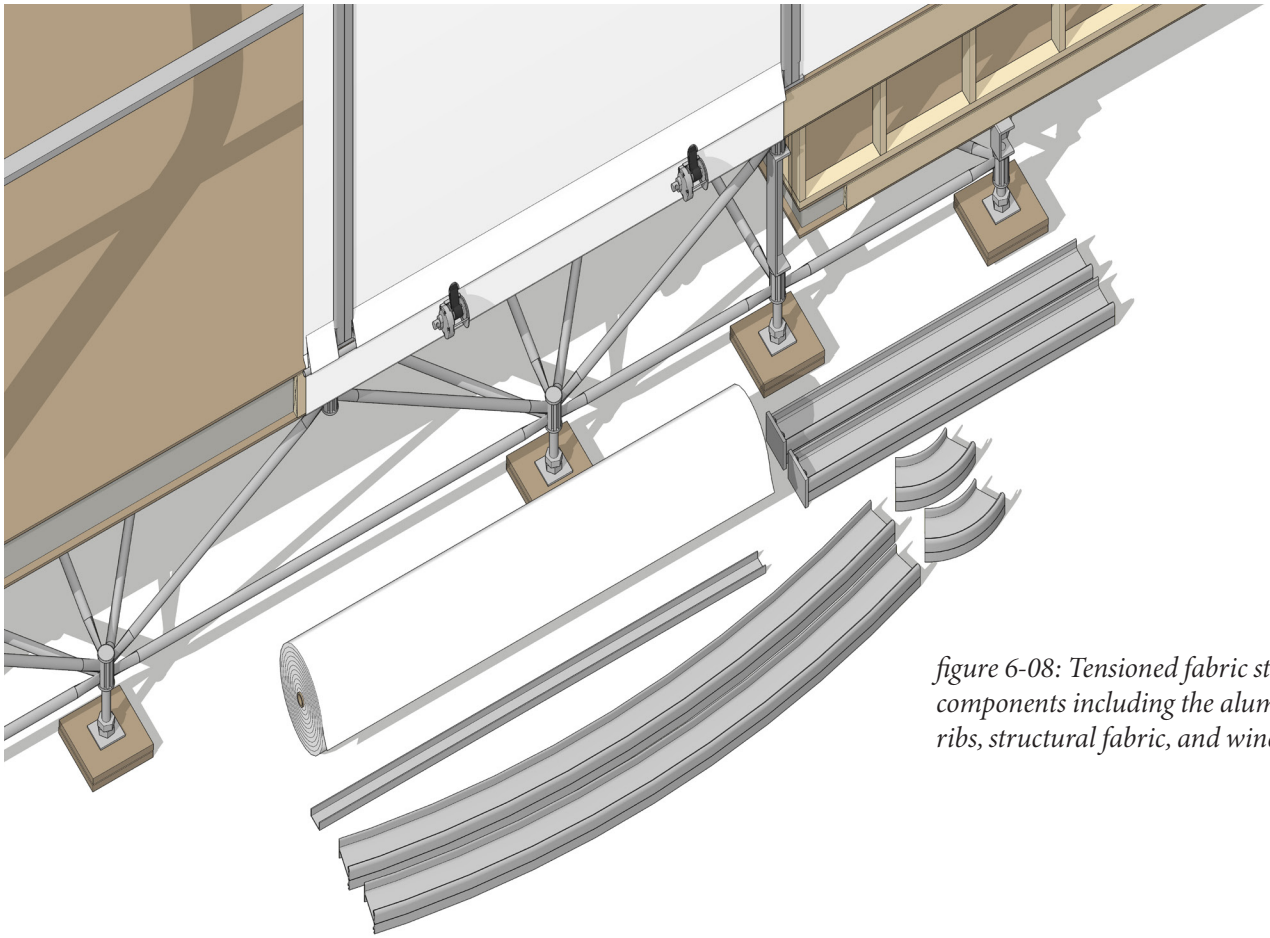


figure 6-08: Tensioned fabric structure components including the aluminium ribs, structural fabric, and winches.

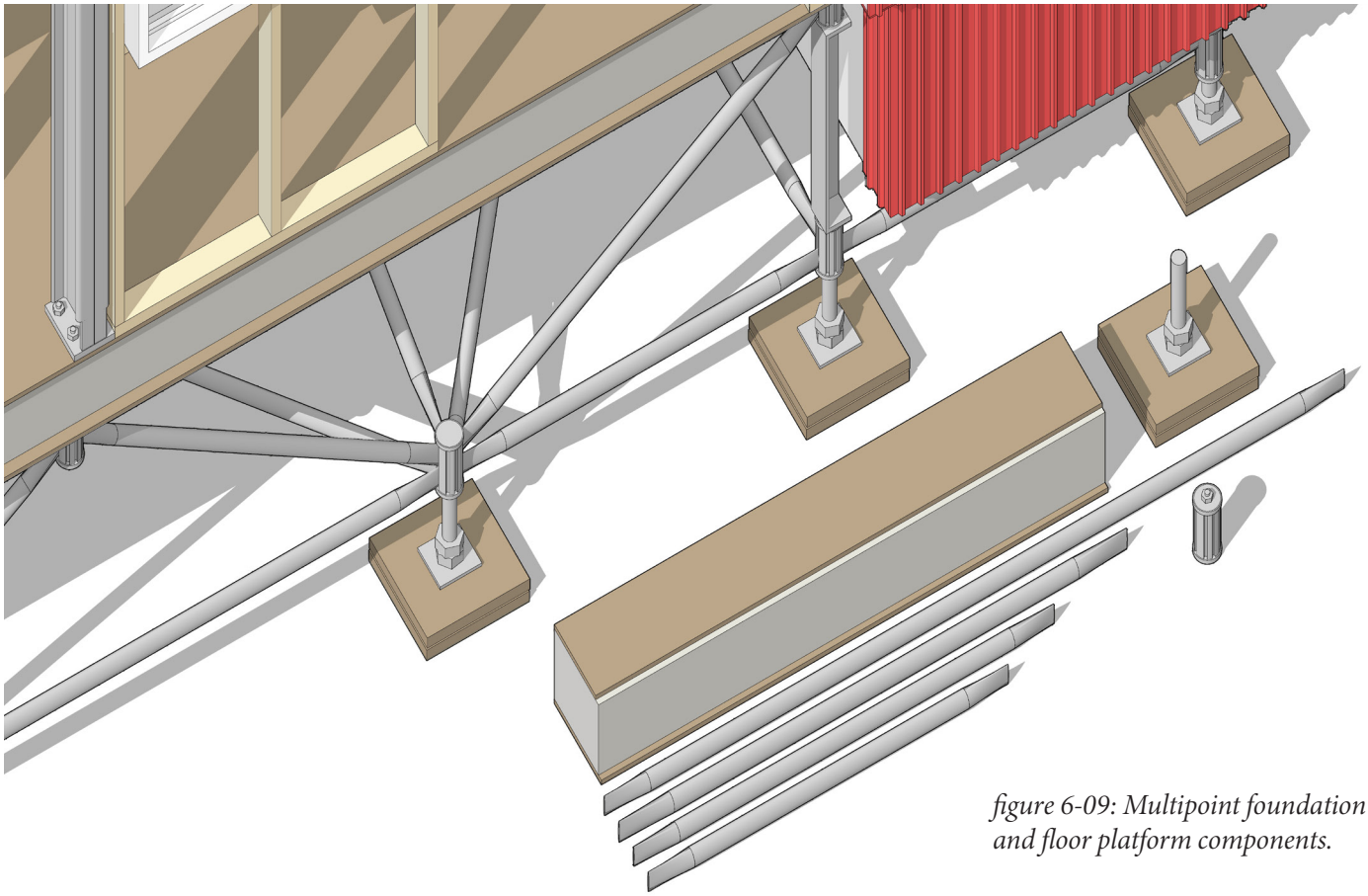


figure 6-09: Multipoint foundation and floor platform components.

Material

The material choices for this project can afford weight savings and address additional challenges. Aluminium is an excellent choice for the structure as it has a high strength to weight ratio, allowing for extremely lightweight structural ribs and multipoint foundations, while also resisting rust or corrosion due to incidental moisture. Aluminium is also simpler to form into specialized shapes, such as the channels in the ribs which hold the fabric in place and form an airtight seal. While aluminium is more expensive than steel, the enormous weight savings, as much as half, reduces the cost of shipping, offsetting some of the material costs. (see figure 6-10)



figure 6-10: Profiled aluminium rib which holds the corded edge of the structural fabric, forming an airtight seal. source: Sprung Structures

The structural fabric material takes advantage of modern technical fabrics to reduce weight, while maintaining high tensile strength and durability in the extreme cold. Combined with a polymer coating, the structural fabric can offer excellent air and water resistance, removing the need for additional membrane barriers. The advantages of modern textiles are also used for the exterior cladding which must be resistant to damage, UV degradation, and extreme cold. Proven products such as the Flexlight range from Serge Ferrari have a polymer coating over a high tenacity polyester, giving the textile the necessary durability while weighing just 500 g/m^2, approximately 1/10 the weight of 24 ga steel cladding.[271] The fabric also has some fire resistance, protecting the interior structural ribs, fabric, and insulation. (see figure 6-11)

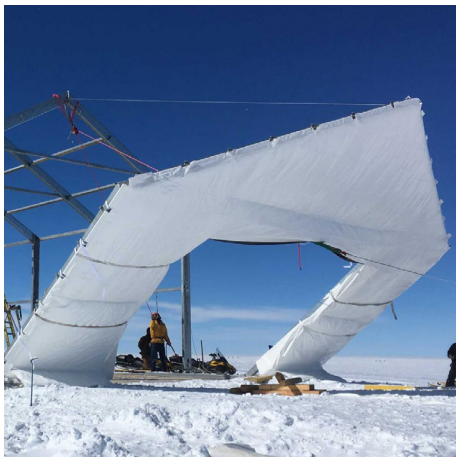


figure 6-11: A Rubb USA project, clad with the Flexlight Range from Serge Ferrari, is constructed in Greenland. source: Rubb USA, 2022

Fibreglass insulation is among the lightest weight for its insulation value, however mineral wool has better fire resistance and insulation for its depth but is much heavier. The enclosure design proposes to use low density fibreglass batts, compressed to 230 mm resulting in an insulation of RSI 5.3. This compression provides stiffness to resist wind and snow loads, and results in an overall significantly lighter system than rigid insulation. The underfloor tufted textile cladding uses fibreglass board insulation which will help protect the SIPs floor platform from fire or damage.

A detailed accounting of the major building assemblies and foundations provides a valuable starting point to understand the major components of the building's weight. This also ensures that the necessary control layers are incorporated throughout the enclosure. Enclosure assemblies are standard practice for architects, but the inclusion of product weight allows designers to better optimize their assemblies, particularly in the North where weight is a critical consideration. (see figure 6-12, figure 6-13, and pages 141 and 142)

271 "Flexlight Thermic 412 Opaque," Serge Ferrari Group, accessed Mar. 30, 2024. https://www.sergeferrari.com/productsflexlight-range/flexlight-thermic-412-and-412-opaque

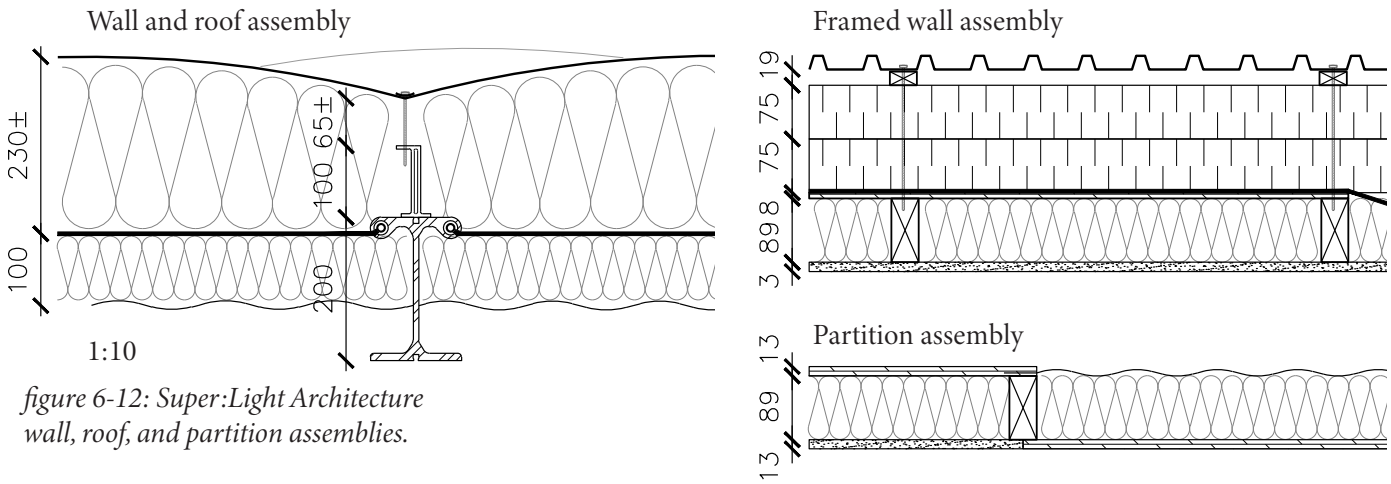


figure 6-12: Super:Light Architecture wall, roof, and partition assemblies.

Table 6-01: Wall and roof assembly

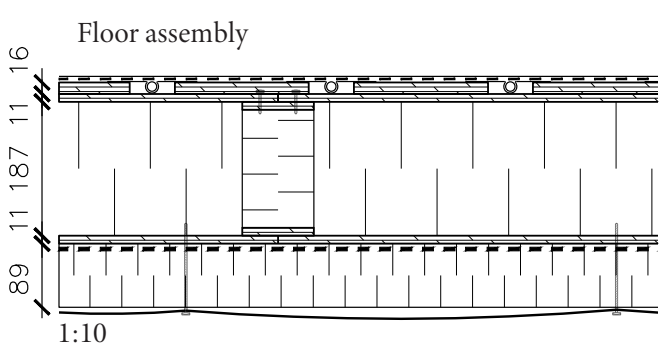
Component	Product	Dimension	Weight	Notes
Interior textile finish	Fire resistant textile (i.e. Nomex)		1.00 kg/m²	
200 mm Aluminium rib	Profiled aluminium rib	@ 3 m OC	4.62 kg/m²	
RSI 2.1 Fibreglass insulation	Owens Corning fibreglass	89 mm	1.13 kg/m²	RSI 1.6
Structural textile	Polymer coated PVDF		0.85 kg/m²	A/V/WB
RSI 5.3 Fibreglass insulation	Owens Corning (compressed)	230 mm	3.12 kg/m²	RSI 5.3
Cladding fasteners	100 mm Galvanized steel screw	8.0 #/m²	0.16 kg/m²	
Exterior textile cladding	Serge Ferrari 412 Opaque		0.498 kg/m²	
Total: 1,650 kg (145 m²)		**430 mm**	**11.4 kg/m2**	**RSI 6.90**

Table 6-02: Framed wall assembly

Component	Product	Dimension	Weight	Notes
13 mm Gypsum	USG Sheetrock	12.7 mm	6.11 kg/m²	
200 mm Aluminium rib	Profiled aluminium rib	@ 3 m OC	4.62 kg/m²	
RSI 2.1 Fibreglass insulation	Owens Corning fibreglass	89 mm	1.13 kg/m²	RSI 2.1
2x4 Lumber studs @ 600 mm OC	Lumber (12% of wall)	89 mm	5.34 kg/m²	
Structural textile	Polymer coated PVDF		0.85 kg/m²	A/V/WB
8 mm Plywood sheathing	Plywood	7.9 mm	4.03 kg/m²	
RSI 5.3 XPS rigid insulation	Owens Corning Foamular 150	150 mm	3.15 kg/m²	RSI 5.3
Cladding fasteners	100 mm galvanized steel screw	8.0 #/m2	0.33 kg/m²	
1x2 strapping @ 600 mm OC	Lumber strapping	19 mm	0.59 kg/m²	
26 ga Steel cladding	Vicwest lapped steel cladding	26 ga	3.91 kg/m²	
Total: 360 kg (12 m²)		**350 mm**	**30.1 kg/m²**	**RSI 7.37**

Table 6-03: Partition assembly

Component	Product	Dimension	Weight	Notes
Interior textile finish	Fire resistant textile (i.e. Nomex)		1.00 kg/m2	
2x4 Lumber studs @ 24" OC	Lumber (12% of wall)	89 mm	5.34 kg/m2	
Acoustic fibreglass insulation	Owens Corning	89 mm	1.16 kg/m2	
13 mm Gypsum	USG Sheetrock	12.7 mm	6.11 kg/m2	
Total: 1,306 kg (96 m²)		**102 mm**	**13.6 kg/m2**	



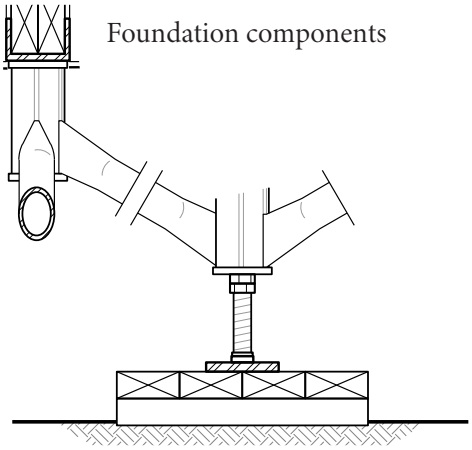


figure 6-13: Super:Light Architecture floor and party wall assemblies, and foundation component weights.

Table 6-04: Floor assembly

Component	Product	Dimension	Weight	Notes
Flooring	Vinyl flooring	3.2 mm	2.60 kg/m^2	
Flooring underlayment	AirGuard underlayment	2.0 mm	0.16 kg/m^2	
16 mm Radiant floor panel	RHT panel w/ alu heat plates	15.9 mm	6.70 kg/m^2	
SIPs (Insulspan R-plus)	7/16" OSB	11.1 mm	7.33 kg/m^2	A/VB
-	7 3/8" EPS	187 mm	3.09 kg/m^2	RSI 5.3
-	7/16" OSB	11.1 mm	7.33 kg/m^2	
Housewrap	Tyvek Homewrap		0.06 kg/m^2	WB
RSI 2.5 Fibreglass board	Knauf Earthwool board	89 mm	3.20 kg/m^2	RSI 2.5
Cladding fasteners	100 mm Galvanized steel screw	8.0 #/m2	0.16 kg/m2	
Exterior textile cladding	Serge Ferrari 412 Opaque		0.498 kg/m^2	
Total: 2,800 kg (90 m^2)		**327 mm**	**31.1 kg/m^2**	**RSI 7.83**

Table 6-05: Party wall assembly

Component	Product	Dimension	Weight	Notes
13 mm Gypsum	USG Sheetrock	12.7 mm	6.11 kg/m^2	FR
Acoustic panel	Sonopan acoustic panel	13.0 mm	2.70 kg/m^2	
2x4 Lumber studs @ 24" OC	Lumber (12% of wall)	89 mm	5.34 kg/m^2	
Acoustic fibreglass insulation	Owens Corning fibreglass	89 mm	1.16 kg/m^{2}2	
13 mm Gypsum	USG Sheetrock	12.7 mm	6.11 kg/m^2	FR
Total: 480 kg (23 m^2)		**115 mm**	**21.4 kg/m^2**	

Table 6-06: Foundation components

Component	Product	Dimension	Weight	Notes
Aluminium chord	3" pipe, 0.148" ga	2.45 m	430 kg	12 members
Aluminium chord	2 1/2" pipe, 0.120" ga	1.58 m	30 kg	76 members
Aluminium diagonal member	2 1/2" pipe, 0.148" ga	2.00 m	257 kg	68 members
Junction component	Extruded aluminium	48 pcs	240 kg	5 kg/pc
Bearing pads	Steel post and lumber pad	24 pcs	205 kg	8.5 kg/pc
Vertical posts	Steel post	2 pcs	18 kg	9 kg/pc
Floor panel support	Steel plate and lumber	26 pcs	78 kg	3 kg/pc
Total: 1,258 kg				

Building Weight

Super:Light Architecture weighs 6,670 kg for the building enclosure and interior partitions. This cuts weight by 48% compared to a baseline project, just short of the 50% target. The space frame foundation is heavier than steel tripod footings, weighing 1,260 kg compared to 560 kg, although the space frame is significantly more resilient. The building and foundation in total weighs 41% less than the baseline project. (see table 6-07, figure 6-14, Appendix A.2 - Baseline Assemblies)

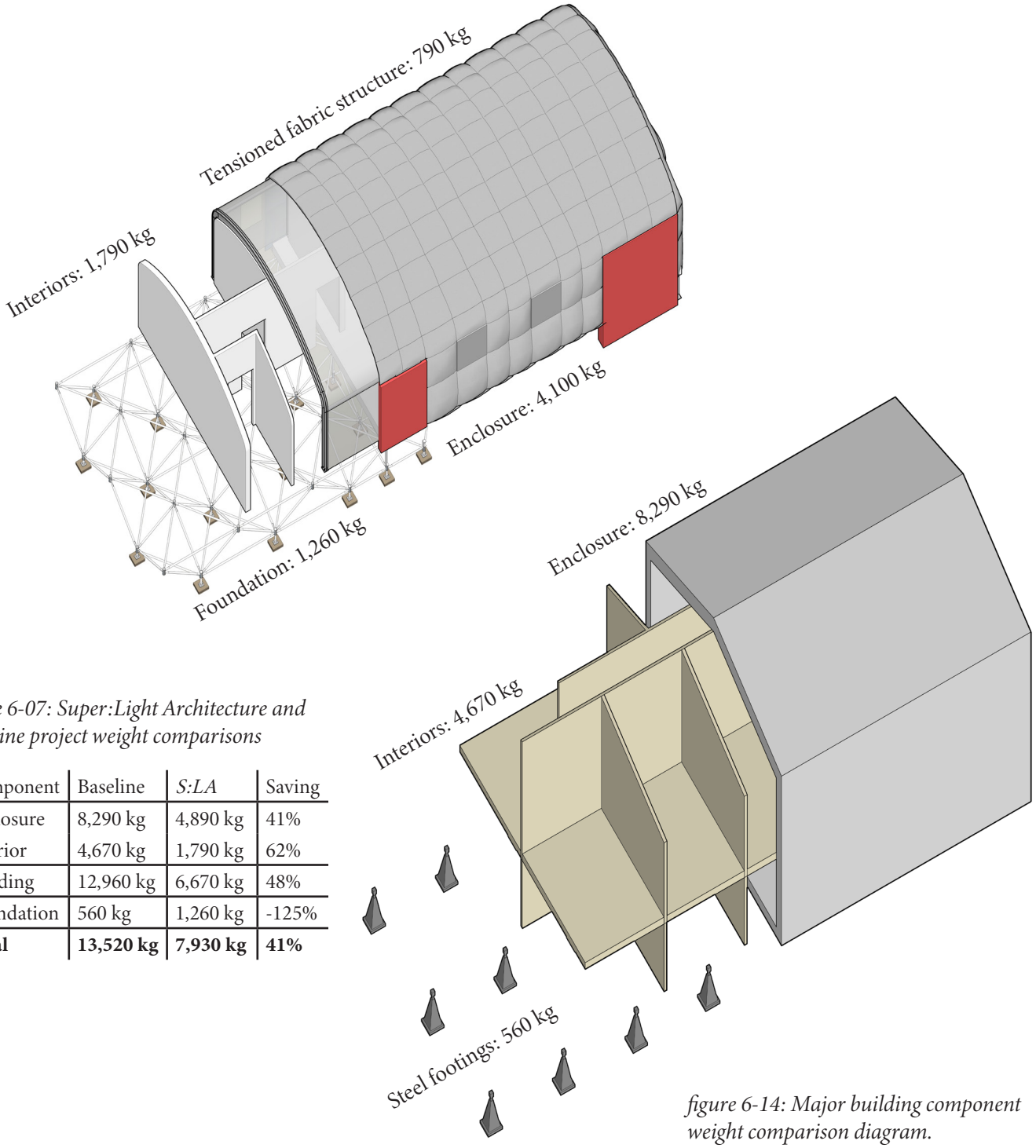


figure 6-14: Major building component weight comparison diagram.

Table 6-07: Super:Light Architecture and baseline project weight comparisons

Component	Baseline	*S:LA*	Saving
Enclosure	8,290 kg	4,890 kg	41%
Interior	4,670 kg	1,790 kg	62%
Building	12,960 kg	6,670 kg	48%
Foundation	560 kg	1,260 kg	-125%
Total	**13,520 kg**	**7,930 kg**	**41%**

6.2.2 - Material Costs and Transportability

Transportability is an important consideration for northern buildings as shipping costs are a major portion of material costs. Lightweightness and compactness reduces shipping costs and simplifies handling in communities with limited infrastructure, reducing the need for heavy machinery. (see table 6-08, table 6-09)

Lightweightness and Compactness

The use of componentized lightweight ribs allows for shipping savings by reducing the weight and bulk of the elements. The structural fabric and textile cladding is an enormous savings over traditional solid panels, and saves a large amount of space by being shipped in rolls. The multipoint foundation is also shipped in components and can be easily assembled on site. Batt insulation is another ideal choice as it is lighter, more compact, and avoids breakages that can occur with board insulation.

Shipping Method

The least expensive shipping method for northern buildings is usually by sealift. The sealift companies NSSI and NEAS charge based on 1,000 kg increments or per 2.5 m^3, whichever is greater, meaning both weight and packing volume must be considered. Sealift companies also place a net weight limit of approximately 12,000 kg on containers, so that they can be unloaded.[272, 273] The shipping costs in the chart indicate materials priced according to weight and materials priced according to volume.

Material and Shipping Cost

The material cost and shipping cost of the building enclosure is approximately $27,000 more than the baseline project, largely due to the material cost of the aluminium ribs and space frame foundation, and the shipping cost of the SIPs floor platform. These components yield significant constructability and performance improvements however, making them a worthwhile investment. The cost of the remainder of the project, including furniture, appliances, millwork, and building systems is similar to the baseline project, resulting in an overall comparable material cost. Shipping costs are also similar between this proposal and the baseline project, however *Super:Light Architecture* includes an enormous increase in insulation, enabled by its lightweightness and compactness.

Table 6-08: Super:Light Architecture material and shipping costs to Grise Fiord

Component (area)	Weight +	Volume (400 kg/m^3)
Material cost	Ship units	**Ship cost** ($493/unit)
Walls (45 m^2)	223 kg +	4.73 m^3
$7,087	2.12 units	**$1,042.55**
Roof (100 m^2)	497 kg +	9.16 m^3
$16,398	4.16 units	**$2,051.08**
Floor (86 m^2)	800 kg +	21.86 m^3
$17,020	9.54 units	**$4,704.52**
Framed walls (12 m^2)	395 kg +	0.62 m^3
$1,442	0.64 units	**$316.95**
Partition wall (96 m^2)	240 kg +	1.97 m^3
$2,105	1.03 units	**$506.73**
Party wall (23 m^2)	1099 kg +	1.38 m^3
$760	1.65 units	**$813.83**
Foundation	1260 kg	
$9,250	1.26 units	**$621.09**
Materials	Shipping	Total
$54,060	**$10,060**	**$64,120**

Table 6-09: Baseline project material and shipping costs to Grise Fiord

Component (area)	Weight +	Volume (400 kg/m^3)
Material cost	Ship units	**Ship cost** ($493/unit)
Walls (85 m^2)	3050 kg +	5.29 m^3
$6,563	5.17 units	**$2,546**
Roof (68 m^2)	2369 kg +	3.43 m^3
$5,670	3.74 units	**$1,844**
Floor (68 m^2)	1959 kg +	2.67 m^3
$6,883	3.03 units	**$1,492**
Int. flr. (63 m^2)	1599 kg +	0.90 m^3
$3,246	1.96 units	**$966**
Partition wall/ Party (138 m^2)	2791 kg +	1.98 m^3
$3,326	3.58 units	**$1,766**
Foundation		4.00 m^3
$3,802	**1.60 units**	**$788.69**
Materials	Shipping	Total
$28,150	**$9,410**	**$37,560**

272 "Packaging and Shipping Guide," Desgagnés Transarctik Inc., Mar. 2023, 6. https://uploads.visionw3.com/sitefiles/arcticsealift.com/documents/2023/packaging_guide_2023.pdf

273 "Packaging Guide," NEAS Group Inc. Apr. 2020, 13. https://neas.ca/wp-content/uploads/NEAS_Packaging_guide.pdf

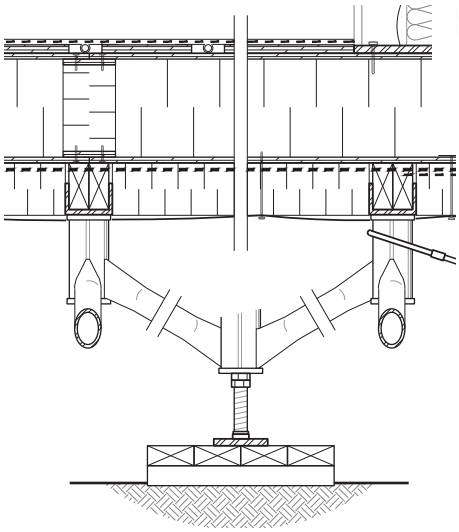


figure 6-15: SIPs floor platform and Multipoint foundation detail. SIPs splines are used to join panels with lumber blocking to attach to foundation.

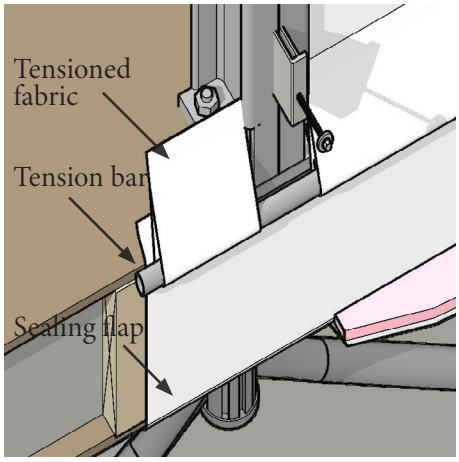


figure 6-16: Tensioned fabric structure attachment to floor platform, with additional air and water sealing flap.

6.2.3 - Constructability

Rapid constructability is important due to the limited building season and available labour, reducing construction costs and allowing for more buildings to be built each year. Simple construction is also useful as it allows for more use of local labour, higher quality construction, and simpler repairs to prolong the life cycle of a project. *Super:Light Architecture* uses a tensioned fabric structure which is specifically designed to save labour and this is is likely to result in significant savings which will more than offset the increased cost of materials.

Foundations and Floor Platform

The foundation is constructed from tubes which are bolted together at a junction component. Another option where machinery is available is to use pile foundations drilled into bedrock or permafrost, forming a more resilient foundation. Whether using piles or a multipoint foundation, adjustability is necessary to accomodate permafrost instability. Although surface footings would be lighter, they are significantly less reliable and require extensive site grading and gravel fill, increasing the labour and machinery required, making them a poor solution for high performance homes. (see figure 6-15)

The floor is constructed from SIPs which are reasonably lightweight and can be rapidly constructed. Using SIPs splines, which create a continuously insulated connection between panels, the panels are joined and connected to the foundation points. With tape or spray foam, air sealing of the panels is relatively simple but does require some care and cannot be done in the extreme cold. The heat distribution panels are made from prefabricated routed sections and plywood strips with an aluminium sheet. This system distributes heat evenly across the vinyl flooring. The hydronic loops can also be prefabricated with the SIPs panels, reducing labour on site, although this affects the flexibility of interior planning.

Tensioned Fabric Structure

The tensioned fabric structure can be constructed extremely quickly, enclosing a project in a matter of hours or days, without the need for machinery. Each rib weighs less than 200 kg, and is composed of several segments which are bolted together and tilted up into place. The tensioned fabric component is also rapidly constructable. It is attached by inserting the corded edge of the fabric into the channel on the aluminium ribs, pulling the fabric over the structure, then sliding the tension bar into the bottom edge of the fabric, which is then winched down on either side, fastening the structure to the floor and foundation. (see figure 6-16, figure 6-17)

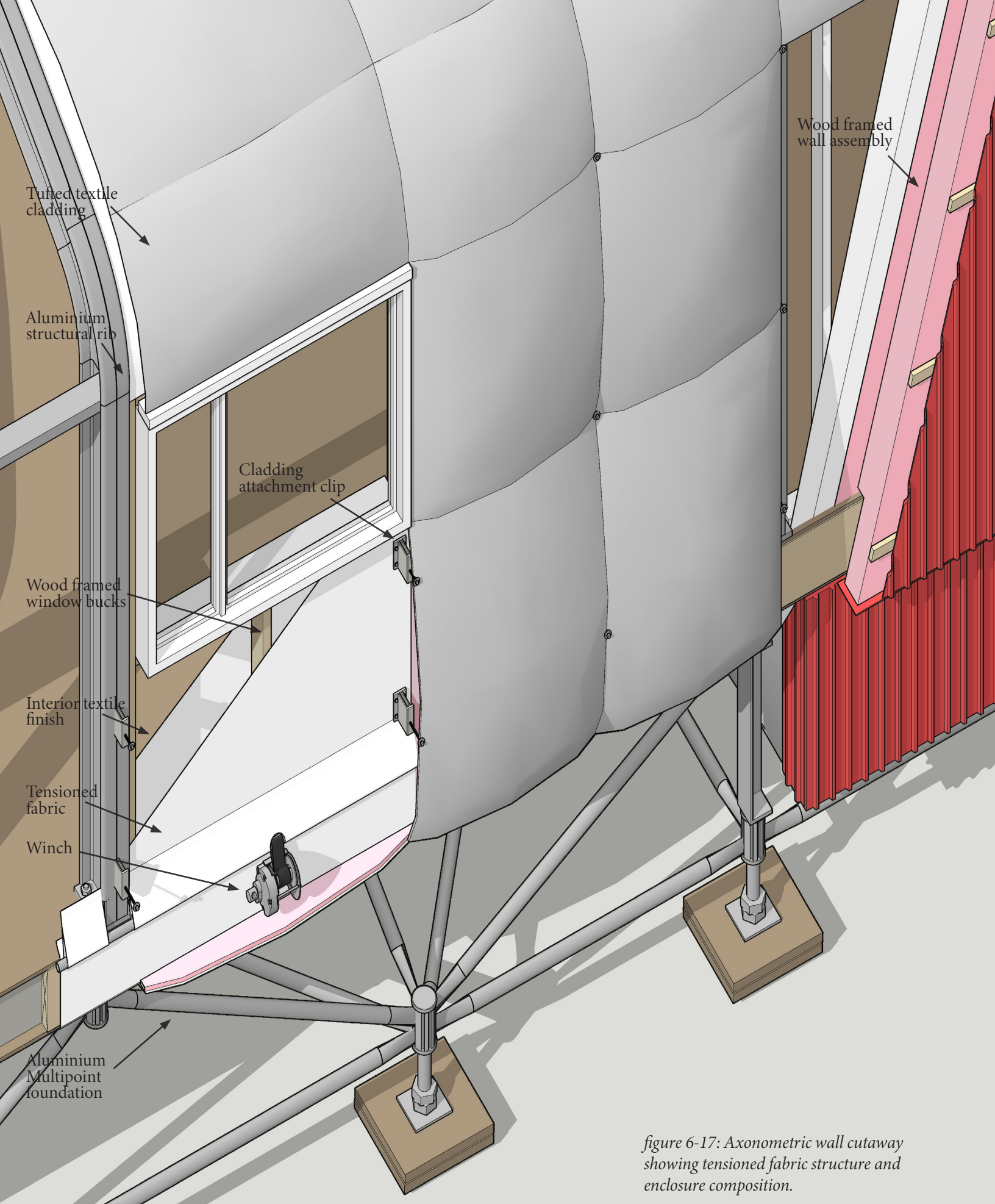


figure 6-17: Axonometric wall cutaway showing tensioned fabric structure and enclosure composition.

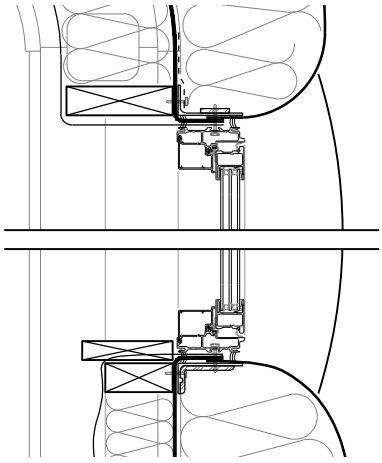


figure 6-18: Window opening detail, showing wood framing opening, fibreglass window girts, and textile cladding attachment.

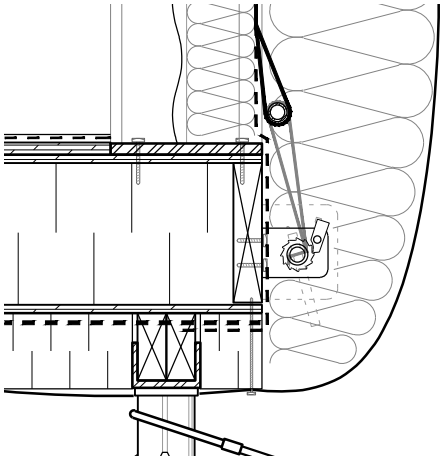


figure 6-19: Enclosure air, vapour, and water sealing detail at floor edge, and tensioned fabric structure attachment.

Enclosure

The air and vapour control are accomplished by the structural fabric, reducing additional layers, however detailing is needed to ensure a continuous barrier. An additional flap is sewn to the structural fabric during production, and this is wrapped under the floor platform and lapped with the floor membrane, forming a continuous barrier. Primary water control is provided by the exterior textile, although the structural fabric is also waterproof.

The cladding is constructed by attaching the textile to the designated points, leaving a cavity and stuffing insulation into the cavity. Working with long segments allows for standard batt rolls to be used, avoiding additional labour with many individual segments. This process is designed to be executed similarly to the process of insulating a wall cavity and fastening an interior membrane. An important consideration is ensuring the pockets are sufficiently stuffed prior to tightening the cladding down to its final depth. Tightening the cladding down compresses the insulation, holding it in place, further supported by the fastening cords. The bottom of the cladding is fastened to a drainage grill which is attached to the floor platform, allowing incidental moisture to drain from the enclosure. This construction process will likely require more care than steel cladding with rigid insulation, but requires no machinery and is much lighter and therefore physically easier. The assembly is also much more compact for shipping and logistics on site. The floor cladding is constructed similarly, and attachment screws can be attached anywhere on the SIPs. (see figure 6-17, figure 6-19)

Openings

Openings such as windows and doors are constructed within wood framing segments which are fixed to girts connected to the aluminium ribs. The tensioned fabric structure is fully constructed beforehand and is fastened to the rough opening with a termination bar and then air sealed, ensuring a continuous environmental barrier and a solid structural connection. The front door and vestibule is constructed with wood framing as this will experience more user impacts and ensuring a reliable door is important as it has been a common source of failures in the past. (figure 6-18)

Interior

The interior partitions and finishes are also relatively simple. Partitions are constructed from wood framing, a quick and familiar process to local labour, and spacing studs at 600 mm reduces the materials and labour needed. The finishes are also designed to be quick to construct, using textile finishes where practical, and either gypsum or prefinished plywood where a solid finish is needed such as washrooms and kitchens. The textile interior finishes are designed to be used in places that do not affect occupant usage such as behind furniture in bedrooms. The floor finish is a vinyl sheet product which offers suitable durability, is easily cleaned, and is quick to install.

Building Systems

The mechanical and plumbing portion of the house has lumber framing infill and partition walls, simplifying building systems integration and providing solid points to connect equipment to. The domestic water supply and wastewater storage are housed in the crawlspace because they take up a large amount of space. The crawlspace is enclosed along the with the main building, keeping the water from freezing. (figure 6-20)

Super:Light Architecture uses air to water heat pumps with hydronic floor heating, removing the need for fuel storage and using a single system for heating and domestic hot water, simplifying installation. The ventilation system is also simple to install, and is run in the ceiling along the central wall, then plugged into the ERV. Electric wiring can be installed traditionally, or can be run in flexible conduit, if the wall or partition is considered to be at risk of fire.

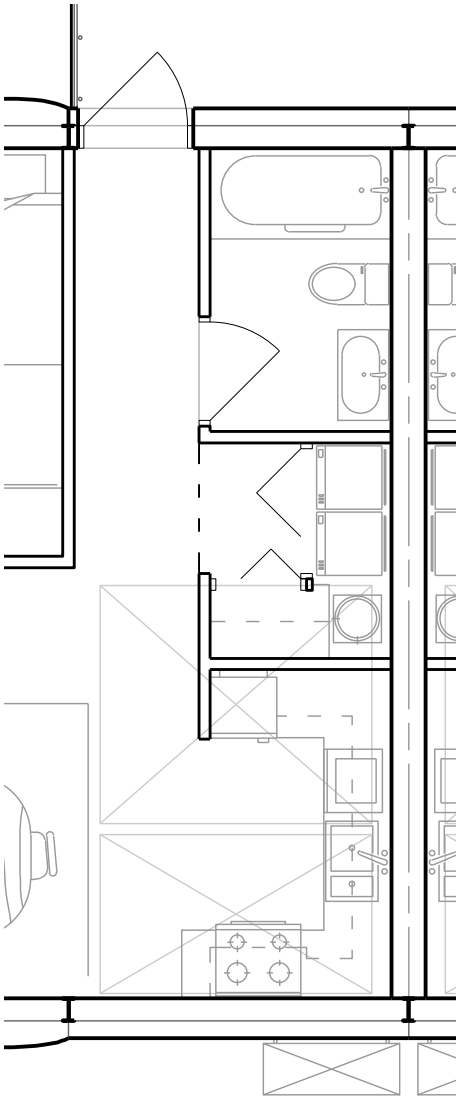


figure 6-20: Wood framed mechanical and plumbing portion of the unit, with water tanks in crawlspace below.

6.2.4 - High Performance

High performance is necessary for buildings in the North, keeping users comfortable and reducing operating costs. A balance of passive design strategies, such as a high performance enclosure, in combination with efficient systems ensures life cycle economic savings. An important consideration for northern projects is to develop an energy consumption estimate. Sophisticated modelling software exists, however simplified models that can provide a rough estimate are also useful as they allow designers to easily understand the energy cost of design choices such as volumetrics, openings, and enclosure design.

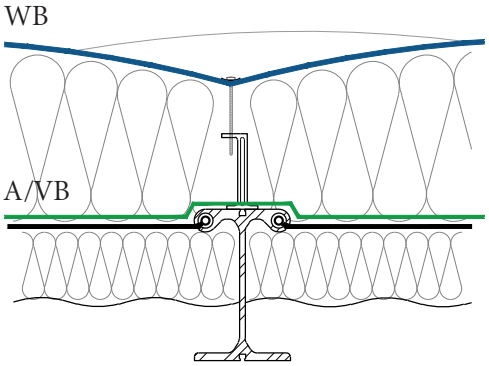


figure 6-21: Control layer diagram of tufted textile cladding.

Enclosure Design

The most impactful energy saving design element is the high performance enclosure, incorporating extensive insulation and airtightness. Insulation is lightweight and does not add excessive shipping costs while significantly reducing operating costs. Airtightness is also important for energy performance and the tensioned fabric structure accomplishes this, interlocking tightly with a channel on the aluminium ribs. The SIPs floor platform is also highly insulative and airtight. (see figure 6-21, figure 6-22)

Another energy conserving design strategy is reducing the overall size of the project and the exterior enclosure area, reducing energy loss. Reducing the scale of a project and improving enclosure area efficiency by using a rowhouse typology also serves to save weight, making this an important consideration for northern projects.

The openings are an impactful design choice as these represent a significant heat loss, as well as additional weight and construction cost. The window and door to wall ratio is 0.12, under the NECB maximum 0.20 ratio. High performance doors with thermally broken frames and triple-paned windows with spacers and gas fill reduce the heat loss associated with openings, while providing visibility which is pleasant when users spend more time indoors during cold weather.

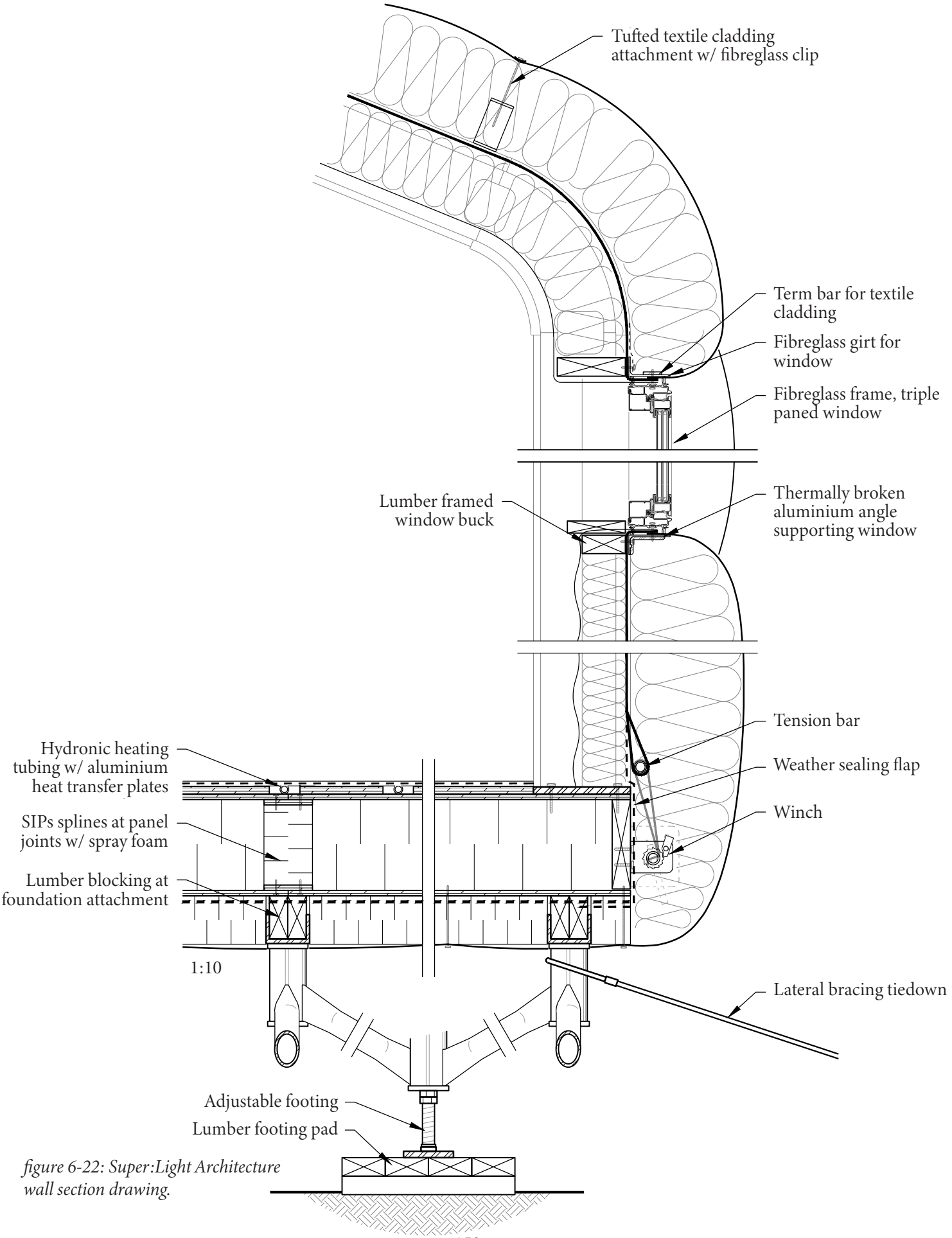


figure 6-22: Super:Light Architecture wall section drawing.

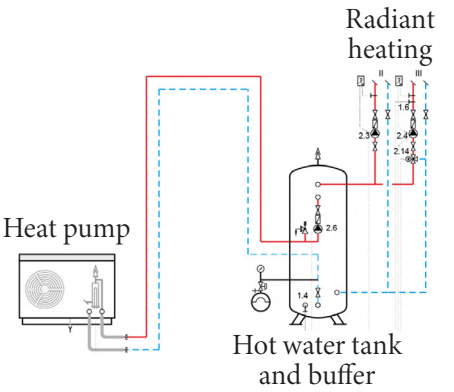


figure 6-23: Electric air source heat pump to hydronic floor heating and domestic hot water system diagram.
source: Stiebel Eltron USA



Heat pump
(125 kg)





Hot water tank
and buffer (54 kg)

Distributor and
backup heater (75 kg)

figure 6-24: Main heat pump system components, which supply both hydronic heating and domestic hot water.
source: Apollo Heat Pumps

Building Systems

Efficient building systems are another critical design consideration for developing a high performance building. *Super:Light Architecture* uses air to water heat pumps with hydronic floor heating. This system requires relatively low water temperatures, between 30°C and 40°C, allowing the heat pumps to operate more efficiently. Current heat pump technology has some limitations at extremely cold temperatures, but this is currently being improved and products are available that can operate safely at all but the lowest temperatures in the North. Additional electric resistance heating ensures that the system will function in the most extreme cold, below the heat pump operating range. (figure 6-23, figure 6-24)

Alternative heating systems are also viable for this project, such as diesel or oil boilers also with hydronic heating. The energy savings due to the high performance form and enclosure make electric systems a more viable option than in past examples of northern housing, although this performance would also extend to the use of more traditional systems.

The heating system also supplies hot water, reducing complexity and allowing the efficiency of the heat pump to reduce energy consumption for hot water. Hot water energy consumption is a major component of energy consumption, and improving the efficiency is enormously impactful. Efficient plumbing fixtures serve to reduce water consumption, and reducing operating costs, both for water supply and wastewater removal. The floor plan condenses all plumbing to the solid framed portion of the project and the shared services wall, reducing plumbing runs, improving hot water efficiency and reducing the risk of blockages.

The ventilation system is another key element of a high performance building, providing fresh air to users and reducing the risk of mould which can cause health effects and building damage. Heat recovery is needed as the exhaust air carries heat energy which is wasted if it is not recycled. *Super:Light Architecture* incorporates an ERV, which warms incoming supply air using the exhaust air, while also recycling interior humidity, saving energy and reducing the risk of frost that is present with HRVs.

Energy Modelling

Energy modelling is a useful tool in designing northern projects. Estimating energy loss based on effective insulation and airtightness measurements, rather than nominal values, allows for designers to make better choices, especially in the North where these can have an enormous impact. *Super:Light Architecture* uses energy modelling to optimize enclosure design and estimate operating costs. Following this, actual testing is necessary to ensure that projects are constructed properly and will perform as predicted. Airtightness testing and ongoing energy monitoring are critical to ensuring successful high performance projects in the North.

Energy modelling for *Super:Light Architecture* was undertaken for three test communities: Iqaluit, Arctic Bay, and Grise Fiord. Iqaluit represents a well-understood setting and allows for comparison against existing solutions and test-cases. Arctic Bay and Grise Fiord are extremely remote, which this proposal has been designed for, and thus are good locations to study. (see figure 6-26)

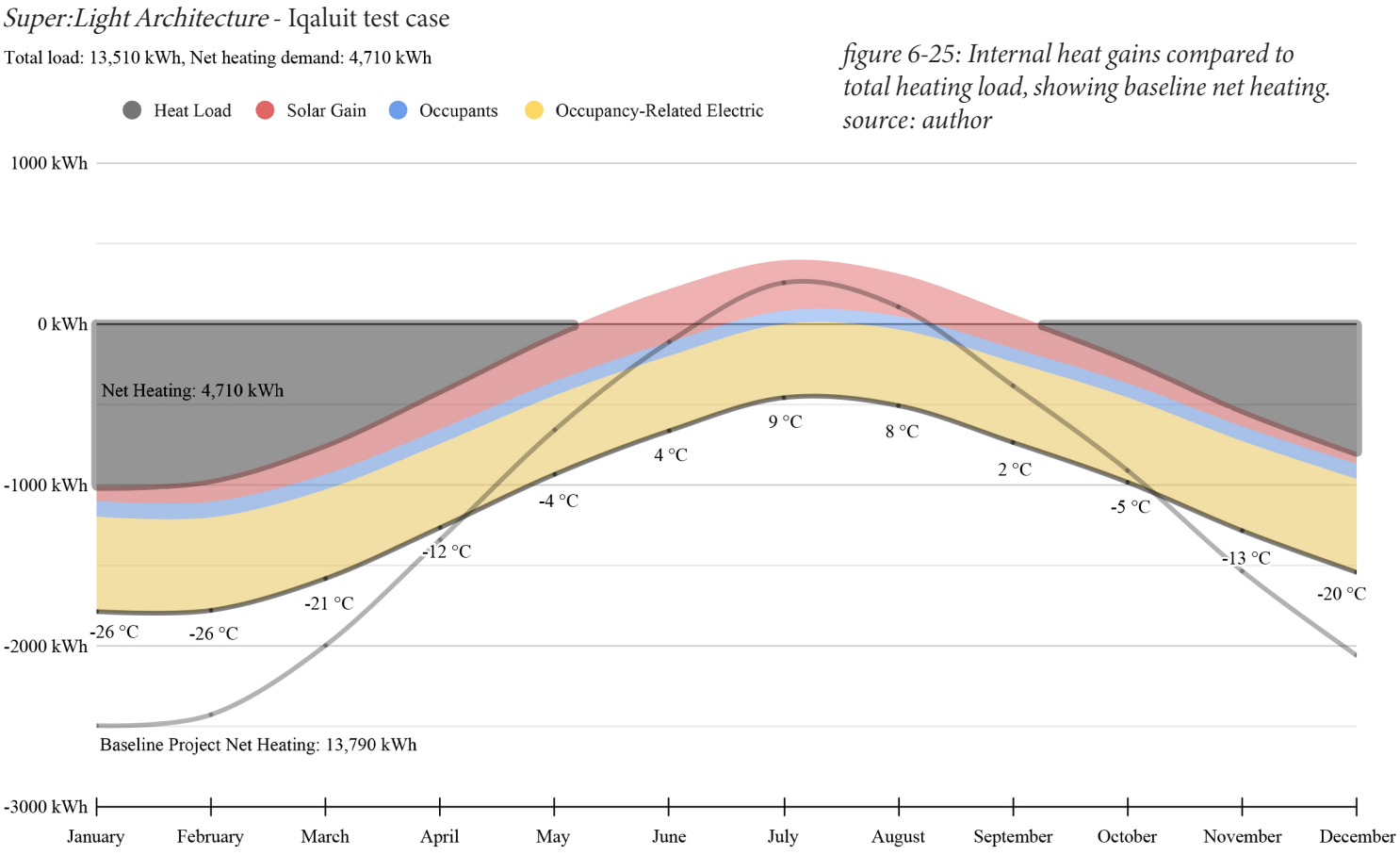
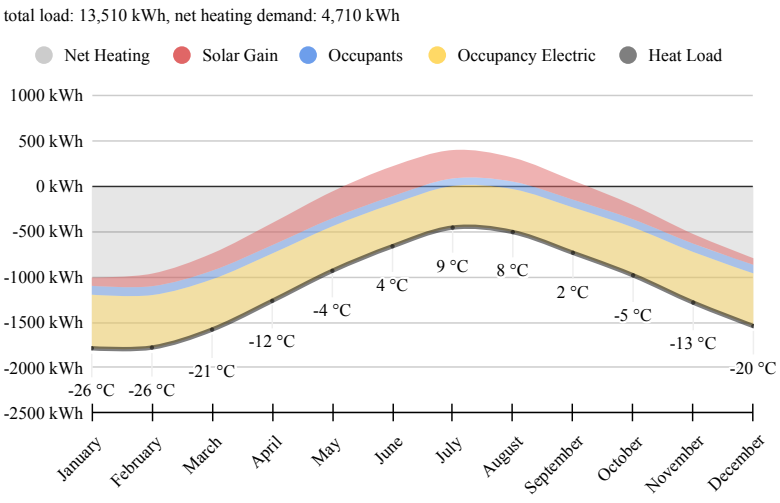
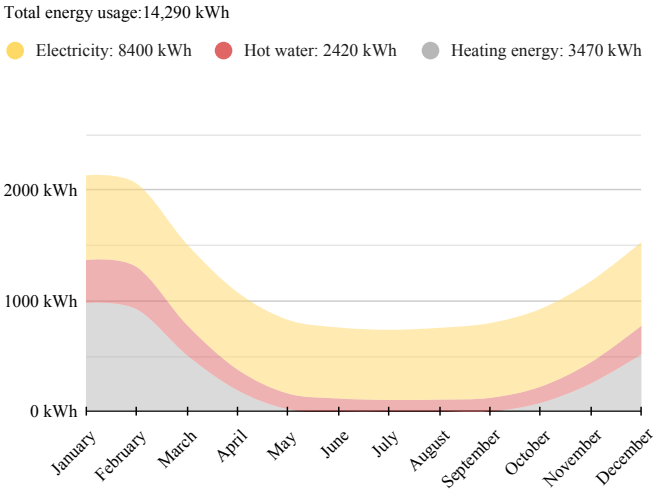


figure 6-25: Internal heat gains compared to total heating load, showing baseline net heating. source: author

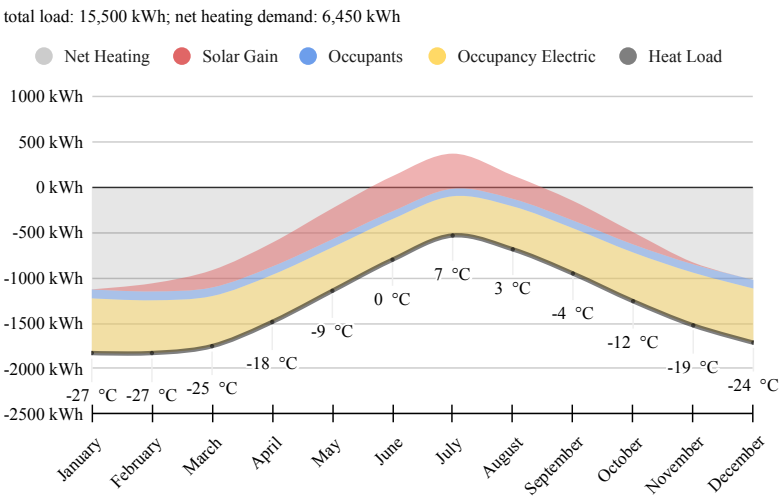
Super:Light Architecture - Iqaluit test case



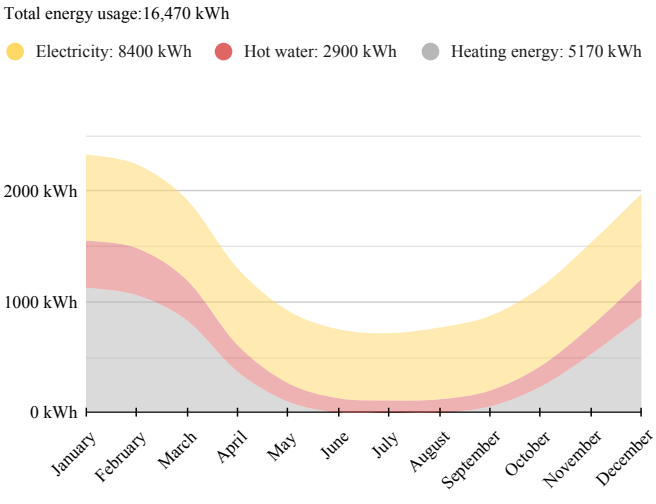
Iqaluit energy usage (heating with heat pump)



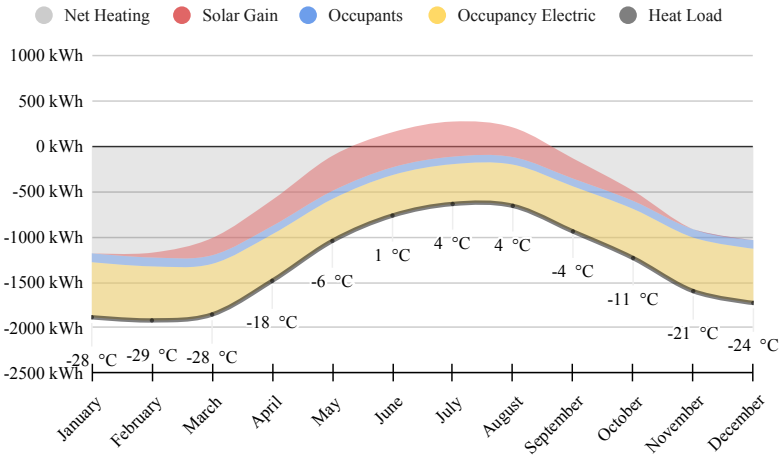
Super:Light Architecture - Arctic Bay test case



Arctic Bay energy usage



Super:Light Architecture - Grise Fiord test case



Grise Fiord energy usage

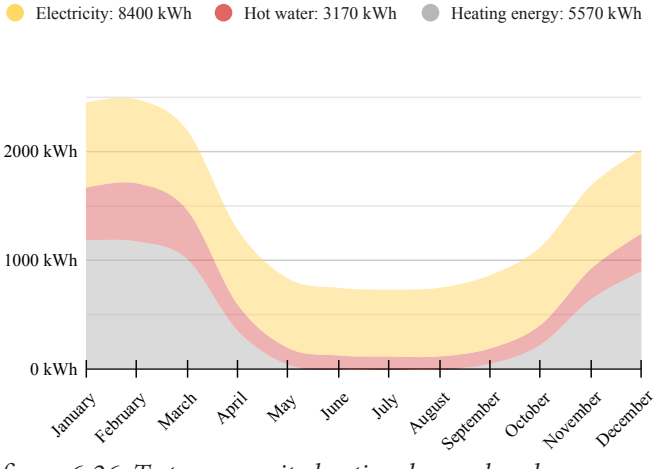


figure 6-26: Test community heating demand and energy consumption graphs. Hot water energy is reduced during summer when heat pumps can operate more efficiently. source: author

Operating Costs

Operating costs are a large portion of the life cycle costs of northern buildings, making energy efficiency a critical concern. Costs for energy, both fuel and electricity, in the North are distorted by subsidies, which complicates cost comparisons between system types.

Diesel is widely used in the North to fuel furnaces and water heaters as well as used to generate electricity in many communities. Although heating with diesel generated electricity is less effiicient than heating directly with fuel, *Super:Light Architecture* reduces operating costs compared to baseline construction. The building efficiency improvements would also apply to a diesel heating system and would reduce operating costs compared to the all-electric system proposed. An all-electric system would reduce operating costs comapred to baseline by $1,560 in Iqaluit, $990 in Arctic Bay, and $600 in Grise Fiord. The use of a diesel system would save costs in these communities, based on current prices which are distorted by subsidides. (see table 6-10, table 6-11, and table 6-12)

Although the current operating costs of a diesel system can be significantly lower, there are additional factors that make electric systems promising. One particularly important factor is the increasing accessibility of renewable energy sources such as wind and solar, which will reduce electricity costs and diesel emissions. Energy costs will increase in the future and this cost increase will likely be greater for diesel than for electricity due to increasing access to renewable energy, making an all-electric system more viable. Another important factor is that an all-electric system would not require fuel storage on site, reducing the risk of fire and environmental damage due to leaks both from tanks and from service trucks. Using renewable electricity with an efficient system, such as the one proposed here, improves northern self-sufficiency and has economic and environmental benefits.

Table 6-10: Iqaluit energy cost comparisons

Baseline	diesel	***Super:Light***	diesel	electric
Heating	$2340 (17200 kWh)	Heating	$752 (5540 kWh)	$902 (3470 kWh)
Hot Water	$813 (5990 kWh)	Hot Water	$765 (5636 kWh)	$459 (2430 kWh)
Electricity	$992 (10000 kWh)	Electricity	$0 (8400 kWh)	$1220 (8400 kWh)
$0.136/kWh (diesel) $0.620/kWh (elec.)	**$4,144 (total)**		**$1,517 (total)**	**$2,585 (total)**

Table 6-11: Arctic Bay energy cost comparisons

Baseline	diesel	***Super:Light***	diesel	electric
Heating	$3030 (21400 kWh)	Heating	$1080 (7590 kWh)	$1533 (5170 kWh)
Hot Water	$850 (5990 kWh)	Hot Water	$800 (5636 kWh)	$701 (2900 kWh)
Electricity	$992 (10000 kWh)	Electricity	$0 (8400 kWh)	$1650 (8400 kWh)
$0.142/kWh (diesel) $0.620/kWh (elec.)	**$4,874 (total)**		**$1,877 (total)**	**$3,884 (total)**

Table 6-12: Grise Fiord energy cost comparisons

Baseline	diesel	***Super:Light***	diesel	electric
Heating	$3060 (21600 kWh)	Heating	$1110 (7810 kWh)	$1770 (5570 kWh)
Hot Water	$850 (5900 kWh)	Hot Water	$800 (5636 kWh)	$830 (3170 kWh)
Electricity	$992 (10000 kWh)	Electricity	$0 (8400 kWh)	$1700 (8400 kWh)
$0.142/kWh (diesel) $0.620/kWh (elec.)	**$4,904 (total)**		**$1,908 (total)**	**$4,305 (total)**

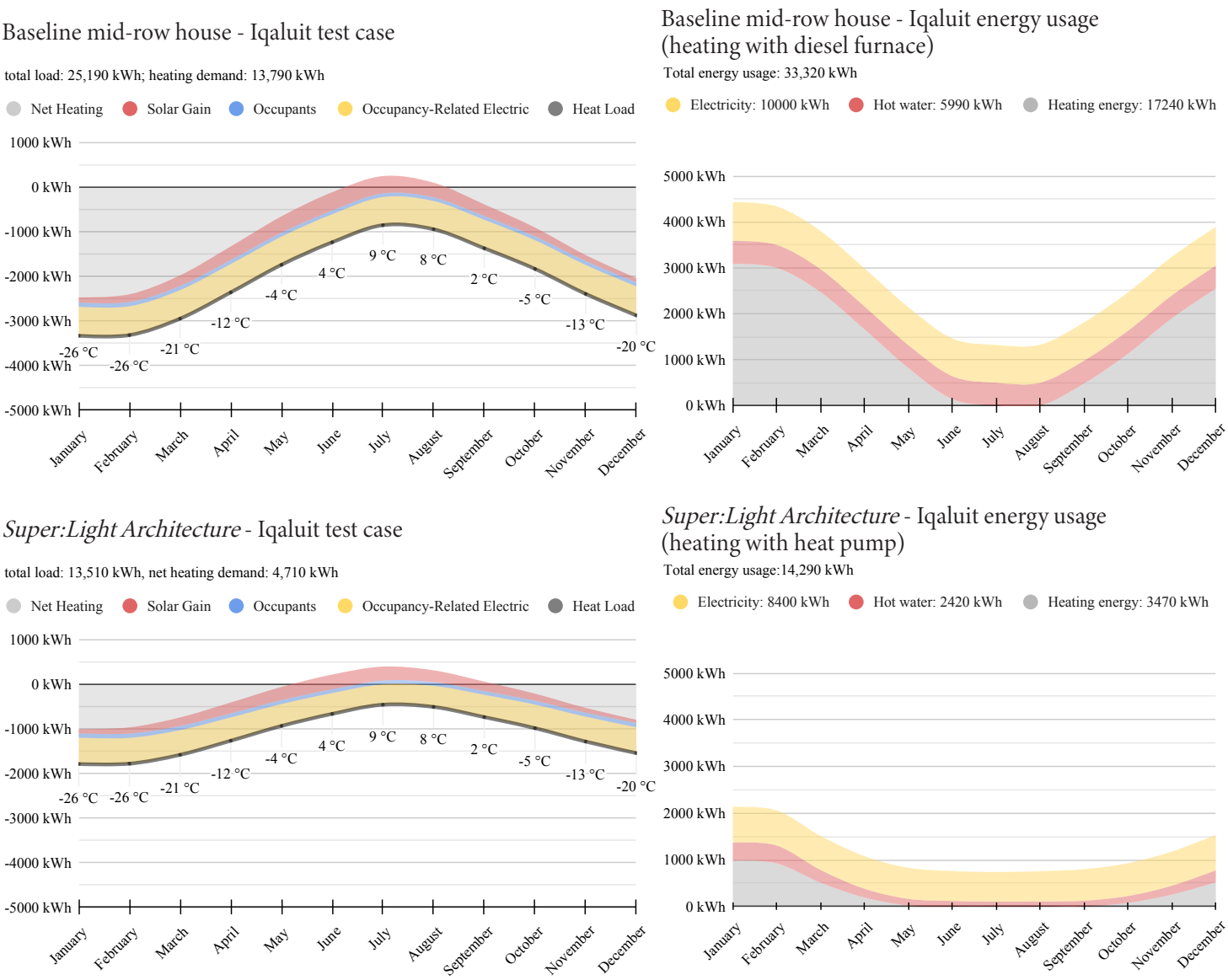


figure 6-27: Super:Light Architecture and baseline project heating demand and energy usage in Iqaluit.

6.2.5 - Comparisons

Super:Light Architecture is designed with the target of half the weight of typical construction, and half the net heating demand. In comparison to the baseline project, *Super:Light Architecture* reduces heating load by 45% and net heating demand by 65%, a net heating demand of 4,700 kWh in Iqaluit. While total heating load is decreased, internal gains are not decreased, allowing the project to be heated for the summer months by internal heat gains from occupancy and electricity usage. Hot water and plug load are less flexible, but heat pumps significantly improve efficiency for hot water supply, and current electrical appliances are also more efficient, saving costs. Total energy consumption for the project, including heating, hot water, and electricity usage, totals approximately 14,300 kWh, compared to 33,000 kWh for the baseline project, set in Iqaluit. (see figure 6-27 and Appendix A.1)

This enormous overall energy savings is made possible by the significant reduction in heating demand and the use of a highly efficient heat pump system for heating and hot water production, and though this efficiency would not be possible with alternative heating systems such as diesel or oil furnaces, the significant heating demand reduction would improve these systems as well.

Super:Light Architecture exceeds its energy target and falls slightly short of its weight target, demonstrating the viability of this architecture and methodology in the challenging context of the North. The weight savings reduce shipping costs and allow for locally available machinery and vehicles to transport materials. The lightweighting also simplifies construction, reducing the need for construction equipment and needing fewer workers, especially in the most remote communities, further reducing costs and allowing for more projects to be built during the short construction season. The energy savings improve economic sustainability by reducing operating costs, and makes the project more resilient when issues arise with building systems or infrastructure. The lightweightness of this proposal allows for its high performance design.

Design Implementation and Limitations

It is critical for vulnerable users and communities that proper consultation takes place in developing appropriate floor plans and determining acceptable designs for users and housing groups. A flexible interior floor plan and exterior design, built on a lightweight core structure, allows for locally sensitive design to address the needs of communities while remaining transportable and constructable across the North.

Super:Light Architecture demonstrates the possibilities for lightweighting northern architecture, in this case using a tensioned fabric structure. This lightweighting allows for the incorporation of a high performance building enclosure, significantly reducing energy consumption and operating costs. Most of this weight saving comes from the reduced weight of the structure. Textile claddings also save weight but requires change of user habits, and further study is needed to determine the appropriateness of these decisions.

A large portion of the weight of the project comes from the floor structure, more than half of the weight the enclosure. Floors cannot sacrifice much rigidity over current practices, and thus there are fewer opportunities for weight savings. While an optimized floor using engineered joists could result in a lighter structure and reduced shipping costs due to bulk, SIPs expedite on site labour, reduce thermal bridging, and are relatively simple to construct to an airtight standard.

Lastly, the use of electric heating systems is made more viable by the reduction in space heating demand, however remote communities that do not have access to renewable energy sources, and that are unlikely to develop them, are not well served by the electric systems in this proposal. These communities will still benefit from the compact and lightweight design, and the high performance enclosure, reducing fossil fuel consumption.



figure 6-28: Super:Light Architecture, view of front entrance.



figure 6-29: Super:Light Architecture, shown in Grise Fiord, NU, the northermost public community in Canada.



figure 6-30: Super:Light Architecture, set in Arctic Bay, NU.

6.3 - *Northern Lightweight Architecture*

Northern Lightweight Architecture is a super high performance proposal which includes meaningful weight savings, allowing it to be transported and constructed easily in the North. The project is intended for larger population centres, which have access to more machinery and construction labour. The construction system is advanced wood framing, which makes use of existing local labour skills and is lightweight and economical. The project follows enclosure best practices with extensive exterior insulation, and thus also aims to establish a future best practice for northern buildings. Some design decisions such as building enclosure, floor structure, and building systems are informed by elements developed for *Super:Light Architecture*. The design of *Northern Lightweight Architecture* is more visually similar to current practice, making it a more familiar design, with significant improvements to building efficiency.

Northern Lightweight Architecture aims to cut heating energy consumption by more than 75% compared to a baseline home, a net heating demand of 3,500 kWh in Iqaluit, and to cut weight by 25%, a weight budget of 10,000 kg.[274] This level of energy reduction allows for several months of passive heating due to internal heat gains, depending on the community, and allows electric heating and hot water to be economically viable. This project uses an electric heat pump for both hydronic heating and domestic hot water. Electric heating allows for the use of renewable power sources, although it is commonly generated by diesel currently. In larger communities of the Inuit Nunangat, renewable power is highly viable, and is already used in many communities in the Northwest Territories, the Yukon, and Nunavik. *Northern Lightweight Architecture* is intended to comply with the NBCC and northern building guidelines, representing a currently practical proposal.

274 *An Energy Standard for Homes in Iqaluit - A Business Case*, report for Department of Planning and Lands City of Iqaluit (Ottawa: Marbek Resource Consultants Ltd., Mar. 2005), 5.



figure 6-31: Northern Lightweight Architecture, overlooking Yellowknife Bay.

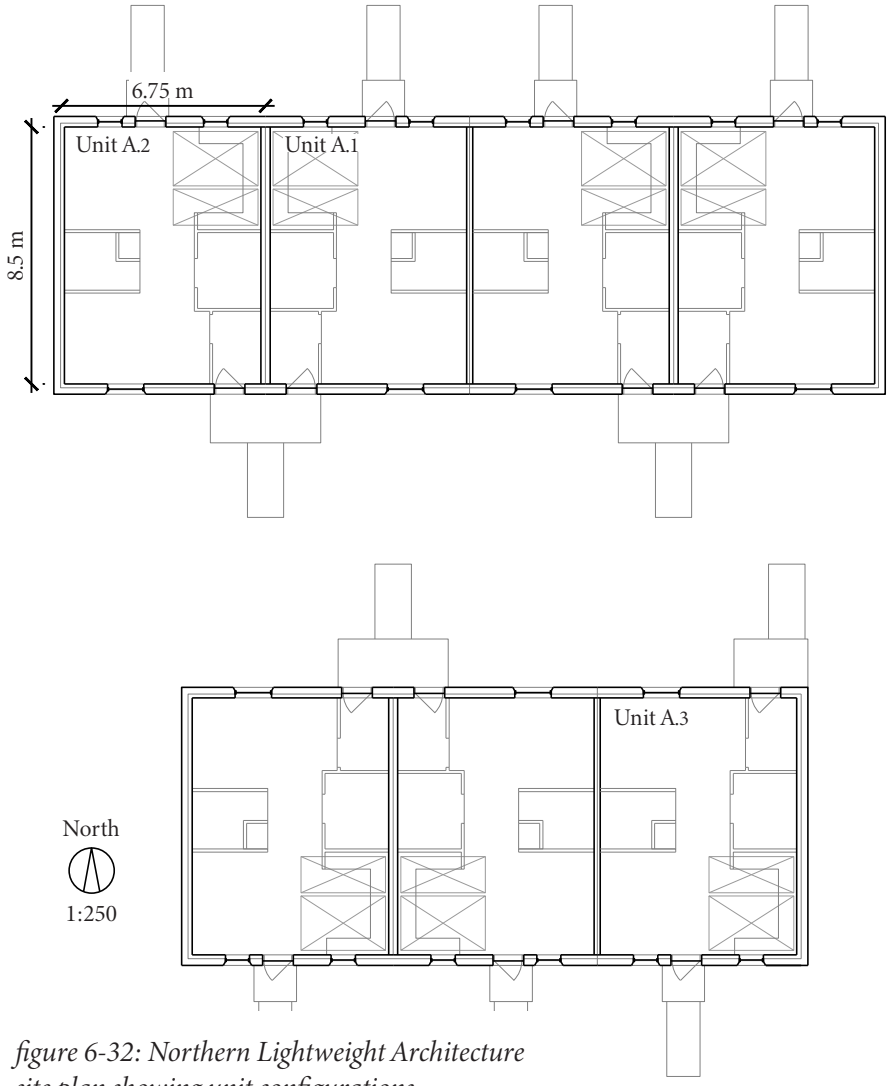


figure 6-32: Northern Lightweight Architecture site plan showing unit configurations.

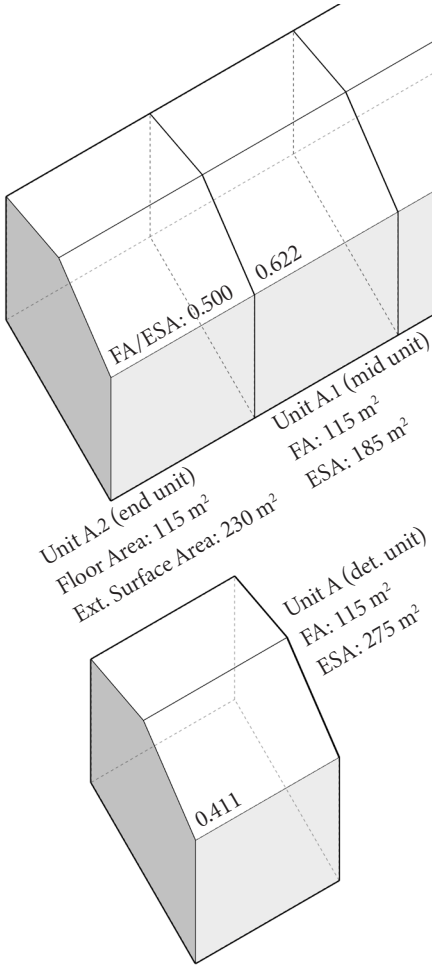


figure 6-33: Enclosure area efficiency diagram.

6.3.1 - Lightweightness

Form and Volumetrics

Form and volumetrics can afford significant weight savings, as well as energy savings, by increasing the enclosure area efficiency. Two storey townhouses or multi-unit residential buildings improve the enclosure area efficiency by creating an overall shape closer to a cube. *Northern Lightweight Architecture* uses a two-storey rowhouse typology, which has excellent enclosure area efficiency and volumetric efficiency, thus reducing enclosure weight and energy losses. This typology also reduces building footprint and increases urban density, reducing the needed expansion of municipal utilities and infrastructure. (see figure 6-32, figure 6-33)

Space Planning

Northern Lightweight Architecture features a large kitchen and dining area that can be used to host gatherings and to prepare country food, and similar to *Super:Light Architecture*, it is open to the living room at the front allowing light through the home, and to avoid isolating rooms. The bedrooms are planned with consideration for multiple household types, for up to five people, including an additional room intended for work such as sewing or a home office, or to be used as a nursery. The interior planning is also somewhat flexible, allowing for different room layouts or uses based on community consultation. This is an important step in northern design and for work with vulnerable communities. (see figure 6-34)

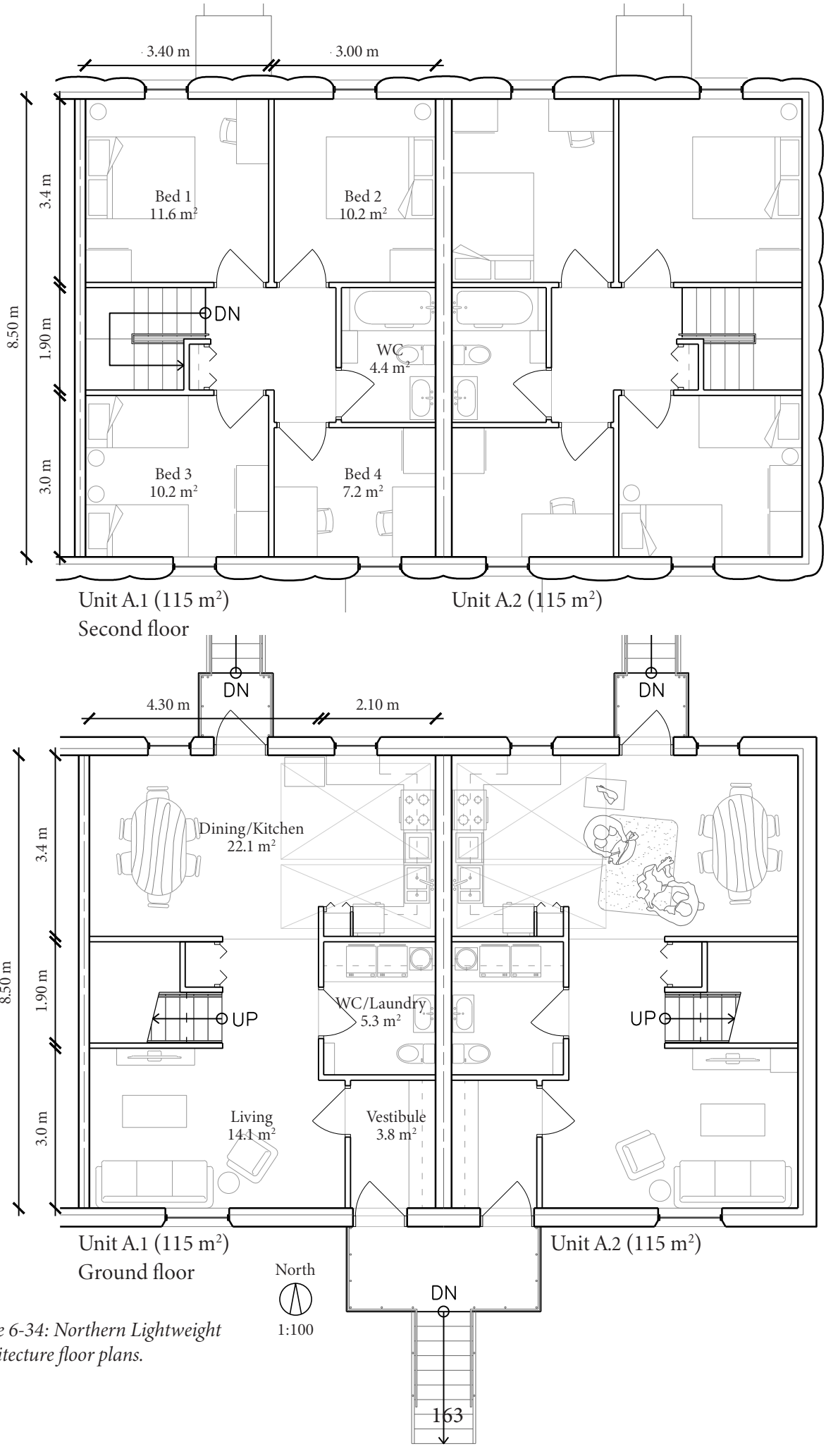


figure 6-34: Northern Lightweight Architecture floor plans.

Construction System and Components

Northern Lightweight Architecture is built with advanced wood framing, a structurally optimized method of building which aligns framing members and reduces excess lumber and sheathing, saving material costs and weight. The wall structural members are lumber, for its economy and lightweightness, while the roof uses engineered wood joists. Optimizing stud or joist spacing with sheathing thickness results in a lighter overall assembly without compromising on structural rigidity, and aligning wall studs and floor joists removes the need for a double top plate, saving weight. (see figure 6-37)

The foundation of the project uses rock socketed or adfreeze piles, as they provide greater bearing capacity and are practical to construct in larger communities. A multipoint foundation is also viable in cases where drilling for pile foundations is impractical. The floor platform is constructed from SIPs as they offer good insulation and airtightness, and are reasonably lightweight. Engineered wood joists are also an acceptable floor construction which will reduce shipping bulk, although may require more labour.

Interior partitions and party walls are constructed with lumber framing as it is economical and simple to construct. Cross bracing can be added for additional rigidity where needed, without the added weight of sheathing. Party walls also require sound and fire isolation, and fibreglass acoustic insulation and gypsum create a lightweight wall that can reduce these risks.



figure 6-35: Engineered wood joist with lumber chords and OSB web.
source: Nordic Structures



figure 6-36: Polyiscocyanurate insulating sheathing which can provide air and vapour control layers.
source: IKO Global

Material

Northern Lightweight Architecture uses a lumber structure as it is relatively lightweight and easily constructable. The sheathing is a mixture of 12.7 mm plywood sheathing at the corners of the building, and insulated sheathing elsewhere. This reduces the heavier sheathing to where it is needed, with the lighter sheathing saving weight, and forming part of the enclosure as it is insulating, airtight, and vapour impermeable. (see figure 6-35, figure 6-36)

The project incorporates the same *Super:Light* tufted textile exterior cladding at the second storey, which is less susceptible to damage. The lower portion of the building follows established enclosure best practices. The exterior insulation chosen is extruded polystyrene as it is among the lightest form of rigid insulation for its insulation value and steel cladding, 26 ga or 24 ga, is fastened to lumber strapping over the insulation. This assembly is durable, lightweight, and constructable, and provides a continuous layer of exterior insulation. (see figure 6-38, and pages 166 to 168)

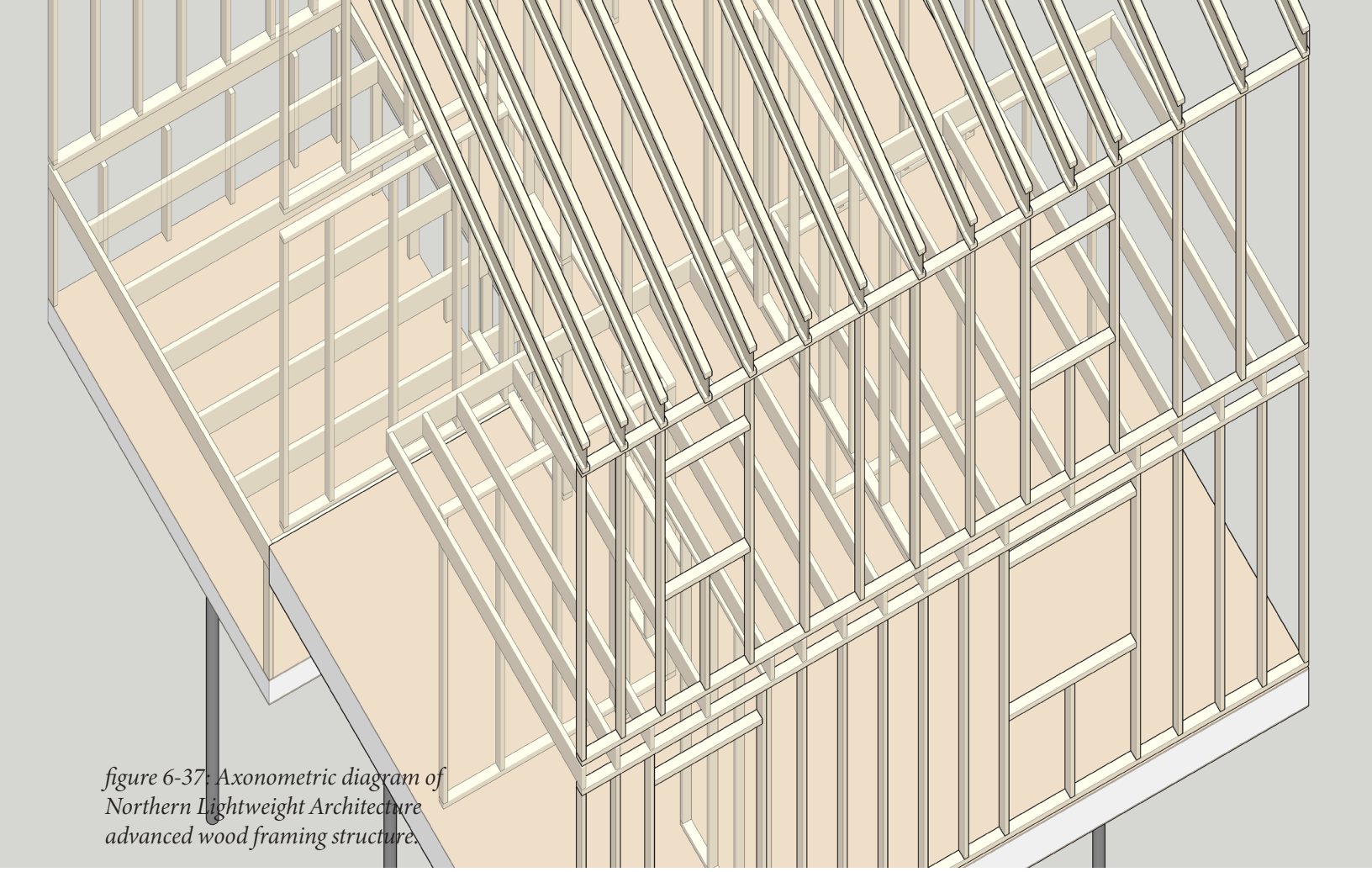


figure 6-37: Axonometric diagram of Northern Lightweight Architecture advanced wood framing structure.

figure 6-38: View of rear entrance showing cladding materials.

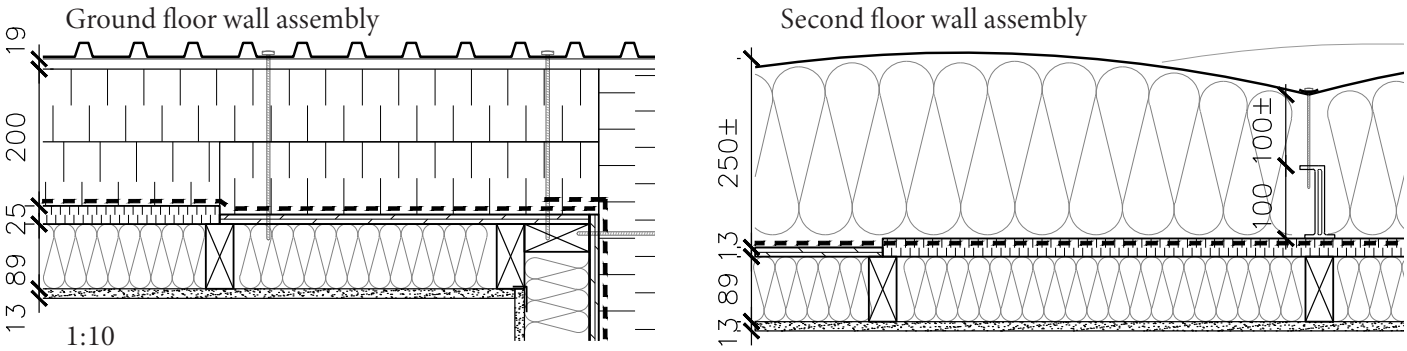


figure 6-39: Northern Lightweight Architecture wall and partition assemblies.

Table 6-13: Ground floor wall assembly

Component	Product	Dimension	Weight	Notes
Gypsum or prefinished plywood	USG Sheetrock	12.7 mm	6.11 kg/m^2	FR
2x4 Lumber studs @ 400 mm OC	Lumber (15% of wall)	89 mm	6.68 kg/m^2	
RSI 2.1 Fibreglass insulation	Owens Corning	89 mm	1.16 kg/m^2	RSI 1.7
13 mm Plywood sheathing	Plywood (half of enclosure)	12.7 mm	3.23 kg/m^2	
25 mm PIC sheathing	RMax	25.4 mm	0.81 kg/m^2	VB
Housewrap	Tyvek Homewrap		0.06 kg/m^2	A/WB
RSI 7.0 XPS rigid insulation	Owens Corning Foamular 150	200 mm	4.20 kg/m^2	RSI 7.0
Cladding fasteners	Galvanized steel screw	8.0 #/m2	0.33 kg/m^2	
1x2 Strapping @ 600 mm OC	Lumber strapping	19 mm	0.59 kg/m^2	
26 ga Steel cladding	Vicwest lapped steel cladding	26 ga	3.91 kg/m^2	
Total: 1,080 kg (40 m^2)		**346 mm**	**27.1 kg/m^2**	**RSI 9.3**

Table 6-14: Second floor wall assembly

Component	Product	Dimension	Weight	Notes
Gypsum or prefinished plywood	USG Sheetrock Ultralight	12.7 mm	6.11 kg/m^2	FR
2x4 Lumber studs @24" OC	lumber (12% of wall)	89 mm	5.34 kg/m^2	
RSI 2.1 Fibreglass insulation	Owens Corning	89 mm	1.16 kg/m^2	RSI 1.8
13 mm Plywood sheathing	Plywood (half of enclosure)	12.7 mm	3.23 kg/m^2	
25 mm PIC sheathing	RMax	25.4 mm	0.81 kg/m^2	VB
Housewrap	Tyvek Homewrap		0.06 kg/m^2	A/WB
RSI 6.7 Fibreglass insulation	Owens Corning (compressed)	250 mm	3.12 kg/m^2	RSI 6.7
Cladding fasteners	Galvanized steel screw	8.0 #/m2	0.33 kg/m^2	
Exterior textile cladding	Serge Ferrari 412 Opaque		0.498 kg/m^2	
Total: 720 kg (35 m^2)		**377 mm**	**20.7 kg/m^2**	**RSI 9.1**

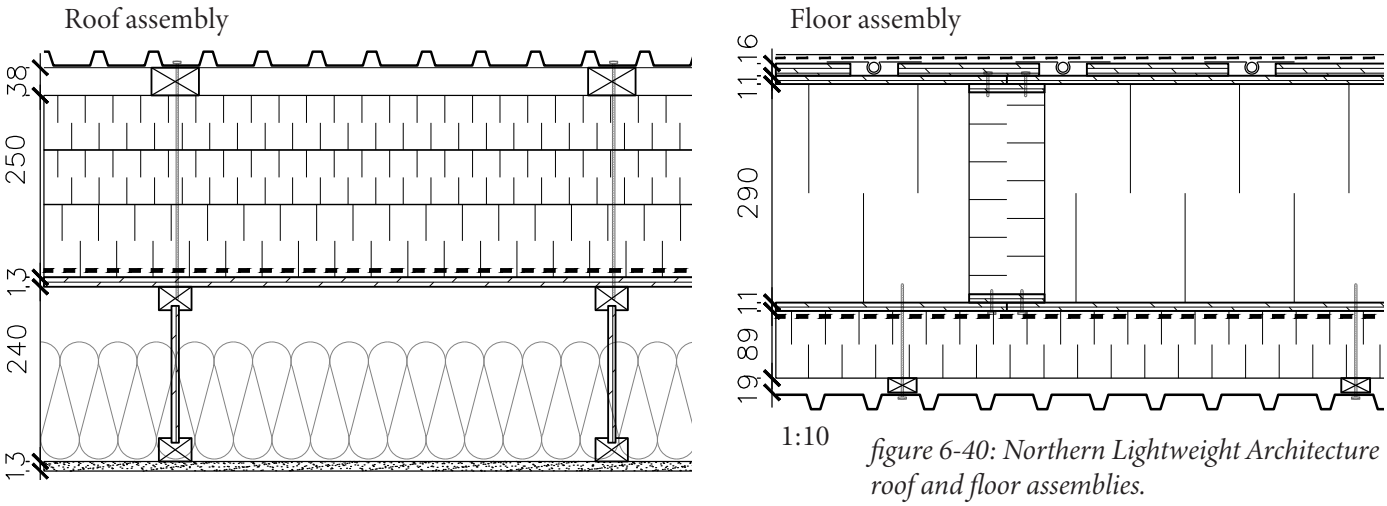


figure 6-40: Northern Lightweight Architecture roof and floor assemblies.

Table 6-15: Roof assembly

Component	Product	Dimension	Weight	Notes
Gypsum or prefinished plywood	USG Sheetrock	12.7 mm	6.11 kg/m^2	FR
240 mm I joist @ 600 mm OC	Woodbeam joists (GPI20)	241 mm	5.61 kg/m^2	
RSI 3.4 Fibreglass insulation	Owens Corning fibreglass	140 mm	1.87 kg/m^2	RSI 3.3
13 mm Plywood sheathing	Plywood	12.7 mm	6.45 kg/m^2	VB
Housewrap	Tyvek Homewrap		0.06 kg/m^2	A/WB
RSI 8.8 XPS rigid insulation	Owens Corning Foamular 150	250 mm	5.20 kg/m^2	RSI 8.8
Cladding fasteners	Galvanized steel screw	10.0 #/m2	0.41 kg/m^2	
2x3 Strapping @ 600 mm OC	Lumber strapping	38 mm	2.06 kg/m^2	
24 ga Steel roofing	Vicwest lapped steel roofing	24 ga	4.882 kg/m^2	
Total: 1,960 kg (60 m^2)		**554 mm**	**32.7 kg/m^2**	**RSI 12.1**

Table 6-16: Floor assembly

Component	Product	Dimension	Weight	Notes
Flooring	Vinyl flooring	3.2 mm	2.60 kg/m^2	
Flooring underlayment	AirGuard underlayment	2.0 mm	0.16 kg/m^2	
16 mm Radiant floor panel	RHT panel w/ aluminium plates	15.9 mm	6.70 kg/m^2	
Structural insulated panel	7/16" OSB	11.1 mm	7.33 kg/m^2	A/VB
-	11 3/8" EPS	289 mm	5.35 kg/m^2	RSI 9.2
-	7/16" OSB	11.1 mm	7.33 kg/m^2	
Housewrap	Tyvek Homewrap		0.06 kg/m^2	WB
RSI 3.1 Fibreglass board	Knauf Earthwool board	102 mm	3.67 kg/m^2	RSI 3.1
1x2 Strapping @ 600 mm OC	lumber strapping	19 mm	0.59 kg/m^2	
Cladding fasteners	Galvanized steel screw	10.0 #/m2	0.41 kg/m^2	
26 ga Steel cladding	Vicwest lapped steel cladding	26 ga	3.906 kg/m^2	
Total: 2,290 kg (60 m2)		**453 mm**	**37.9 kg/m^2**	**RSI 12.3**

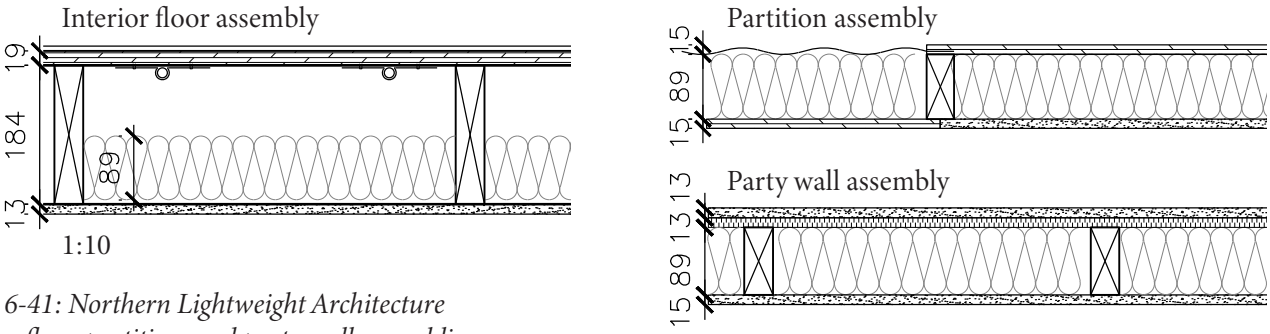


figure 6-41: Northern Lightweight Architecture interior floor, partition, and party wall assemblies.

Table 6-17: Interior floor assembly

Component	Product	Dimension	Weight	Notes
Flooring	Vinyl flooring	3.2 mm	2.60 kg/m^2	
19 mm Plywood subfloor	Plywood	19 mm	9.65 kg/m^2	
Radiant heating	Aluminium heat transfer plates		0.65 kg/m^2	
2x8 Lumber studs @ 600 mm OC	Lumber	184 mm	5.70 kg/m^2	
Acoustic insulation	Owens Corning	89 mm	1.16 kg/m^2	
GWB (where needed)	USG Sheetrock	12.7 mm	4.58 kg/m^2	75% usage
Total: 1,270 kg (52 m^2)		**219 mm**	**24.3 kg/m^2**	

Table 6-18: Partition assembly

Component	Product	Dimension	Weight	Notes
13 mm GWB	USG Sheetrock	12.7 mm	6.11 kg/m^2	FR
2x4 Lumber studs @ 600 mm OC	Lumber (9% of wall)	89 mm	4.01 kg/m^2	
Acoustic fibreglass insulation	Owens Corning fibreglass	89 mm	1.16 kg/m^2	
13 mm GWB	USG Sheetrock	12.7 mm	6.11 kg/m^2	FR
Total: 1,460 kg (84 m^2)		**114 mm**	**17.4 kg/m^2**	

Table 6-19: Party wall assembly

Component	Product	Dimension	Weight	Notes
13 mm GWB	USG Sheetrock Ultralight	12.7 mm	6.11 kg/m^2	FR
Acoustic panel	Sonopan acoustic panel	12.7 mm	2.70 kg/m^2	
2x4 Lumber studs @ 600 mm OC	Lumber (12% of wall)	89 mm	5.34 kg/m^2	
Acoustic fibreglass insulation	Owens Corning	89 mm	1.16 kg/m^2	
13 mm GWB	USG Sheetrock Ultralight	12.7 mm	6.11 kg/m^2	FR
Total: 1,000 kg (47 m^2)		**115 mm**	**21.4 kg/m^2**	

Table 6-20: Foundation components

Component	Product	Dimension	Weight	Notes
Adfreeze or socketed pile	4" steel pile, 3/8" ga, 6 m	172 kg/pile	860 kg	5 piles
Pile cap	Adjustable steel pile cap	15 kg/cap	60 kg	4 caps
Total: 920 kg				

Building Weight

Weight savings for this proposal are more modest than *Super:Light Architecture*, and the enclosure and partitions weigh 10,320 kg and the foundation piles weigh 920 kg. The building is 20% lighter than the baseline project, and is 17% lighter including foundations. This is less than the 25% weight reduction target, however the baseline project is reasonably lightweight to begin with and *Northern Lightweight Architecture* significantly exceeds its energy reduction goals. (see table 6-21, figure 6-42, Appendix A.2 - Baseline Assemblies)

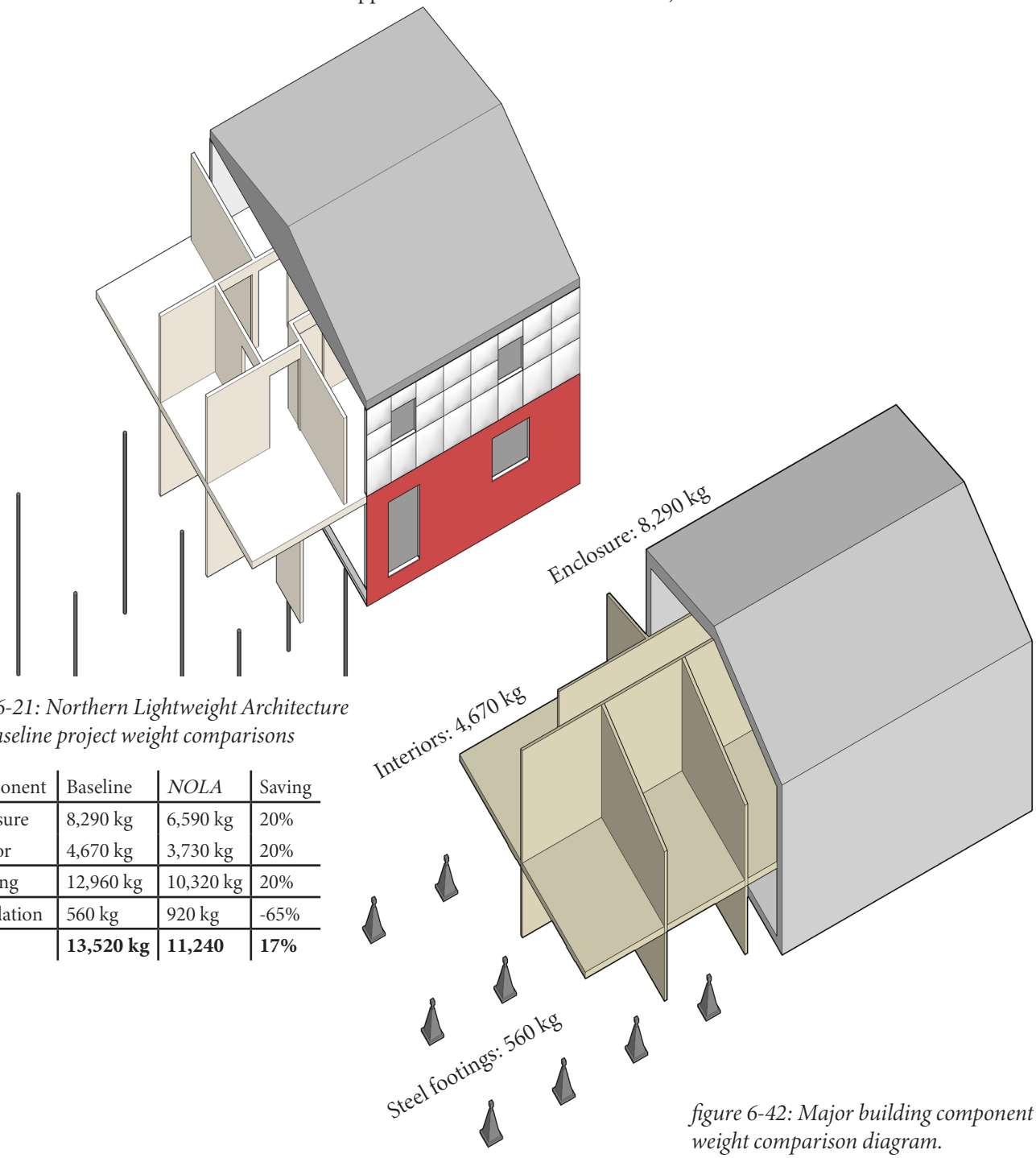


figure 6-42: Major building component weight comparison diagram.

Table 6-21: Northern Lightweight Architecture and baseline project weight comparisons

Component	Baseline	*NOLA*	Saving
Enclosure	8,290 kg	6,590 kg	20%
Interior	4,670 kg	3,730 kg	20%
Building	12,960 kg	10,320 kg	20%
Foundation	560 kg	920 kg	-65%
Total	**13,520 kg**	**11,240**	**17%**

6.3.2 - Material Costs and Transportability

Lightweight and compact building materials result in transportation savings and simplified logistics for unloading and handling materials on site, making it an important consideration for northern projects. *Northern Lightweight Architecture* uses advanced framing and other optimizations to keep weight and bulk down, while increasing insulation for building performance targets. (see table 6-22, table 6-23)

Lightweightness and Compactness

Advanced framing reduces the lumber needed, saving weight and bulk in shipping, and the optimized sheathing also saves weight. The use of textile interior finishes or leaving the structure exposed also reduces weight and bulk over gypsum, and this is further reduced by the use of wider stud spacing for partitions. These also reduce labour, which is a much more significant cost.

Pile foundations are more compact than a space frame, although come at the cost of the machinery required for construction. The SIPs floor is bulkier than traditional construction, but is relatively lightweight, and can be rpaidly constructed. In communities with available labour the reduced shipping costs of engineered wood joists may offset their increased labour time and costs.

The extruded polystyrene exterior insulation is bulky compared to batt insulation, however, the high insulation value for its depth means less volume needs to be shipped compared to expanded polystyrene or rigid mineral wool. The textile exterior cladding and batt insulation used at the upper floor saves weight and bulk compared to using steel cladding and rigid insulation across the entire enclosure.

Shipping Method

Similar to *Super:Light Architecture*, this proposal will likely use sealift transport, as it is the most economical shipping method for most communities in the Inuit Nunangut. *Northern Lightweight Architecture* is also appropriate for population centres in the Yukon or Northwest Territories which have road access to southern Canada, in which case trucking is used. Seasonal limitations and the challenges of unloading in remote communities must be considered when using the sealift.

While Northern Lightweight Architecture has higher material and shipping costs than the baseline project, these are rapidly offset by the significant operating cost savings. The project is also designed to be highly constructable, reducing labour costs which are likely to result in savings.

Table 6-22: Northern Lightweight Architecture enclosure material and shipping costs to Iqaluit

Component (area)	Weight +	Volume (400 kg/m³)
Material cost	Ship units	**Ship cost** ($362/unit)
Walls (40 m²)	820 kg +	10.19 m³
$5,383	4.90 units	**$1,773**
Upper walls (35 m²)	514 kg +	3.35 m³
$2,674	1.85 units	**$671**
Roof (60 m²)	1507 kg	16.35 m³
$10,816	8.05 units	**$2,913**
Floor (60 m²)	828 kg +	21.72 m³
$13,254	9.52 units	**$3,445**
Interior floor (52 m²)	1172 kg +	0.75 m³
$2,363	1.47 units	**$533**
Partition (84 m²)	1363 kg +	1.21 m³
$2,027	1.85 units	**$669**
Party wall (47 m²)	825 kg +	1.29 m³
$1,601	1.34 units	**$486**
Foundation	924 kg	
$3,802	0.92 units	**$335**
Materials	Shipping	Total
$41,920	**$10,820**	**$52,740**

Table 6-23: Baseline project material and shipping costs to Grise Fiord

Component (area)	Weight +	Volume (400 kg/m³)
Material cost	Ship units	**Ship cost** ($362/unit)
Walls (85 m²)	5.17 units	**$1,870**
Roof (68 m²)	3.74 units	**$1,355**
Floor (68 m²)	3.03 units	**$1,096**
Int. flr. (63 m²)	1.96 units	**$709**
Partition wall/ Party (138 m²)	3.58 units	**$1,297**
Foundation	**1.60 units**	**$579**
Materials	Shipping	Total
$28,150	**$6,910**	**$35,060**

6.3.3 - Constructability

Simple and rapid constructability is needed for northern buildings, creating a more productive building season, reducing costs and employing more local labour. *Northern Lightweight Architecture* draws on established labour practices in the North to develop a highly constructable project, while also incorporating current building science practices to improve the energy performance of the project. (see figure 6-44)

Foundations and Floor Platform

Pile foundations require more machinery and labour than surface foundations, but result in a longer lifespan which is less susceptible to permafrost variation, improving longevity. This proposal is designed for larger communities in the North and thus the machinery needed for piles is likely to be available. The floor is constructed from SIPs, creating a stiff platform that is easily and rapidly constructed. The large SIPs floor panels allow for fewer joints and components, simplifying the detailed work needed and expediting construction. The mechanical crawlspace also uses a SIPs floor platform to ensure a continuous building enclosure. (see figure 6-43)

Building Structure

Advanced framing is constructed similarly to typical wood framing, but uses 600 mm stud spacing, single top plates, simpler frames at openings, and overall reduces the number of redundant framing members, reducing weight and material costs.[275] While this process requires some additional training for workers, the principles are easily understood and the process overall reduces the labour required. The roof uses engineered wood joists which do not add significant complexity to the construction process, and are lighter than lumber joists.

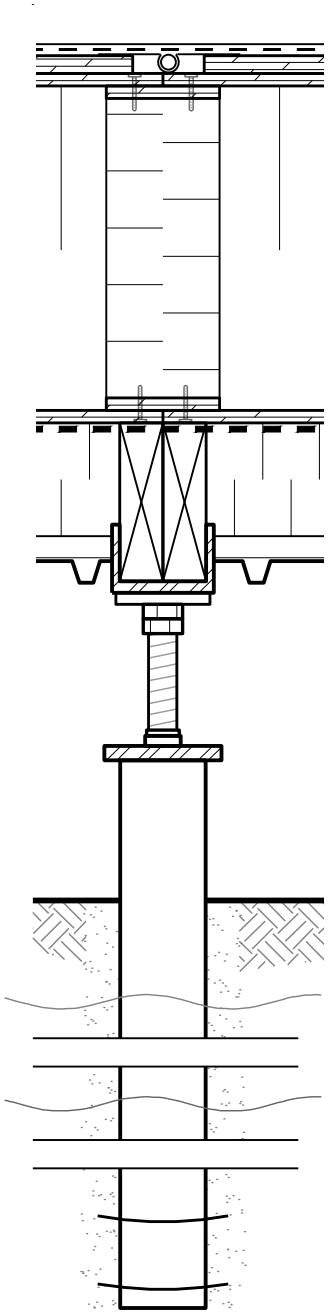


figure 6-43: Adfreeze pile foundation and SIPs floor platform detail with SIPs spline and wood blocking to reduce thermal bridging at pile and panel joints.

275 Joseph Lstiburek, "BSI-030: Advanced Framing," Building Science Corporation, Mar. 10, 2010. https://buildingscience.com/documents/insights/bsi-030-advanced-framing

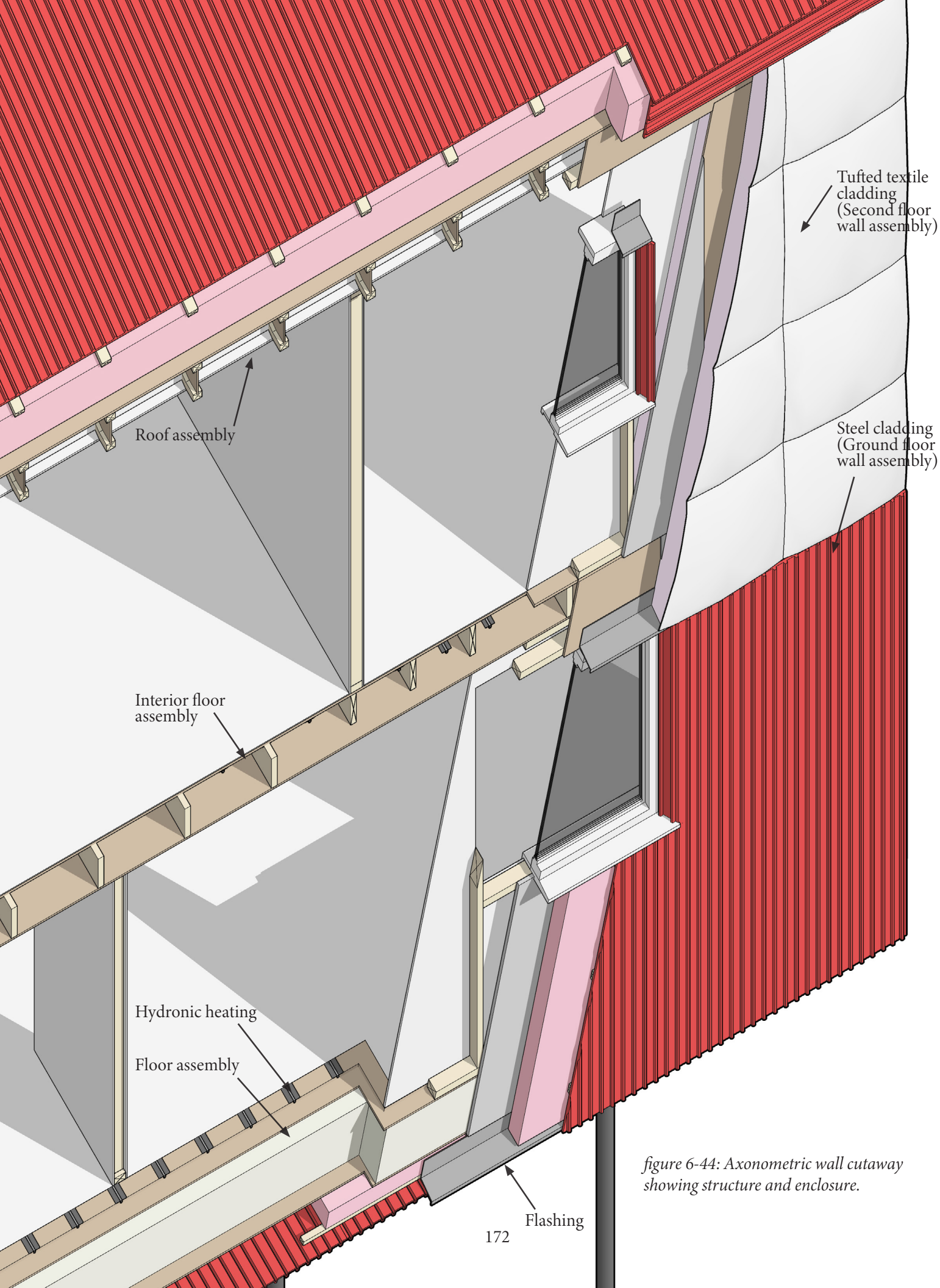


figure 6-44: Axonometric wall cutaway showing structure and enclosure.

Enclosure

Northern Lightweight Architecture follows enclosure best practices, particularly the "Optimal Northern Wall Design Guidelines" developed by RDH Building Science (see Chapter 4.3.3 - RDH Building Science Inc. Research).[276] While current standard practices do not meet the performance that is needed, they do show that local labour can use these construction methods. The assembly is constructed similarly to standard practice however uses much deeper exterior insulation. The interior of the enclosure also uses cavity insulation, but does not rely on an interior membrane barrier for airtightness, simplifying the detailing and reducing damage. This proposal places the air, water, and vapour control layers interior of the insulation, and uses insulated sheathing and housewrap, creating a stiff but lightweight barrier, making construction familiar and simple. (see figure 6-45)

The tufted textile cladding is a novel proposal for the North, and requires more care than standard practice, however the installation of the textile cladding is simplified in this application as it can be fastened to wall studs or sheathing rather than needing to attach to specific points. (see figure 6-47)

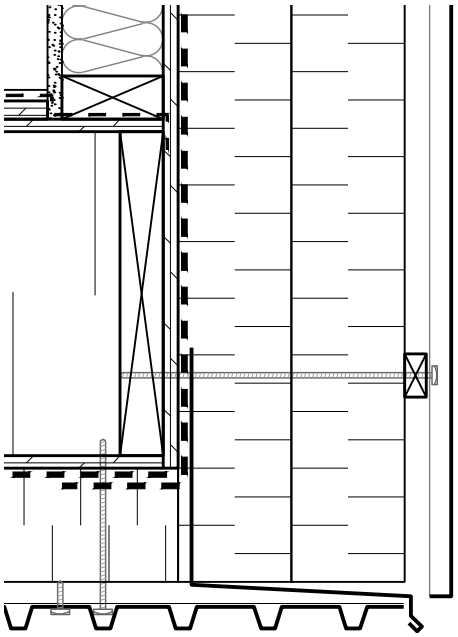


figure 6-45: Floor edge enclosure detail.

Interior and openings

Openings are constructed similar to typical wood framing, although advanced framing uses fewer members, reducing the labour needed on site. Only two sizes of window are used, ensuring that components are interchangeable and replaceable, simplifying installation and repair. The interior partitions are also similar to typical wood framing, and are easily constructed by available labour. (see figure 6-46, figure 6-47)

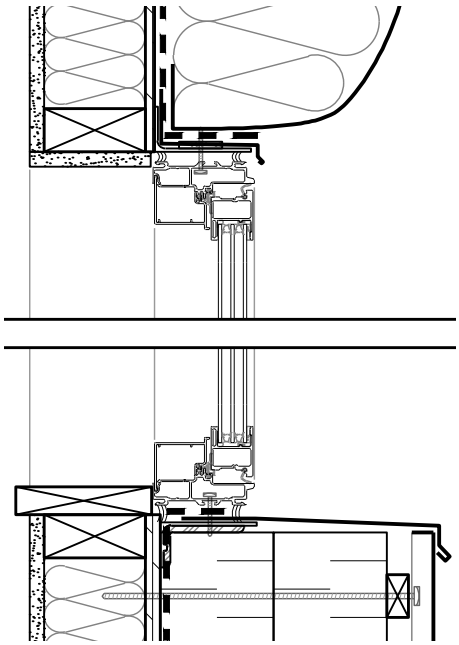


figure 6-46: Window opening detail.

Building Systems

Northern Lightweight Architecture uses an air to water heat pump, avoiding the need for fuel storage and systems, simplifying construction and system installation. System integration is simplified by the more conventional wood framing structure, and prefabricated or site fabricated radiant floor panels can be used for the hydronic heat pipes.

Ventilation is provided by an ERV, and the compact nature of the project allows for short duct runs, simplifying integration. The use of a plumbing crawlspace requires pumps to distribute water throughout the building, somewhat complicating installation, however the plumbing fixtures are localized over the crawlspace, simplifying the overall process.

276 *Optimal Northern Wall Design* Guidelines (Vancouver: RDH Building Engineering Ltd. May 26, 2016), 4.

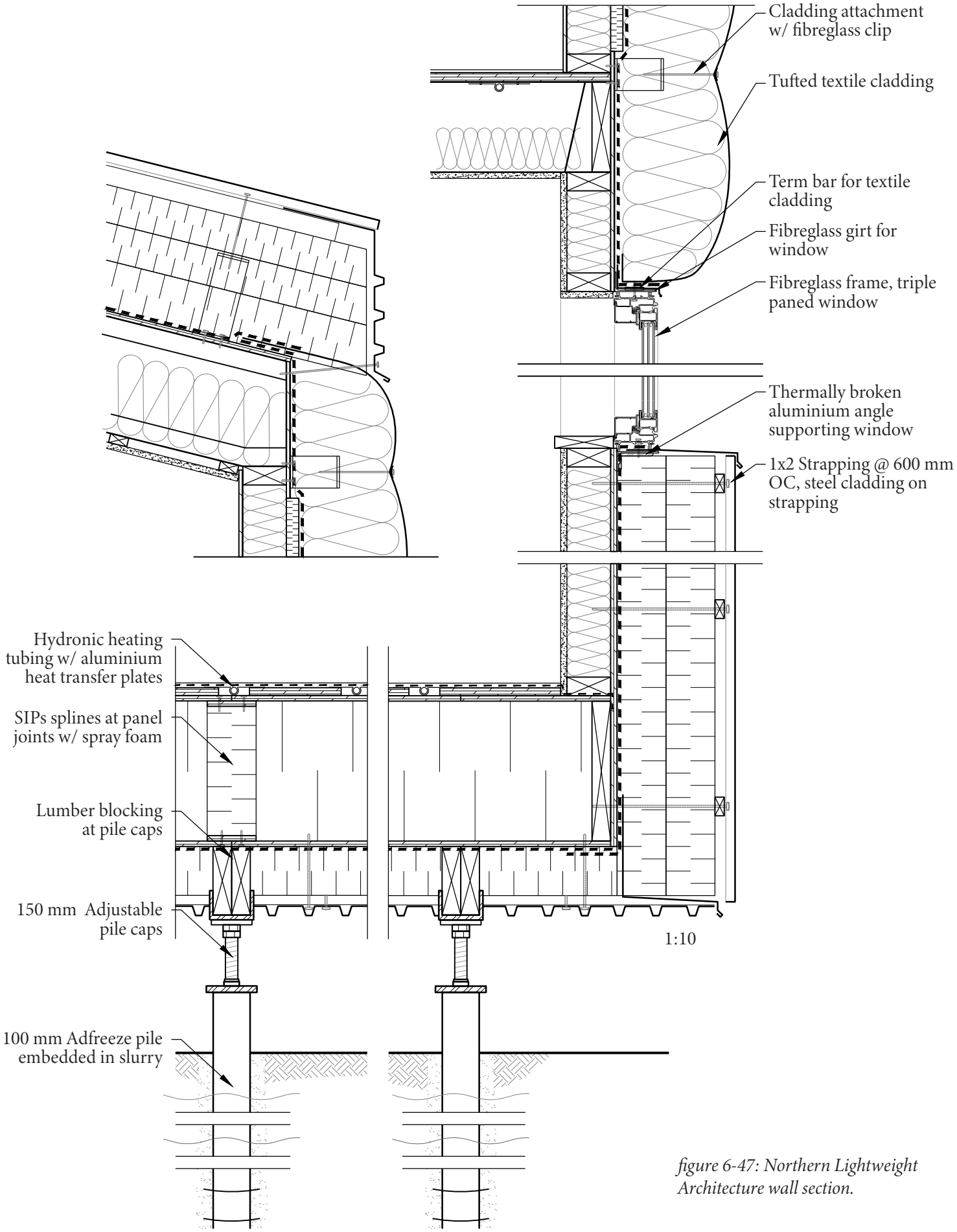


figure 6-47: Northern Lightweight Architecture wall section.

6.3.4 - High Performance

Northern Lightweight Architecture prioritizes high performance design, with an extremely robust enclosure and efficient building systems providing a high quality home for users. The dramatic energy consumption reduction also reduces the costs and pollution from burning diesel for electricity production, improving economic and environmental sustainability.

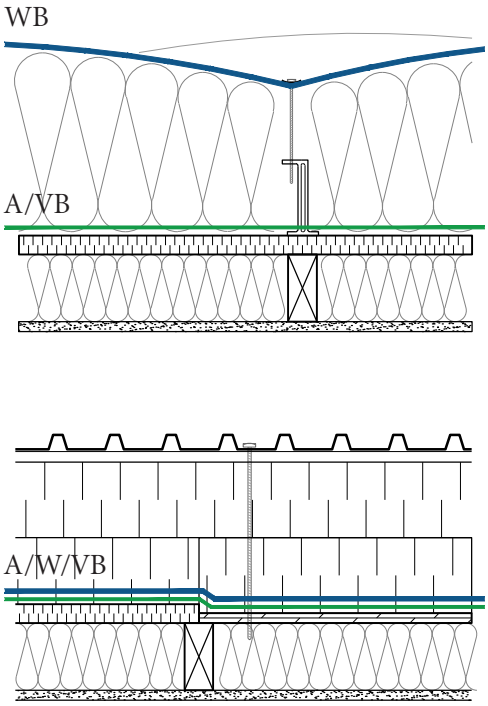


figure 6-48: Control layer diagram of ground and second floor walls.

Enclosure Design

Northern Lightweight Architecture has excellent enclosure area and volumetric efficiency, and the project is highly insulated and airtight, resulting in a high performance building. Enclosure area efficiency also reduces cost as there is less surface area to cover. Insulated sheathing creates a solid air and vapour barrier, while also providing some insulation value, reducing thermal bridging at wall studs, while housewrap provides water control.[277]

The design of openings is particuarly important as they cause significant heat loss, however they are a pleasant feature and the thoughtful design of their placement and size allows for reduced energy losses, while providing a good user experience. The windows are also designed with a chamfered cladding detail, reducing snow buildup. (see figure 6-47, figure 6-48)

Systems

Northern Lightweight Architecture uses an air to water heat pump to power a hydronic floor heating system, providing an efficient and comfortable heating system. Electricity is currently expensive in the North but these systems can take advantage of renewable energy sources, an important consideration for northern communities, both for pollution concerns and for energy costs. More traditional heating systems such as diesel or oil furnaces would also take advantage of this highly efficient enclosure and are viable.

Wind power is becoming attainable in much of the North, and will generate more power in the winters, increasing the viability of forward thinking proposals which make use of electric heating systems. The electric heat pump also provides domestic hot water, increasing the efficiency of this system, which consumes a significant amount of energy.

Ventilation is provided by an ERV which reduces condensation and frost within the unit, as compared to an HRV, which reduces maintenance needs, improving life cycle performance and reducing cost. This system provides ample fresh air, resisting mould growth and keeping users healthy, which has been a shortcoming in existing building practices.

277 John F. Straube and Eric F.P. Burnett, *Building Science for Building Enclosures* (Westford, MA: Building Science Press, 2005), 210.

Energy Modelling

Northern Lightweight Architecture makes use of energy modelling to balance enclosure design and operating costs. Airtightness testing and ongoing energy monitoring are necessary to ensure quality construction and to understand the actual performance of this design, making revisions where needed for performance or constructability.

Energy consumption for the project was modelled in three communities, Iqaluit, Yellowknife, and Kuujjuaq, to understand the heating and electrical demands for the project, and to develop a detailed understanding of the impact of air to water heat pump technology.

Understanding the balancing point of cost between electric systems and diesel furnaces is challenging because there is a complex system of subsidies. Even so, using the current pricing for diesel and electricity, using a fully electric heat pump system, *Northern Lightweight Architecture* can achieve lower overall operating costs in Yellowknife and Kuujjuaq, which have access to lower cost electricity and renewable energy sources, and comparable costs in Iqaluit depending on domestic electricity usage and subsidy rates. This is achieved primarily due to the efficiency gains for hot water production, which consumes more energy than space heating in this project based on consumption for a five person household. (see figure 6-49, figure 6-50, figure 6-51)

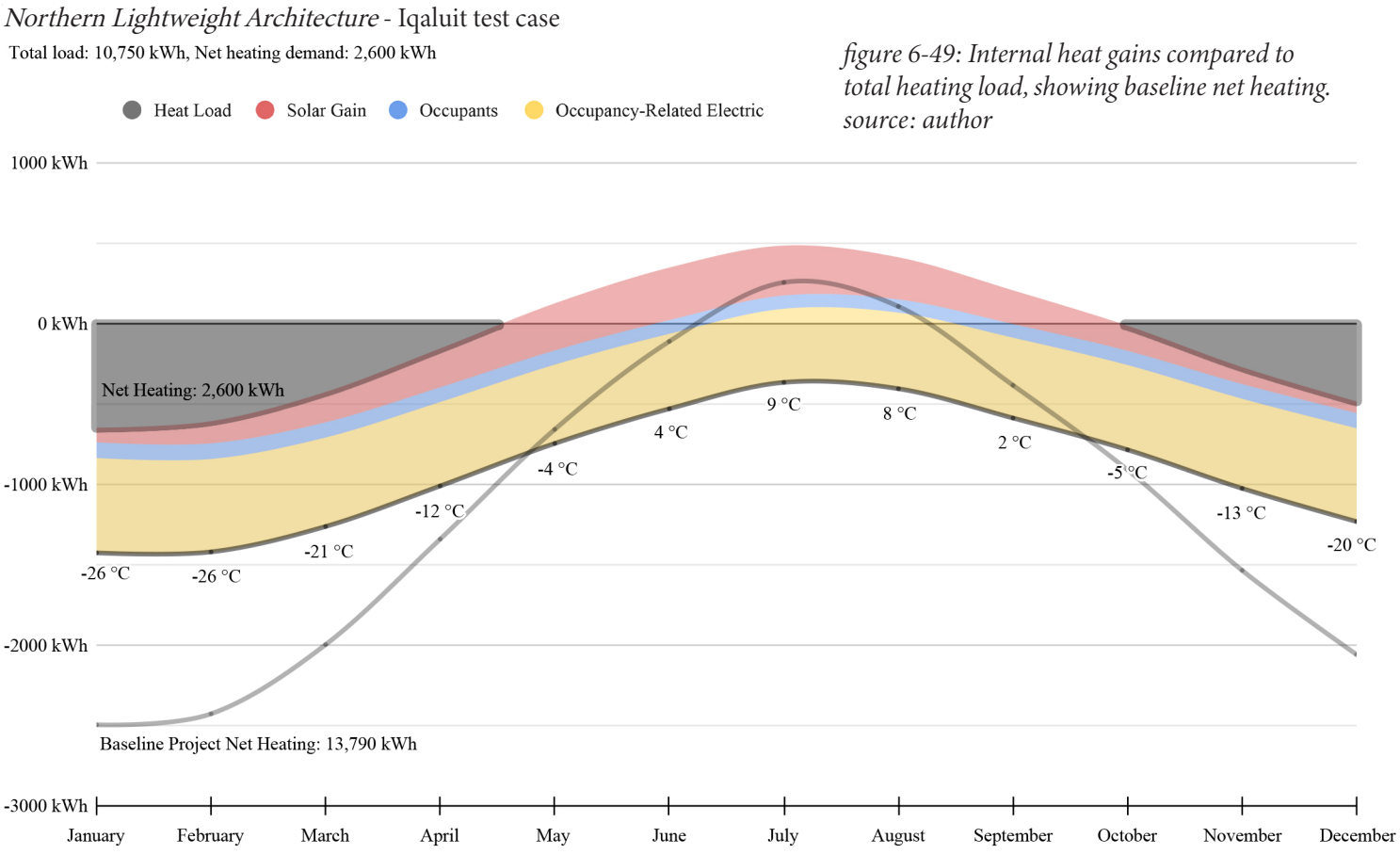
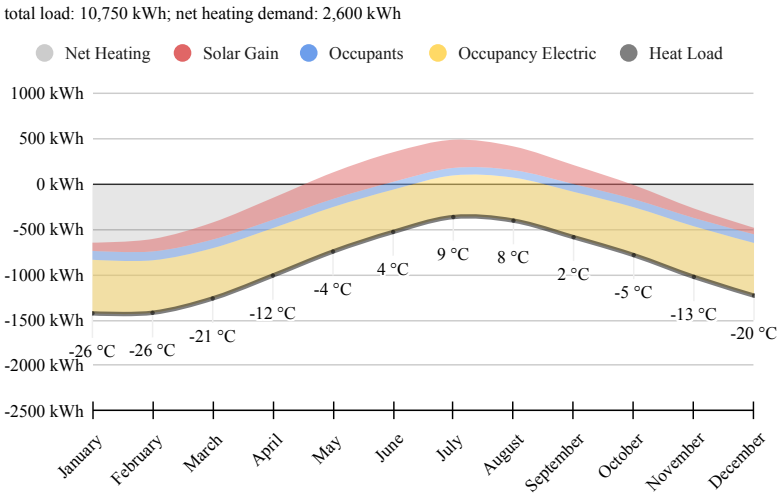
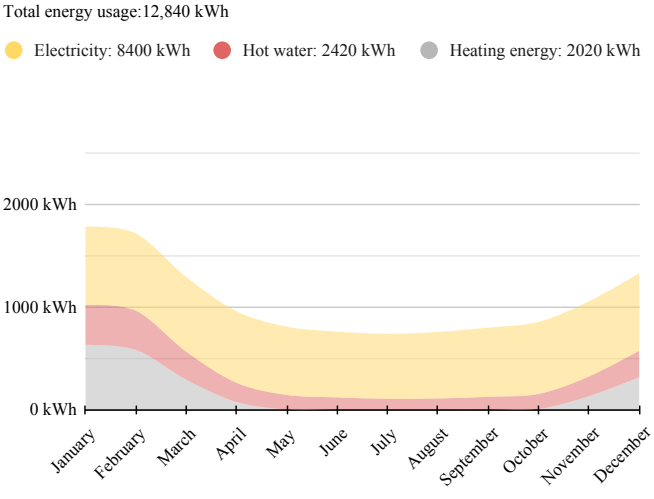


figure 6-49: Internal heat gains compared to total heating load, showing baseline net heating. source: author

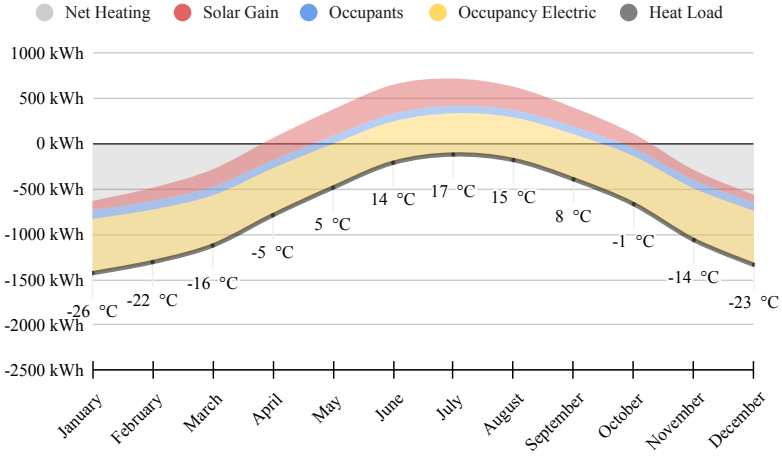
Northern Lightweight Architecture - Iqaluit test case



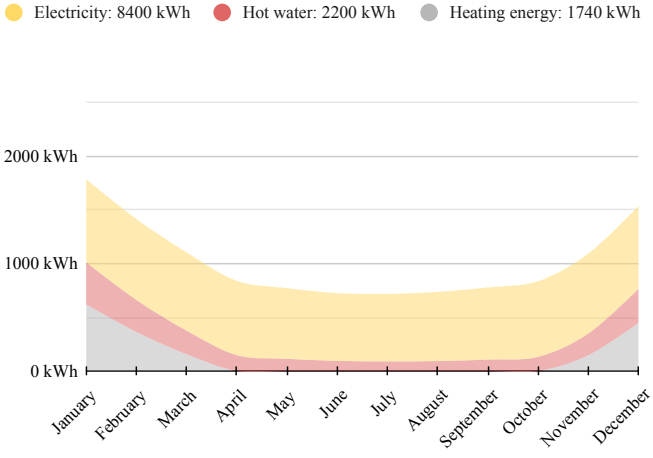
Iqaluit energy usage (heating with heat pump)



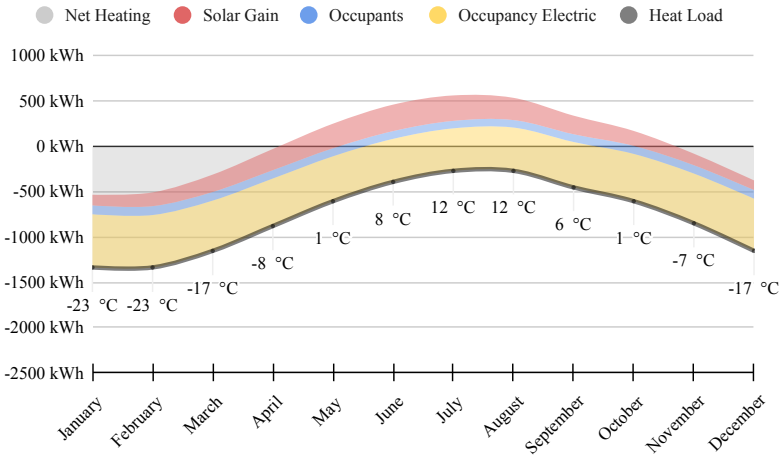
Northern Lightweight Architecture - Yellowknife test case



Yellowknife energy usage



Northern Lightweight Architecture - Kuujjuaq test case



Kuujjuaq energy usage

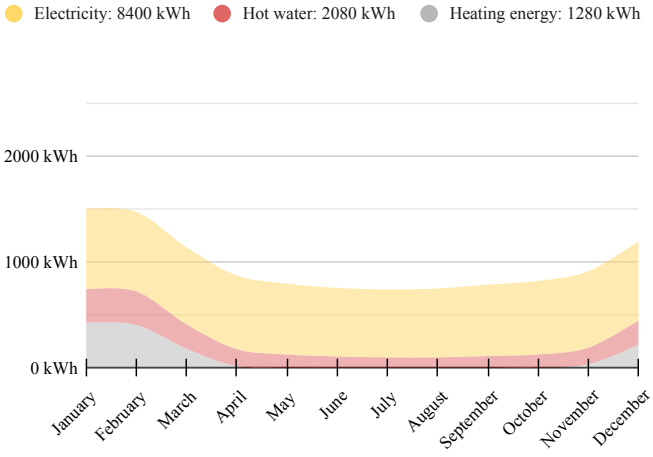


figure 6-50: Test community heating demand and energy consumption graphs. source: author

Operating Costs

Northern Lightweight Architecture is primarly designed for larger communities in the North. Because transportation to larger communities is less expensive, more material to save energy can be shipped, thus reducing operating costs without increasing shipping costs. Fuel and electricity are less subsidized in regions such as Northwest Territories and Nunavik where this project is best situated, and thus the all-electric heating and hot water system can be more accurately compared to a diesel alternative. In these regions, renewable electricity is also more common, and as a result the all-electric proposal significantly reduces operating costs compared to baseline construction and compared to a diesel system.

The savings compared to a baseline project are $2,400 in Iqaluit, $3,000 in Yellowknife, and $2,600 in Kuujjuaq. Although a diesel system would save on operating costs in Iqaluit, reducing domestic electricity usage by 25% would bring the all-electric system to a similar price to a diesel system, whereas current subsidies would offer no savings for this reduction with a diesel heating system. By reducing total energy usage by 12%, the operating costs are reduced by 29%, indicating the significant distortion that the current subsidies have on northern operating costs. Even given these limitations, *Northern Lightweight Architecture* saves around half of the operating costs compared to the baseline project, resulting in significant lifecycle cost savings. (see table 6-24, table 6-25, table 6-26)

Table 6-24: Iqaluit energy cost comparisons

Baseline	diesel	***NOLA***	diesel	electric	electric (*reduced*)
Heating	$2340 (17200 kWh)	Heating	$415 (3060 kWh)	$427 (2020 kWh)	$477 (2620 kWh)
Hot Water	$813 (5990 kWh)	Hot Water	$765 (5636 kWh)	$355 (2430 kWh)	$277 (2430 kWh)
Electricity	$992 (10000 kWh)	Electricity	$0 (8400 kWh)	$950 (8400 kWh)	$482 (*6300 kWh*)
$0.136/kWh (diesel) $0.620/kWh (elec.)	**$4,144 (total)**		**$1,180 (total)**	**$1,731 (total)**	**$1,236 (total)**

Table 6-25: Yellowknife energy cost comparisons

Baseline	diesel	***NOLA***	diesel	electric
Heating	$2510 (14600 kWh)	Heating	$459 (2660 kWh)	$412 (1740 kWh)
Hot Water	$1030 (5990 kWh)	Hot Water	$972 (5636 kWh)	$523 (2210 kWh)
Electricity	$2372 (10000 kWh)	Electricity	$1990 (8400 kWh)	$1990 (8400 kWh)
$0.172/kWh (diesel) $0.240/kWh (elec.)	**$5,915 (total)**		**$3,423 (total)**	**$2,927 (total)**

Table 6-26: Kuujjuaq energy cost comparisons

Baseline	diesel	***NOLA***	diesel	electric
Heating	$2130 (13800 kWh)	Heating	$337 (2660 kWh)	$344 (1280 kWh)
Hot Water	$925 (5990 kWh)	Hot Water	$870 (5636 kWh)	$561 (2080 kWh)
Electricity	$2700 (10000 kWh)	Electricity	$2268 (8400 kWh)	$2268 (8400 kWh)
$0.154/kWh (diesel) $0.270/kWh (elec.)	**$5,755 (total)**		**$3,475 (total)**	**$3,173 (total)**

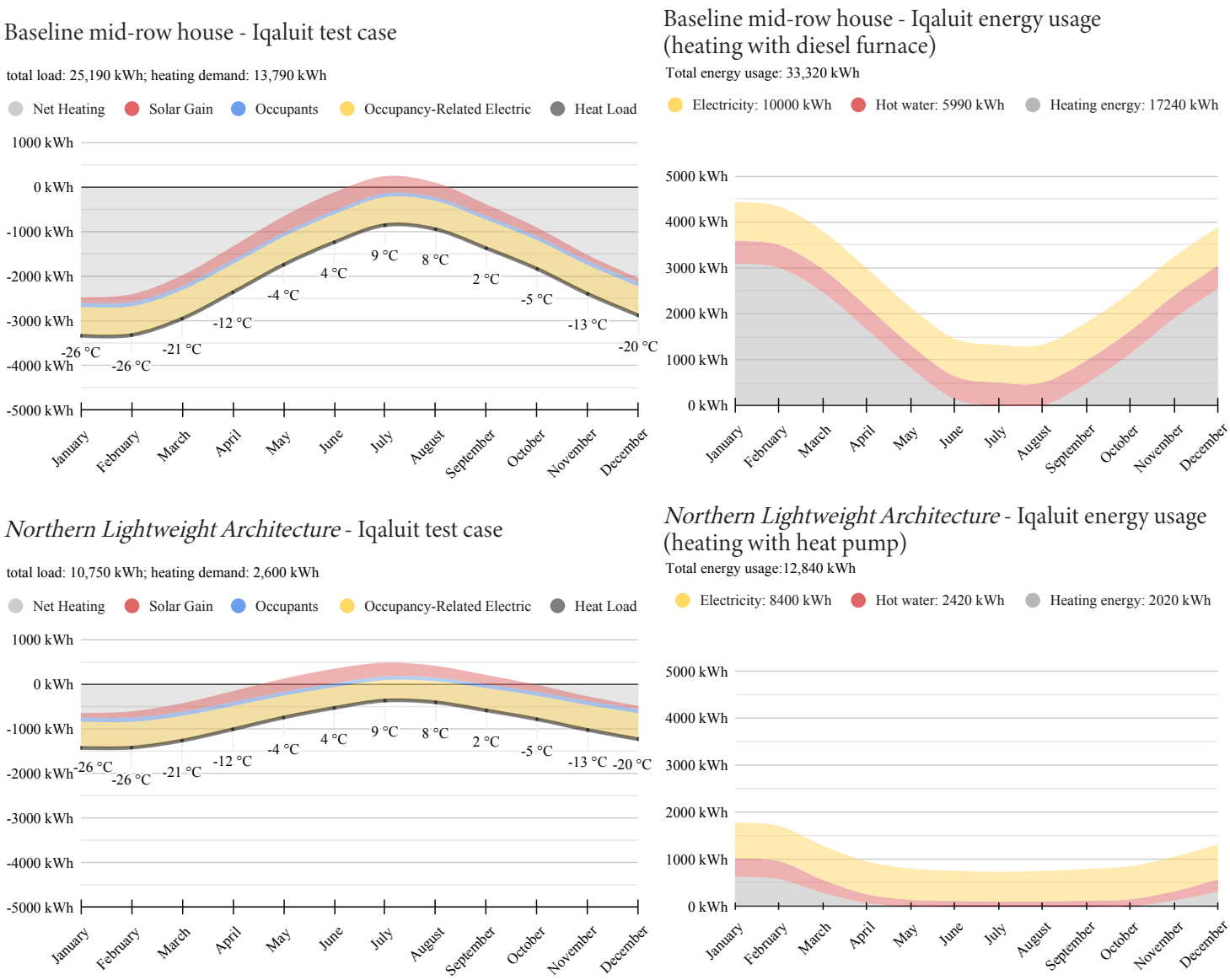


figure 6-51: Northern Lightweight Architecture and baseline project heating demand and energy usage.

6.3.5 - Comparisons

Northern Lightweight Architecture is designed with an energy reduction target of 75% compared to a baseline project, and a weight reduction target of 25%. This proposal reduces total heating load by 57% and net heating demand by 81%, capable of operating without active heating for several months. The efficiency of the heat pump system reduces hot water energy consumption by as much as half, allowing for a total annual energy consumption, including heating, hot water, and electricity usage, of approximately 12,800 kWh, compared to 33,000 kWh for the baseline project, set in Iqaluit. (see Appendix A.1)

Northern Lightweight Architecture massively reduces energy consumption for northern housing, and meaningfully reduces weight compared to baseline construction practices. While some novel practices are used to improve transportability and constructability for northern communities, it remains constructable by currently available labour and comfortable for users. This energy efficiency reduces the high costs of building services in the North. While initial material and shipping costs are higher, although reduced by the lightweightness and constructability, the long term costs are significantly lower and *Northern Lightweight Architecture* will provide a higher quality home throughout its lifecycle.

Design Implementation and Limitations

The implementation of this design should begin with community consultation to determine the appropriateness of the floor plan, exterior appearance, and the building systems, developing locally specific proposals based on the general design elements of *Northern Lightweight Architecture*. The aesthetic appearance and form of this proposal is designed to be more approachable than *Super:Light Architecture*, however this increases transportation and construction costs due to increased weight, although reduces operating costs with its improved energy efficiency.

The particular impact of *Northern Lightweight Architecture* is the enormous reduction in heating demand, made possible by a highly insulated enclosure. This in turn allows for simplification and reduction of the heating system, using electric air to water heat pumps to provide hot water, which is concurrently used to heat the building. In many of the more remote communities in the North, electricity is generated by diesel power plants, and in these communities, a diesel or oil furnace may reduce total fossil fuel consumption. However, these systems do not allow for energy improvements in the future, and as renewable energy becomes available in more places, the building systems proposed here only improve.

The reduction in space heating demand of this proposal compared to baseline construction is enormous, however hot water consumption and domestic electricity usage are unchanged, and although heat pumps can improve efficiency with respect to hot water, this still represents a significant energy cost which is difficult to improve upon. Overall energy consumption of *Northern Lightweight Architecture*, compared to *Super:Light Architecture* is a relatively small savings, about 10%, due to the same demand for hot water and electricity.

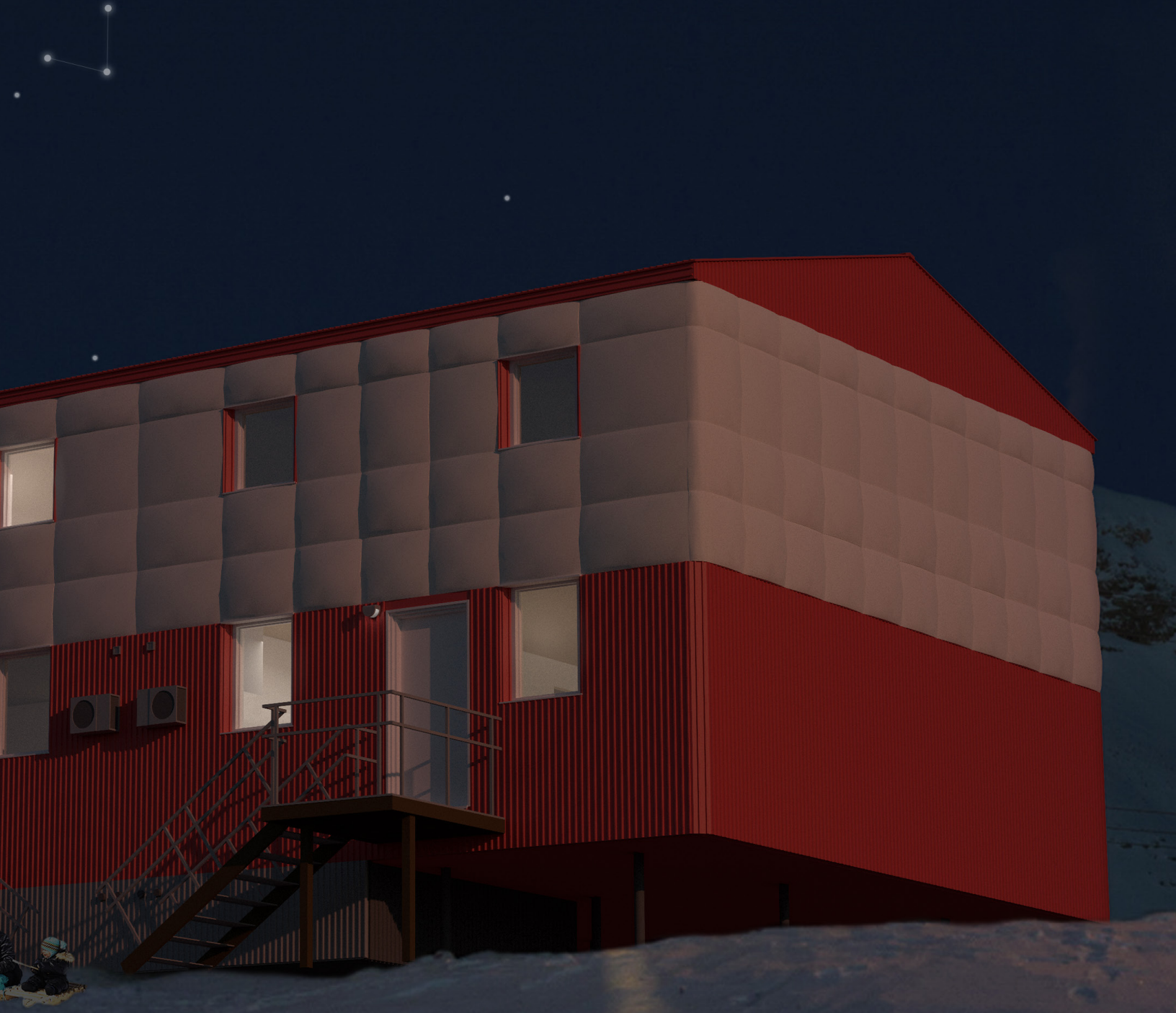
While this project is lighter than the baseline project it is also slightly smaller, to reduce energy consumption. At the same floor area as the baseline project, *Northern Lightweight Architecture* saves approximately 10% of the building weight, although still dramatically reduces energy consumption. The weight savings within the construction of this project allow for the high performance enclosure, however the diminishing returns of building performance mean that a more optimized design may reduce some of the insulation value in favour of material and construction cost savings. This must be carefully balanced with operating costs, and more detailed research into this balance for specific communities is needed.

figure 6-52: Northern Lightweight Architecture, view of street in Iqaluit.





figure 6-53: Northern Lightweight Architecture view during winter.



Chapter 7
Conclusions and Reflections

7.1 - Conclusions

Super:Light Architecture and *Northern Lightweight Architecture* both exceeded their energy reduction targets, dramatically reducing energy demand. While the weight targets were not fully met, the weight reductions throughout these proposals allow for significant building enclosure improvements, such that they could exceed their energy targets. The baseline project is also designed for the northern context and is a reasonably lightweight building to begin with, although this comes at the expense of energy performance. Typical construction practices have made reasonable weight savings over past practices, and the proper implementation of current construction practices, along with new methods, such as advanced framing and enclosure best practices, as shown in *Northern Lightweight Architecture*, can allow for constructable super high performance architecture in the North. Alternative construction methods, such as the use of a tensioned fabric structure in conjunction with textile claddings, seen in *Super:Light Architecture*, can save an enormous amount of weight, while also offering building energy performance improvements.

In the past, energy efficiency improvements have come at the steep expense of added weight, leading to untenable transportation costs and challenging construction on site. *Super:Light Architecture* and *Northern Lightweight Architecture* place a focus on key elements of transportability, constructability, and energy performance, taking advantage of lightweighting wherever possible to allow for energy performance improvements, and prioritizing different elements based on their intended setting. These proposals are developed through a highly analytical process, attempting to balance these key elements in a transparent and repeatable methodology such that this approach can be applied in other parts of the North and throughout architecture at large.

7.2 - Future Research

The North will continue to be a demanding building environment, due to the harsh climate and its remoteness. Advancements in building science and construction have yielded improvements in the past and there is a large field of research in improving northern buildings both from a cultural standpoint, supporting the Inuit and First Nations communities, as well as technical improvements to reduce construction and operating costs. These efforts give optimism to the future of the built environment in the North, and there is a great deal to be learned from it for the rest of the world.

While this thesis contributes to the contemporary discussion of architecture in the North, it is also intended to demonstrate the possibilities of lightweight high performance architectural design, establishing viability in one of the harshest settings in the world. Energy efficient design is an immediate necessity in the North, given the challenges of climate and resupply, and as ongoing climate change demands fossil fuel reduction, buildings proven in the North are valuable to study for the world at large. It is no coincidence that Canada has some of the world's leading building scientists. The climate of even southern Canada requires careful study of building energy performance to keep people safe and comfortable, using the available energy efficiently.

Current research in the North will lead to improvements for buildings everywhere, but the people of the North have their own demands that need to be addressed by future research. Financial limitations are a significant issue for northern communities, and while this thesis has addressed transportation, construction, and operating costs, local economic growth would serve to strengthen northern communities. Further development of trade skills in the North would improve the northern economy and these workers would have a valuable perspective to contribute. From a user's standpoint, community members in the North would benefit from better information regarding energy consumption, as this tends to be opaque and can lead to significant costs, thus improving understanding and access to this information would greatly benefit users. Other important areas of research for northern buildings include accessibility, culturally specific planning and design, greater community involvement in architecture and urban design, and the growth of renewable energy sources in more remote communities.

7.3 - A Lighter Architecture

Traditional forms of shelter in the North, from Inuit and First Nations groups, are lightweight and easily constructable, necessitated by the demands of the setting. In much of the rest of the world, architecture has conventionally represented a major expenditure both economically and environmentally. The materials cost and labour-hours invested are immense, supported by affluent economies. As the concerns of the North, the reduction of material and fossil fuel usage, become increasingly relevant globally, lightweightness becomes an increasingly impactful design methodology.

Lightweightness provides the means to construct more with fewer materials and faster, creating highly efficient buildings, meeting the challenges facing architecture today. The process of lightweighting necessarily examines comfort, material use, and energy consumption, important wider considerations of the built environment. Issues of climate change, fossil fuel depletion, and economic limitations present often paradoxical challenges, similar to those of the North, and lightweightness presents a means of cutting through these, providing high quality shelter to a greater number of people, addressing that core human need upon which architecture is founded.



figure 7-01: Super:Light Architecture in Grise Fiord, NU.
source: author



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Appendix

A.1 - Energy Modelling

An important element of this thesis is energy modelling for northern communities and so a simplified energy modelling chart was developed by the author. The results are based on enclosure insulation values and surface area, as well as air leakage estimations and building volume. The results have been compared against HOT2000 results from past work in northern building research, and have yielded similar results, indicating a reasonable level of utility for the energy modeller.

Heat pump performance was also modelled for the North based on hourly, daily, and monthly climate data to develop a rough estimation of monthly performance for both space heating and domestic hot water. Heat pumps have reduced efficiency at colder temperatures and so detailed modelling of performance based on hourly data allows for adjustment of larger scale estimations to more accurately predict energy consumption.

Baseline Project - Iqaluit, NU

Enclosure Metrics

Volume	340 m3
Ext surf. area	221 m2
GFA	136 m2
Storeys	2
Avg U-value	0.30 W/m2°K
ACH	0.08 ACH
coeff	0.33
Occupants	5

Location

Location	**Iqaluit**	
HDD@18°C	9980 HDD	*(NECB)*
HDD@21°C	10980 HDD	
Yearly avg temp	-8.6	
1% low temp	-41	

Building Dimensions

Height	5	exposed faces
Width	8.5	2
Length	8	0
		mid row house

Yearly Plug Load

10000 kWh	est. yearly

Yearly Estimate Hot Water Load

250 L	*est. daily HW*
Q=mCΔT	ΔT=45°C
47250 kJ	*daily*
4791 kWh	
5988 kWh	*kWh load / ef*

Enclosure Assemblies

	Ext. surf. area	RSI value (eff	windows/door	wind./doors R	avg. RSI	FDWR
Walls	85 m2	RSI: 3.00	12.0 m2	RSI: 0.70	RSI: 2.05	0.141
Roof	68 m2	RSI: 6.80	0 m2	RSI: 1.00	RSI: 6.80	0
Floor	68 m2	RSI: 4.95	0 m2	RSI: 1.00	RSI: 4.95	0
Overall	221 m2	RSI: 3.39	0.30 W/m2°K			

Conductive	Air Leakage	Ventilation	Heat Loss
Avg U * ESA	co*ACH*V	co*ACH*V*H	**Total**
65.21 W/°C	9.35 W/°C	22.44 W/°C	**97.00 W/°C**

Climate data / **Heating load** / **Electricity usage**

Month	Avg temp	Daylight hour	Occupancy	Heat Load	Occu. elec	Occupants	Solar Gain	Elec. offset	Lighting offse	Load - offset
January	-26 °C	5.7	16.0 hrs	-3330 kWh	650 kWh	98 kWh	114 kWh	563 kWh	87 kWh	**2469 kWh**
February	-26 °C	8.6	16.0 hrs	-3316 kWh	646 kWh	98 kWh	172 kWh	563 kWh	83 kWh	**2401 kWh**
March	-21 °C	11.8	15.5 hrs	-2947 kWh	641 kWh	95 kWh	236 kWh	563 kWh	78 kWh	**1975 kWh**
April	-12 °C	15.1	15.0 hrs	-2357 kWh	636 kWh	92 kWh	303 kWh	563 kWh	73 kWh	**1327 kWh**
May	-4 °C	18.3	14.5 hrs	-1740 kWh	631 kWh	88 kWh	367 kWh	563 kWh	69 kWh	**654 kWh**
June	4 °C	20.5	14.0 hrs	-1236 kWh	628 kWh	85 kWh	409 kWh	563 kWh	65 kWh	**113 kWh**
July	9 °C	19.4	13.5 hrs	-852 kWh	629 kWh	82 kWh	389 kWh	563 kWh	67 kWh	~~-248 kWh~~
August	8 °C	16.4	13.5 hrs	-944 kWh	634 kWh	82 kWh	328 kWh	563 kWh	71 kWh	~~-100 kWh~~
September	2 °C	13.1	14.0 hrs	-1370 kWh	639 kWh	85 kWh	262 kWh	563 kWh	76 kWh	**384 kWh**
October	-5 °C	9.8	14.5 hrs	-1832 kWh	644 kWh	88 kWh	195 kWh	563 kWh	81 kWh	**904 kWh**
November	-13 °C	6.6	15.0 hrs	-2393 kWh	649 kWh	92 kWh	131 kWh	563 kWh	86 kWh	**1521 kWh**
December	-20 °C	4.5	15.5 hrs	-2876 kWh	652 kWh	95 kWh	90 kWh	563 kWh	89 kWh	**2039 kWh**
Overall offsets	-8.6 °C			-25193 kWh	7677 kWh	1080 kWh	2995 kWh	6750 kWh	927 kWh	**13789 kWh**

Performance and Systems

Vent. rate	0.20 ACH	*40 cfm*
ACH@50	1.50 ACH@5	0.08 ACH
HRV eff.	0%	0% for no HRV
Furnace eff.	80%	
Hot water eff.	80%	

HOT2000 / ***est vs HOT2000***

61000 MJ	*conduct. loss*	**101.42%**
29000 MJ	*air leak loss*	**103.99%**
10000 kWh	*elec. use*	
90000 MJ	***gross load***	**102.25%**
50000 MJ	*load - offsets*	**99.28%**
20000 MJ	*HW load*	**107.79%**

elec	subsidies	net	base elec
844 kWh	1000 kWh	~~-156 kWh~~	0
839 kWh	1000 kWh	~~-161 kWh~~	0
834 kWh	1000 kWh	~~-166 kWh~~	0
829 kWh	700 kWh	129 kWh	129 kWh
825 kWh	700 kWh	125 kWh	125 kWh
821 kWh	700 kWh	121 kWh	121 kWh
823 kWh	700 kWh	123 kWh	123 kWh
827 kWh	700 kWh	127 kWh	127 kWh
832 kWh	700 kWh	132 kWh	132 kWh
837 kWh	1000 kWh	~~-163 kWh~~	0
842 kWh	1000 kWh	~~-158 kWh~~	0
845 kWh	1000 kWh	~~-155 kWh~~	0
10000 kWh			$470.01

Heat Loss Yearly

Conductive	Air leak + ven	Gross load
17185 kWh	8377 kWh	25562 kWh
67.23%	32.77%	

Peak Load

Heat loss * Δ	1% low temp
6014 W	44 W/m2
20521 BTU/h	*14.0 BTU/hr/*

Heating Offsets

1095 kWh	*occupancy*
7500 kWh	*electrical (75*
2400 kWh	*solar (est.)*

see below

13789 kWh	*heat load - offset (exc. net*	101.39	*kWh/m2*	fuel	elec gen
18580 kWh	*heat load - offset + HW load*			38 MJ/L	3.12 kWh/L
23224.42	*heat load / eff. + HW load / eff.*			10.6 kWh/L	
				$1.43/L	$0.62/kWh
33224 kWh	*total energy*	244	*kWh/m2*	heat fuel cost non gov resid	
				$0.136/kWh	

diesel heating	*23224 kWh*	$3,622	33224 kWh

Super:Light Architecture - Iqaluit, NU

Enclosure Metrics

Volume	259 m3
Ext surf. area	242 m2
GFA	173 m2
Storeys	2
Avg U-value	0.16 W/m2°K
ACH	0.06 ACH
coeff	0.33
Occupants	5

Location

Location	**Iqaluit**	
HDD@18°C	9980 HDD	*(NECB)*
HDD@21°C	10980 HDD	
Yearly avg temp	-8.6	
1% low temp	-41	

Building Dimensions

Height	3	exposed faces
Width	11.5	2
Length	7.5	0

mid row house

Yearly Plug Load

8400 kWh	est. yearly

Yearly Estimate Hot Water Load

250 L	*est. daily HW*
Q=mCΔT	ΔT=45°C
47250 kJ	*daily*
4791 kWh	
2425 kWh	*kWh load / ef*

Enclosure Assemblies

	Ext. surf. area	RSI value (eff	windows/doo	wind./doors R	avg. RSI	FDWR
Walls	69 m2	RSI: 6.90	8.5 m2	RSI: 1.20	RSI: 4.35	0.123
Roof	86 m2	RSI: 7.53	0 m2	RSI: 1.00	RSI: 7.53	0
Floor	86 m2	RSI: 7.83	0 m2	RSI: 1.00	RSI: 7.83	0
Overall	242 m2	RSI: 6.30	0.16 W/m2°K			

Conductive	Air Leakage	Ventilation	Heat Loss
Avg U * ESA	co*ACH*V	co*ACH*V*H	**Total**
38.32 W/°C	4.74 W/°C	8.97 W/°C	**52.03 W/°C**

Climate data / **Heating load** / **Electricity usage**

Month	Avg temp	Daylight hour	Occupancy	Heat Load	Occu. elec.	Occupants	Solar Gain	Plug load	Lighting use	HRV elec.	**Load - offse**	Heat pump COP@avg te	load/COP
January	-26 °C	5.7	16.0 hrs	-1786 kWh	590 kWh	98 kWh	92 kWh	363 kWh	93 kWh	134 kWh	**1007 kWh**	1.03	979 kWh
February	-26 °C	8.6	16.0 hrs	-1779 kWh	578 kWh	98 kWh	139 kWh	363 kWh	82 kWh	134 kWh	**964 kWh**	1.04	924 kWh
March	-21 °C	11.8	15.5 hrs	-1581 kWh	554 kWh	95 kWh	190 kWh	363 kWh	69 kWh	122 kWh	**742 kWh**	1.46	508 kWh
April	-12 °C	15.1	15.0 hrs	-1264 kWh	522 kWh	92 kWh	244 kWh	363 kWh	55 kWh	104 kWh	**407 kWh**	2.12	191 kWh
May	-4 °C	18.3	14.5 hrs	-933 kWh	490 kWh	88 kWh	296 kWh	363 kWh	43 kWh	85 kWh	**59 kWh**	2.82	21 kWh
June	4 °C	20.5	14.0 hrs	-663 kWh	466 kWh	85 kWh	330 kWh	363 kWh	34 kWh	69 kWh	~~-219 kWh~~	3.39	~~-65 kWh~~
July	9 °C	19.4	13.5 hrs	-457 kWh	459 kWh	82 kWh	313 kWh	363 kWh	38 kWh	57 kWh	~~-397 kWh~~	3.82	~~-104 kWh~~
August	8 °C	16.4	13.5 hrs	-507 kWh	474 kWh	82 kWh	264 kWh	363 kWh	50 kWh	60 kWh	~~-314 kWh~~	3.72	~~-84 kWh~~
September	2 °C	13.1	14.0 hrs	-735 kWh	500 kWh	85 kWh	211 kWh	363 kWh	64 kWh	73 kWh	~~-61 kWh~~	3.24	~~-19 kWh~~
October	-5 °C	9.8	14.5 hrs	-983 kWh	528 kWh	88 kWh	157 kWh	363 kWh	77 kWh	88 kWh	**209 kWh**	2.72	77 kWh
November	-13 °C	6.6	15.0 hrs	-1284 kWh	558 kWh	92 kWh	106 kWh	363 kWh	90 kWh	105 kWh	**528 kWh**	2.08	254 kWh
December	-20 °C	4.5	15.5 hrs	-1542 kWh	581 kWh	95 kWh	73 kWh	363 kWh	98 kWh	120 kWh	**794 kWh**	1.54	516 kWh
Overall offsets	-8.6 °C			-13513 kWh	6300 kWh	1080 kWh	2414 kWh	4357 kWh	793 kWh	1150 kWh	**4710 kWh**		**3469 kWh**

Performance and Systems

Vent. rate	0.30 ACH	*46 cfm*
ACH@50	1.00 ACH@5	0.06 ACH
HRV eff.	65%	0% for no HRV
Furnace eff.	85%	
Hot water eff.	198%	*heat pump*

Heat pump	0.080	3.10	*2.30*	*3.90*
	slope	*COP@0*	*COP@-10°C*	*COP@+10°C*

Heat Loss Yearly

Conductive	Air leak + ven	Gross load
10098 kWh	3613 kWh	13711 kWh
73.65%	26.35%	

Peak Load

Heat loss * Δ	1% low temp
3226 W	19 W/m2
11007 BTU/h	*5.9 BTU/hr/sf*

Heating Offsets

1095 kWh	*occupancy*
6300 kWh	*electrical (75*
2400 kWh	*solar (est.)*

see below

4710 kWh	*heat load - offset (exc. net*	27.30	*kWh/m2*	fuel / elec gen
9500 kWh	*heat load - offset + HW load*			38 MJ/L / 3.12 kWh/L
5894 kWh	*heat load / eff. + HW load / eff.*			10.6 kWh/L
				$1.43/L / $0.62/kWh
14294 kWh	*total energy*	83	*kWh/m2*	heat fuel cost non gov resid
				$0.136/kWh

diesel heating	*11177 kWh*	$1,517	19577 kWh
electric heatir	*5894 kWh*	$2,584	14294 kWh

elec	heat	hot water	subsidies	net	Total (e+h+hv	heat+hot wat	base elec
765 kWh	979 kWh	388 kWh	1000 kWh	1133 kWh	$702.43	$450.39	0
753 kWh	924 kWh	382 kWh	1000 kWh	1059 kWh	$656.68	$416.47	0
729 kWh	508 kWh	273 kWh	1000 kWh	511 kWh	$316.52	$163.77	0
697 kWh	191 kWh	188 kWh	700 kWh	377 kWh	$233.61	$82.31	0
665 kWh	21 kWh	142 kWh	700 kWh	128 kWh	$79.25	$15.54	0
641 kWh	0 kWh	118 kWh	700 kWh	59 kWh	$36.70	$5.70	0
634 kWh	0 kWh	105 kWh	700 kWh	38 kWh	$23.59	$3.34	0
649 kWh	0 kWh	107 kWh	700 kWh	56 kWh	$34.70	$4.93	0
675 kWh	0 kWh	123 kWh	700 kWh	98 kWh	$60.99	$9.42	0
703 kWh	77 kWh	147 kWh	1000 kWh	~~-73 kWh~~	$0.00	$0.00	0
733 kWh	254 kWh	192 kWh	1000 kWh	178 kWh	$110.28	$41.67	0
756 kWh	516 kWh	259 kWh	1000 kWh	531 kWh	$329.14	$166.62	0
8400 kWh	3469 kWh	2425 kWh			$2,583.88	$1,360.17	$0.00

Enclosure Metrics

Volume	259 m3
Ext surf. area	242 m2
GFA	173 m2
Storeys	2
Avg U-value	0.16 W/m2°K
ACH	0.06 ACH
coeff	0.33
Occupants	5

Location

Location	**Arctic Bay**	
HDD@18°C	11900 HDD	*(NECB)*
HDD@21°C	12900 HDD	
Yearly avg temp	-13.4	
1% low temp	-44	

Building Dimensions

Height	3	exposed faces
Width	11.5	2
Length	7.5	0
		mid row house

Yearly Plug Load

8400 kWh	est. yearly

Yearly Estimate Hot Water Load

250 L	*est. daily HW*
Q=mCΔT	ΔT=45°C
47250 kJ	*daily*
4791 kWh	
2899 kWh	*kWh load / ef*

Enclosure Assemblies

	Ext. surf. area	RSI value (eff	windows/doors	wind./doors R	avg. RSI	FDWR
Walls	69 m2	RSI: 6.90	8.5 m2	RSI: 1.20	RSI: 4.35	0.123
Roof	86 m2	RSI: 7.53	0 m2	RSI: 1.00	RSI: 7.53	0
Floor	86 m2	RSI: 7.83	0 m2	RSI: 1.00	RSI: 7.83	0
Overall	242 m2	RSI: 6.30	0.16 W/m2°K			

Conductive	Air Leakage	Ventilation	Heat Loss
Avg U * ESA	co*ACH*V	co*ACH*V*HF	**Total**
38.32 W/°C	4.74 W/°C	8.97 W/°C	**52.03 W/°C**

Climate data | **Heating load** | **Electricity usage** | Heat pump

Month	Avg temp	Daylight hour	Occupancy	Heat Load	Occu. elec.	Occupants	Solar Gain	Plug load	Lighting use	HRV elec.	**Load - offse**	COP@avg te	load/COP
January	-27 °C	0.1	16.0 hrs	-1828 kWh	603 kWh	98 kWh	2 kWh	351 kWh	116 kWh	136 kWh	**1126 kWh**	0.94	1126 kWh
February	-27 °C	5.5	16.0 hrs	-1828 kWh	581 kWh	98 kWh	89 kWh	351 kWh	94 kWh	136 kWh	**1061 kWh**	0.94	1061 kWh
March	-25 °C	11.8	15.5 hrs	-1752 kWh	552 kWh	95 kWh	191 kWh	351 kWh	69 kWh	132 kWh	**915 kWh**	1.10	832 kWh
April	-18 °C	16.3	15.0 hrs	-1485 kWh	518 kWh	92 kWh	263 kWh	351 kWh	51 kWh	117 kWh	**613 kWh**	1.66	369 kWh
May	-9 °C	21.1	14.5 hrs	-1143 kWh	479 kWh	88 kWh	341 kWh	351 kWh	31 kWh	97 kWh	**234 kWh**	2.38	98 kWh
June	0 °C	24.0	14.0 hrs	-800 kWh	448 kWh	85 kWh	387 kWh	351 kWh	20 kWh	77 kWh	~~-120 kWh~~	3.10	~~-39 kWh~~
July	7 °C	24.0	13.5 hrs	-533 kWh	432 kWh	82 kWh	387 kWh	351 kWh	20 kWh	62 kWh	~~-369 kWh~~	3.66	~~-101 kWh~~
August	3 °C	16.0	13.5 hrs	-686 kWh	473 kWh	82 kWh	258 kWh	351 kWh	52 kWh	70 kWh	~~-128 kWh~~	3.34	~~-38 kWh~~
September	-4 °C	13.4	14.0 hrs	-952 kWh	499 kWh	85 kWh	216 kWh	351 kWh	62 kWh	86 kWh	**152 kWh**	2.78	55 kWh
October	-12 °C	8.4	14.5 hrs	-1257 kWh	537 kWh	88 kWh	135 kWh	351 kWh	83 kWh	103 kWh	**497 kWh**	2.14	232 kWh
November	-19 °C	1.3	15.0 hrs	-1523 kWh	581 kWh	92 kWh	20 kWh	351 kWh	111 kWh	119 kWh	**831 kWh**	1.58	526 kWh
December	-24 °C	0.0	15.5 hrs	-1714 kWh	597 kWh	95 kWh	0 kWh	351 kWh	116 kWh	130 kWh	**1023 kWh**	1.18	867 kWh
Overall offsets	-12.9 °C			-15501 kWh	6300 kWh	1080 kWh	2288 kWh	4211 kWh	824 kWh	1265 kWh	**6451 kWh**		**5165 kWh**

Performance and Systems

Vent. rate	0.30 ACH	*46 cfm*		
ACH@50	1.00 ACH@5	0.06 ACH		
HRV eff.	65%	0% for no HRV		
Furnace eff.	85%			
Hot water eff.	165%	*heat pump*		
Heat pump	0.080	3.10	*2.30*	*3.90*
	slope	*COP@0*	*COP@-10°C*	*COP@+10°C*

Heat Loss Yearly

Conductive	Air leak + ven	Gross load
11864 kWh	4244 kWh	16109 kWh
73.65%	26.35%	

Peak Load

Heat loss * Δ	1% low temp
3382 W	20 W/m2
11540 BTU/h	*6.2 BTU/hr/sf*

Heating Offsets

1095 kWh	*occupancy*
6300 kWh	*electrical (75*
2400 kWh	*solar (est.)*
see below	
6451 kWh	*heat load - offset (exc. net (*
11241 kWh	*heat load - offset + HW load*
8064 kWh	*heat load / eff. + HW load / eff.*
16464 kWh	*total energy*

37.40	*kWh/m2*	
95	*kWh/m2*	

fuel	elec gen
38 MJ/L	3.12 kWh/L
10.6 kWh/L	
$1.50/L	$0.62/kWh
heat fuel cost non gov resid	
$0.142/kWh	

diesel heating	*13225 kWh*	$1,877	21625 kWh
electric heatir	*8064 kWh*	$3,884	16464 kWh

elec	heat	hot water	subsidies	net	Total (e+h+hv	heat+hot wate	base elec
778 kWh	1126 kWh	425 kWh	1000 kWh	1329 kWh	$823.73	$548.56	0
756 kWh	1061 kWh	425 kWh	1000 kWh	1242 kWh	$769.80	$510.07	0
727 kWh	832 kWh	363 kWh	1000 kWh	921 kWh	$571.21	$355.21	0
693 kWh	369 kWh	240 kWh	700 kWh	603 kWh	$373.77	$174.89	0
654 kWh	98 kWh	168 kWh	700 kWh	220 kWh	$136.65	$39.52	0
623 kWh	0 kWh	129 kWh	700 kWh	52 kWh	$32.04	$5.49	0
607 kWh	0 kWh	109 kWh	700 kWh	17 kWh	$10.27	$1.56	0
648 kWh	0 kWh	120 kWh	700 kWh	68 kWh	$41.99	$6.54	0
674 kWh	55 kWh	144 kWh	700 kWh	172 kWh	$106.79	$24.26	0
712 kWh	232 kWh	187 kWh	1000 kWh	131 kWh	$80.91	$29.97	0
756 kWh	526 kWh	253 kWh	1000 kWh	534 kWh	$331.25	$168.10	0
772 kWh	867 kWh	338 kWh	1000 kWh	977 kWh	$605.53	$369.13	0
8400 kWh	5165 kWh	2899 kWh			$3,883.94	$2,233.30	$0.00

Enclosure Metrics

Volume	259 m3
Ext surf. area	242 m2
GFA	173 m2
Storeys	2
Avg U-value	0.16 W/m2°K
ACH	0.06 ACH
coeff	0.33
Occupants	5

Building Dimensions

Height	3	exposed faces
Width	11.5	2
Length	7.5	0
		mid row house

Yearly Plug Load

8400 kWh	est. yearly

Yearly Estimate Hot Water Load

250 L	*est. daily HW*
Q=mCΔT	ΔT=45°C
47250 kJ	*daily*
4791 kWh	
3173 kWh	*kWh load / ef*

Location

Location	**Grise Flord**	
HDD@18°C	13200 HDD	*(climateatlas)*
HDD@21°C	14200 HDD	
Yearly avg temp	-13.4	
1% low temp	-42	

Enclosure Assemblies

	Ext. surf. area	RSI value (eff	windows/door	wind./doors R	avg. RSI	FDWR
Walls	69 m2	RSI: 6.90	8.5 m2	RSI: 1.20	RSI: 4.35	0.123
Roof	86 m2	RSI: 7.53	0 m2	RSI: 1.00	RSI: 7.53	0
Floor	86 m2	RSI: 7.83	0 m2	RSI: 1.00	RSI: 7.83	0
Overall	242 m2	RSI: 6.30	0.16 W/m2°K			

Conductive	**Air Leakage**	**Ventilation**	**Heat Loss**
Avg U * ESA	co*ACH*V	co*ACH*V*HI	**Total**
38.32 W/°C	4.74 W/°C	8.97 W/°C	**52.03 W/°C**

Climate data | **Heating load** | **Electricity usage** | Heat pump

Month	Avg temp	Daylight hour	Occupancy	Heat Load	Occu. elec.	Occupants	Solar Gain	Plug load	Lighting use	HRV elec.	**Load - offse**	COP@avg te	load/COP
January	-28 °C	0.0	16.0 hrs	-1884 kWh	607 kWh	98 kWh	0 kWh	351 kWh	116 kWh	140 kWh	**1180 kWh**	0.82	1180 kWh
February	-29 °C	3.3	16.0 hrs	-1919 kWh	596 kWh	98 kWh	53 kWh	351 kWh	103 kWh	142 kWh	**1173 kWh**	0.75	1173 kWh
March	-28 °C	11.8	15.5 hrs	-1854 kWh	558 kWh	95 kWh	190 kWh	351 kWh	69 kWh	138 kWh	**1012 kWh**	0.89	1012 kWh
April	-18 °C	17.8	15.0 hrs	-1483 kWh	512 kWh	92 kWh	287 kWh	351 kWh	45 kWh	116 kWh	**592 kWh**	1.67	355 kWh
May	-6 °C	24.0	14.5 hrs	-1044 kWh	462 kWh	88 kWh	387 kWh	351 kWh	20 kWh	91 kWh	**106 kWh**	2.59	41 kWh
June	1 °C	24.0	14.0 hrs	-764 kWh	446 kWh	85 kWh	387 kWh	351 kWh	20 kWh	75 kWh	~~**-154 kWh**~~	3.18	~~-49 kWh~~
July	4 °C	24.0	13.5 hrs	-636 kWh	439 kWh	82 kWh	387 kWh	351 kWh	20 kWh	68 kWh	~~**-271 kWh**~~	3.44	~~-79 kWh~~
August	4 °C	20.3	13.5 hrs	-657 kWh	455 kWh	82 kWh	327 kWh	351 kWh	35 kWh	69 kWh	~~**-207 kWh**~~	3.40	~~-61 kWh~~
September	-4 °C	13.8	14.0 hrs	-939 kWh	497 kWh	85 kWh	222 kWh	351 kWh	61 kWh	85 kWh	**134 kWh**	2.81	48 kWh
October	-11 °C	6.9	14.5 hrs	-1232 kWh	541 kWh	88 kWh	112 kWh	351 kWh	88 kWh	102 kWh	**491 kWh**	2.19	224 kWh
November	-21 °C	0.0	15.0 hrs	-1597 kWh	590 kWh	92 kWh	0 kWh	351 kWh	116 kWh	123 kWh	**915 kWh**	1.43	641 kWh
December	-24 °C	0.0	15.5 hrs	-1727 kWh	598 kWh	95 kWh	0 kWh	351 kWh	116 kWh	131 kWh	**1035 kWh**	1.15	898 kWh
Overall offsets	-13.4 °C			-15736 kWh	6300 kWh	1080 kWh	2352 kWh	4213 kWh	808 kWh	1279 kWh	**6637 kWh**		**5571 kWh**

Performance and Systems

Vent. rate	0.30 ACH	*46 cfm*
ACH@50	1.00 ACH@5	0.06 ACH
HRV eff.	65%	0% for no HRV
Furnace eff.	85%	
Hot water eff.	151%	*heat pump*

Heat pump	0.080	3.10	*2.30*	*3.90*
	slope	*COP@0*	*COP@-10°C*	*COP@+10°C*

Heat Loss Yearly

Conductive	Air leak + ven	Gross load
13060 kWh	4672 kWh	17732 kWh
73.65%	26.35%	

Peak Load

Heat loss * Δ	1% low temp
3278 W	19 W/m2
11185 BTU/h	*6.0 BTU/hr/sf*

Heating Offsets

1095 kWh	*occupancy*
6300 kWh	*electrical (75*
2400 kWh	*solar (est.)*
see below	
6637 kWh	*heat load - offset (exc. net*
11428 kWh	*heat load - offset + HW load*
8744 kWh	*heat load / eff. + HW load / eff.*
17144 kWh	*total energy*

38.47	*kWh/m2*	
99	*kWh/m2*	

fuel	elec gen	
38 MJ/L	3.12 kWh/L	
10.6 kWh/L		
$1.50/L	$0.62/kWh	
heat fuel cost non gov resid		
$0.142/kWh		

diesel heating	*13444 kWh*	$1,908	21844 kWh
electric heatir	*8744 kWh*	$4,305	17144 kWh

elec	heat	hot water	subsidies	net	Total (e+h+hv	heat+hot wat	base elec
782 kWh	1180 kWh	485 kWh	1000 kWh	1447 kWh	$897.11	$610.52	0
771 kWh	1173 kWh	533 kWh	1000 kWh	1477 kWh	$915.59	$630.72	0
733 kWh	1012 kWh	451 kWh	1000 kWh	1195 kWh	$741.13	$493.73	0
687 kWh	355 kWh	240 kWh	700 kWh	582 kWh	$360.86	$167.43	0
637 kWh	41 kWh	154 kWh	700 kWh	132 kWh	$82.09	$19.25	0
621 kWh	0 kWh	126 kWh	700 kWh	47 kWh	$28.98	$4.88	0
614 kWh	0 kWh	116 kWh	700 kWh	30 kWh	$18.35	$2.92	0
630 kWh	0 kWh	117 kWh	700 kWh	47 kWh	$29.23	$4.60	0
672 kWh	48 kWh	142 kWh	700 kWh	162 kWh	$100.48	$22.16	0
716 kWh	224 kWh	182 kWh	1000 kWh	122 kWh	$75.86	$27.44	0
765 kWh	641 kWh	280 kWh	1000 kWh	686 kWh	$425.59	$232.51	0
773 kWh	898 kWh	346 kWh	1000 kWh	1016 kWh	$630.20	$388.73	0
8400 kWh	5571 kWh	3173 kWh			$4,305.48	$2,604.87	$0.00

Enclosure Metrics

Volume	316 m3
Ext surf. area	189 m2
GFA	115 m2
Storeys	2
Avg U-value	0.13 W/m2°K
ACH	0.06 ACH
coeff	0.33
Occupants	5

Location

Location	**Iqaluit**	
HDD@18°C	9980 HDD	*(NECB)*
HDD@21°C	10980 HDD	
Yearly avg temp	-8.6	
1% low temp	-41	

Building Dimensions

Height	5.5	exposed faces
Width	6.75	2
Length	8.5	0
		mid row house

Yearly Plug Load

8400 kWh	est. yearly

Yearly Estimate Hot Water Load

250 L	*est. daily HW*
Q=mCΔT	ΔT=45°C
47250 kJ	*daily*
4791 kWh	
2425 kWh	*kWh load / ef*

Enclosure Assemblies

	Ext. surf. area	RSI value (eff	windows/doo	wind./doors R	avg. RSI	FDWR
Walls	74 m2	RSI: 9.10	10.0 m2	RSI: 1.20	RSI: 4.82	0.135
Roof	57 m2	RSI: 12.10	0 m2		RSI: 12.10	0
Floor	57 m2	RSI: 12.30	0 m2		RSI: 12.30	0
Overall	189 m2	RSI: 7.62	0.13 W/m2°K			

Conductive	Air Leakage	Ventilation	Heat Loss
Avg U * ESA	co*ACH*V	co*ACH*V*H	**Total**
24.80 W/°C	5.79 W/°C	10.93 W/°C	**41.52 W/°C**

Climate data / **Heating load** / **Electricity usage**

Month	Avg temp	Daylight hour	Occupancy	Heat Load	Occu. elec.	Occupants	Solar Gain	Plug load	Lighting use	HRV elec.	**Load - offse**	Heat pump COP@avg te	load/COP
January	-26 °C	5.7	16.0 hrs	-1425 kWh	590 kWh	98 kWh	91 kWh	363 kWh	93 kWh	134 kWh	**647 kWh**	1.03	629 kWh
February	-26 °C	8.6	16.0 hrs	-1419 kWh	578 kWh	98 kWh	137 kWh	363 kWh	82 kWh	134 kWh	**606 kWh**	1.04	581 kWh
March	-21 °C	11.8	15.5 hrs	-1261 kWh	554 kWh	95 kWh	188 kWh	363 kWh	69 kWh	122 kWh	**424 kWh**	1.46	291 kWh
April	-12 °C	15.1	15.0 hrs	-1009 kWh	522 kWh	92 kWh	242 kWh	363 kWh	55 kWh	104 kWh	**154 kWh**	2.12	72 kWh
May	-4 °C	18.3	14.5 hrs	-745 kWh	490 kWh	88 kWh	293 kWh	363 kWh	43 kWh	85 kWh	~~-127 kWh~~	2.82	~~-45 kWh~~
June	4 °C	20.5	14.0 hrs	-529 kWh	466 kWh	85 kWh	326 kWh	363 kWh	34 kWh	69 kWh	~~-349 kWh~~	3.39	~~-103 kWh~~
July	9 °C	19.4	13.5 hrs	-365 kWh	459 kWh	82 kWh	310 kWh	363 kWh	38 kWh	57 kWh	~~-486 kWh~~	3.82	~~-127 kWh~~
August	8 °C	16.4	13.5 hrs	-404 kWh	474 kWh	82 kWh	262 kWh	363 kWh	50 kWh	60 kWh	~~-413 kWh~~	3.72	~~-111 kWh~~
September	2 °C	13.1	14.0 hrs	-587 kWh	500 kWh	85 kWh	209 kWh	363 kWh	64 kWh	73 kWh	~~-208 kWh~~	3.24	~~-64 kWh~~
October	-5 °C	9.8	14.5 hrs	-784 kWh	528 kWh	88 kWh	156 kWh	363 kWh	77 kWh	88 kWh	**12 kWh**	2.72	4 kWh
November	-13 °C	6.6	15.0 hrs	-1024 kWh	558 kWh	92 kWh	105 kWh	363 kWh	90 kWh	105 kWh	**270 kWh**	2.08	130 kWh
December	-20 °C	4.5	15.5 hrs	-1231 kWh	581 kWh	95 kWh	72 kWh	363 kWh	98 kWh	120 kWh	**483 kWh**	1.54	314 kWh
Overall offsets	-8.6 °C			-10783 kWh	6300 kWh	1080 kWh	2391 kWh	4357 kWh	793 kWh	1150 kWh	**2597 kWh**		**2021 kWh**

Performance and Systems

Vent. rate	0.30 ACH	*56 cfm*		
ACH@50	1.00 ACH@5	0.06 ACH		
HRV eff.	65%	0% for no HRV		
Furnace eff.	85%			
Hot water eff.	198%	*heat pump*		
Heat pump	0.080	3.10	*2.30*	*3.90*
	slope	*COP@0*	*COP@-10°C*	*COP@+10°C*

Heat Loss Yearly

Conductive	Air leak + ven	Gross load
6535 kWh	4406 kWh	10941 kWh
59.73%	40.27%	

Peak Load

Heat loss * Δ	1% low temp
2574 W	22 W/m2
8784 BTU/hr	*7.1 BTU/hr/sf*

Heating Offsets

1095 kWh	*occupancy*
6300 kWh	*electrical (75*
2400 kWh	*solar (est.)*
see below	
2597 kWh	*heat load - offset (exc. net*
7387 kWh	*heat load - offset + HW load*
4445 kWh	*heat load / eff. + HW load / eff.*
12845 kWh	*total energy*

22.63	*kWh/m2*	
112	*kWh/m2*	

fuel	elec gen
38 MJ/L	3.12 kWh/L
10.6 kWh/L	
$1.43/L	$0.62/kWh
heat fuel cost non gov resid	
$0.136/kWh	

diesel heating	*8691 kWh*	$1,179	17091 kWh
electric heatir	*4445 kWh*	$1,731	12845 kWh

elec	heat	hot water	subsidies	net	Total (e+h+hv	heat+hot wat	base elec
765 kWh	629 kWh	388 kWh	1000 kWh	783 kWh	$485.34	$276.99	0
753 kWh	581 kWh	382 kWh	1000 kWh	716 kWh	$444.09	$249.19	0
729 kWh	291 kWh	273 kWh	1000 kWh	293 kWh	$181.71	$79.27	0
697 kWh	72 kWh	188 kWh	700 kWh	258 kWh	$159.73	$43.41	0
665 kWh	0 kWh	142 kWh	700 kWh	107 kWh	$66.35	$11.64	0
641 kWh	0 kWh	118 kWh	700 kWh	59 kWh	$36.70	$5.70	0
634 kWh	0 kWh	105 kWh	700 kWh	38 kWh	$23.59	$3.34	0
649 kWh	0 kWh	107 kWh	700 kWh	56 kWh	$34.70	$4.93	0
675 kWh	0 kWh	123 kWh	700 kWh	98 kWh	$60.99	$9.42	0
703 kWh	4 kWh	147 kWh	1000 kWh	~~-146 kWh~~	$0.00	$0.00	0
733 kWh	130 kWh	192 kWh	1000 kWh	54 kWh	$33.44	$10.19	0
756 kWh	314 kWh	259 kWh	1000 kWh	329 kWh	$203.97	$87.96	0
8400 kWh	2021 kWh	2425 kWh			$1,730.60	$782.04	$0.00

Enclosure Metrics

Volume	316 m3
Ext surf. area	189 m2
GFA	115 m2
Storeys	2
Avg U-value	0.13 W/m2°K
ACH	0.06 ACH
coeff	0.33
Occupants	5

Building Dimensions

Height	5.5	exposed faces
Width	6.75	2
Length	8.5	0
		mid row house

Yearly Plug Load

8400 kWh	est. yearly

Yearly Estimate Hot Water Load

250 L	*est. daily HW*
Q=mCΔT	ΔT=45°C
47250 kJ	*daily*
4791 kWh	
2205 kWh	*kWh load / ef*

Location

Location	**Yellowknife**	
HDD@18°C	8170 HDD	*(climateatlas)*
HDD@21°C	9170 HDD	
Yearly avg temp	-4	
1% low temp	-44	

Enclosure Assemblies

	Ext. surf. area	RSI value (eff	windows/door	wind./doors R	avg. RSI	FDWR
Walls	74 m2	RSI: 9.10	10.0 m2	RSI: 1.20	RSI: 4.82	0.135
Roof	57 m2	RSI: 12.10	0 m2		RSI: 12.10	0
Floor	57 m2	RSI: 12.30	0 m2		RSI: 12.30	0
Overall	189 m2	RSI: 7.62	0.13 W/m2°K			

Conductive	Air Leakage	Ventilation	Heat Loss
Avg U * ESA	co*ACH*V	co*ACH*V*HF	**Total**
24.80 W/°C	5.79 W/°C	10.93 W/°C	**41.52 W/°C**

Climate data | **Heating load** | **Electricity usage** | Heat pump

Month	Avg temp	Daylight hour	Occupancy	Heat Load	Occu. elec.	Occupants	Solar Gain	Plug load	Lighting offse	HRV elec offs	**Load - offse**	COP@avg te	load/COP
January	-26 °C	6.2	16.0 hrs	-1428 kWh	598 kWh	98 kWh	100 kWh	373 kWh	91 kWh	134 kWh	**633 kWh**	1.02	620 kWh
February	-22 °C	8.9	16.0 hrs	-1307 kWh	579 kWh	98 kWh	143 kWh	373 kWh	80 kWh	125 kWh	**487 kWh**	1.34	364 kWh
March	-16 °C	11.9	15.5 hrs	-1125 kWh	554 kWh	95 kWh	192 kWh	373 kWh	68 kWh	112 kWh	**285 kWh**	1.82	156 kWh
April	-5 °C	15.0	15.0 hrs	-790 kWh	517 kWh	92 kWh	242 kWh	373 kWh	56 kWh	88 kWh	~~-60 kWh~~	2.70	~~-22 kWh~~
May	5 °C	18.0	14.5 hrs	-486 kWh	483 kWh	88 kWh	290 kWh	373 kWh	44 kWh	66 kWh	~~-375 kWh~~	3.50	~~-107 kWh~~
June	14 °C	19.8	14.0 hrs	-213 kWh	456 kWh	85 kWh	319 kWh	373 kWh	37 kWh	46 kWh	~~-648 kWh~~	4.22	~~-153 kWh~~
July	17 °C	18.7	13.5 hrs	-122 kWh	454 kWh	82 kWh	301 kWh	373 kWh	41 kWh	40 kWh	~~-716 kWh~~	4.46	~~-161 kWh~~
August	15 °C	15.9	13.5 hrs	-182 kWh	469 kWh	82 kWh	256 kWh	373 kWh	52 kWh	44 kWh	~~-626 kWh~~	4.30	~~-145 kWh~~
September	8 °C	12.9	14.0 hrs	-395 kWh	497 kWh	85 kWh	208 kWh	373 kWh	64 kWh	59 kWh	~~-395 kWh~~	3.74	~~-106 kWh~~
October	-1 °C	9.8	14.5 hrs	-669 kWh	529 kWh	88 kWh	158 kWh	373 kWh	77 kWh	79 kWh	~~-107 kWh~~	3.02	~~-35 kWh~~
November	-14 °C	6.9	15.0 hrs	-1064 kWh	569 kWh	92 kWh	111 kWh	373 kWh	88 kWh	108 kWh	**292 kWh**	1.98	147 kWh
December	-23 °C	5.1	15.5 hrs	-1337 kWh	596 kWh	95 kWh	82 kWh	373 kWh	96 kWh	128 kWh	**564 kWh**	1.26	448 kWh
Overall	-4.0 °C			-9118 kWh	6300 kWh	1080 kWh	2403 kWh	4475 kWh	796 kWh	1030 kWh	**2261 kWh**		**1735 kWh**

Performance and Systems

Vent. rate	0.30 ACH	*56 cfm*
ACH@50	1.00 ACH@5	0.06 ACH
HRV eff.	65%	0% for no HRV
Furnace eff.	85%	
Hot water eff.	217%	*heat pump*

Heat pump	0.080	3.10	*2.30*	*3.90*
	slope	*COP@0*	*COP@-10°C*	*COP@+10°C*

Heat Loss Yearly

Conductive	Air leak + ven	Gross load
5458 kWh	3680 kWh	9138 kWh
59.73%	40.27%	

Peak Load

Heat loss * Δ	1% low temp
2699 W	24 W/m2
9209 BTU/hr	*7.5 BTU/hr/sf*

Heating Offsets

1095 kWh	*occupancy*
6300 kWh	*electrical (75*
2400 kWh	*solar (est.)*
see below	

2261 kWh	*heat load - offset (exc. net*	19.70	*kWh/m2*	fuel
7051 kWh	*Heat + HW demand*			38 MJ/L
3940 kWh	*(Heat + HW demand)/eff.*			10.6 kWh/L
				$1.82/L
12340 kWh	*total energy*	108	*kWh/m2*	heat fuel cost non gov resid
				$0.172/kWh

diesel heating	*8296 kWh*	$3,423	16696 kWh
electric heatir	*3940 kWh*	$2,927	12340 kWh

elec	heat	hot water	subsidies	net	Total (e+h+hv	heat+hot wat	base elec
773 kWh	620 kWh	391 kWh		1785 kWh	$423.38	$239.95	773 kWh
754 kWh	364 kWh	298 kWh		1415 kWh	$335.67	$156.89	754 kWh
729 kWh	156 kWh	219 kWh		1104 kWh	$261.93	$89.13	729 kWh
692 kWh	0 kWh	148 kWh		840 kWh	$199.19	$35.07	692 kWh
658 kWh	0 kWh	114 kWh		772 kWh	$183.11	$27.06	658 kWh
631 kWh	0 kWh	95 kWh		726 kWh	$172.09	$22.44	631 kWh
629 kWh	0 kWh	90 kWh		718 kWh	$170.36	$21.23	629 kWh
644 kWh	0 kWh	93 kWh		737 kWh	$174.85	$22.02	644 kWh
672 kWh	0 kWh	107 kWh		778 kWh	$184.65	$25.32	672 kWh
704 kWh	0 kWh	132 kWh		836 kWh	$198.32	$31.36	704 kWh
744 kWh	147 kWh	202 kWh		1093 kWh	$259.30	$82.80	744 kWh
771 kWh	448 kWh	317 kWh		1536 kWh	$364.31	$181.41	771 kWh
8400 kWh	1735 kWh	2205 kWh			$2,927.15	$934.67	$1,992.48

Enclosure Metrics

Volume	316 m3
Ext surf. area	189 m2
GFA	115 m2
Storeys	2
Avg U-value	0.13 W/m2°K
ACH	0.06 ACH
coeff	0.33
Occupants	5

Location

Location	**Kuujjuaq**	
HDD@18°C	8550 HDD	*(NECB)*
HDD@21°C	9550 HDD	
Yearly avg temp	-4.6	
1% low temp	-39	

Building Dimensions

Height	5.5	exposed faces
Width	6.75	2
Length	8.5	0
		mid row house

Yearly Plug Load

8400 kWh	est. yearly

Yearly Estimate Hot Water Load

250 L	*est. daily HW*
Q=mCΔT	ΔT=45°C
47250 kJ	*daily*
4791 kWh	
2078 kWh	*kWh load / ef*

Enclosure Assemblies

	Ext. surf. area	RSI value (eff	windows/doors	wind./doors R	avg. RSI	FDWR
Walls	74 m2	RSI: 9.10	10.0 m2	RSI: 1.20	RSI: 4.82	0.135
Roof	57 m2	RSI: 12.10	0 m2		RSI: 12.10	0
Floor	57 m2	RSI: 12.30	0 m2		RSI: 12.30	0
Overall	189 m2	RSI: 7.62	0.13 W/m2°K			

Conductive	Air Leakage	Ventilation	Heat Loss
Avg U * ESA	co*ACH*V	co*ACH*V*HF	**Total**
24.80 W/°C	5.79 W/°C	10.93 W/°C	**41.52 W/°C**

Climate data | **Heating load** | **Electricity usage** | Heat pump

Month	Avg temp	Daylight hour	Occupancy	Heat Load	Occupancy-R	Occupants	Solar Gain	Plug load	Lighting offse	HRV elec offs	**Load - offse**	COP@avg te	load/COP
January	-23 °C	7.3	16.0 hrs	-1337 kWh	586 kWh	98 kWh	118 kWh	371 kWh	87 kWh	128 kWh	**536 kWh**	1.26	426 kWh
February	-23 °C	9.4	16.0 hrs	-1337 kWh	577 kWh	98 kWh	152 kWh	371 kWh	78 kWh	128 kWh	**511 kWh**	1.26	405 kWh
March	-17 °C	11.9	15.5 hrs	-1155 kWh	554 kWh	95 kWh	192 kWh	371 kWh	68 kWh	114 kWh	**314 kWh**	1.74	181 kWh
April	-8 °C	14.5	15.0 hrs	-881 kWh	524 kWh	92 kWh	234 kWh	371 kWh	58 kWh	95 kWh	**32 kWh**	2.46	13 kWh
May	1 °C	16.8	14.5 hrs	-608 kWh	495 kWh	88 kWh	271 kWh	371 kWh	49 kWh	75 kWh	~~**-246 kWh**~~	3.18	~~-77 kWh~~
June	8 °C	18.1	14.0 hrs	-395 kWh	474 kWh	85 kWh	292 kWh	371 kWh	44 kWh	59 kWh	~~**-456 kWh**~~	3.74	~~-122 kWh~~
July	12 °C	17.4	13.5 hrs	-274 kWh	468 kWh	82 kWh	280 kWh	371 kWh	46 kWh	51 kWh	~~**-558 kWh**~~	4.06	~~-137 kWh~~
August	12 °C	15.2	13.5 hrs	-274 kWh	477 kWh	82 kWh	245 kWh	371 kWh	55 kWh	51 kWh	~~**-531 kWh**~~	4.06	~~-131 kWh~~
September	6 °C	12.7	14.0 hrs	-456 kWh	500 kWh	85 kWh	205 kWh	371 kWh	65 kWh	64 kWh	~~**-334 kWh**~~	3.58	~~-93 kWh~~
October	1 °C	10.2	14.5 hrs	-608 kWh	521 kWh	88 kWh	164 kWh	371 kWh	75 kWh	75 kWh	~~**-166 kWh**~~	3.18	~~-52 kWh~~
November	-7 °C	7.9	15.0 hrs	-851 kWh	548 kWh	92 kWh	127 kWh	371 kWh	84 kWh	92 kWh	**84 kWh**	2.54	33 kWh
December	-17 °C	6.6	15.5 hrs	-1155 kWh	575 kWh	95 kWh	106 kWh	371 kWh	90 kWh	114 kWh	**379 kWh**	1.74	218 kWh
Overall	-4.6 °C			-9330 kWh	6300 kWh	1080 kWh	2386 kWh	4455 kWh	800 kWh	1045 kWh	**1857 kWh**		**1276 kWh**

Performance and Systems

Vent. rate	0.30 ACH	*56 cfm*		
ACH@50	1.00 ACH@5	0.06 ACH		
HRV eff.	65%	0% for no HRV		
Furnace eff.	85%			
Hot water eff.	231%	*heat pump*		
Heat pump	0.080	3.10	*2.30*	*3.90*
	slope	*COP@0*	*COP@-10°C*	*COP@+10°C*

Heat Loss Yearly

Conductive	Air leak + ven	Gross load
5684 kWh	3832 kWh	9516 kWh
59.73%	40.27%	

Peak Load

Heat loss * Δ	1% low temp
2491 W	22 W/m2
8500 BTU/hr	*6.9 BTU/hr/sf*

Heating Offsets

1095 kWh	*occupancy*
6300 kWh	*electrical (75*
2400 kWh	*solar (est.)*

see below

1857 kWh	*heat load - offset (exc. net*	16.18	*kWh/m2*	fuel / elec gen
6647 kWh	*Heat + HW demand*			38 MJ/L / 3.12 kWh/L
3354 kWh	*(Heat + HW demand)/eff.*			10.6 kWh/L
				$1.63/L / $0.27/kWh
11754 kWh	*total energy*	102	*kWh/m2*	heat fuel cost non gov resid
				$0.154/kWh

diesel heating	*7821 kWh*	$3,476	16221 kWh
electric heatir	*3354 kWh*	$3,174	11754 kWh

elec	heat	hot water	subsidies	net	Total (e+h+hv	heat+hot wat	base elec
761 kWh	426 kWh	317 kWh		1503 kWh	$405.85	$200.48	761 kWh
752 kWh	405 kWh	317 kWh		1475 kWh	$398.13	$195.02	752 kWh
729 kWh	181 kWh	229 kWh		1139 kWh	$307.59	$110.75	729 kWh
699 kWh	13 kWh	162 kWh		874 kWh	$236.05	$47.36	699 kWh
670 kWh	0 kWh	126 kWh		795 kWh	$214.76	$33.90	670 kWh
649 kWh	0 kWh	107 kWh		756 kWh	$204.12	$28.82	649 kWh
643 kWh	0 kWh	98 kWh		742 kWh	$200.23	$26.55	643 kWh
652 kWh	0 kWh	98 kWh		750 kWh	$202.60	$26.55	652 kWh
675 kWh	0 kWh	112 kWh		787 kWh	$212.43	$30.11	675 kWh
696 kWh	0 kWh	126 kWh		822 kWh	$221.88	$33.90	696 kWh
723 kWh	33 kWh	157 kWh		913 kWh	$246.60	$51.38	723 kWh
750 kWh	218 kWh	229 kWh		1197 kWh	$323.28	$120.71	750 kWh
8400 kWh	1276 kWh	2078 kWh			$3,173.52	$905.52	$2,268.00

Heat Pump Modelling

Estimating heat pump energy usage based on monthly temperatures significantly overestimates their performance as particularly cold days or even hours can dramatically increase energy usage. From comparison between hourly data for a week in February of 2024, and daily average temperatures of the same period, as well as daily data for the winter of 2023/2024, compared to monthly data for the same period, it was determined that reducing the COP@0°C by 10%, while maintaining the same efficiency slope, produced a reasonably consistent result. While this estimation is limited by the availability of actual heat pump performance data, it provides a starting point for estimating energy consumption.

Northern Lightweight Architecture **- Iqaluit, NU**

month	Avg.	COP	Load	Load/COP	Baseline Load	*-10% COP@0*	Climate Avg.		Load (clim.)	Load/COP (clim.)
Jan.	-20.6 °C	1.82	1280 kWh	702 kWh	3002 kWh	*866 kWh*	-26 °C	1.41	1444 kWh	1027 kWh
Feb.	-25.5 °C	1.44	1431 kWh	996 kWh	3356 kWh	*1310 kWh*	-26 °C	1.42	1437 kWh	1011 kWh
Mar.	-19.6 °C	1.90	1250 kWh	657 kWh	2930 kWh	*803 kWh*	-21 °C	1.83	1277 kWh	698 kWh
Apr.	-9.9 °C	2.67	951 kWh	357 kWh	2230 kWh	*410 kWh*	-12 °C	2.48	1022 kWh	411 kWh
May	-3.1 °C	3.20	742 kWh	232 kWh	1739 kWh	*260 kWh*	-4 °C	3.17	754 kWh	238 kWh
June	3.6 °C	3.73	536 kWh	144 kWh	1256 kWh	*158 kWh*	4 °C	3.73	536 kWh	144 kWh
July	7.0 °C	4.00	431 kWh	108 kWh	1010 kWh	*118 kWh*	9 °C	4.15	369 kWh	89 kWh
Aug.	6.7 °C	3.97	440 kWh	111 kWh	1032 kWh	*121 kWh*	8 °C	4.05	409 kWh	101 kWh
Sep.	2.3 °C	3.63	576 kWh	159 kWh	1350 kWh	*175 kWh*	2 °C	3.58	594 kWh	166 kWh
Oct.	-2.2 °C	3.27	714 kWh	218 kWh	1674 kWh	*244 kWh*	-5 °C	3.07	794 kWh	259 kWh
Nov.	-5.8 °C	2.99	825 kWh	276 kWh	1934 kWh	*312 kWh*	-13 °C	2.44	1037 kWh	424 kWh
Dec.	-13.3 °C	2.40	1056 kWh	440 kWh	2475 kWh	*514 kWh*	-20 °C	1.91	1247 kWh	653 kWh
				4400 kWh			historical			5221 kWh

avg	climate avg
4400 kWh	5221 kWh

-817 kWh	*Estimation compared to using hourly data*		
5292 kWh	*Estimate based on adjusted COP@0*		
97.0 W/°C	**41.4 W/°C**	***HEAT LOAD (W/°C)***	
baseline	0.0787	3.445	*COP settings*
	m	*+b, COP@0*	*y=mx+b*
	10% off COP@0 seems to give decent estimate		

temp	COP	
-20	1.87	*95f water temp*
-6.66666	2.92	

Super:Light Architecture **- Iqaluit, NU**

month	Avg.	COP	Load	Load/COP	Baseline Load	*-10% COP@0*	Climate Avg.		Load (clim.)	Load/COP (clim.)
Jan	-20.6 °C	1.82	1610 kWh	883 kWh	3002 kWh	*1089 kWh*	-26 °C	1.41	1816 kWh	1292 kWh
Feb	-25.5 °C	1.44	1800 kWh	1253 kWh	3356 kWh	*1648 kWh*	-26 °C	1.42	1808 kWh	1272 kWh
Mar	-19.6 °C	1.90	1572 kWh	827 kWh	2930 kWh	*1009 kWh*	-21 °C	1.83	1606 kWh	878 kWh
Apr	-9.9 °C	2.67	1196 kWh	449 kWh	2230 kWh	*515 kWh*	-12 °C	2.48	1285 kWh	517 kWh
May	-3.1 °C	3.20	933 kWh	291 kWh	1739 kWh	*327 kWh*	-4 °C	3.17	948 kWh	299 kWh
Jun	3.6 °C	3.73	674 kWh	181 kWh	1256 kWh	*199 kWh*	4 °C	3.73	674 kWh	181 kWh
Jul	7.0 °C	4.00	542 kWh	136 kWh	1010 kWh	*148 kWh*	9 °C	4.15	465 kWh	112 kWh
Aug	6.7 °C	3.97	554 kWh	139 kWh	1032 kWh	*153 kWh*	8 °C	4.05	515 kWh	127 kWh
Sep	2.3 °C	3.63	724 kWh	200 kWh	1350 kWh	*221 kWh*	2 °C	3.58	747 kWh	209 kWh
Oct	-2.3 °C	3.26	902 kWh	276 kWh	1682 kWh	*309 kWh*	-5 °C	3.07	999 kWh	326 kWh
Nov	-5.8 °C	2.99	1037 kWh	347 kWh	1934 kWh	*392 kWh*	-13 °C	2.44	1305 kWh	534 kWh
Dec	-13.3 °C	2.40	1328 kWh	554 kWh	2475 kWh	*647 kWh*	-20 °C	1.91	1568 kWh	821 kWh
				5536 kWh			historical			6567 kWh

monthly avg t	climate avg
5536 kWh	6567 kWh

-1023 kWh	*Estimation compared to using hourly data*		
6657 kWh	*Estimate based on adjusted COP@0*		
	52.0 W/°C	***HEAT LOAD (W/°C)***	
	0.0787	3.445	*COP settings*
	m	*+b, COP@0*	*y=mx+b*

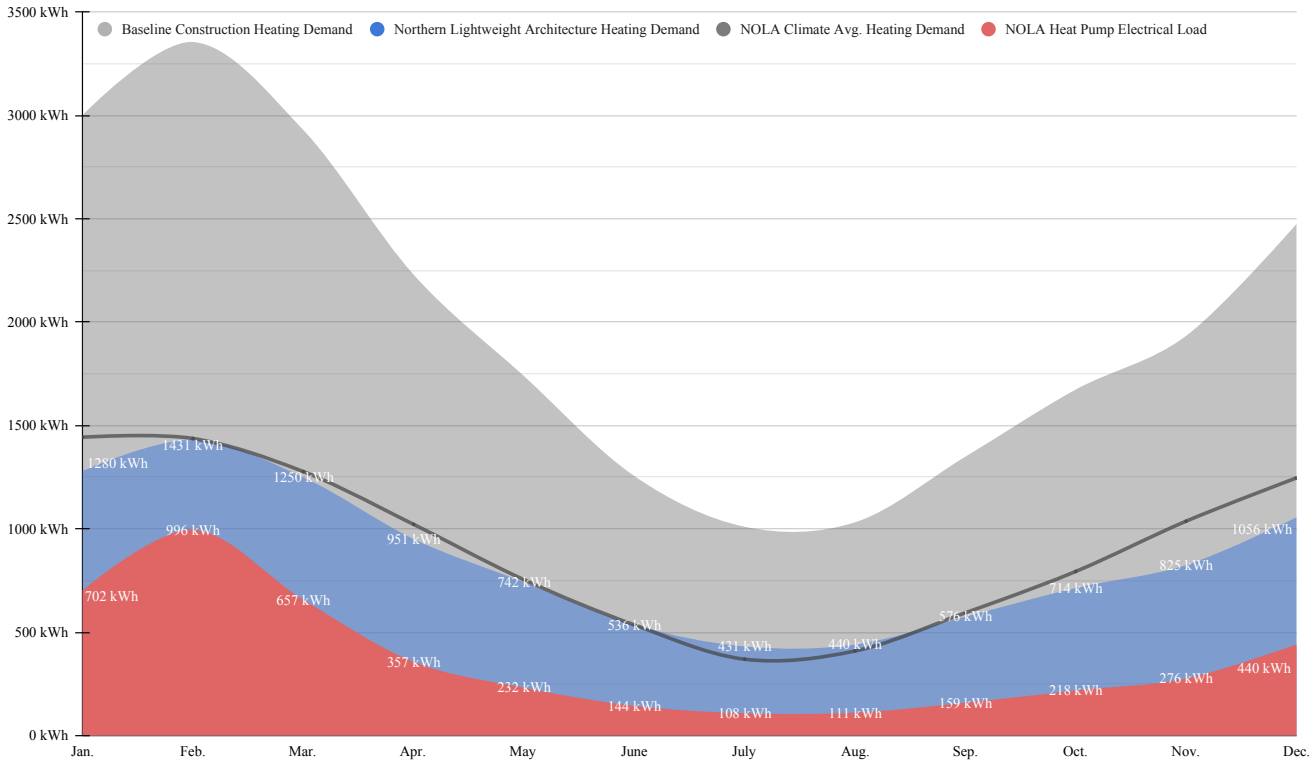
temp	COP	
-20	1.87	*95f water temp*
-6.66666	2.92	

https://en.climate-data.org/north-america/canada/nu

Northern Lightweight Architecture - Iqaluit, NU

Monthly Heating Demand

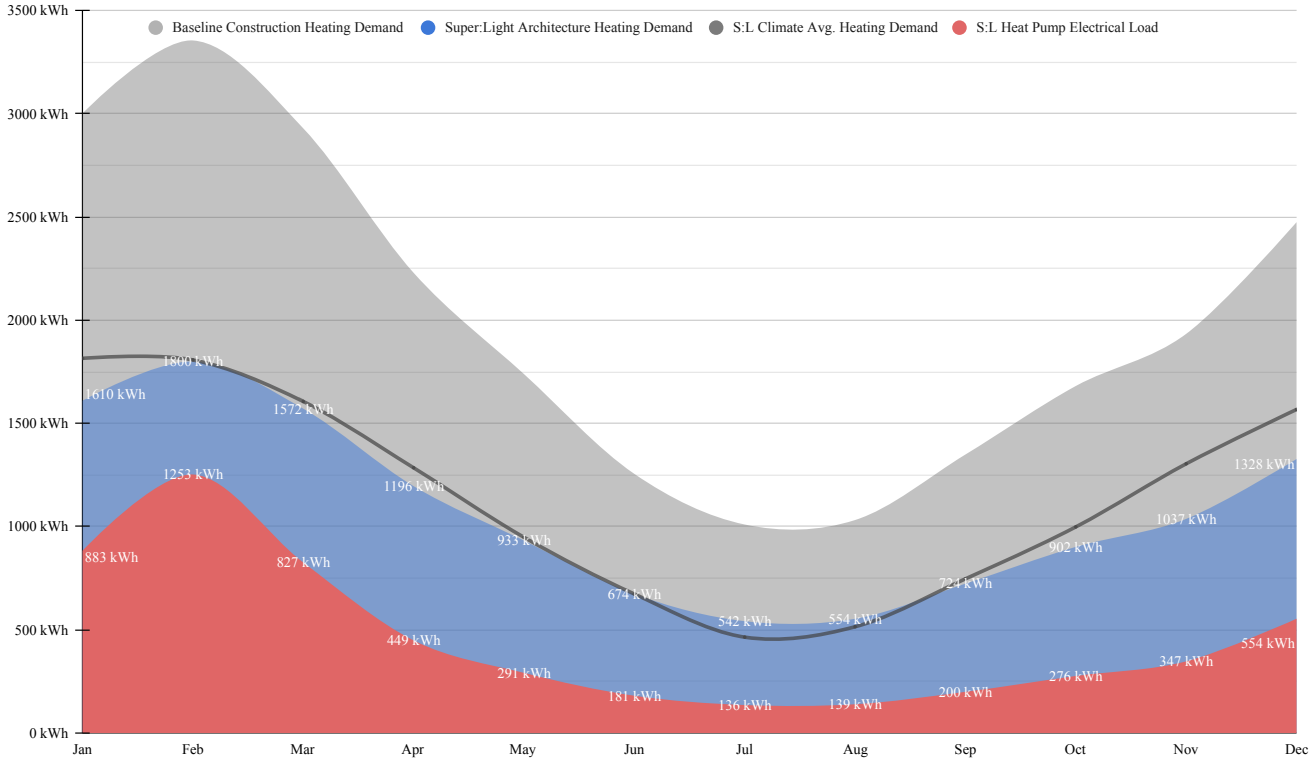
2023/2024 and climatic average data, Σ Heat Pump Electrical Demand = 4,400 kWh



Super:Light Architecture - Iqaluit, NU

Monthly Heating Demand

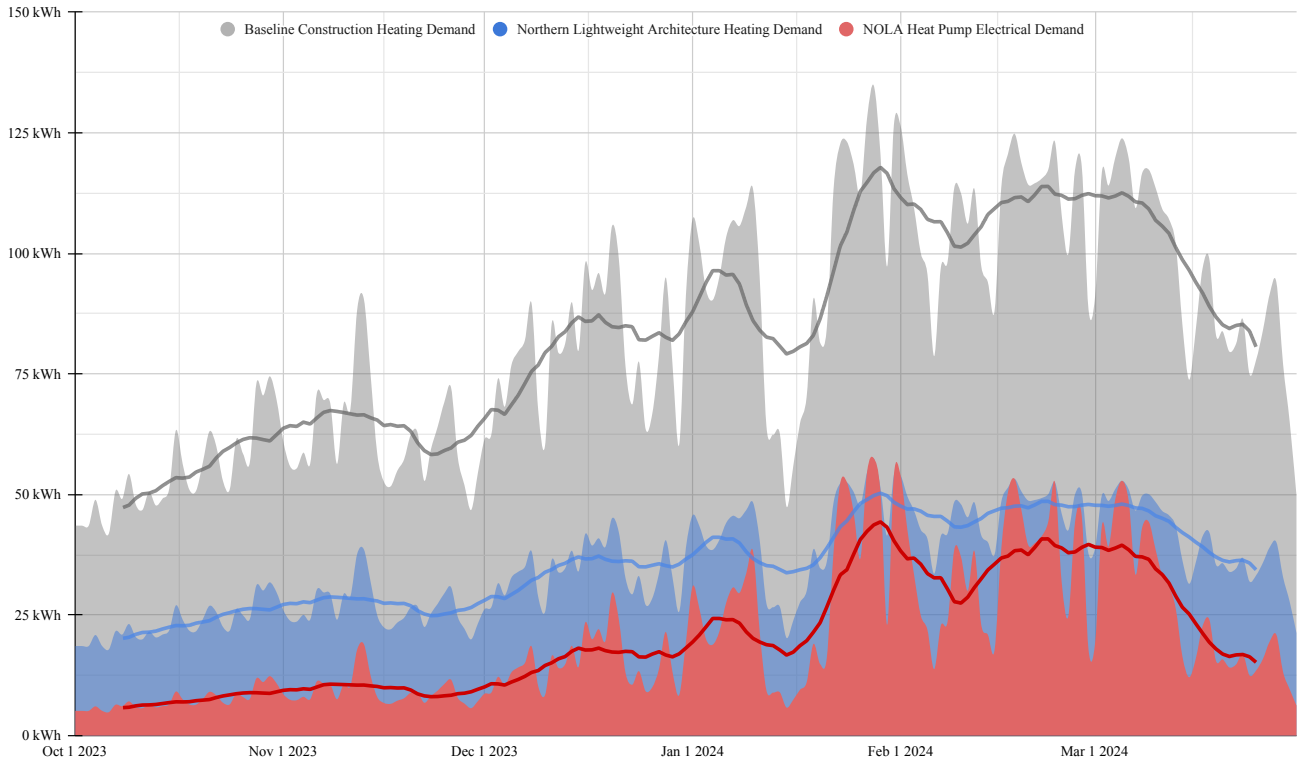
2023/2024 and climatic average data, Σ Heat Pump Electrical Demand = 5,540 kWh



Northern Lightweight Architecture - Iqaluit, NU

Daily Heating Demand

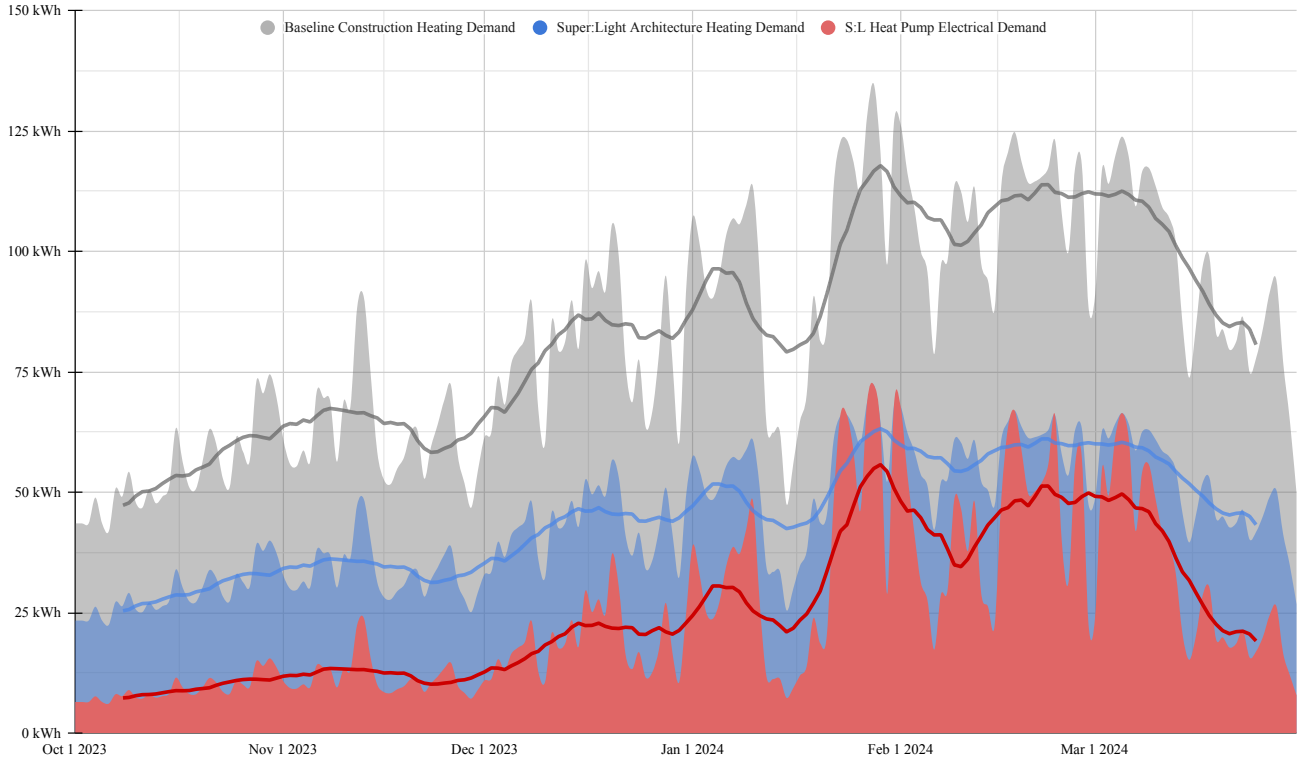
Oct. '23 to Mar. '24, Σ Heat Pump Electrical Demand = 3,640 kWh



Super:Light Architecture - Iqaluit, NU

Daily Heating Demand

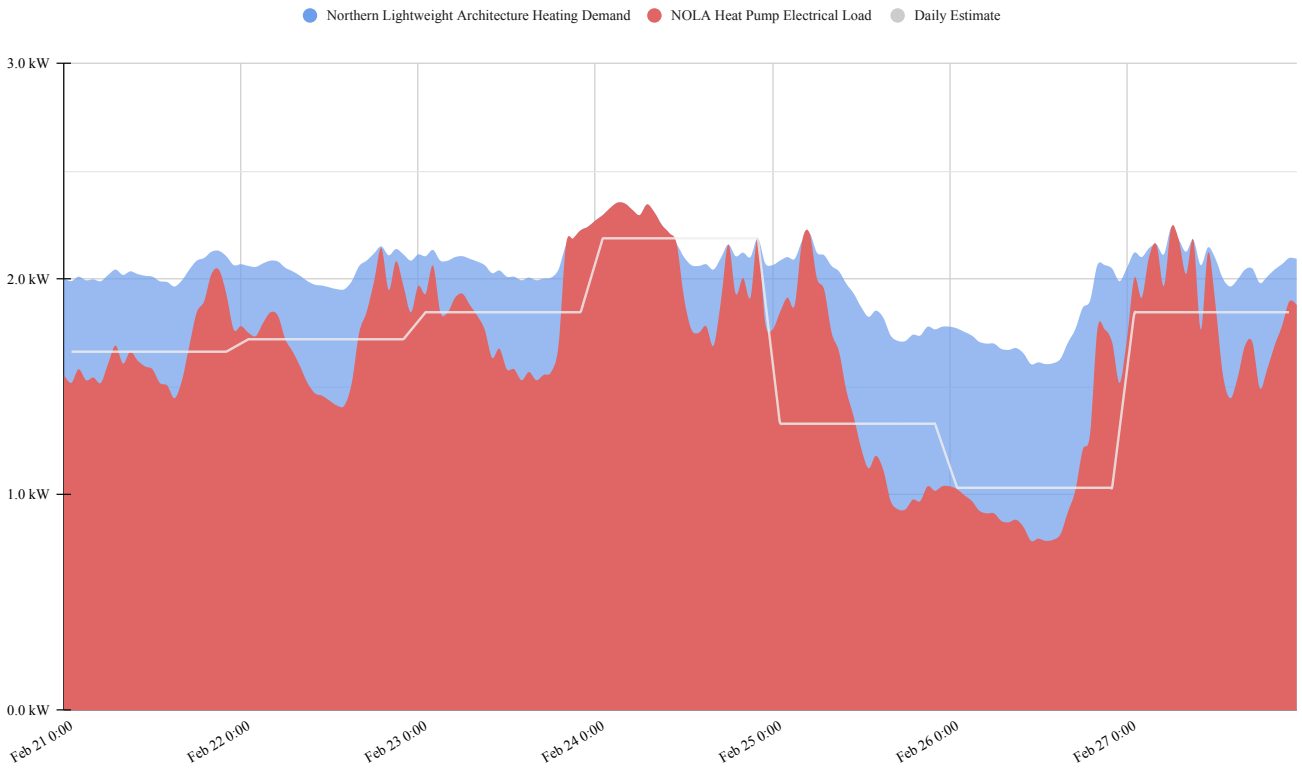
Oct. '23 to Mar. '24, Σ Heat Pump Electrical Demand = 4,580 kWh



Northern Lightweight Architecture - Iqaluit, NU

Hourly Heating Demand

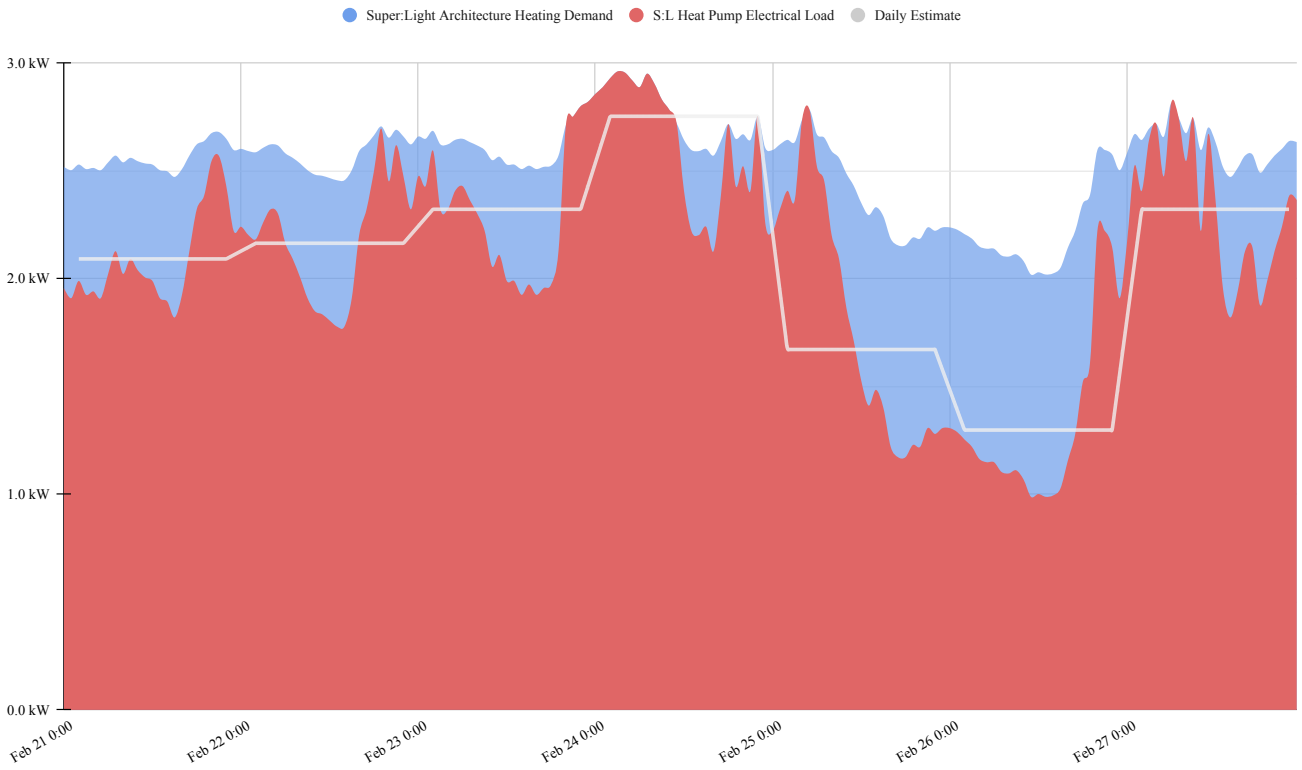
Week of Feb. 21 to Feb. 27, 2024, Σ Heat Pump Electrical Demand = 345 kWh



Super:Light Architecture - Iqaluit, NU

Hourly Heating Demand

Week of Feb. 21 to Feb. 27, 2024, Σ Heat Pump Electrical Demand = 434 kWh



A.2 - Baseline Assemblies

These assemblies are based on discussion with a northern architect, and information in the RDH report *Energy Efficient Housing Guidelines for Whitehorse, YT: Energy Optimized House.*[278] While the exact assemblies vary, most examples are similar and are likely to yield similar weights and energy performances. While these assemblies are not high performance, they have better performance than basic designs in southern Canada and are designed to be lighter and cheaper to ship, representing a realistic baseline.

Table A-27: Baseline wall assembly

Component	Dimension	Weight	Notes
13 mm Gypsum	12.7 mm	6.11 kg/m^2	FR
6 mil Polyethylene		0.14 kg/m^2	A/VB
2x6 Lumber studs @ 400 mm OC	140 mm	14.0 kg/m^2	20% of wall
RSI 3.4 Fibreglass insulation	140 mm	1.87 kg/m^2	RSI 2.5
13mm OSB sheathing	12.7 mm	8.38 kg/m^2	
RSI 1.0 Mineral wool insulation	38 mm	2.66 kg/m^2	RSI 1.0
2x2 Strapping @ 600 mm OC	38 mm	1.18 kg/m^2	
Housewrap		0.06 kg/m^2	WB
Engineered wood siding	9 mm	6.21 kg/m^2	
Total: 3,450 kg (85 m^2)	**212 mm**	**40.6 kg/m^2**	**RSI 3.5**

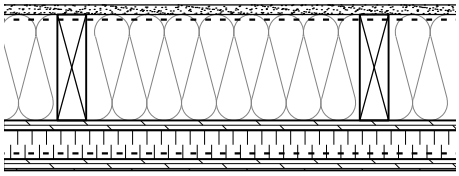


figure A-77: Baseline wall assembly.

Table A-28: Baseline roof assembly

Component	Dimension	Weight	Notes
13 mm Gypsum	12.7 mm	6.11 kg/m^2	FR
6 mil Polyethylene		0.14 kg/m^2	A/VB
302 mm I joist @ 400 mm OC	302 mm	9.51 kg/m^2	
RSI 7.4 Fibreglass insulation	300 mm	4.27 kg/m^2	RSI 6.8
13 mm OSB sheathing	12.7 mm	8.38 kg/m^2	
Housewrap		0.06 kg/m^2	WB
Asphalt shingles	6 mm	10.8 kg/m^2	
Total: 2,670 kg (68 m^2)	**327 mm**	**39.3 kg/m^2**	**RSI 6.8**

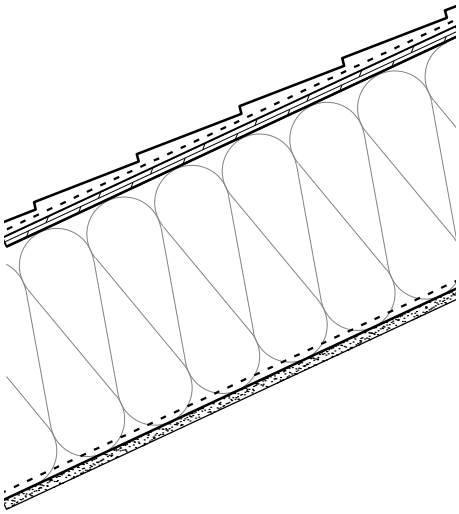


figure A-78: Baseline roof assembly.

Table A-29: Baseline floor assembly

Component	Dimension	Weight	Notes
Flooring	3.2 mm	2.60 kg/m^2	FR
Flooring underlayment	2.0 mm	0.16 kg/m^2	
16mm OSB subfloor	15.9 mm	10.5 kg/m^2	
6 mil Polyethylene		0.14 kg/m^2	A/VB
302 mm I joist @ 400 mm OC	302 mm	9.51 kg/m^2	
RSI 5.3 Fibreglass insulation	229 mm	2.67 kg/m^2	RSI 5.0
Housewrap		0.06 kg/m^2	WB
Engineered wood siding	9 mm	6.21 kg/m^2	
Total: 2,170 kg (68 m^2)	**330 mm**	**31.8 kg/m^2**	**RSI 5.0**

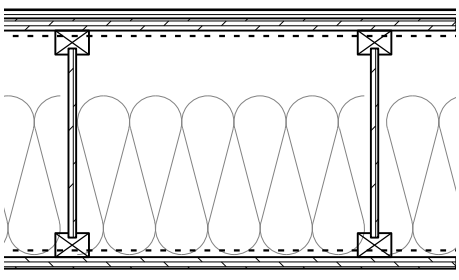


figure A-79: Baseline floor assembly.

278 *Energy Efficient Housing Guidelines for Whitehorse, YT: Energy Optimized House*, report for Natural Resources Canada (Canada: RDH, Nov. 24, 2016), 5.

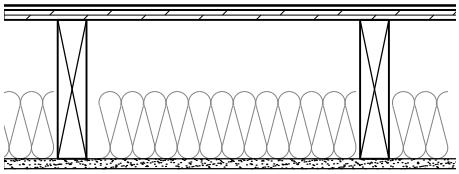


figure A-80: Baseline interior floor assembly.

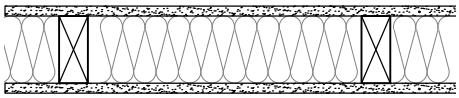


figure A-81: Baseline partition and party wall assembly.

Table A-30: Baseline interior floor assembly

Component	Dimension	Weight	Notes
Flooring	3.2 mm	2.60 kg/m²	
13 mm OSB subfloor	12.7 mm	8.38 kg/m²	
2x8 Lumber joists @ 400mm OC	184 mm	8.29 kg/m²	
Acoustic fibreglass insulation	89 mm	1.16 kg/m²	
13 mm Gypsum	12.7 mm	6.11 kg/m²	FR
1,600 kg (63 m²)	**215 mm**	**25.4 kg/m²**	

Table A-31: Baseline partition and party wall assembly

Component	Dimension	Weight	Notes
13 mm Gypsum	12.7 mm	6.11 kg/m²	FR
2x4 Lumber studs @ 400 mm OC	89 mm	8.90 kg/m²	20% of wall
Acoustic insulation	89 mm	1.16 kg/m²	
13 mm Gypsum	12.7 mm	6.11 kg/m²	FR
Total: 3,070 kg (138 m²)	**114 mm**	**22.3 kg/m²**	

Table A-32: Baseline foundation components

Component	Dimension	Weight	Notes
Steel footing	12 posts	40 kg/post	
Bearing pad	12 pads	6.7 kg/pad	
Gravel fill		N/A	
Total: 560 kg			



figure A-82: Housing in Inuvik, NWT which is similar in form to the baseline project used here. source: John Straube