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# KHS Workshop Feasibility Study

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# TABLE OF CONTENTS

## TERMS

ACH – Air Changes per Hour
CIPP – Commercial and Institutional Power Producer Program
GHG – Greenhouse Gas
HHO – Home Heating Oil
HRV – Heat Recovery Ventilator
HVAC – Heating, Ventilation, and Air Conditioning
IAQ – Indoor Air Quality
LHV – Lower Heating Value
MJ – Megajoule
MgO – Magnesium Oxide
OSB – Oriented Strand Board
Pa – Pascals
PI/KHS – Pitquhirnikkut Ilihautiniq/Kitikmeot Heritage Society
PV – Photovoltaic
QES – Qulliq Energy Corporation
RMA – Return Merchandise Authorization
SIP – Structural Insulated Panels
TES – Thermal Energy Storage
VOC – Volatile Organic Compounds

## EXECUTIVE SUMMARY

The Pitquhirnikkut Ilihautiniq/Kitikmeot Heritage Society (PI/KHS) has been researching and planning a new cultural facility in Cambridge Bay, Nunavut for the past five years. In 2019, they approached the Southern Alberta Institute of Technology's (SAIT) Green Building Technology (GBT) department to assist with designing the facility to address the arctic environment, limited infrastructure, short building season, and history of poor-performing buildings in northern communities. Green building practises capture innovative construction methods that reduce building energy needs, improves occupants' comfort and health, and promotes sustainable and regenerative building practises, all while recognizing total cost constraints. Preliminary discussions between GBT and PI/KHS identified a broad range of solutions available to provide a comfortable, resilient, energy-efficient, healthy building that is cost-effective to build and affordable to maintain. It was decided that a pilot project should be built to select and confirm construction methods and building features for the new cultural facility. The pilot building would reduce the risk of novel technologies in this remote arctic community, while building capacity in Cambridge Bay for innovative construction methods and associated equipment. The building is being designed for a 50-year lifetime, and will consider and accommodate future climate change impacts. It was decided that the planned cultural workshop space would be about a quarter of the size of the large cultural facility.

Extensive community engagement sessions were held virtually to identify issues with current buildings, desired features for cultural activities, and preferences for style and finishing. The GBT team outlined a basic building that is a unique hexagon shape with three shorter additional extensions, mimicking the regional historical design of connecting independent buildings. The building design was revised and refined with community participation and a translated version was prepared for the community's Elders and to recognize the integral Indigenous participation in the project.

The GBT team included features and recommendations in the building design that are expected to meet the overall objectives of an energy-efficient, healthy, and comfortable building that accommodates cultural activities while recognizing historical building styles. Moderate-sized south-facing windows are included to connect with solar cycles, however these can lead to overheating in the summer months. To mitigate this effect a large awning has been included, which can also accommodate solar panels. Another innovation includes diesel-based heating that can be retrofitted into electric heating in preparation for future low-emission electricity from local or utility renewable energy systems.

An energy model was prepared to compare the workshop as designed to a baseline building built to National Energy Code of Canada for Buildings (NECB) prescriptive requirements. The workshop design requires 37% less energy than the NECB requirements, including renewable energy generation. Additionally, a class C cost estimate has been prepared. Completion of the workshop building inclusive of site preparation, project management, and evaluation and monitoring for one-year post construction has been estimated at $1.2 million.

Upon securing funding, the next phase of the project is to finalize detail design and specifications for construction. This will be followed by procurement of the building and components for assembly, testing and training at a convenient location such as Calgary, Alberta. The building will be disassembled, transported, and reassembled in Cambridge Bay in September 2022, then monitored and evaluated quantitatively for building performance and qualitatively for success as a cultural workshop for a year.

## INTRODUCTION

Since 2016, Pitquhirnikkut Ilihautiniq/Kitikmeot Heritage Society (PI/KHS) has been laying the foundation to develop a new cultural facility dedicated to the documentation, revitalization and mobilization of Inuinnait knowledge. The project, titled Nunamiutuqaq (Building from the Land), bridges traditional principles of Inuit architecture with cutting-edge technologies and materials to revitalize Inuit traditions of building in harmony with the Arctic landscape.

## PROJECT BACKGROUND

The Inuinnait Knowledge Centre is conceived as a means to focus PI/KHS' identity and capacity as an Inuinnait organization. Over the years, PI/KHS has struggled to find a coherent voice in Nunavut, being all-too-often torn between representing the interests of all Kitikmeot Region communities, Cambridge Bay residents, and Nunavummiut as a whole. PI/KHS's identity has also been challenged by the location of its headquarters in the Cambridge Bay High School building. It is variously perceived as a high school library, an Elders Centre, or a community Internet site, but rarely locally recognized for the in-depth programming and research in which it excels. The creation of a new facility as a stand-alone research centre will seek to create more coherence in what PI/KHS does and how it is perceived. The Inuinnait Knowledge Centre is envisioned as a space dedicated specifically to the documentation and mobilization of Inuinnait culture, language, and history. The vision for an Inuinnait Knowledge Centre was also inspired by the local need for spaces where Inuinnait can collectively build knowledge according to their own needs, priorities, and schedules.

PI/KHS has also outgrown its existing facilities. The May Hakongak Centre (currently hosting PI/KHS) lacks available/suitable space for the type of cultural programming requested by the community. For example, the cultural afterschool program (attended daily by 40-50 students) requires the entire centre to be closed to the public during peak hours. Cultural activities that are messy (ie. skinning hides, soapstone carving, the butchering of meat) cannot take place within the building due to the proximity to library resources and computers, and needs to be relocated to other facilities, which can be difficult to find. Lack of available space for materials, supplies, and collections is also increasingly becoming an issue. Retrofitting and/or expanding the current building is not an option. The current facility is owned by the territorial government and there is limited leverage to realize sustainable goals.

### *PROJECT HISTORY*

As a research organization, PI/KHS envisions the Inuinnait Knowledge Centre as an important case study in how Indigenous knowledge can be partnered with modern materials and technologies to innovate new directions for more vernacular architectural design in the Canadian Arctic. In 2016, PI/KHS began extensive research into Inuinnait principles and knowledge surrounding traditional architecture, through means of archaeological fieldwork, traditional building reconstructions and community engagement workshops. By 2017, a set of cultural principles was drafted that would guide the construction of the new building, including architectural flexibility, cultural compatibility, and environmentally sustainable/renewable building design. This year also saw the development of a new 5-year strategic plan and concept paper designed to lead the organization towards this goal of a new facility. In 2018, PI/KHS implemented a new philanthropy program and social enterprise designed to begin generating independent revenue towards the future construction and maintenance of our facility. In 2019, PI/KHS team's research into renewable energy and building technologies put them in contact with GBT.

While this partnership was initially intended to develop a pre-feasibility study to assess facility costs and technologies for a future net-zero facility, KHS and GBT quickly recognized the lack of available information and existing documentation regarding the performance of green technologies and materials in similar Arctic conditions. For cost estimates, supply-chains, material/technology efficacy, local industry involvement, and design needs to be properly and realistically scoped, it was realized that KHS should conduct a highly controlled pilot study, rather than chance much more costly mistakes in the final building design. In 2021 the program was redirected towards the creation of a more manageable structure – in the form of a 1,131 square foot cultural workspace that would allow testing and monitoring of selected building materials, building of partnerships and supply chains, and fostering local capacity required to build, manage, and operate the future facility. By prioritizing openness of project data and results, this joint research program will also allow KHS and GBT to address significant knowledge gaps in northern green and renewable architecture by creating, compiling, and sharing detailed information regarding materials and technology performance, community knowledge and priorities, and live data from the ongoing monitoring of the pilot structure.

## *CULTURAL AND HISTORICAL INFLUENCE*

For centuries, Inuinnait have literally been at home on the land. The physical environment provides all the materials they need to not only survive, but also to thrive, in the extreme climate of the Arctic. Their winter houses, igluit, are made of snow. Their tents, tupiit, created from the skins of caribou and other animals that sustain us with food. The tree line at the southern edge of our territory once provided us with the wood we need to frame our tents, buildings and transportation. With the introduction of outside culture, ideas and materials to the region starting around 1910, the localized and land-based vernacular of Inuit architecture began to change. Critical knowledge surrounding Inuinnait architecture began to be lost. As reliance on western housing increased, so too did the social and wellness issues related to living in them. The houses built in our communities are often high cost, overcrowded, made with low-grade materials, and have designs unsuited to our cultural lifestyle. This takes a toll on occupants' physical and mental health, which further impacts the lives we lead outside of our homes.

Since its inception, PI/KHS has initiated programs designed to break the deep cycle of northern architecture that does not fit Inuit culture or lives. This work researches and builds awareness around architectural and spatial principles that Inuinnait have successfully followed for centuries. Much of this work has focused on archaeological excavation and reconstruction. PI/KHS has partnered with the University of Toronto since 1999 to conduct regular archaeological field seasons to document the evolution of Inuit and pre-Inuit dwellings in our region over the last 4000 years. Particular attention has been paid to these structures' architectural strategies for adapting to social and environmental change. By investigating archaeological dwellings and traditional knowledge of cultural structures, PI/KHS have begun to outline key steps for transforming the ways that future buildings are conceived and designed for the Arctic.

The Inuinnaqtun language has also played a key role in the project's conception of architecture. Despite being a language with only 600 speakers remaining, Inuinnaqtun has many key terms that define the overlap between constructed spaces and the activities engaged therein. Much of this language has fallen out of use with the absence of culturally supportive architecture. PI/KHS has worked closely with language experts to restore critical terminology for locally conceived buildings. Design blueprints for the pilot workshop were developed firstly in the Inuinnaqtun language, and later translated into English. The project's involvement of language also addresses the need for the creation of new Inuinnaqtun vocabulary to address the environmentally conscious practices, technologies, materials that inform our contemporary work.

## *PILOT PROJECT OVERVIEW*

The pilot project began in 2021 with the design of a 1,131 square foot modular building as a customized cultural workspace and smaller-scale version of the final facility. This workspace is designed to bridge extensive research in local and traditional Inuit knowledge with recent advances in renewable and energy efficient materials and technologies – many of which have not yet undergone Arctic testing. It is also informed by the experiences of community members within their own homes, learning through their challenges and the solutions they design. This pilot structure will be shipped to the community in August 2022 (only 1 sealift is available per year), and assembled in September following a detailed geo-technical study. The building will be used to test and monitor the performance of renewable/sustainable building materials and technologies in our Arctic environment to target Net-Zero goals, to develop key partnerships and track lessons learned, to test the supply chain, to develop realistic cost estimates for the final structure, to build local capacity for our final facility's construction and maintenance, to develop a long term O&M plan, and to assess the replicability and applicability of selected building technologies to other projects in northern communities. The workspace is developed as a self-contained satellite hub, custom designed to facilitate traditional activities (preparation of skins, fabrication of traditional tools, sewing, etc.), and will be closely monitored and adjusted until December 2023 through workshops and site-based activities to ensure its compatibility with desired cultural uses.

The findings from the workshop will form the basis of the technical feasibility study and final building design, on which construction will begin April 2024 and be completed by March 2026. The final energy efficient building is envisioned as approximately 3,500 square feet distributed on 2 floors (with an estimated first floor size of 2,500 square feet). This new space will accommodate the museum and the archives (with environmentally-controlled collections storage), an innovation hub (flexible space for entrepreneurs to try new concepts), community gathering space, a board room, office space, a dedicated space for the Elders, and the northern research library. Community members have suggested taking advantage of the future site slope to integrate traditional subterranean storage and freezer spaces. In line with traditional Inuit architecture concepts of flexibility and modularity, the outdoor space around the building will be designed to accommodate seasonal activities-including meat preparation, hide drying, and outdoor cooking spaces – activities that are necessary for upholding traditional cultural ecosystems and ways of life. The building is specifically designed to help revitalize Inuit vernacular and spatial concepts that have been displaced by western architecture.

This project is built on the innovation and ingenuity of Inuinnait culture to solve building challenges in the North. This project is rooted in the community and relies heavily on a stakeholder engagement process and local capacity building.

**Inuit architecture:** PI/KHS has been working since 2016 to recover Inuinnait architectural concepts, principles and terminology through conversations and workshops with local Elders, land users, and knowledge holders, and by leading an Inuinnait Archaeology program documenting the evolution of regional architecture and its adaptation to systems of environmental and social change over the last 4000 years.

**Knowledge and needs assessment:** In the spring of 2021, PI/KHS and GBT engaged with the community through meetings, workshops, design charrettes and dozens of interviews with local industry experts (construction and energy sector), home and cabin owners, Elders and knowledge keepers, traditional architecture experts, and the municipal government as well as industry experts in Alberta with cold climate expertise. A meeting with the Board of Elders and staff allowed for the collection of design requirements to ensure that the building would perform well for each cultural activity offered by the Centre. Engagement with community stakeholders is an ongoing process that will be carried throughout the entire project. KHS is planning a land-based visioning exercise with the community to introduce and use the land as a cultural space and further inform the design. The pilot project will be monitored and tested through cultural activities, and feedback will be received after each workshop.

**Capacity building:** The Nunamiutuqaq program is specifically designed to build awareness of green and renewable energy and energy efficient infrastructure among community members and industry experts in Cambridge Bay and foster collaborations with Alberta-based industry experts to share expertise and develop stronger research, experience and business opportunities for partners in the Arctic. Local contractors and builders as well as a renewable energy firm (Qillaq Innovations, CHOU Consulting/Development, and Aurora Energy Solutions) and Alberta partners (ZS2 Technologies, Williams Engineering, others) were involved early in the project and continue throughout the design process. Together, the community and partners have identified challenges and solutions, and this project aims to further build the community's expertise by linking local entrepreneurs to the research team and external industry experts, and by creating an innovation hub for the community to explore and test new research areas (such as building automation systems and solar water heaters). By promoting and building local entrepreneurship capacity, this project will be supported on-site during construction and throughout long-term operation and maintenance.

## *PARTNERS*

Pitquhirnikkut Ilihautiniq / Kitikmeot Heritage Society (PI/KHS) is an Inuit-directed research centre based in Cambridge Bay, Nunavut. Incorporated in 1996, PI/KHS has spent 25 years dedicated to the renewal of Inuinnait culture and the Inuinnaqtun language, and to innovating through the wisdom and experience of Inuit. Its mission is to preserve and renew Inuinnait knowledge, language, and culture for the benefit of all Inuit. Its vision is to concentrate and connect the resources, expertise, and technology critical to Inuinnait cultural and linguistic survival. Since 2002, PI/KHS has independently operated the May Hakongak Cultural Centre based in Cambridge Bay, Nunavut. This dynamic centre functions as a community-focused gallery, library, archives, and museum space, which serves to redefine the role that Inuit people and culture play across all of these spheres. In addition to hosting these facilities, the organization addresses projects of critical importance to the revival of Inuit culture, language, and history. PI/KHS focusses on the urgent needs of Inuinnait—a distinct regional group of Inuit living in the Central Canadian Arctic in the communities of Cambridge bay, Kugluktuk, and Gjoa Haven. The Inuinnaqtun language—the foundation of Inuinnait culture—has less than 600 fluent speakers remaining. By most estimates, it is a language that will be extinct in less than two generations. Guided by a five-year Strategic Plan (2019-24), the organization is leading a coordinated and transformational effort to reverse the loss of Inuinnaqtun in our communities by partnering with Elders, language specialists, competent speakers, and academic linguists to create multiple programs to document the language, mentor the next generation of competent speakers, and develop digital tools for knowledge sharing. PI/KHS has undertaken several monumental digital projects with the help of long-term partners to make Inuit language, culture, and knowledge accessible to communities through the development of several Knowledge Atlases. Over the last number of years, PI/KHS has also sought to document and preserve Inuinnaqtun terminology/pronunciations as well as place names, through ongoing partnerships with local Language Specialists and Elders-in-Residence.

In addition to language initiatives, PI/KHS has over 20 years of experience researching and designing exhibits for local, national, and international audiences, delivering oral history and traditional knowledge projects, facilitating land camps, and hosting technology revitalization projects involving Elders and youth. They additionally run an Inuit social enterprise (www.kaapittiaq.ca), whose creation of products relies on Indigenous-to-Indigenous business networks, local training, and advocacy for female and northern entrepreneurship. We prioritize the building of strong social and knowledge relationships between generations of Inuinnait through an annual Elders-in-Residence program and traditional technology workshop initiatives.

SAIT's Green Building Technologies (GBT) group is one of six applied research areas in SAIT's Applied Research and Innovation Services (ARIS) department. ARIS is SAIT's department for applied research, employing more than 70 full-time employees in support of 100+ industry research collaborations annually. GBT's 20-member team is comprised of engineers, architects, technologists, environmental scientists, and red seal tradespersons. All GBT needs for grant writing, business operations, finance, human resources, accounting, and legal personnel are met in-house, or through involvement of SAIT faculty and students, most commonly from the Schools of Business, Energy, and Construction. GBT's key research themes are: 1) net-zero energy, 2) building integrated renewable energy, 3) smart building management, 4) materials and advanced component assembly, 5) architectural ecology and 6) education and industry transformation. GBT may utilize outside contractors for short term, specialized project needs where appropriate. To achieve the objectives of this project, GBT researchers will partner with Kitikmeot Heritage Society, local Cambridge Bay industries and regional industry partners from Alberta. SAIT has a strong history working with Indigenous peoples, with over two decades of collaboration on applied research and fee-for-service activities with Indigenous industries and communities in Alberta. This is their first project in the High Arctic. GBT has collaborated on applied research and fee-for-service activities with Indigenous industries and communities in Alberta. They understand the need to build relationships and work toward collaborative solutions, they are a trusted partner with a transparent process of work execution, and they have a general understanding and respect for the process of reconciliation. The core GBT team working on this project comprises the following members:

- Melanie Ross – Research Manager
- Tom Jackman – Principle Investigator, Solar expert
- Ben Hildebrandt – Principle Investigator, Material and component development
- Amanda Robertson – Project Coordinator, Project management
- Hayley Puppato – Project Coordinator, Environment Scientist
- Leo Lu – Project Coordinator, Architectural Technologist
- Alex Kodyra – Project Coordinator, Architectural Technologist
- Jeremie Ryan – Technical Aid, Red Seal Plumber, Mechanical and ventilation systems specialist

PI/KHS and GBT built a supportive ecosystem of local and national organizations, partners and consultants around this project, enabling the collaborative to navigate parts of the project beyond any one organization's expertise. This year, KHS retained the services of a sustainable development consultant, who is supporting the team with community engagement and outreach, grant writing, day-to-day project management, and liaison with consultants. Multiple local contractors and renewable energy start-ups in Cambridge Bay – including the Municipality of Cambridge Bay, CHOU Consulting & Development, Qillaq Innovations, and Aurora Energy Solutions – and other northern and Alberta-based industry partners – ZS2 Technologies, Williams Engineering, and others - have regularly joined project meetings and design charrettes early in the program to bring their local and cold climate building expertise to project costing, design, and infrastructure development as appropriate. Northern and Indigenous companies will be prioritized if they are the right fit and have the right technology for this project. This will be determined at the time of procurement. Refer to Appendix A - Project Partners for a detailed list of project partners.

## *KHS WORKSHOP ACTIVITIES*

The design of the workshop space was also guided by information gathered through meetings, workshops and interviews with staff, the Board of Elders, knowledge keepers, local industry experts (construction and energy sector), Alberta industry experts, and home and cabin owners. We also organized a workshop during which PI/KHS staff, the research team and community language experts met with Dr. Max Friesen, an archeologist who has been working on traditional architecture in the Cambridge Bay area for decades. The goal of these meetings was to ensure that the space reflected the cultural needs and that it would perform well for each activity offered by the Centre. Some of the key design considerations were as follows:

- As most cultural activities require participants to sit on the floor, staff indicated the need to have warm, soft flooring for sewing, while meat butchering and skin preparation required colder, harder surfaces; emphasizing the need for floor temperature differential within one space.
- The Elders reflected on the management of heat flow and light in traditional buildings, such as venting at the top of the igloo and windows made of compacted ice. Large south facing windows are required, allowing heat and light for activities such as sewing. Summer heat gains will have to be managed in the summer. Activities such as meat butchering requires cooler temperature and access to water.
- In winter times, snowbanks were built around entrances to protect the structures from extreme winds and snow drifts. Those could be mimicked for a small building such as the workshop.
- Staff and Elders discussed an entrance/vestibule design that mimics the entrance of the igloo characterized by a vertical tunnel with cold-trapping characteristics and ample room for storage. In

particular, this entrance should allow for storage at different temperatures to store skins, fabrics, tools etc.; all having their own optimal temperature profile.

- The need for a sitting area around the edge of the main workshop space led to conversations on height requirements for benches, work surfaces and windows. Too often, interiors are designed for average heights that do not reflect those of the Elders, typically under five feet.
- Stakeholders reflected on the need to have specialized wastewater catchments for meat butchering and skin preparation workshops – in particular the ability to trap blood and grease is essential.
- Working with the KHS language expert, the Inuinnaqtun building environment terminology was captured. This work leverages PI/KHS existing projects on traditional environmental knowledge, Inuit environmental engagement, and vernacular architecture. In particular, the workshop participants reflected on the overlap between language revitalization and cultural revival through the lens of traditional architecture. For example, language experts shared with the group Inuinnaqtun terms that were no longer used, due to the lack of cultural space designed to conduct a particular activity.

As part of the workshop activities focussed on building research and conceptual design, community members and industry experts provided feedback that was captured in a comprehensive database of key construction knowledge, including constraints and issues with existing renewable materials and technologies, how to increase the cultural and domestic usability of built spaces, Arctic-specific design needs and considerations for building envelopes, foundations, water/sewage, heating, shipping times and supply chain recommendations, building automation systems, and high-risk factors from climate change to human error. The following highlights these key considerations:

- There are concerns with climate impacts on buildings in terms of moisture, extreme winter cold, high summer heat gains, high winds, deep snow, freezing rain, and permafrost degradation. Design and materials must account for these concerns.
- Durable materials are required for extreme seasonal conditions, heavy snow loads, freezing rains, etc.
- Due to site considerations there are specific concerns in terms of landscaping and climate, including the slope of the site and accumulating water, permafrost degradation, and changing weather conditions. The design must account for these physical considerations.
- The design of the building should fit into the landscape and not look obtrusive. There should be a flow to the building to match the arctic landscape as well as draw on traditional shapes and layouts. A culturally and regionally appropriate design will be conducted through the feedback and involvement of community members, Elders, and researchers.
- It was identified that there would be large lead times on procuring materials, due to supply chain issues because of the pandemic and also the availability of materials in the Arctic versus other areas of the country, such as Alberta. There are more logistics to getting materials to Cambridge Bay, with barges only being able to drop off materials once a year, weight limits on these ships, and increased shipping costs, all of which will have to be carefully considered.
- Due to the consideration for durable, low embodied carbon, less toxic materials, it is ideal to leverage GBT's relationships with trusted industry partners and innovative technologies to provide the best materials possible for this design.
- Local materials are preferred when possible, there are lower shipping costs and shipping times can be significantly shorter, it supports local businesses and promotes companies that are Indigenous/equitable/socially transparent, and there tends to be less embodied carbon in locally manufactured products. In the Arctic there are very few local suppliers of building materials and therefore it is difficult to source product locally. However, through procurement it is recommended to prioritize local and Indigenous-owned suppliers.

- It is preferred to first build the workshop at SAIT and then disassemble and rebuild in Cambridge Bay. This will test constructability and allow for GBT to create assembly documentation, or allow the assemblers from Cambridge Bay to set the workshop up for the first time with GBT in Alberta. Community members have concerns with constructing, deconstructing, and reconstructing the workshop in terms of structural stability, however this will not be a problem. It is preferred to do this test in order to ensure that all of the systems integrate effectively before it is shipped to Cambridge Bay.
- Within the community it is important to foster long term collaborations between industry partners to facilitate knowledge exchange and support through research and innovation activities. This will be conducted through contracts and will be explicitly communicated to project partners prior to choosing their systems or technologies.
- It is important to keep building designs simple and not overdesigned. These lead to high cost of operation and maintenance in the buildings. Additionally, when systems are overdesigned in this community, occupants tend to turn off equipment, not use equipment properly, or neglect maintenance of equipment due to lack of knowledge. For example, occupants turn off HRVs due to the noise, which has led to the buildup of mould and the inefficient use of this technology. Simple systems with training will mitigate this concern.
- When it comes to design of the buildings, it is important to make sure there are minimal spaces around the buildings for snow drifts to pile up. This is an important building design consideration that will address maintenance and usability challenges (such as snow removal and accessibility of doors/ramps).
- Occupants are severely inconvenienced when water/sewage trucks can’t get to site due to weather. Design considerations of where the trucks will come to deliver water and pump sewage is critical to ensure that these facilities are operable during the winter. Additionally, it is recommended to add sensors to the water and wastewater tanks that will alert occupants of levels approaching empty/full for water/sewage tanks respectively.
- Faulty roof and ceiling designs have led to fresh air intakes frosting up and fine snow blowing into the attics. Humidity and heat of exhaust air can cause a "chimney snow man", which leads to a heavy load on the structure and creates long term damages. Design will need to ensure minimal snow loading on the roof and positioning vents to ensure that exhaust air cannot lead to the buildup of ice and snow. Even when using Arctic vents, have snow/ice built up on the vents, which blocks the air entry. One mitigation strategy is to install vents 4-5 inches off the roof, not more than that.
- Single- and two-story buildings raised off the ground to allow for airflow underneath buildings is common practice in order to prevent permafrost melt.
- Mould has been identified as a concern in existing buildings in this community. Temperature differential between cold and warm ceilings creates condensation and mould. High ceilings would mitigate this problem. Buildings that are airtight lead to mould due to occupants turning off HRVs due to the noise, draft, and perceived waste of energy. Efficient HRVs/ERVs with proper training and education for occupants would mitigate this problem.
- HRV have been reported as noisy and they supply cold drafts, freeze-up or use significant electrical energy to defrost. Humidity problems also arise because the number of occupants in a building is typically much higher than in the south, in part due to cultural practices, but mostly due to the housing crisis. As a result, these systems are not designed to handle the high humidity inside and extremely dry conditions outside.
- HRVs can fail due to intake pipe freezing up because of the hot humid interior air meeting the extremely dry cold outside air. HRVs and ERVs (energy recovery ventilators) can fail due to the cold temperature, although a hydronic heating coil has been identified as a mitigation strategy. Without adequate ventilation, the high interior humidity also causes windows and doors to ice over and not operate correctly. This in turn leads to damaged windows and doors causing cold drafts, and unnecessary additional repairs.

- Air conditioning is generally not currently required in Cambridge Bay. However, temperatures are rising in the spring and summer due to climate change, and air conditioning may be required in the future.
- Near net-zero energy/high performance is desired in order to mitigate high utility and fuel costs.
- There is near constantly a Northwest wind so doors and windows should not be installed on this side. Also, 6 months of the year ice will form on doors, and screens should be installed to keep the doors from freezing shut. A common practice used in the past for doors has been old style freezer doors as storm doors.
- Potable water is delivered by truck and pumped into storage cisterns (or tanks) up to twice per week or as needed. There is no piped sewage systems but every building has a holding tank that is emptied by the municipal sewage service on a weekly basis. During the pandemic, it was recommended to empty the tanks on a daily basis.
- The septic tank is often preferred by community members to remain outside due to health and safety considerations, but the drinking water tank is always stored inside the building. Outside tanks must be prevented from freezing, and often electric heating elements are required which adds to utility cost. Inside tanks must be accessible for cleaning, otherwise biofilms can develop. Some community members try to use heat loops from boilers in the septic tanks.
- There is a lot of dust in Cambridge Bay, this can impact the efficiency of solar panels in the summer, while snow loads impact them in the winter. They must be designed at angles and orientations that prevent the buildup of snow/dust and help facilitate its shedding.
- The only energy sources in Cambridge Bay are electricity from the local diesel generating station, home heating oil that is delivered by truck to storage tanks outside each building, independent diesel generators, or privately owned solar photovoltaic systems that are not allowed to be grid-tied.
- Homes and buildings are heated by combustion of home heating oil, or with excess heat from independent diesel generators. Electric heating equipment is not used as it is prohibitively expensive. Most water tanks are heated through hydronic systems.
- Design of buildings' foundations need to have the least impact on the landscape around them. It is important to not melt the permafrost under the building, as permafrost is critical in the Arctic due to its role in ensuring the ground is watertight, and by maintaining wetland and lake ecosystems for local flora and migrating fauna (Richter-Menge & Overland, 2009). Screw jack foundation systems have been used for community buildings and buildings are now found to be shifting as the permafrost and watershed change. A geotechnical survey and associated recommendations will need to be conducted by a qualified company.

Observed materials used in current Cambridge Bay construction can be found in Appendix B – Cambridge Bay Construction Materials. A summary of the community engagement and workshops comments can be found in Appendix C – Community Engagement Results.

## NORTHERN BUILDING AND TECHNOLOGY RESEARCH

The following section is research conducted for the feasibility study on the specifics of existing infrastructure and potential solutions to concerns raised by community members. Given all the feedback and priorities for the project, undertaken research in the key areas below are to inform the design and construction of the workshop.

### *SITE CONDITIONS*

Climatic conditions, landscape conditions, sun path cycle, and net zero constraints were assessed in order to best inform building design and operation measures.

#### *Climatic Conditions*

Weather is the current, short-term variation in temperature, humidity, precipitation, wind, and clouds. Climate is the trend of weather over a period of time, which is usually 30 years. Climatic conditions that were investigated for this site include snow loads, wind pressures, near-surface permafrost, summertime losses, maximum temperature, ice accretion loads, total precipitation, and mean temperature. Sea level rise, earthquakes, wildfires, and coastal erosion were not concerns for this site, which will be further explained.

Future climatic modeling and predictions is an intricate and heavily studied field. The IPCC (Intergovernmental Panel on Climate Change) uses representative concentration pathways (RCP) to assess future climatic conditions. RCPs are greenhouse gas concentration pathways used for climate modeling by the RCP4.5 (moderate emissions scenario) and RCP8.5 (high emissions scenario). RCPs were utilized to assess future climatic conditions of Cambridge Bay, Nunavut.

The following are definitions of terms used in table 1.

- Ice Days: days where the temperature does not exceed 0°C. Average ice days from 2000 to 2021 was 240 days.
- Maximum Temperature: the warmest temperature for a day. Annual Max temp from 2000 to 2021 was -9°C.
- Mean Temperature: the average temperature for a day. Annual Mean temp from 2000 to 2021 was -12.9°C.
- Maximum 1-Day Total Precipitation: the most precipitation (snow and rain) that is expected to fall within a day (the wettest day of the year). Annual total precipitation from 2000 to 2021 was 190mm.
- Ice Accretion Loads: the buildup of frozen ice, typically from frozen rain or from sea water on ships.
- Permafrost: ground that stays frozen for two or more years.

Based on data from table 1, there is expected to be an increase in snow loads, rapid spring melt, maximum temperature, ice accretion loads, total precipitation, and mean temperature. There is expected to be a decrease in near-surface permafrost. Extreme winds have a range of change and a very low confidence level.

*Table 1 Table of climatic conditions and associated changes for Cambridge Bay for the parameters of snow load, extreme wind, permafrost, rapid spring melt, increased heat, ice accretion loads, total precipitation, and mean temperature. Data taken from ClimateData.ca was taken from the 50th percentile.*

| Parameter | Change | Source | Additional Data |
|---|---|---|---|
| **Snow Load** | +0.2 to 12.5% change in 50 year snow load | CanRCM4LE (Table 6.1). +3°C ensemble (25p, 75p) North Data. Projected changes in design snow loads (SLs). https://climate-scenarios.canada.ca/?page=buildings-report | 1986-2016 baseline. 5.4% (0.2%, 12.5%) Very low to low confidence |

| | | | |
|---|---|---|---|
| **Extreme Wind** | -6.1% to +10.4% change in 50 year hourly wind pressures | CanRCM4 LE (Table 5.1) +3°C ensemble (25p, 75p), North Data. (50-year return period hourly wind pressure) https://climate-scenarios.canada.ca/?page=buildings-report | 1986-2016 baseline. 1.6% (-6.1%, 10.4%)<br>Very low confidence |
| **Permafrost** | -45% change in near-surface permafrost extent | CanRCM4 LE-CanESM2 RCP8.5 (Figure 6.8). Near-Surface Permafrost Extent based on the Surface Frost Index (SFI). https://climate-scenarios.canada.ca/?page=buildings-report | High confidence that future global warming will result in significant permafrost thawing in the regions studied. Approx. -45% (+3°C) |
| **Rapid Spring Melt** | 12.9% change in summertime losses | Blunden, J. and D. S. Arndt, Eds., 2020: State of the Climate in 2019. Bull. Amer. Meteor. Soc., 101 (8), Si–S429 https://doi.org/10.1175/2020BAMSStateoftheClimate.1<br>pg. S252 | 1981-2010 baseline. September 2019 -33%. September monthly average trend for the Arctic Ocean is -12.9% +/- 2.2% relative to 1981-2010 average. |
| **Increased Heat** | +21% to 31% change in average annual maximum temperature | ClimateData.ca - Annual Maximum Temperature Cambridge Bay RCP 4.5 Mean p50 & RCP 8.5 Mean p50 | 2022-2072 RCP4.5p50 +21.1% average from 2000-2021<br>2022-2072 RCP8.5p50 +30.7% average from 2000-2021 |
| **Ice Accretion Loads** | +5.2% to 79% change in 20 year ice accretion loads | CanRCM4LE (Table 6.2) +3°C ensemble (25p, 75p) North Data. https://climate-scenarios.canada.ca/?page=buildings-report | CanRCM4 LE projects overall increases in future design ice accretion loads over most of Canada.<br>1986-2016 baseline. 33.0% (5.2%, 79.0%) |
| **Total Precipitation** | +9% to 13% in total precipitation | ClimateData.ca - Annual Total Precipitation Cambridge Bay RCP 4.5 Mean p50 & RCP 8.5 Mean p50 | 2022-2072 RCP4.5p50 +9.2% (17.6mm) average from 2000-2021<br>2022-2072 RCP8.5p50 +8.5% (20.9mm) average from 2000-2021 |
| **Mean Temperature** | +16% to 24% change in mean temperature | ClimateData.ca – Mean Temperature Cambridge Bay RCP 4.5 Mean p50 & RCP 8.5 Mean p50 | 2022-2072 RCP4.5p50 +16% average from 2000-2021<br>2022-2072 RCP8.5p50 +24% average from 2000-2021 |

Sea level rise is not a concern since this location experiences postglacial isostatic adjustment of over 2 mm/year, meaning that the land is rising (Calihoo & Romaine, 2010). In the next 90 years, there is a range of -25 cm to +45 cm sea level rise, dependent on climate change (Calihoo & Romaine, 2010). With average sea level rise of -1 mm/year to +4 mm/year from 1870 to 1995, there is variability in sea level rise (Calihoo & Romaine, 2010). From reports of community members, sea level rise is not a concern in this community, and specifically this site is not directly on the coast. Earthquake do not occur in this region. Wildfire is not a concern because there is not ample vegetation that could burn in this area, and coastal erosion is not a concern at this site because it is not on the coast.

### *Landscape Assessment*

KHS's preferred site is located at the intersection of Okalik and Natik Streets, adjacent to existing residential uses. The proximity to the ocean, the existing community, the CHARS facility, and the scenic and spacious surrounding landscape for outdoor cultural activities are features of the site that KHS has indicated are attractive. It is the intent of KHS to integrate the building's design with the surrounding landscape. Assuming a floor area of approximately 100 $m^2$, the minimum parking requirement would be 8 spaces. The proposed site is approximately 3,500 $m^2$ in size which provides adequate space for the proposed building footprint, future museum building, parking, and outdoor activity spaces. Figure 1 outlines the proposed site in blue.

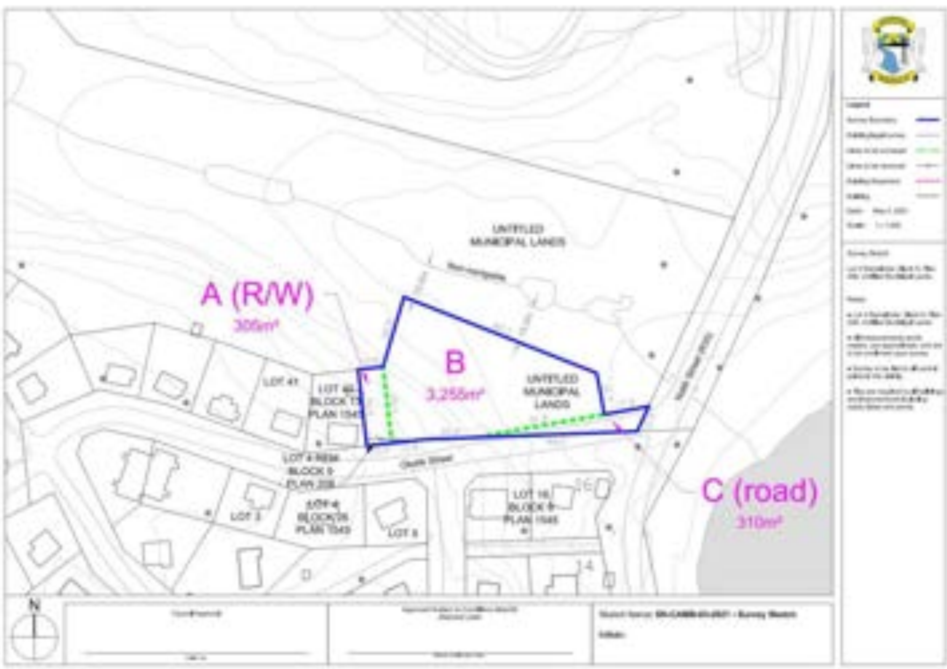


*Figure 1 Proposed site for KHS. Source: Municipality of Cambridge Bay*

The municipality of Cambridge Bay is relatively flat and has elevations of 0 masl (meters above sea level) to 80 masl, with the community's topography remaining relatively flat except for the sharp shores along the ocean (Franz Environmental Inc., 2010). Specifically, this site slopes to the North-East, towards a snowmobile path and out to the ocean. There is some pooling of spring runoff towards the lower elevation of the site, as shown in figure 2. Through additional monitoring of the site conditions and a geotechnical study, there will be more information about the site in order to make informed decisions about structural design.

*Figure 2 KHS site location demonstrating pooling of spring run-off. Source: KHS*

### *Sun Path Cycle*

Sun path cycle is the diurnal (daily) and seasonal path of the sun in the sky due to the earth's rotation. At different latitudes across the globe there are different diurnal and seasonal sun patterns. Typically, the sun rises in the East and sets in the West, however at high latitudes such as in Cambridge Bay, this is not the case. From the end of November to mid-January the sun does not rise, and by late May to July the sun does not set. During the winter months the town goes without sun for 6 weeks and vice versa in the summer. The town gains 20 mins of daylight each day once the sun does start to rise again. Figures 3 and 4 show the sun path of Cambridge Bay on January 1st, 2020 and July 1st, 2020.

Southern Alberta
Institute of Technology
1301 16th Avenue NW
Calgary, Alberta, Canada
T2M 0L4

*Figure 3 Sun Path of Cambridge Bay on January 1st, 2020. Source: Suncalc.org*

*Figure 4 Sun Path of Cambridge Bay on July 1st, 2020. Source: Suncalc.org*

To address this sun path, the roof will be sloped so that the solar panels face south year-round to maximize solar potential. Window height, positioning, and orientation were optimized to maximize passive solar during colder months and minimize passive solar during hotter months.

## *INFRASTRUCTURE AVAILABILITY AND REQUIREMENTS*

In addressing requirements for the building, the local infrastructure availability and associated constraints were assessed. This includes electricity, fuel, potable water, and wastewater.

### *Electricity and Fuel*

Electricity is supplied to the town of Cambridge Bay by Qulliq Energy Corporation (QEC). QEC provides electricity to the entire Nunavut Territory, however there is no interconnection between the 25 power plants servicing 25 separate communities. QEC exclusively generates electricity from diesel generators with all the diesel transported in the summer and stored for year-round fuel supply, and the grid is unable to handle large amounts of renewable energy. The responsibility of QEC is to provide reliable energy, not clean energy, and gaining access to produce clean energy is of concern in the community.

QEC has a policy framework to permit residential customers to generate renewable electricity under a net-meter program. The renewable energy systems under this program are limited to 10 kw AC and the residential client is responsible for purchase and installation of the system as well as operations and repairs. While this policy framework is in place, Aurora Energy Solutions, a private renewable energy firm located in Cambridge Bay, advises that only a handful of grid-connected renewable energy has been approved in Cambridge Bay. Aurora has also confirmed with QEC that no micro-grids with transfer switch (to prevent export to the grid) would be permitted.

Research has been carried out with an objective of building a near net-zero building, but achieving these criteria does not reflect the reality of northern community infrastructure. QEC recently launched a Commercial and Institutional Power Producer Program (CIPP), but it is still in its infancy. No one in Cambridge Bay has successfully accessed the program to date (including the Canadian High Arctic Research Station, which installed a solar wall for that purpose in 2018), due to a slow-moving application process and limits to the amount of power being accepted. CIPP applicants must additionally bear all costs associated with the renewable energy project. The Pembina Institute reviewed QEC's CIPP in 2020, and concluded that "the proposed policy will do little to encourage renewable energy uptake for commercial and institutional customers in Nunavut" (Pembina Institute, 2020), with the Pembina Institute suggesting an increase of power purchase agreement rates for diesel power – meaning that if the QEC takes these recommendations then electricity from the grid will increase in price.

Electricity rates in Cambridge Bay are $.7539/kWh for residential and $.6473/kWh for commercial sites. Residents are eligible for a subsidy of 50% on 700 kWh per month from April through September and 1,000 kwh per month from October through March. No commercial or institutional subsidies were found for Cambridge Bay. Electricity from diesel-fuel generators distributed through the community has a carbon footprint of 0.80 kg/kWh. This compares to 0.57 kg/kWh for the Alberta electricity grid, which is considered high-emission electricity.

Heating oil is delivered to residences and buildings for $1.04/L. Also known as Home Heating Oil (HHO) or Fuel Oil, the energy density is approximately 38.7 MJ/L. This energy source converts to $0.10/kWh to compare to the electricity rate of $0.6473/kWh for commercial clients mentioned above. While available, affordable, and energy-rich, heating oil has a carbon footprint of 2.57 kg/L (Government of Alberta, 2019) which converts to 0.24 kg/kWh. In other words, one tonne of GHG (greenhouse gases) results from burning 389 liters of heating oil. These 389 liters costs $405 for the oil. The federal carbon tax, currently at $40/tonne, adds 10% to the price of this heating energy. The carbon tax is scheduled to increase to $170/tonne by 2030 which is over 40% of the current value of the oil. That same 389 liters, or one-tonne quantity, is equivalent to 15 GJ of heat based on the energy intensity mentioned above.

There is no natural gas or propane available at the site. For comparison purposes, where natural gas is available, the final distributed price in residential volumes with various service fees is about $10/GJ, therefore the same 15 GJ's of energy would cost about $150, less than half the cost of heating oil. In addition, natural gas does have a lower carbon footprint at 1.94 kg/m$^3$ which works out to 0.78 tonnes for 15 GJ of energy or 22% less carbon emission than the equivalent energy in heating oil.

Table 2 summarizes energy costs and carbon footprints in common units of kWh for Cambridge Bay and contrasts that to typical prices for energy across Alberta.

*Table 2 Energy costs in CAD/kWh and carbon footprint in kg CO2e/kWh for heating oil and electricity in Cambridge compared to natural gas and the electrical grid in Alberta. Source: Primary.*

| | Energy Source | unit sold | price | cost/kwh | kg CO2e/kwh |
|---|---|---|---|---|---|
| Cambridge Bay | heating oil | liters | $ 1.04 | $ 0.097 | 0.24 |
| | electricity | kwh (comm.) | $ 0.6473 | $ 0.647 | 0.80 |
| | | | | | |
| Alberta utilities | natural gas | GJ | $ 10.00 | $ 0.036 | 0.19 |
| | alberta elec grid | kwh | $ 0.15 | $ 0.150 | 0.57 |

Cambridge Bay community energy is far more expensive than Alberta utilities and has higher carbon footprints.

### *Water and Wastewater*

The Municipality of Cambridge Bay provides potable water and picks up wastewater from residences and businesses. The service is provided two or three times per week, requiring each building to have 200 to 500-gallon water and wastewater tanks and to protect them from freezing.

Residents do not drink water from their water cisterns as it is shock chlorinated and does not taste good. There were previous times where water coming from the treatment plant in Cambridge Bay was yellow, and residents do not trust the water to drink or cook with. Instead, residents buy bottled water – which is not only expensive but is not environmentally conscious as single-use plastic is wasteful, or they fill reusable bottles, which is also not ideal due to additional costs. Accessible potable water is an ongoing issue in the arctic, as is also evidenced by the current water access crisis in Iqaluit. In Iqalit, there was fuel contamination within the municipal water supply, and from October 12$^{th}$ 2021 to November 4$^{th}$ 2021 the city has spent over $1.5 million on this crisis, which isn't yet resolved (Murray, 2021). Also, residents will melt ice for tea, as it is a cultural tradition and this water is believed to be sweeter. Designing a system to facilitate ice water melt within the building will be further investigated. To help reduce bottled water consumption, a carbon filter can be installed at taps that are used for consumption, or for the entire building. Carbon filters will improve the taste, color, and smell of the water, and is a relatively cheaper option of treatment compared to other technologies. Carbon filters will need to be replaced as specified by the manufacturer and are disposed of in the landfill, however this waste is not hazardous. Carbon filters will be useful in this community as the water is already safe to drink, therefore no additional filters for health reasons need to be added.

There is no storm water drainage system; surface drainage channels direct spring meltwater into the bay. Additionally, the Municipality provides a weekly garbage pick-up service.

### *Waste Options*

End-of-life options are important for all manufacturers to consider in order to aid in shifting to a circular economy. Designing and manufacturing products that are built to last (opposite to planned obsolescence), have minimal packaging, are made to be reused, can be remanufactured and refurbished, and finally can be recycled using our current recycling facilities are all important circular economy aspects for manufactures and designers to consider.

The Arctic does not have the same infrastructure and access to programs for waste management as seen in the south. Many communities in Nunavut produce more waste than their landfills can accommodate, which results in the burning of municipal waste. Much of the regional landfills are filled with materials for construction and consumption that were made in the south and shipped north. There is little to no diversion (manufacturer take-backs, recycling, composting, etc.) of waste from landfills. Commonly, northern landfills are past their intended lifetime, resulting in waste entering the ecosystems. Berms and burn pits are recommendations made to the territorial government to address landfill problems, and neither of these are sustainable options that should be actioned. To extend the lifespan of the dump, Cambridge Bay started a recycling program in 2014 for cans, plastic containers, and juice box containers, and sectioned-off different cells for other waste streams such as tires and batteries (Varga, 2014), but in 2021 it this program is not running. However, all recyclables will still need to be transported out of the territory in order to be recycled. Figure 5 shows the separation of batteries, in order to help separate hazardous waste from the dump.


*Figure 5 Some hazardous waste, such as batteries, are separated from other waste in Cambridge Bay. Source: Hamlet of Cambridge Bay.*

While this project cannot directly address landfill infrastructure, choices can be made to ensure that construction and operation phase waste is not contributing to the problem. In order to do so, low/zero waste products and packaging should be prioritized over products with compostable, recyclable, and landfill packaging (since the community does not have composting or recycling programs). Additionally, as mentioned above, it is critical to design for functionality and for the intended occupants. Not only will this promote the use of the workshop, but it will ensure that the materials and equipment are actually used and not left in place/turned off or thrown out due to the lack of knowledge of operation or complicated operations and maintenance. Another example is prefabricated building assemblies in order to reduce construction waste of off-cuts or mismeasurements. This type of structure would also allow for a design for disassembly, a concept to allow disassembly of the building at the end of its life instead of a demolition – saving salvageable materials from the landfill. A component of design for disassembly includes utilizing screws/nails instead of glues for material reuse.

In principle, it is redundant to ship up technologies or excess materials that will just end up in the landfill. Waste has been designed out of the building (through prefabricated panels and functionally designed equipment), therefore the next steps are to clarify this concern to manufacturers and suppliers during the procurement process and to use waste diversion as a factor for consideration for purchase orders.

## BUILDING STRATEGIES AND TECHNOLOGIES

The following are building strategies and technologies identified and researched for Cambridge Bay. This includes traditional building typologies, design and construction technologies, building system technologies, mechanical system technologies, electrical system technologies, and renewable energy technologies. This information is intended to be used to support the recommendations of different technologies for the KHS Workshop.

Appendix D: PI/KHS Workshop: Sustainability Decision Making Matrix provides context and summary for the following section. This matrix lists out different strategies considered in the building categories of heating and ventilation, cooling, lighting, energy recovery, renewables, energy source, energy storage, solar heat gain control, envelope, foundation, and water treatment. For each strategy, a description and explanations on impacts for sustainability and functional space are provided. Energy savings, durability, and equipment cost are categorized into 'high', 'medium', and 'low' for each strategy. Additionally, operations and maintenance are listed. This matrix describes the strategies in layman's terms while providing information to support recommendations for the workshop building.

## *TRADITIONAL BUILDING TYPOLOGIES*

The building shape and layout was conceived during community engagement. GBT detailed the structure and dimensions which was then evaluated by the KHS team and refined over several meetings and presentations. The resulting design is quite unique and reflects cultural influence while being designed for northern construction methods and materials. While designing this building, GBT incorporated the regional culture and integrated the relationship with the Innuait people and their land to reflect the people and place where it is being built.

During a meeting with Max Friesen, an Archaeologist at the University of Toronto who has been studying Cambridge Bay and surrounding areas since 1999, cultural features and uses within traditional buildings was explained. Some of these features include a sunken entrance tunnel in snow homes to trap the cold, benches at the back of the home for sleeping, south-facing slopes to pick up small amounts of sunlight, digging into the ground for passive insulation and to cut down on the wind profile, double walls on the outside of snow homes for insulation, and a semi-circular wall to block the wind at the entrance. The rounded style of roofs like the igloo was to prevent snow from building up on the roof, this shape helps the wind blow off the excess snow to the other side of the dwelling. These aspects were emulated in the design of the building, by using a round central room with smaller rooms around it, the ramp in a semi-circle to the south of the building, and a transition entrance with a cooler and warmer side. It is anticipated the workshop building will be a very popular center for the intended cultural activities, and the space was designed with a place for all to gather, perform hide/skin preparation, butchering and meat hanging, and a communal kitchen based on the local history and respecting the historical way of life of the community.

Accessibility is a critical concept in green buildings, especially certifications that have social and equity components. Some accessible design strategies include wider hallways, sloped entrances, and no stairs – all of which have additional benefits for able-bodied people including space for social distancing and accessibility for elders or people with children/strollers. Accessibility was addressed during the design phase through the addition of a ramp leading to the same entrance as the stairs, accessible door entrances, and an accessible bathroom.

The workshop layout is in Appendix E – Workshop Drawings along with an Inuinnaqtun version (translated to the local Indigenous language).

### *Resiliency*

Resiliency in buildings is defined as "the intentional design of buildings, landscapes, communities, and regions in response to vulnerabilities to disaster and disruption of normal life" (Resilient Design Institute, n.d.). Resiliency and sustainability overlap with concepts such as energy and water independence, resource storage, community, and environmental impacts, however resilient design focuses more on fortitude and emergency planning. The concept of resiliency has become on the forefront of individuals' minds more due to extreme weather events, caused by climate change, and in-light of the global pandemic. Energy, food, and water security have been prioritized due to these recent changes, and individuals, communities, and governments are addressing these challenges. Resilient design in buildings includes diverse and redundant systems for energy, water, and transportation, passive and flexible systems, locally available and renewable resources, and social equity (Resilient Design Institute, n.d.).

Community centers are typically buildings that act as emergency shelters and disaster relief, and to do so these buildings need to be resilient in order to support the community. A way to create resilient designs includes diversity. By creating systems that are redundant, it is less likely that the entire functionality of the building will be lost if one system shuts down. For example, energy should be sourced from multiple sources – between the grid, different types of renewables, and backup generators or energy storage, there is an increased resiliency of the building in case one of these systems fail. This should be completed with all the key functional aspects of the building – energy, water, and food. Due to the remote location, climatic restrictions, and lack of infrastructure, water security is more difficult. However, there are opportunities to support resiliency such as integrating on-site water collection and water treatment. In more southern climates, it is recommended to have a two-week supply of emergency food. In the Arctic a larger supply is recommended. Food storage is a familiar concept within Inuinnait culture, with an example of dry meats stored in the sides of cliffs in the Bathurst Inlet. It is critical to address resiliency, especially in a community building.

### *User Accessibility and Function*

A key component of green building philosophy is durability – creating spaces that function, are accessible, are beautiful, and have connections with nature and community to promote the longevity of the building. If occupants enjoy and are connected to their space, they are more likely to take care of the building.

Through design meetings with community members, Elders, and the archeologist, crucial considerations for space were identified. Based on this feedback, the entrance was designed as a transitional space between the cold outside and warm inside, and will be a suitable temperature for storage. Another thermal design consideration is the floor temperature based on function. There are 4 functions on the floor – tool making, meat preparation, hide preparation, and sewing – all of which require different temperatures and can be achieved with different hydronic heating zones. For example, the meat preparation section will need a colder floor in order to not spoil the meat, however the sewing work will need a warmer floor as occupants will be sitting on the floor. A structural consideration is the windows and door height. Conventional heights are too tall for Elders. High storage areas and sitting benches will also need to be made accessible to those who are 5’ 4” and below.

Exterior design is being conducted in Phase 2 and recommendations will be determined from subsequent research.

### *Biophilic Design*

Bio means living, philia means love. The biophilia hypothesis suggests that humans possess an innate/genetically determined tendency to seek connections with nature and other forms of life. Incorporating biophilic elements such as natural materials and emulating the surrounding environment’s textures and tones into the design helps promote and enhance human-nature relationships within the residence. Studies have proved that this has a positive impact on mental and physical health. There are 6 principles of biophilic design, from environmental features, natural shapes and forms, natural patterns and processes, light and space, place-based relationships, and evolved human-nature relationships.

Some biophilic design tactics for use in the Arctic include the use of natural materials, incorporating daylighting when possible, promoting cultural connections through design, and encouraging a sense of place. Through the design phase there was consultation with community members and feedback from Elders about the design of the building and how this design can facilitate a cultural connection within the community. Moving forward, it is important to continue that participation with the interior design of the buildings, including the textures and colors of the finishes and interior lighting. Biophilic design relates back to the functionality of the space – and if occupants don’t find connection to nature, each other, and themselves within the space then it will not be utilized to its full potential.

## *DESIGN AND CONSTRUCTION*

The technology utilized in the building structure of the KHS Community Centre must be optimized to ensure a smooth and successful construction process, long term durability of the building, and proper performance of the building envelope (the outer shell of the building that serves to separate the interior and exterior environments). In the design and construction of any building there are many decisions to be made in terms of materials, products, and systems. These decisions must consider four key factors: cost, performance, ease of construction, and durability. In many construction projects, cost and ease of construction are the key aspects that are considered with minimal to no attention given to performance and durability. In remote and northern communities such as Cambridge Bay, all four of these factors must be considered. The following list and sections further explain these key factors:

1. Cost is a strong factor in any construction project to ensure expenditures fit within the available budget.
2. Performance should be strongly considered to ensure the building provides a comfortable environment that meets the usage needs for the building. Additionally, performance of the envelope assemblies will strongly influence the operational and maintenance costs for the building.
3. Ease of construction is a key factor to be considered in Cambridge Bay due to the limited resources available, cost of labour to construct and commission buildings, and the short construction season.
4. Ease of operation is important in northern communities to ensure operation and maintenance of the building, accounting for the local workforce.
5. Durability is overlooked in most construction projects as budgets take a strong priority. In Cambridge Bay, durability should be a key consideration as maintenance, material, and labour costs are higher and the location presents unique climactic conditions that may result in premature failure of insufficient materials and systems.

### *Cost*

Most construction projects will utilize upfront cost as the key factor in making decisions relating to design and construction. Due to the location and climatic concerns of Cambridge Bay, it is recommended to increase investment into the building structure and envelope components. This will reduce operational and maintenance costs moving forward. If cost cutting measures are required to stay within budget, it is recommended that these measures be minimized on building envelope components.

### *Envelope Performance*

Envelope performance often holds lower priority during building design and construction compared to construction costs. It must be understood that added focus and expenditure towards increased envelope performance will lead to increased building durability and decreased operational and maintenance costs. Additionally, upfront investment in envelope performance is most often a one-time investment leading to savings for the life of a building. Post-construction envelope improvements are significantly costlier and time consuming than if those same improvements were to be incorporated at the original time of construction.

When considering envelope performance, three main categories should be considered: durability, thermal performance, and airtightness. They are explained below.

*Durability*

Up-front investment in higher quality and more durable envelope materials and components will ensure better long-term envelope performance and reduced maintenance requirements. Following the design of a building, a phase known as value engineering is often completed to suggest cost saving options. In many cases, this will include substituting a lower cost material or product for that originally specified in the building design. In most cases, lower cost materials and components are less durable than their costlier alternatives. Careful consideration should be taken to ensure that the final materials and products utilized are selected primarily for their durability and performance properties, not their cost alone.

*Thermal Performance*
Space heating makes up a significant portion of energy demands in Cambridge Bay. Increasing the thermal resistance of building assemblies during construction will provide energy savings for the life of the building. During the design phase of the building, the wall, roof, and floor assemblies should be evaluated based on the thermal resistance of the systems being utilized, and the resulting space heating requirements.

A phenomenon known as the law of diminishing returns should be considered. When increasing insulation in an assembly, adding an additional value of insulation will result in diminishing amounts of heat savings for each amount of insulation added. This is illustrated in figure 6, and results in the greatest energy savings per inch of insulation added for the first several inches, after which the amount of energy savings per inch of insulation decreases. This should be considered when determining final thermal performance values for the KHS Community Centre to ensure optimal energy savings are achieved for the cost of construction.

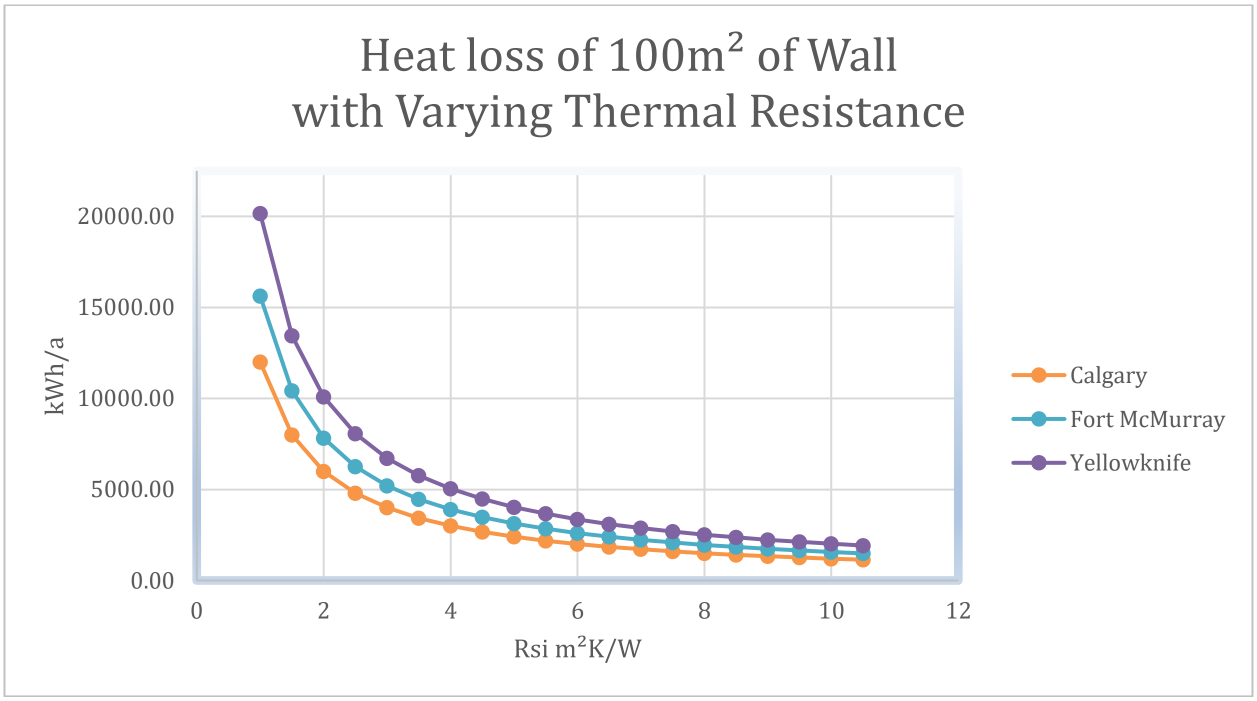


*Figure 6 Figure of diminishing returns. Source: Primary*

*Airtightness*
Just like an unzipped parka can lead to an uncomfortable outdoor stroll in the winter, air leakage can result in significant heat loss from buildings. Concentrated areas of air leakage such as drafts at exterior doors can also lead to significant frost buildup in the winter. In worst case scenarios, air leakage can be the largest source of heat loss in a building. Full architectural details should be developed in the design phase to address continuity of the air barrier at all transitions, connections, and penetrations through the building envelope. Combined with the use of a medium to heavy duty self-adhered weather barrier membrane, high-quality sealants and air barrier tapes, and well-sealing windows and doors with easily replaceable seals will ensure long-term airtightness of the building.

With increased airtightness, there is increased awareness and advocacy for healthy building materials to reduce sick building syndrome (SBS) – a term used to describe occupant's acute health and discomfort linked to spending time in a building. Therefore, it is important to utilize healthy building products, including those that have low/no VOCs (volatile organic compounds).

### *Ease of Construction*
The remote location and temperature concerns of Cambridge Bay increase the necessity of reducing on-site construction requirements and making those tasks as simple as possible. It is recommended to use prefabricated modular or panelized systems with simple yet durable connection detailing. These systems should also incorporate, where possible, pre-installed and detailed windows and doors. Moving the majority of the construction process to an offsite factory setting will help ensure the quality of the constructed building, reduce construction labour time, reduce potential weather impacts during the construction process, and reduce waste generated during construction.

### *Maintenance and Durability*
Maintenance and durability go hand-in-hand. Materials, products, and systems that are less durable require more frequent maintenance and, for shorter lived components, more frequent replacement. Considerations for maintenance and durability of the building structure can be broken into four primary categories: finishes, operable components, enclosed components, and envelope detailing. These are explained below.

*Finishes*
The key components of a building structure that require maintenance are the interior and exterior finishes. Vinyl siding should be avoided due to its brittle nature in cold weather. Cladding materials should be selected that maintain impact durability in cold weather such as metal or composite wood materials. Site applied paints or stains should be avoided for exterior materials as these will require regular maintenance and re-application every 5-15 years. Factory applied finishes should be selected as these can last over 20 years. When selecting exterior finishes, dark and bold colours should be avoided as these have been known to fade due to UV exposure over time.

Interior finishes will be protected within the building and will not be subjected to the same degradation as exterior finishes. The main source of degradation will be physical wear and tear due to building use. Materials with a high wear resistance should be selected for high traffic areas.

*Operable Components*
Operable assemblies such as doors and windows should be selected both for their durability and for the ease of maintenance to replace seals that will wear over time. Key materials to be considered for window frames and door frames and panels are steel, aluminum, and fibreglass. These materials require minimal maintenance. Wood performs better from a thermal standpoint but will require refinishing in regular intervals ranging from 7-15 years. Vinyl windows should be avoided as vinyl can become very brittle in cold weather making it very susceptible to impact damage. Windows that open in a swinging motion should be favoured over those that slide. This is because the seals used to prevent air leakage and water entry in swinging windows have a significantly lower wear rate and seal notably better. Proper sealing of windows and doors will prevent air leakage leading to frost build-up on windows and doors as well as the related moisture damage as the frost melts during warmer weather.

*Enclosed Components*
Components that are not easily maintained, such as the materials enclosed within a wall assembly which perform a key function of building performance, should be selected for their durability to minimize repairs and replacement. Failure of one of these components will result in costly repairs due to the labour required to remove materials that have been installed over these components and the shipping of specialized equipment to the remote community. Weather barrier membranes are the key components which fall into this category and are primarily tasked with preventing water entry into the building assembly and air leakage through the building assembly. While many low-cost weather barrier membranes are available, these typically degrade faster and can also be damaged during installation and the construction processes. To ensure long-term durability and proper functioning of the weather barrier, it is recommended to use a medium to heavy duty self-adhered (has an adhesive on the backside) weather barrier membrane. Additionally, depending on the assembly used, an interior polyethylene sheet membrane (or

other similar membrane material) is often used as a vapour barrier in the assembly. These do not typically wear over time but care should be taken that they are not damaged during construction.

*Envelope Detailing*
One of the key aspects of building construction required to ensure long-term durability is the envelope detailing. Enclosure detailing is concerned with how all of the different components are connected together and must be done properly to ensure proper control of water, air, vapour, and heat loss through the assembly. Focusing on connection details between walls/roofs, wall/floors, and how windows and doors are installed is key. It is also important that detailing around smaller envelope penetrating components such as electrical components and vents is conducted carefully to ensure they do not present a path for airflow or moisture entry. A drainage plane of 5-13mm should be provided behind the cladding system to allow free drainage of moisture. This will greatly reduce the likelihood of moisture entry from the exterior into the assembly and will also help facilitate drying of the assembly should it happen to get wet. The placing of a drainage plane between the backside of a cladding system and the underlying weather barrier is known as a rainscreen.

One item used very frequently to provide sealing between components is sealant (also referred to as caulking). Sealant can provide excellent protection against air leakage and moisture entry but it is a component that needs to be annually inspected, and removed and replaced when it wears out sometimes in as little as 5 years. Using a high-quality silicone-based sealant can more than double the material costs for sealant but can extend the replacement timeline to 20 years or more. Special thought can also be taken during building design to minimize the amount of sealant needed during construction.

With proper planning, execution and consideration of the items noted above, building durability can be increased and maintenance needs decreased. This will increase the longevity of the building and its structural components as well as reduce maintenance costs.

## *BUILDING SYSTEMS*
Special considerations are also required for foundation and envelope systems to not only meet the four objectives noted above but also satisfy local conditions and priorities identified during community engagement

### *Foundations*
The following are different types of foundations used in the Arctic:

1. Triodetic foundations: metal-based foundations that can withstand flooding, permafrost, and other solids. Figure 7 shows a triodetic foundation from Multipoint-Foundations.

*Figure 7 Triodetic foundation. Source: Multipoint-Foundations*

2. Blocks and wedges: the main beams supporting the building are supported at intervals, by pads of horizontally placed timbers that are stacked to create an air space underneath the building. These pressure-treated blocks are placed on a gravel pad that has been stamped down and leveled at time of placement. The air space is necessary to prevent the transmission of heat from the structure into the underlying ground as well as to facilitate releveling of the structure. If there is settlement over each year, a pair of wedges provides the adjustment capability. Figure 8 shows a diagram of this foundation system.

*Figure 8 Pad and wedges foundation system. Source: Qillaq Innovations*

Steel piles: pile foundations are an option for foundation systems for permafrost regions. These are drilled deep into the ground until it hits bedrock for stability. This type of foundation is the costliest and have been reported to fail in the region due to melting of the permafrost. Qillaq Innovations typically recommend piles because there is less civil work, less gravel, and less site disturbance. Minimizing site disturbance is important as it was identified as a concern by the Elders in order to not disturb bird populations, and it will help with revegetating the site. Figure 9 shows a cross-section of steel piles.

*Figure 9 Cross-section of steel piles. Source: Qillaq Innovations*

3. Screw piles: jacks that can be periodically adjusted to keep the house level. These jacks are placed on wooden platforms on a gravel pad to spread the weight. Qillaq Innovations out of Cambridge Bay recommends Screw Jacks or Clock and wedges. Figure 10 shows adjustable screw jacks.

*Figure 10 Adjustable screw jacks. Source: Qillaq Construction*

The geotechnical report has not yet been completed for this site. EnGlobe Corp. is conducting this study and the appropriate recommendations for foundation types will be concluded from this study along with the research gained in this feasibility report.

### *Envelope and Materials*

Material transparency and healthy materials are literally the building-blocks of green buildings. Material selection influences factors such as embodied carbon, supply chain and environmental toxicity, energy demand, water foot printing, waste, biophilic design, and indoor air quality (IAQ). Prioritizing materials that have third-party verified labels for their environmental footprint, toxicity assessment, and VOCs (volatile organic compounds) – which contribute to poor IAQ – has become increasingly popular in green buildings. Manufacturer information, such as an Environmental Product Declaration (EPD), is useful to determine embodied carbon, toxicity, energy and water demand, and end-of-life options.

Feedback during community engagement identified key priorities to be addressed in the design and construction of the workshop and community centre. These include:

1. Weight and size restrictions for shipping
2. Materials need to be:
    a. non-toxic
    b. affordable
    c. durable
    d. easy to maintain or replace
    e. mould resistant

    f. local where possible
    g. considered for end of life uses
3. Built to withstand extreme temperatures
4. Building envelope needs to be well sealed and air tight
5. Building must withstand interior humidity levels without resulting mould growth
6. Building to be easy to construct with tele-handler (no crane available)

The two overarching priorities that should influence envelope and material selection should be shipping constraints and need for ease of construction. Within these, other considerations should be factored in.

Panelized construction can lead to lower site construction requirements while maintaining higher performance levels, and do not have the shipping/site logistics concerns of shipping completed modular buildings. Based on this, it is recommended that a panelized construction system utilizing expanded polystyrene insulation (EPS, also referred to as Styrofoam) be used. Panelized construction systems typically fall within two categories: structural insulated panels (SIPs) or framed systems.

- SIPs are an excellent system for achieving a quickly constructed insulated structure that is very airtight. Traditional SIPs consist of EPS insulation with OSBs (oriented strand board) on each side. While OSB is susceptible to moisture damage and mould growth, a few Alberta manufacturers including ZS2 technologies have been utilizing magnesium oxide (MgO) based panels in place of OSB in order to provide SIPs with superior strength, better fire resistance, as well as moisture and mould resistance.

- Contrarily, many manufacturers and home builders throughout North America utilize panelized wall systems that consist of wood framed sections that are pre-constructed and are quickly assembled on site. These can be done to varying degrees of completeness – for example fully finished walls with only joints needing to be treated. Wood framed panelized walls can be designed and manufactured to facilitate a variety of building constraints and requirements. While the manufacturing process may not be as streamlined as that for SIPs, wood framed panelized walls can be constructed utilizing EPS insulation and MgO panels and can achieve high levels of airtightness and durability.

SIPs and framed wall systems provide excellent solutions for building construction in Cambridge Bay, but there are 2 factors that need to be addressed:
1. Panelized systems are typically constructed with linear and perpendicular connections. Complicated joining techniques will have to be developed and refined to address the preliminary octagonal building shape that has been proposed.
2. MgO boards can be utilized on the interior as a durable finish surface but a weather barrier and cladding system will still be needed on the exterior of the panels. This is commonly done with wood-framed wall systems and may also be possible with SIPs.

Windows and doors should also be installed in the panelized system where possible prior to shipping to improve the durability and performance of those installations by completing them in a factory environment. This will also minimize the amount of complicated construction detailing needed on site.

In the interest of long-term durability and minimal maintenance we recommend the roof system consist of a full waterproofing membrane under standing-seam metal roofing. Additionally, standing-seam metal roofing can easily accommodate the installation of solar panels without compromising its integrity. Wall cladding should be either metal or composite wood. We recommend against cementitious cladding materials as they have proven to be very brittle in any temperature and may be damaged during shipping and installation.

Preliminary designs have indicated a mechanical room will be provided as opposed to mechanicals being located in the crawl space below the building. The floor system should be highly insulated with an EPS insulation. This can be accomplished utilizing SIPs or framed systems. We also recommend a false floor be provided above the main floor structure to provide a location for routing services without penetrating through the insulated and airtight floor structure.

## *MECHANICAL SYSTEMS*

### *Heating*

For occupant comfort in Cambridge Bay a central heating system is required with effective heat distribution method. A central heating appliance can be a furnace for forced air distribution or a boiler for hydronic distribution and each have different characteristics.

Forced air systems require ducting to all areas of the building to distribute heated air and return cooler air back to the furnace for re-heating. Air filtration and humidification are usually included in the air distribution system. Zoning is not commonly practised with forced air systems and the heated air is sent to all outlets when the system runs. The distribution ducting may include dampers that are set upon commissioning to adjust the amount of air sent to each space. Generally, one thermostat is mounted in a central location, on an interior wall, and it controls the forced air system when temperature reading deviates from the setpoint temperature.

Hydronic systems utilize piping systems from a central boiler to send heated fluid to hydronic distribution which may be in-floor tubing, baseboards, or forced air using a water-to-air heat exchanger with a fan and ducting system. Zoning is typically included in hydronic systems with each space having its own thermostat that will direct heated fluid just to that zone. When the hydronic system uses fluid-based distribution, such as in-floor or baseboard, there is little air movement and no opportunity to add air filtration and humidification with the central heating system. Those functions are accomplished in the ventilation system discussed below.

There have been issues raised by community members about glycol loops in hydronic systems. First, there can be problems due to extreme cold conditions, such as condenser loops freezing and leading to equipment failures. Next is maintenance of these loops. The Cambridge Bay High School has never changed or cleaned their hydronic loops due to cost and a lack of disposal options. The following addresses these concerns:

- High-quality glycol can prevent freezing of the system without compromising the performance of the loops. Adding glycol (an antifreeze agent) to the system will prevent the pipes from freezing during times when the building is not heated, for example during a power outage.
- Ethylene glycol is a popular glycol choice, however this is toxic and is not recommended. Instead, propylene glycol is recommended and is FDA approved (it is used in industrial food processing). Disposal options are limited in the arctic, however propylene glycol can be safely diluted in a municipal system, and it is recommended to discuss this with the municipal sewage treatment plant.
- Glycols have different lifespans depending on their quality. High-quality, pre-mixed glycols can be used for 20 years, whereas other products can be used for 3-5 years.

The central heating appliance, whether a boiler or a furnace, can use electricity, diesel, or heating oil which are the primary energy sources in Cambridge Bay. In other locations wood, propane or natural gas are commonly available energy sources.

### *Ventilation and Humidity Control*

Ventilation is required to maintain the quality of indoor air. Without ventilation the interior air space degrades with accumulated odors, volatile organic compounds (VOC's), increased levels of $CO_2$ and water vapour as well as potentially other gasses and airborne contaminants. The indoor air must be recirculated and some fresh outdoor air must be introduced to the air stream to maintain overall air quality. A heat-recovery-ventilator (HRV) or an energy-recovery-ventilator (ERV) should be included to reduce energy needed to heat or cool the incoming air and then the air should be conditioned to the desired indoor temperature before distribution throughout the building. In some cases, the recirculated air and fresh air are combined meaning that all air flow is fresh air. However, this causes issues when the outdoor air is far colder than the indoor air. An example of this can occur when there is ice build up in the HRV/ERV. The air ventilation system may be integrated with the heating system or installed as an independent mechanical component, the latter of which is more likely with a hydronic heating system. To maintain air quality electro-static or media filters and humidification should be included in the piping system. Other features such as de-humidifiers or UV (ultraviolet) sterilization can also be included in the ventilation air system. Since bringing in fresh air increases energy for heating or cooling, this function is often controlled with variable speed fans and timers or manual control that increase or decrease the amount of fresh air.

While all aspects of indoor air quality can be addressed with ventilation, high humidity levels have the most obvious problems such as condensing on windows or other cold surfaces, accumulating moisture in building components, and the resultant degradation of materials and risk of mould. In extreme cold climates like Cambridge Bay, the excess moisture on doors and windows turns into ice impeding correct operation and often reducing air sealing and creating cold drafts. Of course, too low of humidity levels also causes discomfort with cracking skin, dry cough and static shocks.

The ventilation systems need to be designed to circulate the indoor air, provide the optimal humidity level, and bring in fresh air that is conditioned to ideal temperature prior to distribution.

### *Cooling*

Cooling of building indoor air is accomplished with refrigeration cooling of the air. This can be included in the central ventilation system or installed locally to cool just one space. The refrigerated cooling can be a conventional compressor driven unit or an air-source or water-source heat pump system. Upon review of the Cambridge Bay climate, no refrigerated cooling should be required, although passive solar gains need mechanisms to limit overheating the indoor spaces.

### *Plumbing Systems*

Unlike most urban settings, in Cambridge Bay potable water is delivered to site and stored in cisterns for occupant use. This water needs to be pressurized for distribution throughout the building and a portion needs to be directed to a hot water heater and associated hot water distribution piping. The fresh water cistern needs to be kept from freezing which is accomplished if it is located in the heated living space or a partially heated adjacent space.

Similarly, the waste water from all drains is captured in a tank that needs to be heated, or located in a partially heated space. Waste water is picked up and disposed in the community waste facility on a regular basis.

## *ELECTRICAL SYSTEMS*

As mentioned above, electricity in Cambridge Bay is provided by a Qulliq Energy Corporation (QEC) at standard North American specifications: 120/240 Volts, single phase 60 hertz alternating current. The utility endeavours to be a reliable electricity source with redundant generators and local technicians to deal with any outage issues. The standard voltage enables a plethora of electrical devices to be utilized in the building with an extensive selection of lighting, kitchen appliances, entertainment devices, and communication systems.

It is anticipated that the new development for KHS will be based on the existing electricity grid standard, even if the systems is self-generating or eventually transitions to off-grid. The only conceivable alternative would be a 12-volt direct current electricity that is used in recreational vehicles and marine applications, however there is limited devices available for this voltage and it is not considered a viable option for the intended building uses. Energy-efficiency should be a primary consideration in all electrical devices considering the cost and carbon footprint of grid-supplied electricity and the limitations on self-generated electricity discussed earlier. Energy efficient systems include HRVs (heat recovery ventilation) and ERVs (energy recovery ventilation) with pre- and post-heaters on the fresh air, high-efficient furnaces with programmable thermostats, air-source or ground-source heat pumps, and radiant heating. LED (light emitting diode) lighting is recommended as a lower electrical usage system compared to fluorescent lighting, and occupancy-controlled lighting (automatic/vacancy sensors) is recommended to help reduce electrical costs. Efficient appliances are typically identified with an EnergyStar rating from the US EPA (United States Environmental Protection Agency) (which also has a WaterSense label for water conservation) or Energuide Rating from Natural Resources Canada. Consumption and human behaviors are important to energy conservation, as even a high-performance building could have high energy usage with high-consumption occupants.

## *RENEWABLE ENERGY SYSTEMS*

In addressing renewable energy systems, it is imperative to ascertain grid connection constraints with renewable energy integration, as well as designing a system that can function year-round with renewable energy generation and energy storage. There are constraints in terms of grid interconnection, renewable energy sources, and energy storage designs within Cambridge Bay, and they are further discussed in this section.

### *Grid Interconnection*

As mentioned above, QEC has a policy framework for all grid-connected renewables up to 10 kW AC (alternating current) and 12 kW DC (direct current). Given the high-carbon footprint and expense of heating oil and QEC electricity, the incorporation of renewable energy will be very beneficial to achieve project goals. Solar photovoltaic (PV) and wind generation can be grid-connected and reduce the electrical energy needed from QEC. The addition of a battery system would further reduce exports and imports from QEC. Solar thermal, which directly reduces heating energy use, is not affected by the grid connection regulation. Each of these technologies is discussed further in this section.

Because of the 10kW limitation, it will be difficult to generate all of the energy the proposed workshop building is forecasted to consume, which is almost 40,000 kWh per year. Table 3 outlines renewable energy possibilities for the KHS workshop.

*Table 3 Renewable energy possibilities and calculations for the proposed KHS workshop. Source: Primary*

| Workshop Energy Required (kwh) | | 40,000 |
|---|---|---|
| solar PV - 5 kw AC | 5,700 | |
| wind - 5 kw AC | 13,000 | |
| solar thermal - 90 tubes | 6,300 | |
| total renewable energy | | 25,000 |
| Net grid energy required (kwh) | | 15,000 |

The cost of 15,000 kWh grid electricity will be about $9,700 annually and will total 12 tonnes $CO_2$e carbon footprint. At this point, further development on the site for additional renewable energy will have constraints of approval time and the current 10 kW limitation per site.

### Solar Energy

Solar PV panels can be installed to generate electricity and reduce the demand for electricity from QEC, the local electric utility. Solar PV panels have been included in the preliminary design incorporated into an awning over the south-facing glazing. This solar awning will also reduce summer heating by shading the windows in the summer time. Some solar PV panels are also shown on the roof of the building. Another option is to mount solar PV on the site, but not on the building. These could be conventional ground mount however a two-axis tracker would be far more productive given the sun path for the high-latitude site. A two-axis tracker follows the sun rotating the solar array from northeast to northwest and from vertical to almost horizontal angles, keeping the panels facing directly at the sun under almost all conditions. A single-axis solar tracker was installed and tested in 2019 in Whitehorse, Yukon by Cambridge Energy Partners and Solvest. Their test tracker functioned below -40°C weather, and showed that the solar panels increased in efficiency at lower temperatures (Carreau, 2019). Figure 11 shows the dual axis solar tracker from Deger Energie.

*Figure 11 Dual Axis Tracker. Source: Deger Energie*

Solar thermal technology could also be included. One idea is to mount solar thermal collectors almost vertically on the outside of the veranda providing southeast, south, and southwest thermal collection. The heated fluid from the solar thermal collectors will be piped to the mechanical area and can be used for domestic water heating as well as space heating loads. While the solar PV will reduce purchased electrical energy, solar thermal will reduce heating energy required by the heating electrical system. Figure 12 shows solar thermal collectors integrated into a fence.

*Figure 12 Solar thermal collectors as part of a fence. Source: Simple Solar Heating Ltd.*

### Wind Generation

The solar resource in Cambridge ranges from 24 hours sunlight to 24 hours darkness in winter. This makes solar a fantastic energy supply for a few months of the year and completely ineffective for a few months of the year. Wind generation, however, is very promising to provide energy in the winter and can complement summer solar generation. Wind and solar are often complementary as sunny days are often associated with less wind, and cloudy days typically have more wind. The wind industry is dominant in large-scale (mega-watt) generating stations. QEC may consider a large wind turbine, however that is outside the scope of KHS project consideration. Small scale wind, up to 10 kW, could be very productive provided the wind station is engineered for cold temperatures. A vertical-axis turbine may be more robust in this environment than a horizontal axis unit. Figure 13 shows a vertical-axis wind turbine.

*Figure 13 Crestview Solar wind turbine. Source: Primary*

There are concerns within the community about the noise from the turbine, birds in the area potentially getting hurt from this equipment, and children playing on the turbine. There will need to be additional studies in the future about the concerns raised by the community along with the durability of wind turbines in extreme cold temperatures.

### *Storage Systems*

The benefit of a storage battery in a grid-connected site is that it will reduce the amount of electricity that is exported to the grid when the loads are less than the generation, and shift that stored energy to later use thereby reducing the energy imported from the grid. Energy storage can also be setup for backup power in the event the grid goes down, increasing resilience of the site.

Lithium battery based electrical storage systems are commercially available from 3 kW of energy up to 100 kW or more. They do require sophisticated controls to oversee when to charge or discharge the batteries, when to disconnect from the grid to enable non-grid operation if the grid goes down, when or if to export surplus renewable energy to the grid, and several other control parameters. One possible product is the Evolve by Egauna Technologies, shown in figure 14. The control unit is common for 5 kW energy supply and up to three battery modules of 14 kWh each for a maximum storage capacity of 42 kWh. One interesting capability of this unit is it can be programmed to maximize self-consumption (store surplus energy for later use on-site) while keeping a reserve percentage in case the grid goes out. However, at this time the Evolve only has one DC input, and this site will need at least two for solar and wind generation.

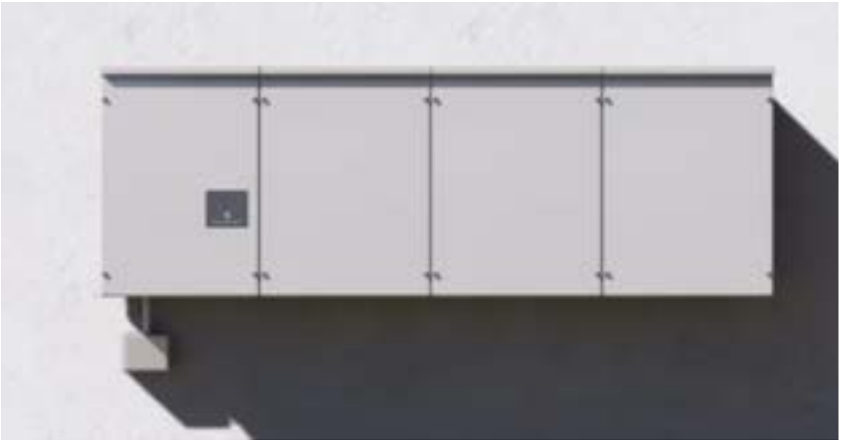

*Figure 14 Eguana Evolve with controls on the left and 3 batteries (42 kW). Source: Eguana Technologies*

### *Energy Model*

An energy model was developed for the workshop using RETScreen Clean Energy Management Software. A reference building (referred to as the 'base case') and different iterations of the workshop (referred to as the 'proposed case') were modelled in this software in order to determine energy, fuel, and greenhouse gas (GHG) emission savings based on design differences. The full reports and a table of model inputs can be viewed in Appendix F – Energy Model Report, and key aspects of that report will be discussed in this section[1]. The building 'base case' is what is required by the National Energy Code for Buildings in Canada (NECB) prescriptive prediction of performance. This is the minimum efficiencies, insulation, etc., that is required by code. Proposed case 1 ('Proposal 1') through Proposal 3 have higher insulation than what is required by code. The building envelope R-values, as shown in table 4, are the R-values that were modelled within RETScreen.

*Table 4 Building Envelope R-Values for the base case (NECB), and proposed cases 1-3 (Proposal 1-3). Source: Primary.*

| | **NECB** | **PROPOSAL 1** | **PROPOSAL 2** | **PROPOSAL 3** |
|---|---|---|---|---|
| | R-Value | R-Value | R-Value | R-Value |
| **ROOF (ABOVE DECK INSULATION)** | 46.93 | 60 | 60 | 60 |
| **WALLS (ABOVE GRADE)** | 31.03 | 40 | 40 | 40 |
| **FLOORS (ABOVE GRADE)** | 39.99 | 40 | 40 | 40 |
| **DOORS** | 4.05 | 4.05 | 4.05 | 4.05 |
| **FENESTRATION - FIXED** | 4.05 | 4.05 | 4.05 | 4.05 |
| **FENESTRATION - OPERABLE** | 4.05 | N/A | N/A | N/A |

For the mechanical systems and energy source/generation, the three proposed cases also differ. Proposal 1 uses all electric energy from the grid. Proposal 2 uses a mix of electricity from the grid and diesel for on-site heating, with no renewable generation. And proposal 3 is the ideal situation, where there is the maximum solar and wind allowed, electricity from the grid, and diesel for heating, with the most efficient systems and heat-recapture.

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[1] Note: in the appendix the base case information in the Proposal 3 RETScreen report is incorrect. The base case for this proposal considered the increased electricity generated by Proposal 3's renewables, and integrated this increased electricity into the consumption of the base case. Therefore, only the proposed case 3 information within that report is correct, and should be compared to the base case information within the Proposal 2 RETScreen.

There were a few assumptions for these models. The local plant generation efficiency used was 34.2%, and the on-site transfer efficiency used was 93% (with assumed transportation and distribution loss of 7%). For on-site combustion there was an energy conversion rate of 80% for the furnace and 66% for the boiler. All of the consumed energy is the intrinsic energy of the fuel or the raw materials, while the energy for the renewables is the system output energy. Additionally, all models considered the following occupancy of the workshop building:

- Monday to Friday regular staff work hours (estimated 20 days/month): 9am-5pm (3-4 people)
- Workshop hours (estimated 10 days/month): 1pm-5pm, 7pm -9pm (6-8 people)
- Larger meetings and cultural events (estimated 3 days/month): 3 hours/day (12-15 people)

In base case, there is significant energy required for heating at 82.9% of the entire building's fuel consumption. This is seen in figure 15 below, along with the 12.6% electrical equipment fuel consumption. Similar charts will be shown for Proposals 1-3 for comparison to the base case.

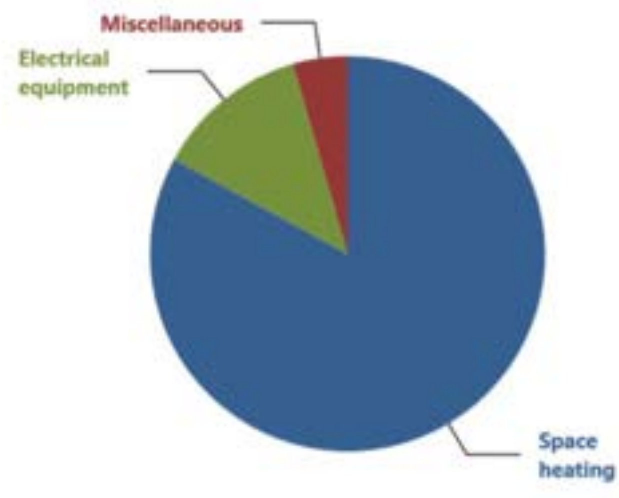


*Figure 15 Base case fuel consumption in a variety of uses. Source: RETScreen.*

Proposal 1 was modelled with all electrical supply, meaning that the only source of energy is electricity from the grid, and that all equipment (such as the boiler) is electricity-powered. Overall, the fuel consumption in MWh (mega watthours) was reduced from the base to proposed case 1 by 12.6%. A reason for this decrease is an increase in efficiency of the building envelope and a 95% efficiency of the electrical furnace and boiler. However, the cost of fuel has increased by 202% from the base case to the proposed case, and the GHG emissions in tCO2 (total carbon dioxide) has increased by 102%. This is because of the type of energy used. An increase in fuel cost and GHG emissions in the proposed case is due to the change in the type of fuel. The base case used an on-site diesel generator and the electrical grid (which is also powered by diesel generators). The proposed case used the electrical grid and renewable energies. However, because an on-site diesel generator provides not only electricity but also heat from the same amount of fuel, there is significantly lower fuel costs and lower GHG emissions for the base case. The changes in fuel type and fuel consumption can be seen visually in figure 16.

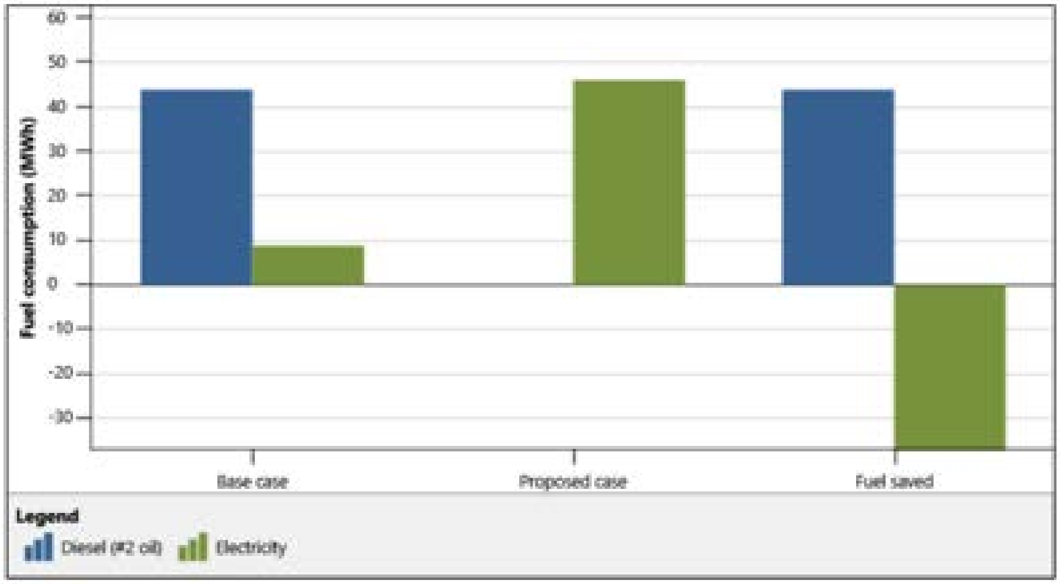


*Figure 16 Fuel type and fuel consumption of proposed case 1 and the base case. Source: RETScreen.*

As seen in figure 17, the space heating is 14.6% less fuel consumption for the proposal 1 compared to the base case. The space heating conditions are different, with proposal 1 using hot water in hydronic tubes (radiant heating), and this was not used in the base case. There was also a 2.8% reduction of fuel consumption for electricity.

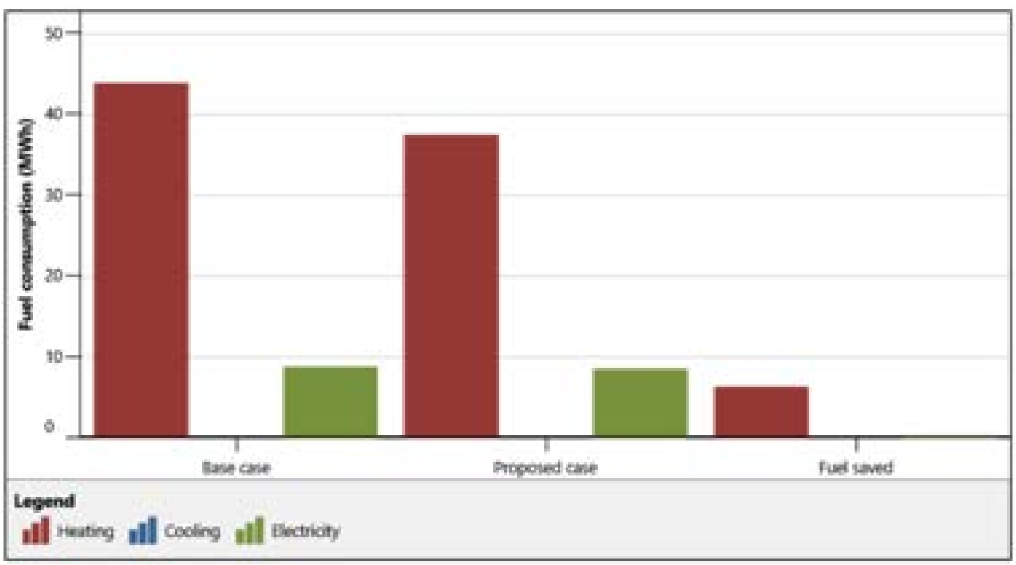


*Figure 17 Fuel consumption for uses of proposed case 1 and base case. Source: RETScreen*

Figure 18 shows the fuel consumption sections for proposal 1. Space heating and hot water are the sections with the largest fuel consumption at 57.6% and 23.7%, respectively. Compared to the base case (which has a space heating consumption of 82.9%), the space heating requirement has significantly decreased in proposal 1.

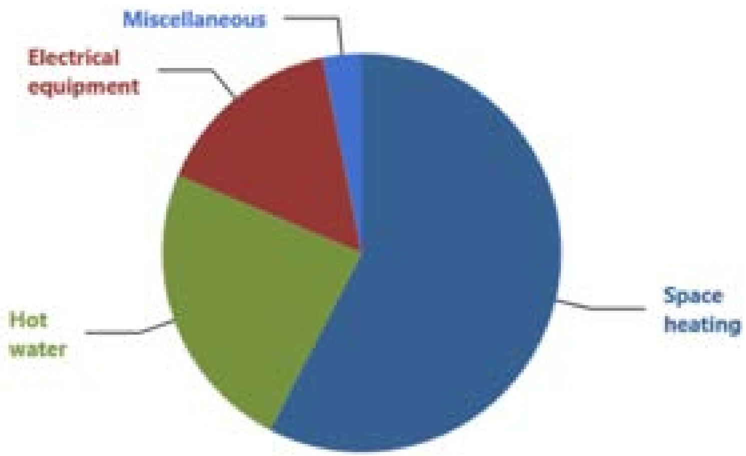


*Figure 18 Proposed case 1 fuel consumption in a variety of uses. Source: RETScreen.*

Proposal 2 was modelled with energy from the grid and on-site diesel. Overall there was a 5.3% decrease of fuel consumption compared to the base case, due to a decrease in heating fuel consumption (by 7%) but an increased electricity fuel consumption (by 2.8%). Additionally, there was a slight (1.3%) decrease in fuel cost and a slight (3.2%) decrease in GHG emissions. Fuel consumption of the base case and proposal case 2 is shown in figure 19.

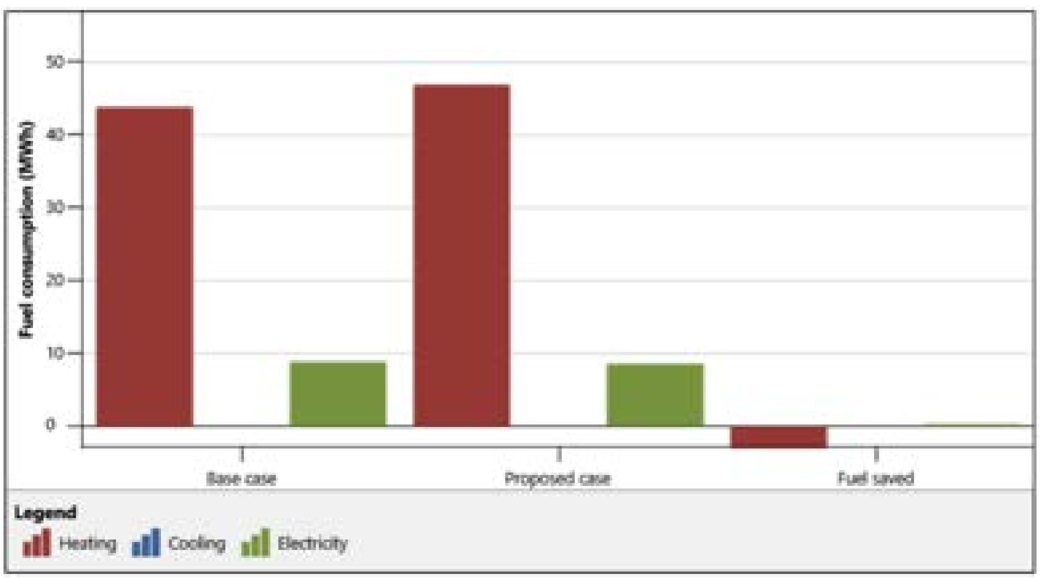


*Figure 19 Fuel consumption for uses of base case and proposal 2. Source: RETScreen.*

Figure 20 shows the majority of the fuel consumption of proposal 2 is the space heating (56.8%), followed by hot water (27.7%) and electrical equipment (12.8%). The miscellaneous section includes energy for lights and mechanical equipment. Proposal 3 has the same fuel consumption per section.

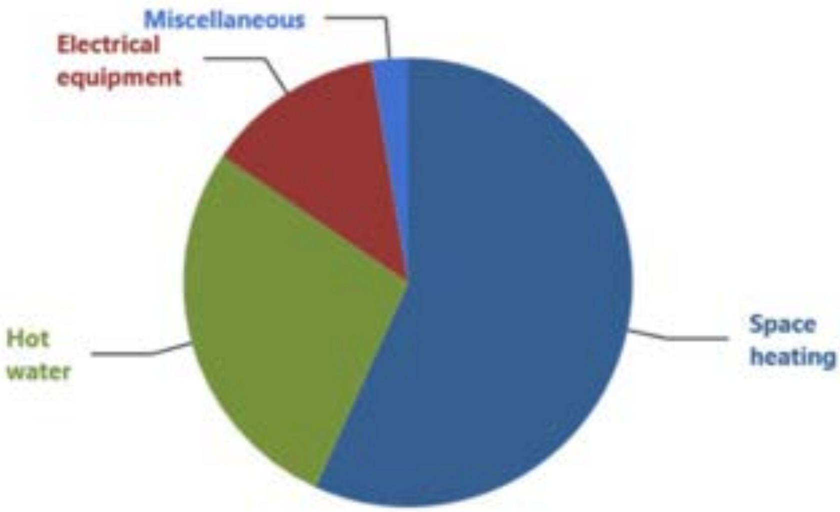


*Figure 20 Proposed case 2 fuel consumption in a variety of uses. Source: RETScreen.*

Contrarily, proposal 3 is the most efficient case. This case considered on-site diesel and on-site renewable options. Twelve 450W solar panels (total 5.4kW) and a total of 4.6kW of wind turbines was modelled, in order to meet the 10kW renewable energy capacity limit placed on the municipality. The twelve panels were placed on the south side of the building, and the wind turbine used is the RETScreen basic estimation. There is a GHG emissions of -17.82 tonnes, and this is tonnes of $CO_2$ saved when compared to the equivalent energy generated by fossil fuels. There is an excess of 13,814 kWh of electricity generated by the renewables, and this can be stored with on-site batteries.

Note: the base case information in the Proposal 3 RETScreen report is incorrect. The base case for this proposal considered the increased electricity generated by proposal 3's renewables, and integrated this increased electricity into the consumption of the base case. Therefore, only the proposed case 3 information within that report is correct, and should be compared to the base case information within the Proposal 2 RETScreen.

Table 5 summarizes the energy and carbon footprints for the base case (NECB prescriptive prediction) and proposed cases 1-3.

*Table 5 Energy and carbon footprints in kWh, GJ, and tonnes of $CO_2$ for the NECB prescriptive prediction (base case) and proposed cases 1-3. Source: Primary from RETScreen models.*

| | | NECB Prescriptive Prediction | | | Proposed Case 1 | | | Proposed Case 2 | | | Proposed Case 3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Energy/ Carbon Footprint | kg-C/kWh | kWh | GJ | $tCO_2$ | kWh | GJ | $tCO_2$ | kWh | GJ | $tCO_2$ | kWh | GJ | $tCO_2$ |
| Electricity (Cambridge Bay Specific) | 0.795 | 8,850.69 | 31.86 | 7.04 | 46,131.26 | 166.07 | 36.67 | 8,600.42 | 30.96 | 6.84 | -13,814.58 | -49.73 | 0.00 |
| Fuel (Diesel) | 0.253 | 43,935.22 | 158.17 | 11.12 | 0 | 0.00 | 0.00 | 46,993.14 | 169.18 | 11.89 | 46,993.14 | 169.18 | 11.89 |
| Total | | 52,785.91 | 190.03 | 18.15 | 46,131.26 | 166.07 | 36.67 | 55,593.56 | 200.14 | 18.73 | 33,178.56 | 119.44 | 11.89 |
| | | | | | | | | | | | | | |
| Renewable Eletricity Generation | 0.795 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -22,415.00 | -80.69 | -17.82 |

## FINANCIAL FEASIBILITY

A Class C Cost Estimate was developed for the workshop space and can be found in Appendix G – Financial Feasibility. Table 6 shows a summary of the key elements with a total cost for the three-year duration of this project, including the design, construction, and monitoring phases. The Class C Cost Estimate is based on all of the components needed to design, build and evaluate a building in Cambridge Bay, Nunavut, also including: materials, specialty consultants, labour hours, research, communication between all partners involved, community engagement, workshops, meetings, test builds at SAIT in Calgary, Alberta and the final build in Cambridge Bay. The building design and construction process will bring together all of the engagement feedback gathered from the community, the partners, the Elders and will support the costs for research and work behind this project.

*Table 6 Table of summarized costs for the KHS Workshop from the Class C estimate.*

| ELEMENT | COST |
|---|---|
| BUILDING SHELL – MATERIAL | $231,710 |
| BUILDING INTERIORS – MATERIAL | $65,100 |
| SERVICES – MECHANICAL, ELECTRICAL | $205,141 |
| SITE AND ANCILLARY WORK | $63,400 |
| GENERAL REQUIREMENTS | $191,535 |
| ALLOWANCES/CONTINGENCY | $227,065 |
| DESIGN ACTIVITIES | $174,850 |
| ADDITIONAL ACTIVITIES (RESEARCH, MARKETING, ETC.) | $81,450 |
| **TOTAL COST** | **$1,240,251** |

To fund this total cost, there are multiple partners and grants that have been approved, submitted, are in progress, or there is a planned application. A project workplan was created for this three-year project, outlining the objectives and quantifiable results, along with the start and end date of each activity. Table 7 shows this timeline. This is a general outline that is subject to change.

*Table 7 Table of project workplan activities and timelines.*

| PROJECT ACTIVITY AND OUTPUT (RESULT) | START DATE | COMPLETION DATE |
|---|---|---|
| COMMUNITY & STAFF ENGAGEMENT – INFORMING DESIGN, CREATING DATABASE OF REQUIREMENTS. CREATE NETWORK OF LOCAL CONTRACTORS & ENTREPRENEURS TO SUPPORT THE PROJECT. | May 2021 | July 2021 |
| BACKGROUND RESEARCH | April 2021 | October 2021 |
| DESIGN, DRAWING AND SPECIFICATION DEVELOPMENT – OUTPUT: DRAFT DRAWINGS AND CLASS C ESTIMATES (ATTACHED) | May 2021 | August 2021 |
| FINALIZE DESIGN SPECIFICATIONS, DESIGN BUILDING INSTRUMENTATION, ASSESS RENEWABLE ENERGY OPTIONS | September 2021 | December 2021 |
| GEOTECHNICAL SURVEY – DESKTOP EXERCISE | September 2021 | December 2021 |
| MATERIAL ACQUISITION, CONSTRUCTION OF BUILDING AT SAIT-GBT, TESTING OF SYSTEMS, DECONSTRUCTION AND PREPARATION FOR SHIPPING | January 2022 | June 2022 |
| SITE PREPARATION | June 2022 | July 2022 |
| GEOTECHNICAL SURVEY (3 VISITS) | June 2022 | December 2022 |
| SHIPPING | July 2022 | August 2022 |
| CONSTRUCTION OF WORKSHOP IN CAMBRIDGE BAY | August 2022 | October 2022 |
| ENERGY MONITORING OF WORKSHOP | November 2022 | October 2023 |
| OBSERVATION OF WORKSHOP PERFORMANCE THROUGH CULTURAL ACTIVITIES | November 2022 | October 2023 |
| FINAL REPORT AND RECOMMENDATIONS FOR PHASE 2 (3,500 SQUARE FOOT MUSEUM/OFFICE BUILDING) | November 2022 | December 2023 |

## EVALUATION AND MONITORING

The following section describes the energy used vs forecast energy, actual vs model weather, interior comfort, comparative cases of other buildings, construction process and time, and occupant satisfaction.

### *Energy Used Vs Forecast Energy*

An electrical energy monitoring system should be used to capture all electrical loads energy usage and any electrical generation onsite. This system uses small current sensors that clamp around all circuit and main feed wires to gather Amperage. Voltage sensors will be installed to monitor each phase' voltage. Together these sensors will be used to calculate electrical power and energy for all monitored loads. The data gathered by the electrical monitoring system will be compared against forecasted energy usage from the energy model. This comparison will help guide control system tuning and aid in HVAC commissioning.

### *Actual Weather Vs Model Weather*

Weather Normals (30-year daily average weather) will be used against actual weather conditions in analysis using the monitoring system's data to gain insight and context of energy usage deviating from the modeled or expected values. This will ensure that any action applied to the HVAC system is in response to the weather's variation from the "norm", and not solely based on excessive or minimal energy usage from the model. Also, generation forecasts from renewable energy systems are based on average weather therefore actual weather conditions can explain generation variance.

### *Interior Comfort: Temperature, Humidity, Air Quality*

Temperature sensors should be installed as the primary control for heating and cooling. It is recommended to install thermostats/temperature sensors in accordance with the HVAC design and building layout to ensure even heating/cooling. Humidity sensors should act as the driver for ventilation control to ensure no excess of moisture inside the building, and to maintain a comfortable interior. $CO_2$ sensors can be installed and integrated with thermostats to allow for a version of occupancy control and air quality management. An increase in $CO_2$ that typically comes with an increase in occupancy should trigger ventilation to maintain comfortable CO2 levels. Increased levels of $CO_2$ have been reported to cause drowsiness, lethargy, and a sense of stale air (Prill, 2000). Depending on HVAC design, high $CO_2$ readings could trigger HRV operation to bring in fresh air, and stop the re-circulation of interior air.

### *Comparative Cases of Other Buildings*

For a broader assessment of building performance, a duplicate monitoring system can be installed on a different building that can be used to compare the subject building performance. For example, if the subject building has upgraded insulation with expected energy savings then a similar building without the upgrade should also be monitored. In this situation heating energy has to be isolated from total energy and indoor temperature also needs to be recorded to normalize the results.

### *Construction Process and Time*

Wiring for the sensors for the monitoring system should be roughed-in during construction to avoid surface-mounted wiring or having to re-open finished walls. While there is a trend to wireless sensors for research grade results over a long term with limited site access, the reliability of wired sensors is still preferred. Installing the programming and communication hardware is best at the final stage stages of construction or post-occupancy. All the data analysis and reporting is done remotely, however occasional site visits may be required to validate sensor installation and correct operation.

### *Occupant Comfort*

The recommended monitoring system should be used in the overall HVAC system's commissioning, which should balance energy usage and occupant comfort. A monitoring period should be established (typically 1-year) where an evaluation of the system's performance should be completed and data-backed revisions can be made. A brief survey to occupants should also be provided on an on-going basis to evaluate occupant comfort and aid in overall occupant satisfaction. This data will also be used during commissioning to provide the environment desired.

## RECOMMENDATIONS AND NEXT STEPS

The recommendations provided below on the building footprint and functional areas; foundation and envelope; mechanical and ventilation systems; windows, shades, and solar awnings; energy systems, renewable energy, and energy storage; safety; and next steps are based on the research conducted during the first phase of this project and the preliminary design phase. These recommendations are based on community engagement and professional experience, however they might be adapted or changed as the project continues in subsequent phases.

### *BUILDING FOOTPRINT AND FUNCTIONAL AREAS*

A hexagonal central building has been proposed to mimic traditional round buildings with vertical walls and a domed roof. The addition of 'wings' off of the main building replicates additional spaces for specified tasks. One of the wings will include an entranceway with a cooler temperature near the exterior door, transitioning to a warmer temperature in the central room. Through additional design conversations, it was decided to merge two of the three original wings in order to mitigate snow loads/piling in-between the wings. This also provides more space for cultural activities such as a bigger kitchen with a larger sink to wash hides and skins. The other wing is for quiet activities, acts as a meeting room, a dining room, and storage space. Addressing accessibility, the ramp runs along the south of the building, and stops at the main entrance where the stairs also lead to. The circuitous entranceway reflects the tunnel entranceway of traditional buildings albeit in a horizontal rather than vertical plane.

### *FOUNDATION AND ENVELOPE*

The building should be constructed utilizing a panelized construction system to accommodate shipping constraints and provide a simplified site construction process. The panelized system can be either of SIP or wood framed construction and should consist of EPS insulation with MgO panels to provide long term durability, airtightness, and mould resistance. Windows, doors, weather barrier, and a rainscreen metal or composite wood cladding system should be installed prior to shipping leaving only panel connections left to be sealed and closed-up on site. This will lead to quick site construction and a higher performing building due to as much detailing as possible being completed in a factory environment.

A highly insulated floor structure with false floor to the interior should be installed over the foundation system which will be designed by Williams Engineering based on Geotechnical data gathered by EnGlobe. The false floor will provide a location for running services without compromising the airtightness and thermal performance of the main floor system.

### *MECHANICAL AND VENTILATION SYSTEMS*

The following are recommendations for potable water, heating, and ventilation in the workshop.

#### *Potable Water*

The following are recommendations for potable water in the workshop:

- Potable water is to be stored in an interior located cistern. Due to this storage location it is recommended that bacterial checks be performed to ensure that there is no bacterial growth and shock chlorination may be required at times. It is recommended that the cistern be accessible and large enough to get inside to physically clean out, as community members typically clean the cistern once a year.
- To deliver an effective and consistent water supply, a stainless-steel bodied shallow well jet pump is recommended to be installed outside of the cistern and a foot valve should be installed on the suction line.

- A well water pressure tank is recommended to cut down on the number of cycles for the jet pump. This pressure tank must be located after any water filtration or treatment trains to ensure that bacterial growth is kept to a minimum.
- Filtration or treatment can be included under the advisement of City water supply officials. To help reduce bottled water consumption, a carbon filter is recommended. This can be installed at taps that are used for consumption, or for the entire building.
- Water will be heated through an indirect water heater which will be fed by the building heating boiler. This method ensures a near limitless supply of hot water for as long as the boiler can operate.
- Logic plumbing is the preferred method of water delivery as it reduces the number of connections, cuts the amount of pipe greatly, and has the lowest volume of in-system water when compared to trunk and branch or home run styles of system design.
- Water and wastewater tanks should be located on the side of a building that is able to be accessed easily by the municipal trucks.

### *Wastewater*

It is recommended the workshop use the community waste water collection service. From our understanding of the intended cultural activities, it is anticipated there will not be much more waste water than a residence. The community prefers waste water to be contained outside the building, therefore a waste tank should be located just outside the building and convenient for truck access. The tank must be well-insulated and shielded from wind, and it is recommended to utilize a wind screen in order to reduce heat loss. An electric heating element is required to keep the contents at 5°C.

### *Heating*

The following are recommendations for heating in the workshop:

- Hydronic thermal tubes heated by a diesel-powered boiler is recommended as the primary heat source to heat the space, designed to be simply retrofitted to all-electric in the future. The site plans to have on-site electricity generation from solar photovoltaic panels and wind turbines complemented with electric storage batteries.
- A permanently installed diesel generator is recommended that can be used to power essential loads in the event of grid outage, if there is not yet battery backup.
- An indirect water heater is proposed to cut down on the total amount of equipment and save floor space. It will function to deliver potable hot water and will act as a heat battery to cut down on the number of cycles performed by the boiler to increase its longevity.
    - This type of water heater is often employed in areas with water quality concerns as there is no dead spaces for bacteria to propagate which can occur in a standard hot water tank.
    - Some manufacturers have proven track records which show that this style of system can function with limited maintenance for 20+ years.
- To deliver heat to the building, an in-floor system is proposed which will present a large thermal mass to maintain heat in the building for much longer than forced air systems.
    - The weakness of this system is that it does not drop heat quickly, so it is recommended that ventilation be used in conjunction to better control the temperature inside the building.
- Air barriers are proposed on both doors to reduce heat loss due to drafts when they see use. These air barriers can be activated on a motion detector to cut down on their run time and save energy when they are not required.
    - The proposed motion detector may not be feasible if there is not a method of capturing motion outdoors from an indoor location, as they will not function in outdoor climactic conditions. In this

event, a magnetic switch on the door is an alternative choice, but is not preferable as the curtain will be less effective due to the delay between opening the door and the air curtain activating.

### *Ventilation*

The following are recommendations for ventilation in the workshop:

- Ventilation will be used as a method of transferring heat within the space and properly mixing the air to reduce the stratification effects that commonly occur with in-floor heating systems.
- A fresh air rate of 1.5 ACH (air changes per hour) is recommended. This will make up part of the total ventilation rate in the building which is achieved by recirculating the air through the rooms. The whole building ACH should be 4.0 ACH.
- Fresh air will be run through an HRV to recapture energy from exhausted air.
- A humidifier will be required to increase the humidity levels in the building due to very low moisture levels from outside air. This humidification process adds a main point of complexity, as exhaust air will be humid, and will rapidly lose heat through the HRV. This heat loss can cause icing in the HRV heat exchanger which can cause damage or entirely block the air stream.
    - To counter the icing issue, it is recommended that an interior air intake be placed on the incoming air stream to warm the incoming air and reduce the chance of freezing. This air stream will need to be balanced to ensure that proper ACH is maintained.
    - A dehumidifier may be required to operate when the outdoor air temperature drops below a certain setpoint to remove excess moisture from the exhausted air. The temperature setpoint will be defined by the mixing ratio between fresh air and tempering indoor air. For example, a 50/50 mixing ratio will likely sit with a -18°C setpoint if the indoor temperature is 21°C, which will ensure that there is no chance of freeze up and will adequately deliver air that is warmer than 0°C to the HRV.

### *Electrical*

The recommended electrical system should be 120/240 single phase voltage, 60 hertz alternating current. Ideally, the electrical supply and distribution panel should be sized to accommodate all-electric energy from the grid and interconnection of enough renewables to achieve a net-zero electric building. While this is not achievable today, it is anticipated QEC will facilitate grid upgrades and flexible service contracts to allow far more renewables in the near future.

## *WINDOWS, SHADE CONTROL, SOLAR AWNING*

The community centre offers a unique challenge in effectively designing solar shading and sunlight control. Being located in Northern Canada, Cambridge Bay experiences arctic sun path patterns where during certain parts of the year, 24 hours of light or dark will occur. This is unique to this area of Canada as the majority of the country experiences sunlight from the south year-round. The main concern with this is overheating inside buildings, especially those which utilize passive heating as recommended for the centre. Options in mitigating this include planned window size and orientation design, external elements such as solar awnings, transitional films on windows, and more as described in the Mitigating Overheating when Passively Heating report as found in Appendix G. Of these options, a controllable transitional film is recommended. Such a system allows for automated (scheduled) or manually adjusted tinted films to react to increases or decreases in sunlight. A system that allows for both would be best, in the case that occupants require to manually adjust the films per room/location, as well as schedule film transitions based on seasonal patterns. The other viable option is the solar awning, wherein solar panels could be installed on it to generate more renewable energy for the building.

## *ENERGY SYSTEMS, RENEWABLE ENERGY, ENERGY STORAGE*

To achieve project goals of improved environmental performance, on-site renewable energy should be pursued and included in the project. A solar thermal array awning on the veranda can be used for water and space heating and minimize excessive solar heat gain through the windows at the same time, creating a controlled system. Although it will not provide any energy during the winter months it will be very effective in the spring and fall, and provide heat only when needed in the summer - thereby reducing other energy sources and their carbon footprint. See Appendix H – Mitigating Overheating When Passively Heating Report for further analysis of the summer scenario.

Renewable electricity from solar and wind should be pursued while respecting QEC limitations. Hopefully those limits will be modernized as they prevent the workshop from becoming a net-zero electric facility. While on-building PV panels have been included in the design, specifically on the south awning and roof, it is apparent that off-building two-axis tracking would be more productive given the high-latitude sun path in Cambridge Bay. In addition, a vertical axis wind turbine can be installed on the site and will complement renewable electricity generation.

At this time the QEC limitation of 10 kW of renewable generation can be allocated to 5 kW wind and 5 kW solar. This is not enough capacity to consider seasonal energy storage capability that could be achieved with hydrogen electrolysis and fuel cell generation, for example. An electric battery complementing the renewable energy systems will significantly increase self-generation and reduce grid imports and exports of electricity. It will also provide a level of resilience with backup electricity in the event of a grid outage. The renewable energy system can also control an on-site backup generator that would improve resilience, although there will be GHG emissions when the generator operates.

## *SAFETY*

Magnesium oxide (MgO) boards, as supplied by ZS2 Technologies in their panels, are water-resistant, anti-mould, and anti-bacterial; non-combustible and have zero flame spread; do not contain toxic ingredients (asbestos, formaldehyde, ammonia, or benzene) or VOCs (volatile organic compounds); are impact resistant, and can be recycled or composted. MgO boards increase the durability, fire rating, insulation, and moisture resistance of SIPs. ZS2's TechPanels are manufactured in a factory setting, meaning that there is increased quality control versus conventional framing construction that is done on-site. This also helps to prevent on-site oversite or mistakes that can affect the quality of the building, for example, mistakes can cause leaks in fenestration framing that can allow moisture or water to infiltrate and cause mould, mildew, or other problems.

The building cladding will be chosen based on durability, fire resistance, and ease of maintenance. It is important to choose a cladding that can be cleaned easily in case of vandalism. The base of the building is recommended to be closed off for site safety, and all attached equipment (e.g. PV panels) must be firmly fixed to the building to prevent damage in high winds or snow loads. Through design it is critical to design to prevent snow and ice build up alongside the building, and to ensure that no snow and ice can build up on the roof due to the potential for falling snow and ice that can injure people.

## *NEXT STEPS*

Immediate next steps in the project include: finalising the design in detail and preparing construction drawings with details to be approved by the municipality, the preliminary workshop design has been drafted with key attributes included for the construction and mechanical systems. Site positioning along with windows, shading, and accessibility have been suggested. Renewable energy systems to reduce emissions and promote resiliency have been proposed. Exterior use details remain to be confirmed as well as final dimensions, connections, and specific equipment.

The premanufactured building will be assembled at SAIT with all mechanical, electrical, and renewable energy systems installed and commissioned. Preferably this assembly will include Cambridge Bay construction companies for training and experience. The building will subsequently be disassembled and transferred to Cambridge Bay for re-assembly on the KHS site. By including Cambridge Bay construction workers from the beginning it is believed the on-site assembly will be more successful and the local workforce will be more experienced for future projects and building maintenance.

Additionally, it is recommended to conduct a building monitoring experiment in Cambridge Bay. Monitoring of energy and IAQ in 2-4 residential homes, the workshop, and another commercial building within the community for 3 years can be used to create a real-time dashboard and track occupant use behaviours based on real-time feedback of actions. The proposed energy monitoring includes electricity and fuel oil, and the IAQ monitoring includes temperature, humidity, VOCs, $CO_2$, and PM (particulate matter – 10 and 2.5).

Finally, the energy model will be updated and the carbon emissions analysis will be completed at the end of the monitoring period to finalise the research and outcomes performance report.

Ongoing efforts to secure additional funding are also underway to support a number of funding opportunities, as mentioned in this report, as well as marketing and communications activities to record the project through events, workshops, design, construction, monitoring and use.

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## APPENDIX A – PROJECT PARTNERS

The following appendix will outline the project partners for PI/KHS, SAIT, the community, and industry partners.

## APPENDIX A – PROJECT PARTNERS

### PI/KHS

**Bessie Omigoetok (Board Chair), David Amagainek, Annie Atighioyak, Mabel Etegik, Eva Kakolak, Mary Kaotalok, Noah Kuptana, Susie Maniyogina, Ann Wingnek (Board of Directors).** PI/KHS is guided by an elected and volunteer board of 10 Directors. Board membership consists entirely of Elders in accordance with local/cultural governance structures recognizing acquired life experience, skills, and wisdom as valued qualities for leadership. Being the last generation to be raised on the land with Inuinnaqtun fluency, these Elders are dedicated to ensuring the transfer of their knowledge to younger generations, and that the structure, operations, and programming of the organization remains grounded in Inuit Qaujimajatuqangit (traditional culture and values). Our board is the driving force behind the new building program's adherence to Inuinnait language, concepts and priorities. The Board works directly with staff, project engineers, and consultants, meeting on a monthly basis to review and revise project plans to ensure their compatibility with traditional architecture and contemporary cultural revitalization needs.

**Emily Angulalik** (Executive Director) is a founding member of PI/KHS, and has served the organization in various capacities as Director, language specialist, and translator for 25 years. She was awarded the 2021 Indspire award for her lifetime dedication to seeing the Inuinnaqtun language thrive. Emily anchors our building program in local culture and language. She works directly with board members (many, unilingual in Inuinnaqtun) to ensure all elements of the building have correlates in Inuinnait culture and terminology. She oversees the work of our Cultural Program Coordinator (Eileen Okhina), and a team of 5 Elders in Residence, who lead conversations on the programming design needs for the new building. She also oversees the work of Inikhaliuqatigiit (Trailmakers), a committee to foster this project's representation across the Inuinnait region.

**Brendan Griebel** (Project Lead, Manager of Collections and Archives) has worked for PI/KHS since 2007, and in the fields of Arctic anthropology and museology for over 20 years. He is a researcher of Inuit culture and materiality, has a PhD in Anthropology from the University of Toronto, and holds the 2021-22 Fulbright Research Chair in Arctic Studies. He is a curator and collaborator with multiple national and international museums, and is co-founder/Director of a private museum based in Alberta. He is additionally the founder and Manager for the PI/KHS' social enterprise Pitquhikhainik Ilihainiq Inc., and Principle for the Arctic-based consultancy Intuit Research. Brendan has led the vision for an Inuinnait Knowledge Centre since 2016, drafting key concept papers and partnerships to bring the project to fruition. He is PI/KHS' lead correspondent with project consultants and funders at municipal, territorial and federal levels.

**Lyndsey Friesen** (Manager of Communications and Philanthropy) oversees the organization's fundraising and investment relationships, public-facing communications (social media, press, and program outreach), and ensures that PI/KHS messaging is both consistent and impactful. Lyndsey has played a key role in the building program's communications, including project website development (www.nunamiutuqaq.ca), press releases, and preparations for an upcoming capital campaign.

**Kim Crockatt** (Chief Financial and Operations Officer) oversees the work of all departments and staff at PI/KHS, and is the direct link between staff and Board. Having spearheaded the fundraising and construction of the May Hakongak Cultural Centre in 1999, Kim plays a key administrative role in the management and implementation of the new building program's finances, permitting, and Agreements with multiple funders and program partners. A founding member of PI/KHS and long-term resident of Cambridge Bay, Kim has worked with PI/KHS for 25 years in addition to serving as Executive Director for the Nunavut Literacy Council for 15 years.


*Figure A-11 PI/KHS Organization Chart*

## GBT

**Melanie Ross** (BArchSc) joined SAIT's Green Building Technologies (GBT) team in 2019 as research associate and business administration. She is responsible for overseeing research activities within the 850-metre-square GBT Lab and Demonstration Centre, which opened on SAIT campus in June 2017, becoming the first net-zero commercial building in Calgary. Ross brings more than 10 years of experience with recognized architecture, planning and engineering firms to her role as GBT team lead within Applied Research and Innovation Services (ARIS). She has a solid background in projects ranging from LEED, WELL, and other third-party certifications to energy management and existing building performance, including sustainability planning and policy development. Her work as a technical advisor, reviewer and taskforce committee member as well as an education faculty member for a number of industry organizations gives her further insight into the strategic and technical nuances of sustainability systems and projects.

**Tom Jackman** joined SAIT's GBT team within Applied Research and Innovation Services (ARIS) in 2012. He holds an MBA and has more than a decade of experience in automated manufacturing, as well as 10 years' experience in renewable energy, energy management and monitoring. Jackman leads GBT's building-integrated renewable energy efforts and has considerable expertise in managing applied research and innovation projects involving industrial partners and SAIT students in the areas of solar photovoltaics, solar thermal hydronics and solar air heating, as well as distribution and integration of multiple energy sources into advanced mechanical systems. Jackman is a member and the Treasurer of the Board of Directors of the Alberta Energy Efficiency Alliance aimed to drive coordinated action on energy efficiency from a common voice to enhance the economic and environmental success of Alberta. He is a member and past-Chairman of the Board of Directors of the Friends of Fish Creek Provincial Park, a member of the Canadian Solar Industries Association, and also a member-at-large of the Solar Energy Society of Alberta, Canada Green Building Council, Net-Zero Energy Home Coalition and Decentralized Energy Canada.

**Ben Hildebrandt** received an Architectural Technologies diploma from SAIT in 2013 with a focus in Building Development Technologies and has worked for several years as a building science technologist. During that time, he diagnosed and oversaw the repair of building envelope issues in single and multi-family buildings. He has also served as a building envelope consultant on multiple multi-family and commercial construction projects in Calgary and Fort McMurray. Ben's mechanical and troubleshooting strengths stem from his background as an Aircraft Maintenance Engineer. Ben's focus with Green Building Technologies is to help facilitate material and component development, testing and fabrication to help industry partners bring new sustainable materials and products to market.

**Amanda Robertson** joined the GBT team within SAIT's Applied Research and Innovation Services in 2021. Robertson comes to GBT with a Project Management certificate from Mount Royal University and 9+ years of project management experience with a large North American commercial construction company. She has spearheaded the deployment of a paperless system to be used by construction companies to reduce project costs by thousands of dollars. Within GBT, her involvement with the Alberta Native Friendship Centers helps make centers sustainable and aids in knowledge dissemination back into communities.

**Hayley Puppato** joined the GBT team in 2019. Hayley has a diploma in Environmental Technologies and a BSc in Environmental Science. She has contributed to all imperatives in a Living Building Challenge project, including net positive waste, living economy sourcing, biophilic environment, and urban agriculture. Research in these areas promote full certification and sustainability values in all aspects of building green residential homes. Her involvement with different GBT project are significant to the clients, the community, and the whole of the region, where aspects of green buildings are starting to be integrated into designs and construction.

**Leo Lu** graduated from architectural technologies program of SAIT and holds a master degree of biochemistry and chemistry. With trainings in these disciplines, he participated in early stages of many projects in SAIT GBT Lab and contributed his knowledge to materials development, green house drafting and energy modelling, for example. He focuses effort on designs and technologies incorporating more chemistry to enhance a greener future.

**Jeremie Ryan** is a Red Seal journeyman plumber and a graduate of SAIT's plumber apprenticeship program. Ryan started working with the GBT in 2012. A student at the time, he applied his newly gained knowledge directly to help construct the solar thermal portion of the GBT Building Integrated Renewable Lab (BIRE). He is currently managing and performing data analysis on an ongoing research project monitoring five near identical net zero houses built by Mattamy Construction Ltd. in an attempt to prove whether they maintain net zero energy or whether occupant lifestyle will negatively impact the energy usage of the houses. Data analysis is presented from energy values gathered from an electrical monitoring system, which allows for characterization of energy usage and comparison to a design model for the home in an effort to define net zero model accuracy.

**Alexandra Kodyra** completed her undergraduate degree in graphic design at ACAD and graduated SAIT's Architecture Technologist program in 2019. Through working at the Green Build Technologies Lab, she has participated in projects involved with Carbon Zero and the Living Building Challenge, and aims to apply sustainable systems and practices towards her future work and studies.

## COMMUNITY PARTNERS

The PI/KHS team relies on support from a network of construction and energy partners including BlueSky Engineering (facilitating our carbon inventory and climate action plan development), Brightspot (facilitating dissemination of project results and creational of community-centered resources), and Indigenous Clean Energy (third party evaluation of our project results and levels of Indigenous engagement). Multiple local contractors and renewable energy startups in Cambridge Bay--including the Municipality of Cambridge Bay, CHOU Consulting & Development, Qillaq Innovations, and Aurora Energy Solutions--have joined us for weekly meetings and design charrettes since the beginning of this program to bring their local expertise to all project costing, design, and infrastructure development.

**Qillaq Innovations** is a 100% Inuit owned company based in Cambridge Bay, Nunavut. Qillaq Innovations offers a variety of essential services such as construction and contracting, earth works and heavy equipment, petroleum products and services, and snow removal. Cambridge Bay is where the senior managers of Qillaq Innovations are located. All the directors are well known in this community and throughout Nunavut. Since they are a locally based company, they are committed to continually training and employing local workforce.

**CHOU Consulting & Development** was established in 2013 in Cambridge Bay Nunavut as a consulting and development company focused on growing the north through construction and entrepreneurship. Stuart Rostant and Amanda Doiron both have Master's degrees in Architecture and over 10 years of experience living and developing properties and businesses in Cambridge Bay Nunavut. With a primary focus on quick build, energy efficiency, and affordability CHOU has developed a number of residential and commercial properties. Pushing the typical construction methods used in the North, CHOU is currently working on a pilot project using GreenStone ICE Panels (Insulated Composite Envelope) as an RTM (Ready to Move) home to investigate the logistics and affordability of off-site construction in helping to provide access to homeownership throughout the Territory of Nunavut.

**Aurora Energy Solutions Inc.** is based in Cambridge Bay, Nunavut. Aurora provides renewable energy system installations and program consulting. Consulting services also include power system analysis, data collection, and surveying.

**Sophie Pantin** is an independent consultant, currently on a 6-month contract with PI/KHS. Sophie's work out of Cambridge Bay includes project management and network building (e.g. interviews with community's stakeholders and creation of local partnerships), as well as managing day to day operations (e.g. grants applications, building permitting and overseeing researchers and consultants work). Sophie has 10+ years of experience in environmental engineering and sustainable development at the local level. Through her work at the Green Municipal Fund, she assisted municipal governments with their climate mitigation and adaptation goals and was a member of the Expert Panel on Climate Change Adaptation and Resilience Results (Environment and Climate Change Canada).

**Blue Sky Energy Engineering & Consulting Inc.** is a multi-disciplined engineering and consulting company that provides services focused on energy conservation, process optimization and engineering. Blue Sky Engineering is facilitating our carbon inventory and climate action plan development.

**The Municipality of Cambridge Bay** is working on a small homes project. Although PI/KHS's pilot is centered on cultural and museum uses, the research, knowledge and expertise gained could support the municipal project directly (choice of construction materials, HVAC, mechanical and electrical design) or indirectly (through local entrepreneurship and business development).

**Englobe Corp.** is one of Canada's premier firms specializing in the areas of engineering, soil/biomass treatment, quality management and asset integrity, and environmental engineering. We have retained the services of Englobe to conduct the series of geotechnical investigations.

**Brightspot Climate Inc.** is an independent climate change and energy consultancy that aims to work collaboratively with industry experts, community stakeholders and project developers to apply innovative and efficient solutions to mitigating climate change.

## INDUSTRY PARTNERS

The GBT team industry partners on this project include: Williams Engineering, Foundation Engineering; ZS2, Panels/Design; Crestview, Vertical Axis Wind Turbine; Adaptive Habitat, Design; Levven Electronics, Smart Switches; Innotech Windows and Doors, Windows; and Lunos Canada, HRV Systems.

## APPENDIX B – CAMBRIDGE BAY CONSTRUCTION MATERIALS

Commonly used Cambridge Bay construction materials for building structure, framing, foundations, roofing, siding, doors, windows, ramps and stairs, and flooring.

Appendix B – Cambridge Bay Construction Materials

Materials we observed that are commonly used in current Cambridge Bay construction include the following.

- Building structure materials
  - Double partition wall of ½" STD Drywall, Ice Panels, ½" drywall (interior walls)
  - Magnesium or OSB (oriented strand board) Face SIPs (structural insulated panels)
- Framing
  - Traditional wood framing
  - Steel stud framing
- Foundations
  - Blocks and wedges
  - Screw piles
- Roofing
  - Metal/Steel
  - 2-ply, torched-on MBM roof system is recommended for northern buildings
  - EPDM or Rubber roofing
- Siding
  - Metal cladding
  - Wood siding (Spruce or Cedar – Stained)
- Doors
  - Exterior doors – insulated metal or freezer doors.
- Windows
  - Insulated frame PVC, vinyl, or pultruded fibre reinforced plastic frames
  - Metal windows with thermal break frames
  - Protected wood windows
- Ramps and Stairs
  - Open metal or fibreglass grating is preferred surface materials for exterior ramps, stairs and landing
  - Wood surfaces are acceptable where traffic is light
  - Concrete
  - Steel
- Flooring
  - Marbleized linoleum
  - Vinyl Composite Tiles (indoors only)
  - Roll carpeting

## APPENDIX C - COMMUNITY ENGAGEMENT RESULTS

The following appendix outlines the community engagement comments from several workshops conducted by PI/KHS and SAIT along with community members and industry partners.

1. Overall Design
   - Overdesigned buildings lead to high costs of operation and maintenance. Systems end up being by-passed when they are overdesigned/overengineered. Think about the end user and what they will be comfortable using, maintaining, and operating.
   - Supply chain for spare parts should be considered when designing a building in CB. Barge only come up once a year and there is a weight limitation
   - All construction waste will end up in the local dump as there is no recycling in the community. Garbage is burned. Minimizing construction waste should be a priority.
   - Minimize curves in design - it creates snow drifting and accumulation areas. Be aware of snow drifting when building modular/with curves. See Anana's camp in CM. University of Guelph or Waterloo can do snow modelling.
   - Cambridge Bay is extremely windy, snow drifting to consider. Northwest wind is the dominant wind, as such do not install windows or doors in this direction.
   - Windows and natural light, overheating during 24 hrs daylight
   - Overlap between language revitalization and cultural revival through the lens of traditional architecture. For example, language experts shared with KHS staff Inuinnaqtun terms that were no longer used, due to the lack of cultural space designed to conduct a particular activity.
   - Staff and Elders discussed an entrance/vestibule design that mimics the entrance of the igloo with its cold trapping characteristics and ample room for storage. In particular, this entrance should allow for storage at different temperatures to store skins, fabrics, tools etc.; all having their own optimal temperature profile. Does this design affect the energy efficiency?
   - The Elders reflected on the management of heat flow and light in traditional buildings, such as venting at the top of the igloo and windows made of compacted ice. Large south facing windows are required, allowing heat and light for activities such as sewing. Summer heat gains will have to be managed in the summer. Activities such as meat butchering requires cooler temperature and access to water.
   - Switch the location of the quiet space – on the building right side – entrance on the left side – closer to the road and mechanical room ends up in the middle, furnace/bathroom attached to the vestibule, and bigger kitchen in middle pod. Attached to the drying outdoor space/winter storage.

2. Building envelope
   - Considerations: ease of assembly, energy efficiency optimized, costs, tested for Arctic conditions, modularity.
   - Contractors in the community have had troubles with SIP in the past. It saves time in the south to assemble, but often the panels are not straight and/or are difficult to work with for finishing work.
   - Consider smaller average height of building occupants, and as such how low the windows should be.
   - Insulation: Air Crete is manufactured in Cambridge Bay. Available material to consider.
   - Metal cladding (walk-in freezer) used as building envelope.
   - Roof:

    - Poorly designed roof, also increase humidity issues. "House rain" from the ceiling in the spring. Removed it and installed vaulted ceiling instead.
    - Roofs do not last as long. 24 hrs daylight and extreme temperature. Shingles do not work. Metal roofing is the preferred option
    - Need a slight slope on the roof to allow for water drainage. Snow accumulation will not be problem with the wind, but some worries that there will be accumulation where the roofs meet.
- Doors:
    - Doors freeze up in the winter, because of high humidity in the house and extreme temperature differential between outside and inside. Must change weather stripping seasonally.
    - Need storm doors to prevent ice built up around doors in the winter. In the past, houses had old style freezer doors as storm doors.
    - 6 months of the year, there is ice built up around doors. Install screen doors to prevent main door from freezing

3. Water system/plumbing
    - Drinking water/wastewater is delivered/removed by trucks.
    - Drinking water: shock chlorination. In the spring and summer – very high natural organic matter content. Both leads to taste and odour issues and formation of disinfection by products (DBPs), and as such residents do not drink tap water, but rather buy drinking water at the store. Consider easy to use/clean POU system? Activate carbon? Filtration?
    - Drinking water tank is inside the building, in the mechanical room. Minimum size requirements from by-law (I believe it is 500 gallons, but I need to check). Drinking water tank needs to be easily accessible, as we need a visual to show when it is almost empty and need to be accessible for cleaning once a year (prevent formation of biofilm). Also need a visual outside (usually a red light) for water truck. Visual clue inside is especially important when there is a blizzard: water truck might not come for days and building occupants need to be ready ahead of time.
    - Ice water is a preferred option to make tea. Include ice/snow collection for indoor use.
    - Rainwater harvest: not an option in Cambridge Bay as the region is considered a desert.
    - Needs a system to tell us when drinking water tank is full – visual clue outside and/or inside. Human error often happens when filling up the tanks; simple overflow leads to ice build up one the external piping. Operator will break the ice with hammer and typically break the pipe. Install steel external piping and bolt it to the exterior of the building.
    - Consider a berm area with water proof membrane for the tanks – when overflowing occurs (and it will occur!).

    - Wastewater systems: either outside protected or inside the crawl space. If outside need glycol systems. Wastewater system outside: need glycol heat tracing system. However, sometimes building occupants forget to turn them on in the winter - frozen pipes burst. Septic tank installation should take into account the permafrost. Once upper layer is removed, permafrost will melt and tank will collapse.
    - Always consider human error in installation and/or operation of piping and sewage system. Balance the need for protection from freezing and damages and consequences if system fails (i.e. wastewater tank inside the crawl space can have serious

consequence if it fails). Municipality always install sewer outside and not in the crawl space, and have not had any issues so far.
- Exterior connection for piping: consider flexible piping? Ground will shift throughout the season and solid connectors do not allow for movement.
- Sewer vents are frozen solid in the winter
- Specialized wastewater catchments for meat butchering and skin preparation workshops – in particular the ability to trap blood and grease is essential.
- Ensure water systems are all congregated in one spot / reduce plumbing. Consider water delivery and access when positioning the tanks and the buildings.
- How will we achieve water reduction/what kind of systems do they recommend, considering the type of cultural activities that will take place? Low flow can be a problem as it can plug the line.
- Greywater is not something commonly used in Cambridge Bay – any thoughts?

4. Building foundations
    - Permafrost degradation. Many people in the communities need their home re-leveled. Walls are cracking because of ground of movement. Foundations do not allow for movement.
    - Community builders are moving away from crawl space. Gets too hot in the summer and it can lead to water damages (see “Water Systems” chapter). Under the house, insulate with spray foam.
    - Screw jacks used for community buildings. CHARS campus is on piles.
    - We have heard pros and cons for piles vs screw jacks. What does SAIT recommend?
    - Pile vs screw jacks – piles create less disturbance on the land, and require less civil work (and less gravel to be trucked to the site) but they are more expensive.
    - Contractors recommend not blocking/paneling the foundations – snow needs to move through to protect permafrost.

5. HVAC
    - Passive solar:
        - Need to be optimized for wintertime.
        - Too much heat gain in the summer. Consider: blinds, shutters (could be used for safety and window protection as well), electrochromic windows (however – they might crack with extreme cold and will be hard to replace – we must consider the supply chain), or using Sunpath chart and block sun penetration through architectural design.
        - Install operable windows – need to be able to release excess heat in the summertime.
        - Designed home with integrated passive solar. South facing windows, no windows on north walls.
        - Residents who are taking advantage of passive solar stop paying diesel bill in spring and summer months. However, heat gains are an issue - no heat loss during the night because of the 24hrs daylight. Open all windows.
    - Heat gain from dryer or boiler room can make a house unbearably hot in the summer. Boiler needs to be on in the summer for water heater – this creates large heat gain.
    - Humidity issues

    - Some houses have faulty roof and ceiling design. The vents and fresh air intake are placed in space between the ceiling and roof. Fine snow coming through the vents; temperature differential between cold roof and warm ceiling creates condensation and mold ("ceiling rain"). Residents had to take ceiling out and have cathedral roofing. Sacrifice energy efficiency to control humidity.
    - Design an air chamber to deal with humidity issue. Cold dry air is in contact with warm highly moist air – create "chimney snowman".
    - Mold is the main problem in northern housing. HRV is not powerful enough, not designed for overcrowded houses/intergenerational housing. Original home built in 1970's. Never had mold issues.
- Consideration in the ventilation design for supply and return air locations is also crucial in the workshop space to ensure air quality and minimize condensation.
- Ease of operation/simplicity of systems otherwise systems are by passed. Need to be able to fix with minimal maintenance and based on what local maintenance/contractors can do.
- Current KHS Centre has issues with cooling and heating. Extremely hot in summer and freezing in winter. Elders often bring additional heaters in the coldest months
- Piping is not in the exterior walls - too susceptible to freeze.
- Carbon monoxide build ups in chimney and sewer vents.
- Hydronic heating systems can be a challenge. Very rare to do hydronic flush and change the glycol. Although it would improve the heating efficiency, costs of barrels and new glycol is a barrier (as everything has to be shipped up). Furthermore, there is no safe disposal option for the used glycol.
- Most of the houses in the community have boilers and not furnaces.
- HRVs:
    - HRVs: occupants often turn them off because of the noise, which leads to humidity build up inside the house (mould and ice built up)
    - HRVs: create a "cold draft", which perceived as negative by home occupants. HRVs end up being shut down. Needs to place fresh air intake away from home/building occupants
    - HRVs are failing in really cold temperature. Install heating coil and fail-safe system.
    - Condenser glycol loop "froze" and turned to sludge, leading to equipment failure.
    - Simple design with switch control mounted on the wall. Using pre-heated coil from boiler.
    - Even when using Arctic Vents, have built up on the vents, which blocks the air entry. Install vents 4-5 inches off the roof, not more than that.
    - Need to find ways to shed humidity and heat of exhaust air before it has a chance to freeze – otherwise hot moist air in contact with cold dry air outside creates "chimney snow man", which leads to a heavy load on the structure and creates long term damages.
- Water heater: Consider using electrical on-demand water heater, to control overheating issues from boiler in the summer
- Floor heating is needed for workshops. Elders and participants sitting on the floor.
- Not sure if the electrical boiler makes sense considering the lifetime of the infrastructure and the high carbon intensity of the grid

6. Lighting
    - Emphasize natural light, while being mindful of solar gains.
    - Should the design also take advantage of daylight sensors to adjust lighting levels automatically? How are those systems, what needs to be considered, what is their lifespan, how easy are they to fix? Would they actually make a difference?
    - Install lighting that can go up and down. Something similar was done in Taloyoak. Appropriate for sewing, not in the way, come down from the ceiling.

7. Building Management System and Energy Management System
    - Educate the building occupants to not bypass the system and/or allow temporary overdrive of system with BMS resetting to default settings overnight.
    - Consider the ease of operation and maintenance, and complexity of operation for building manager – simple, straightforward, easy to maintain. Or have systems designed by the youth who are tech savvy. New tech wave might interest the youth in the community. If systems are too complex, they will be by-passed. Keep simple electrical panels, with on/off switches.
    - BMS: Simplicity and ease of update. Create a non-proprietary system. Can have big impacts for the whole community. Refer to RKI grant.
    - Municipality: IT equipment becomes obsolete before it even gets implemented. Difficult to receive support. Consider a simple, straightforward system
    - Many buildings are not commissioned and are using default settings that have never been updated.
    - What control systems is SAIT proposing: vacancy sensor, how this would affect Elders that will be sitting on the ground not moving for a few hours?
    - Include some thinking around opening hours and how energy will be optimized through controls and temperature set points.
    - See RKI grants. A dedicated Energy Management Control System (EMCS) that would incorporate an intelligent and user-friendly method to analyze the energy consumption and control major mechanical equipment would be essential for the operation of the facility
    - See RKI grant: User friendly interface.
    - Visual access to building systems reduces the need to overengineer.
    - At the High School/KHS space: Difficult to keep up with IT side of things. Everything is already obsolete; and it is really expensive to update the automation systems (because a lot of them are proprietary, need to send a technician up to Cambridge Bay). Cost is prohibitive – so systems end up being disconnected. Research needs: design a BAS that is simple, reliable, doesn't require maintenance or IT updates and not proprietary.

8. Land location
    - Orientation of the building: make sure water systems are accessible by trucks.
    - In winter times, snowbanks were built around iglu entrances to protect the structures from extreme winds and snow drifts. Those could be mimicked for a small building such as the workshop.
    - What is the best orientation to optimize energy efficiency but also accommodate the needs of the Elders and KHS?

- Can we just do civil work in a way that allows wheelchair accessibility without making a ramp? We are on a slope, it seems to me that there is no need to go down and put stairs up – just use the natural slope to our advantage?
- Elders stressed the importance of leaving the water undisturbed. Generation of birds and people have used this piece of land.
- We have settled on where it will be on the land, to accommodate potentially two buildings, allow for outdoor activities and not block the view – update SAIT on this.
- Workshop space – closer to the drainage area – but far away enough that it is not wet. The bigger building can go closer to the road. This will allow for both buildings to be on the land without blocking the view for one or the other.
- Windows facing the wetlands – having the quiet room face the drainage area (but not CHARS).
- Be mindful of snow collection
- Can place the parking between the workshop and the big building- allow for the water trucks to turn and back up towards the workshop instead of having to back up all the way from the top of the road or having to create a path around the workshop.

9. Renewable energy strategy

Barriers:

- Upfront equipment costs, and costs of transportation. Availability of spare parts and on-site monitoring
- Connection to the grid
- Being off grid for a commercial building is unlikely – too many roadblocks right now from regulatory perspective
- 

Waste to energy:

- Cambridge Bay is working on thermal oxidation of waste and waste heat recovery. However, our building would not be able to be connect to a district energy system due to major heat loss in transmission in the winter. Heat recovery possible only at the building level.
- Methanogenesis of organic waste and sewer heat recovery are explored, but technology still in its infancy.

Wind:

- Wind turbines: horizontal vs. vertical design. Cambridge Bay is extremely windy, so turbine efficiency would not be the main decision factor. Simple mechanical design, ease of repair and parts replacement should be considered above efficiency.
- Downside of wind turbines: need to be winterized. Small scale wind turbines installed on cabins create vibrations that can be felt inside by the occupants. Noise of large-scale wind systems might bother community residents.
- Wind has many roadblocks and acceptance in an urban environment with lots of children will not be easy to get. If any wind is to be installed, it will need its own separate study.

Solar PV:

- Solar PV: There is a lot of dust in Cambridge Bay. This might impact the efficiency of solar panel in the summer. Snow loads in the winter . Design vertical panels?
- Design options: 1) close circuit renewable system: running essential on the grid and running renewable energy systems for research only. 2) Switch system: switch back and forth between grid and renewable systems for the pilot (checked with QEC and this is not allowed) – see below.
- We know solar works in the Arctic. The challenges are connection to the grid, and materials and supply chains
- Analytics of power production: some homes in the community have installed solar panels. However, the local power producer (QEC) is not providing clear data on power production. There is a strong need to measure outputs and yearly savings/return on investments.
- How much PV can we produce – seasonal assessment of heating costs. How much diesel do we anticipate we will need over the winter months?
- How do solar trackers perform under Arctic conditions? One CB resident reported concerns with moving parts compromised by cold and ice – they went with flat panels.

<u>Solar water heater:</u>

- Explore this option? It has never been done in the Arctic.
- Overheating in the summer because the boiler is on to heat the water. We are wondering if solar thermal can be used in the summer to help with overheating, and turning off the boilers? Has it been tested in extreme cold environment?
- Solar water heater: Real estate taking away between solar water heater vs solar PV. If solar water heater doesn't work – can we easily retrofit to solar PV? Still need provision for full capacity for water heating.
- Would need a proof of concept beforehand and estimated recovery rate.
- What is the estimated hot water load for the building? How many collectors do you estimate is needed to achieve this energy production? What does that mean for dark month of the year, are we running the risk under sizing our water heater/diesel tank? Need to see a production throughout the month, and proof that it will work when full sun and extreme cold temperature.

<u>Energy storage:</u>

- Is this a viable option? What would a battery system look like? Costs, gain, pros and cons?
- Cost of shipping batteries to Cambridge Bay is prohibitive. Lifetime of the battery is 3-4 years, and they would have to be disposed of in the dump. There are no recycling facilities and leakage will be an issue.
- Consider thermal storage, instead of Li or lead-acid battery. What kind of thermal bank designs are available? Storing extra heat in water heaters?

<u>Integration to the grid (refer to the Qulliq Energy CIPP program folder in the SAIT drive):</u>

- Regulatory Context in Cambridge Bay: two options 10Kw and the CIPP program.
- Can connect to the grid if the system is less than 10kW.

- Discussion with QEC (Tom R.): the only option for us will be to be in the CIPP program. The transfer switch is not an acceptable option for QEC (Tom checked with them already).
- QEC regulations: Only one community building is allowed to have renewables. Rest needs to go under CIPP.
- The rate at which QEC is buying is not advantageous and has been reviewed by the Pembina Institute: https://www.pembina.org/pub/recommendations-qec-cipp-application All that to say that the CIPP is our best shot, with the understanding that we are doing it to reduce our environmental footprint, not to save on energy costs.

## 10. Logistics

- Barge arrives in September. This is beginning of winter weather. When assembling buildings, only indoors work is possible. Nobody will assemble weather barriers in a blizzard.
- Pay for volume. Need to compact and stack to have minimal unused space.
- Consider costs of transportation to Montreal and the barge vs costs of air transport and a charter
- Shipping construction material by air can be challenging because of inconsistency in delivery time (the charter will only leave once it is full)
- Transportation within the Municipality: limitation for height is 12 feet because of power line. 20,000 lbs weight restriction
- There is no crane in town. But have access to telehandlers (~50 feet). Working within these parameters. Easy construction, modular is best.

## 11. Interior Design

- The need for a sitting area around the edge of the main workshop space led to conversations on height requirements for benches, work surfaces and windows. Too often, interiors are designed for average heights that do not reflect those of the Elders.
- As most cultural activities require participants to sit on the floor, staff indicated the need to have warm, soft flooring for sewing, while meat butchering and skin preparation required colder, harder surfaces; emphasizing the need for floor temperature differential within one space. However, there is concern that the space is too small to include separation of the floors into two different flooring materials. Consider hard floor with option to turn on in-floor heating. Then install temporary padding to soften the floor for sewing workshops?
- Thinking around Health and Safety of occupants – how are the materials chosen respectful of the occupants. Include thinking around mould. What are you proposing?

- Moveable walls/removable doors between the different sections – to increase space as/when needed. Fit in well with the modularity concept. If we do this then we don't need an additional sink in the main room – because messy activities can be done partially in the kitchen and around.
- Include lots of low storage and sitting area all around the structure

- Include a beam (non-structural) across the main room for games

12. Energy model
    - Operating schedule: Occupancy of the building should be taken into considerations. This is not a residential dwelling. Need to consider how many workshops a week/how many participants, so we get a good understanding of usage patterns. Internal loads and change due to variations in occupancy.
    - Importance of energy modeling in the decision making. It seems to me that we did it the other way: made some decision, then model it. But we should be modeling different options to understand decision making better.
    - Domestic hot water consumption
    - Envelope optimization – how they affect building energy efficiency, increasing envelop tightness, vs gain in energy efficiency vs costs. And why we are choosing certain materials.
    - Need a clear understanding of the different heating requirements throughout the year and how it will be compensated by what in terms of our energy sources.
    - Avoid building and operating a facility based on usage numbers that may only be achieved a few days a year.

13. Involvement of local workforce
    - In most projects the people that are actually installing the systems don't ever have any input on the process or design. This is an absolute must for this project – long term operation and maintenance will be done by local contractors. We can't ship contractors from the south to maintain our building- this is contrary to KHS vision/mandate and cost would be prohibitive.
    - Moving the project to the North is also a risk mitigation strategy – people who knows, who have experience and can handle the situations as they arise.

14. Commissioning and training
    - Recommend a building commissioning agent for the project to ensure the systems are installed and operating properly from the first day of operation.
    - The owner's training is also another critical component to ensure proper operation. It is highly recommended that this training be video-taped and well documented so future new staff is educated in the same manner as the original staff which tend to turn over at many similar facilities

15. Operation and maintenance
    - Supply chain for spare parts should be taken into account when designing a building/home. Barge only come up once a year and there is weight limitation
    - Plan to have a sea can with critical spare parts available

16. Climate change

    Refer to Climate Risk Assessment.

    Refer to NISI standards:

o Building in permafrost (https://www.scc.ca/en/nisi/building-in-permafrost),

o Extreme weather, including managing snow load risks and erosion management (https://www.scc.ca/en/nisi/extreme-weather), and

o Community Systems (https://www.scc.ca/en/nisi/community-systems).

## APPENDIX D – PI/KHS WORKSHOP: SUSTAINABILITY DECISION MAKING MATRIX

The sustainability matrix lists out building categories of heating and ventilation, cooling, lighting, energy recovery, renewables, energy source, energy storage, solar heat gain control, envelope, foundation, and water treatment.

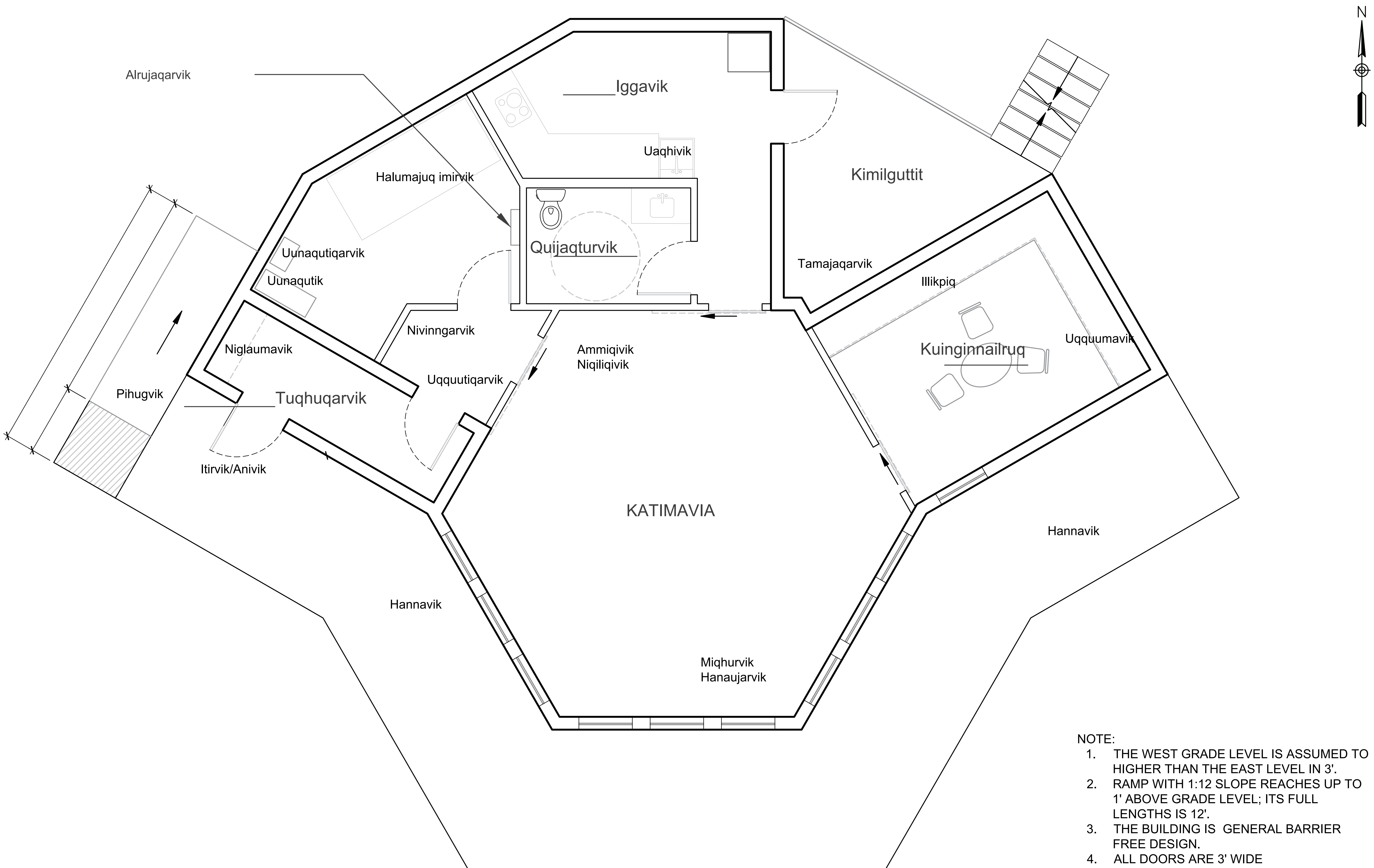
**PI/KHS Workshop: Sustainability Decision Making Matrix**
**19-Nov-21**

| Category | Strategies | Description | Impacts for Sustainability | Functional Space | Energy Savings | Durability | Equipment Cost | Operations and Maintenance |
|---|---|---|---|---|---|---|---|---|
| **Heating and Ventilation** | Forced Air Distribution | Uses a blower to distribute warm air around the building and to return cold air to the furnace. | Around 80% efficiency. Dependent on the energy source. | Cannot differentiate temperatures between rooms. Requires vents. | Low | Medium | High | Replace filter and service every 1-2 years. |
| | Hydronic Distribution | Uses a fluid to heat or cool the building. | High energy efficiency. Dependent on the energy source. | In-floor heating, can utilize different loops for different functional spaces within one room. | High | Medium | Low | Check system every year, replace glycol every 5-7 years. |
| | Electric Boiler | Boiler that uses electricity to heat water supplied to taps and/or radiators. | Around 80-90% efficient. Dependent on the energy source. | In-floor heating, can utilize different loops for different functional spaces within one room. | High | Medium | Medium for equipment, high for operation cost in the arctic. | Little maintenance - visual inspection to ensure everything is in working order. |
| | Combined Heat and Power (CHP) | An added efficient unit used to generate electricity and capture waste heat for reuse from the energy source. The energy source can be combustion, steam, or fuel cells. | Adds 60-80% efficiency to total system. Dependent on the energy source. | Used on generators/combustion systems and is used with other heating and ventilation systems. | High - when compared to combustion without co-generation | Medium | Medium | Inspections every 4000 hours, overhaul every 25,000-50,000 hours. |
| | Air-Source/Water-Source Heat Pump | Air-source heat pump: transfers heat from outside air to inside air.<br>Water-source heat pump: transfers heat from outside air to inside water systems. | 1:1.5 to 1:3 electricity input : create thermal energy output. | Cannot differentiate temperatures between rooms. Requires vents. | Low in cold climates - temperatures lower than -10 to -20 will reduce efficiency. | Medium | Medium | Annual maintenance and systems checks. |
| **Cooling** | Vapor-Compression Systems | The refrigerant turns from a liquid to a gas and absorbs heat, which is then transferred outside. | Refrigerants (CFCs and HCFCs) affect the ozone layer. | Cannot differentiate temperatures between rooms. Requires vents. | Low | Medium | Medium | Regular maintenance. |
| | Compressor System - Air-Source/Water-Source Heat Pump | Liquid or air absorbs heat from the inside air, is compressed, and then condensed - releasing heat to the outside air, then continues the cycle. | 1:1.5 to 1:3 electricity input : create thermal energy output. | Cannot differentiate temperatures between rooms. Requires vents. | High | Low | High | Used year-round for heating and cooling. More frequent maintenance. |
| | Addressing Passive Solar Gains | Passive solar gains are when solar energy is absorbed and stored in thermal mass (walls and flooring). Addressing passive solar gains is required in the design phase. | Design element - does not require input energy. | Beneficial to reduce glare or bright sunlight. | Medium | High | Low | Addressed in the design phase. |
| **Lighting** | LEDs (Light Emitting Diode) | Illuminated by an electrical current passing through a microchip. | 90% more efficient than incandescent | LEDs have heat sinks and do not overheat. | High | LEDs do not burn out, they slowly dim overtime. | Medium | Replace when necessary. |
| | Fluorescent | Inside a glass tube, gases interact to produce ultraviolet light that causes a phosphor coating to emit white light. | 4-6x more efficient than incandescent. Mercury and phosphorus is hazardous. | Omnidirectional light (light emits from all directions) - which reduces efficiency and can cause over lighting of spaces. | Medium | 13x the lifespan then incandescent. | Low | Replace when necessary. |
| | Incandescent | Illuminated by heating a wire surrounded by inert gas to generate light. | 10% efficient (90% of energy is released as heat). | Omnidirectional light (light emits from all directions) - which reduces efficiency and can cause over lighting of spaces. | Low | Low | Low | Lower lifespan - more replacements. |
| **Energy Recovery** | HRV | HRVs (heat recovery ventilators) warms outdoor air to distribute inside, and is typically used in climates where outdoor air is humid. | More sustainable than no energy recovery. | Can be noisy and can create drafts if there are not pre- or post-heaters. | High | Medium | Medium | Replace filter and service every 1-2 years. |
| | ERV | ERVs (energy recovery ventilators) function similarly to HRVs, but recovers energy within humidity and helps control humidity levels between outdoor and indoor air. | More sustainable than no energy recovery. | Can be noisy and can create drafts if there are not pre- or post-heaters. | High | Medium | Medium | Replace filter and service every 1-2 years. |
| **Renewables** | PV Solar | Solar photovoltaics (PV) panels convert solar energy to electricity. | Minimal sustainability impacts. No operational carbon but there is embodied carbon, can be recycled or refurbished. | On roof or mounted as a stand-alone system. | About 20% efficiency. | High | Medium | Brush off debris, dust, and snow. Service every year or when necessary. |
| | Thermal Solar | Solar thermal collectors use solar energy to heat tubes filled with water or glycol that can then be used for space heating. | Minimal sustainability impacts. No operational carbon but there is embodied carbon, can be recycled or refurbished. | On roof or on walls. | About 90% efficiency. | High | Medium | Fluid replacement every 12-15 years, service every 2 years. Ensure water to glycol ratio can withstand extreme cold. |
| | Wind Turbine | Wind turbines use wind to physically move the turbine, which is converted into electricity. | Minimal sustainability impacts. No operational carbon but there is embodied carbon, can be recycled or refurbished. | On roof or as a stand-alone system. Can be very noisy. | About 40% efficiency. | Medium | High | Annual maintenance and systems checks. |
| **Energy Source** | Grid Connection | Connected to the energy grid, which is typically spread across countries or continents, however in Cambridge Bay there is a grid only for this community. The grid is powered by diesel generation. | Diesel generation - high carbon emissions. | No storage space or noise. | Low | n/a | High | n/a |
| | Home Heating Oil | Home heating oil is derived from crude oil, and is combusted to heat either air or water in a furnace or boiler. | High carbon emissions. | Storage space of oil. | Low | Medium | High | Yearly service. |
| | Diesel Generator | By burning diesel, the generator will generate mechanical and chemical energy that converts to electricity. | Diesel generation - high carbon emissions. However, more thermal energy can be captured on-site. | Can be noisy and requires operation: fueling and turning on/off. | Medium | Medium | High | Oil change at 500 hours, addition of coolant and fuel, routine systems maintenance. |
| **Energy Storage** | Lithium-Ion Battery | Rechargeable battery that holds energy in electrodes for later electrical energy usage. | Material extraction is unsustainable. Limited disposal or recycling options. | Small storage space. | Storage | Low | High | Relatively simple, most batteries can be viewed in an app on a smartphone. |
| | Thermal Mass | Thermal heat stored in high-density materials that adsorb and hold heat (such as concrete or bricks). | Low if materials are local and non-toxic. | It is the flooring. | Storage | High | Low | Can cause overheating if not designed properly. |
| **Solar Heat Gain Control** | Window Placement | By placing bigger windows to the Southern-orientations, more passive solar gains can be utilized. | Low | Activities or objects that can be affected by sunlight should be done or stored in the northern side of the building - away from sunlight. | Medium | High | Low | Addressed in the design phase. Undergo regular window maintenance. |
| | Shade Control | Roof overhangs can be placed to allow or stop different levels of sunlight from entering the building through the windows. | Low | Little to no effect on functional space | Medium | High | Low | Addressed in the design phase. Undergo regular roof maintenance. |
| | Solar Awning | Incorporate PV panels on the South-East, South, and South-West facing orientations with a large overhang (7 feet) to act as shade control and to generate electricity. | Minimal sustainability impacts. No operational carbon but there is embodied carbon, can be recycled or refurbished. | Little to no effect on functional space | High - solar heat control plus electricity generation | High | High | PV maintenance. |
| **Envelope** | SIPs | Structural insulated panels (SIPs) are pre-fabricated wall assemblies designed to be fast to install, have higher thermal performance, and contribute to increased indoor air quality. | Less waste due to pre-fabrication. Larger variety of materials, including fire and water resistant and more durable materials. | Little to no effect on functional space. | Range: medium to high depending on thermal performance. | Range: medium to high depending on insulation value. | Range: medium to high depending on insulation value. | Maintenance on cladding and panel connections. |
| | Conventional | Conventional framing, or stick framing, requires measuring, cutting, and assembling the building frame on-site. | Higher construction waste. Increased thermal bridging (heat loss and water transfer). | Little to no effect on functional space. | Range: low to medium depending on thermal performance. | Range: low to medium depending on insulation value. | Range: low to medium depending on insulation value. | Maintenance on cladding. |
| | Windows (U-Value) | U-value is the transfer of heat through a structure, and a lower U-value in windows mean the window is more efficient. Triple-paned windows will have lower U-values. | More material use with lower U-value, but better performance and more durable. | Lower U-value results in less heat loss/drafts/humidity issues. | Range: low to high depending on U-value selected | Range: low to high depending on U-value selected | Range: low to high depending on U-value selected | Maintenance on seals. |
| | Doors (R-value, thermal bridging) | R-value is how well a material stops heat transfer, and a higher R-value in doors means the door is more efficient. Thermal bridging is the transfer of heat through a material with high thermal conductivity, which leads to a decrease in efficiency. Thermal bridging can happen in doors with steel framing therefore doors without thermal bridges are preferred. | More material use with higher R-value, but better performance and more durable. | Higher R-value results in less heat loss/drafts/humidity issues. | Range: low to high depending on R-value selected | Range: low to high depending on R-value selected | Range: low to high depending on R-value selected | Maintenance on seals. |
| **Foundation** | Triodetic | Multi point foundation made of interlocking tubes arranged in series of triangles. | Low impact to permafrost and made of recyclable material | Cannot have a crawl space. | None | High | Medium | Occasional inspections. Can adjust with ground movement. |
| | Blocks and Wedges | Pads of horizontally placed timbers that are stacked to created air space underneath buildings. Wedges are used to level out the stacked timbers. | Low impact to permafrost | Can have a crawl space. | None | Medium | Low | Occasional inspections. Can adjust with ground movement. |
| | Screw Jacks | Is a type of jack that is operated by turning a leadscrew. It will lower and raise heavy loads. | Low impact to permafrost | Can have a crawl space. | None | Medium | Low | Occasional inspections. Can adjust with ground movement. |
| | Steel Piles | A galvanized steel pile that is driven into the ground. | Some impact to permafrost. Piles are driven into the ground but not dug like concrete piles. | Can have a crawl space. | None | Medium | High | Occasional inspections. |
| | Concrete Slab on Grade | A shallow foundation where a gravel pad is installed and then concrete is poured on top. | Not recommended on permafrost. | Cannot have a crawl space. | Low - no wind blowing underneath | High | Medium | Occasional inspections. |
| | Concrete Piles | Either a precast concrete pile or a cast in place concrete pile. Both are reinforced with rebar and high-quality concrete. | Most impact on permafrost. Dug into the ground - most site disturbance. | Can have a crawl space. | None | Medium | High | Occasional inspections. |
| **Water Treatment** | Carbon Filter | Carbon blocks and granulated carbon remove chlorine by chemically bonding to the chlorine, which improves taste and odor. | Low - these filters are disposable, however they do not require energy to run and improves the water quality. Improving water quality will reduce the need to buy water bottles. | Little to no effect on functional space. Filters can be applied to all of the building's water or to certain taps. | Filters the pumped water - does not specifically require electricity. | n/a | Low | They need to be replaced when stated by the manufacturer. |

* water and wastewater equipment will be looked into during design

## APPENDIX E – WORKSHOP DRAWINGS

The following is the preliminary design for the workshop and the Inuinnaqtun translation of the floorplan.




1 HEXAGON FLOOR PLAN

Scale: 3/16" = 1'-0"

NOTE:

1. THE WEST GRADE LEVEL IS ASSUMED TO HIGHER THAN THE EAST LEVEL IN 3'.
2. RAMP WITH 1:12 SLOPE REACHES UP TO 1' ABOVE GRADE LEVEL; ITS FULL LENGTHS IS 12'.
3. THE BUILDING IS GENERAL BARRIER FREE DESIGN.
4. ALL DOORS ARE 3' WIDE
5. ALL EXTERIOR WINDOWS REQUIRE SECURITY BARS AND SECURITY HARDWARE.
6. ALL EXTERIOR REQUIRE INSTALLATION OF SECURITY HARDWARE.
7. WATER TANK CAPACITY = 500 Gal.



THE CONTRACTOR SHALL CHECK AND VERIFY ALL COMPONENTS AND DIMENSIONS WITH MECHANICAL ENGINEER PRIOR TO CONSTRUCTION

APPROVALS:

Name | Signature/Stamp | Date

| | |
|---|---|
| Client | |
| Contractor | |
| Architect/ Engineer | |

NOT FOR CONSTRUCTION

ISSUED FOR/REVISION:

| # | Date | Comments |
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| | | |

SAIT

1301 - 16th. Ave. N.W. Calgary, Alberta T2M 0L4

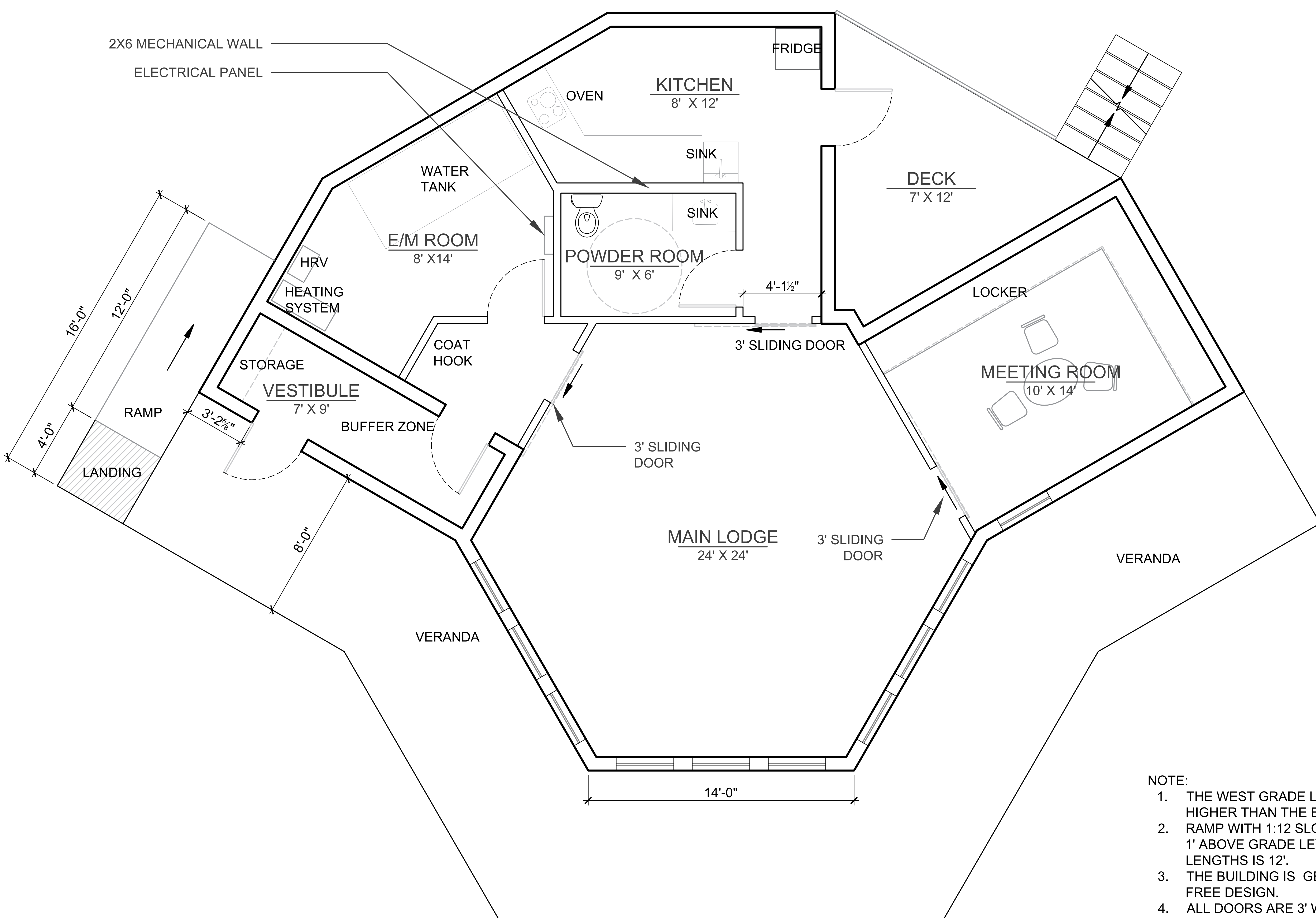
PROJECT:

KHS CAMBRIDGE BAY WORKSHOP

DRAWING NAME:

MAIN FLOOR PLAN

| | | | |
|---|---|---|---|
| Contact: | SAIT GBT | | |
| Phone: | 403-774-5327 | | |
| Drawn: | LL | Checked: | |
| Date: | 2021-08-19 | | |
| SAIT Project Number: | 2020-020 | | |
| Drawing Scale: | 3/16" = 1'-0" | Sheet: | A1 2 of 8 |




NOTE:

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6. ALL EXTERIOR DOOR REQUIRE INSTALLATION OF SECURITY HARDWARE.
7. WATER TANK CAPACITY = 500 Gal.

## 1 HEXAGON FLOOR PLAN

Scale: 3/16" = 1'-0"



THE CONTRACTOR SHALL CHECK AND VERIFY ALL COMPONENTS AND DIMENSIONS WITH MECHANICAL ENGINEER PRIOR TO CONSTRUCTION

APPROVALS:

Name Signature/Stamp Date

| | | |
|---|---|---|
| Client | | |
| Contractor | | |
| Architect/ Engineer | | |

NOT FOR CONSTRUCTION

ISSUED FOR/REVISION:

| # | Date | Comments |
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SAIT

1301 - 16th. Ave. N.W. Calgary, Alberta T2M 0L4


PROJECT:

KHS CAMBRIDGE BAY WORKSHOP

DRAWING NAME:

MAIN FLOOR PLAN


Contact: SAIT GBT

Phone: 403-774-5327

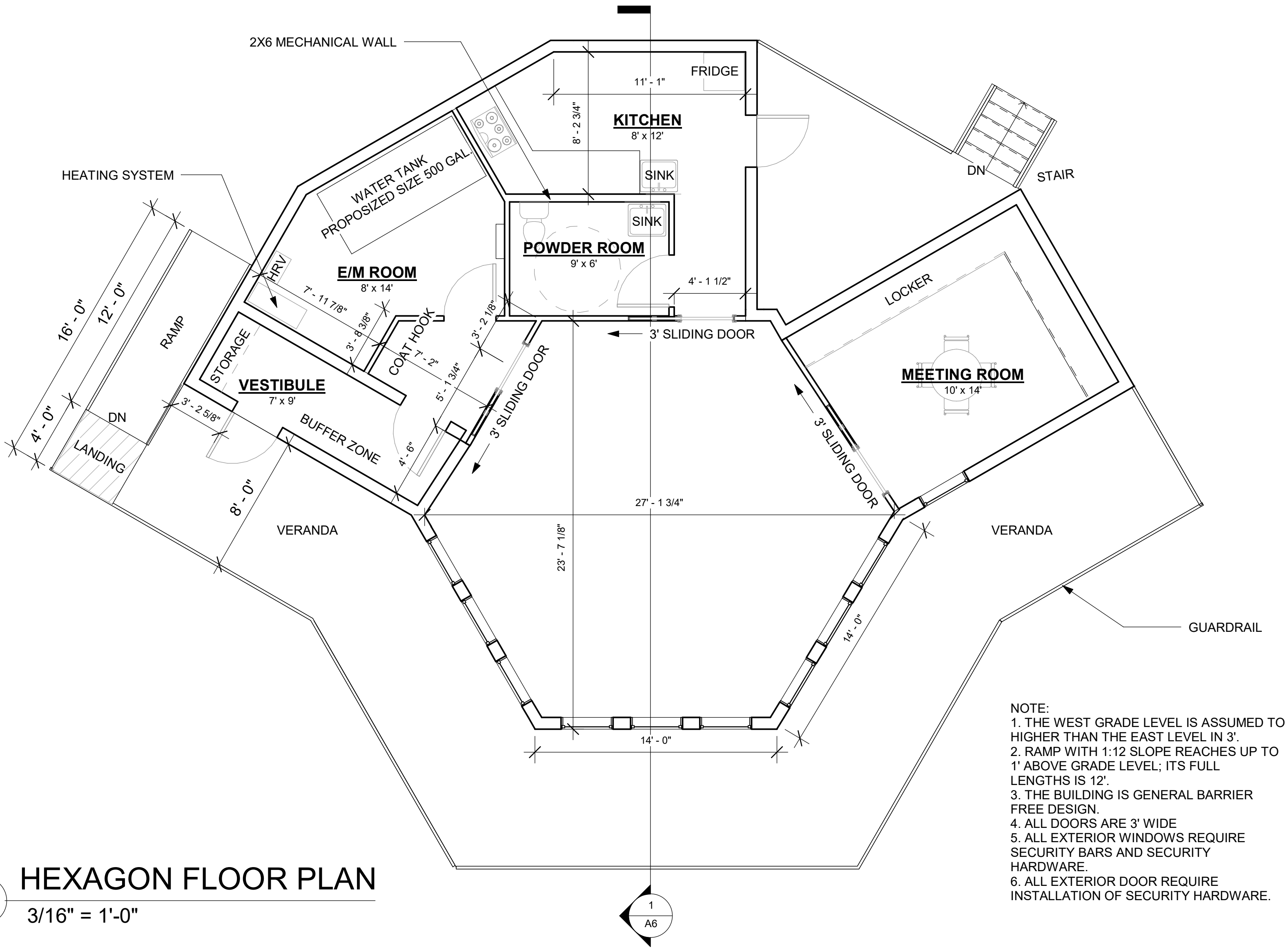

Drawn: LL Checked:

Date: 2021-08-19

SAIT Project Number: 2020-020

Drawing Scale: 3/16" = 1'-0"

Sheet: A1




NOTE:
1. THE WEST GRADE LEVEL IS ASSUMED TO HIGHER THAN THE EAST LEVEL IN 3'.
2. RAMP WITH 1:12 SLOPE REACHES UP TO 1' ABOVE GRADE LEVEL; ITS FULL LENGTHS IS 12'.
3. THE BUILDING IS GENERAL BARRIER FREE DESIGN.
4. ALL DOORS ARE 3' WIDE
5. ALL EXTERIOR WINDOWS REQUIRE SECURITY BARS AND SECURITY HARDWARE.
6. ALL EXTERIOR DOOR REQUIRE INSTALLATION OF SECURITY HARDWARE.

## 1 HEXAGON FLOOR PLAN

3/16" = 1'-0"



THE CONTRACTOR SHALL CHECK AND VERIFY ALL COMPONENTS AND DIMENSIONS WITH MECHANICAL ENGINEER PRIOR TO CONSTRUCTION

APPROVALS:

Name Signature/Stamp Date

Client

Contractor

Architect/Engineer

NOT FOR CONSTRUCTION

ISSUED FOR/REVISION:

| No. | Date | Comments |
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KHS CAMBRIDGE BAY WORKSHOP

HEXAGON FLOOR PLAN

Contact: SAIT GBT
Phone: 403-774-5327
Drawn: TS Checked: ____
Date: 2021.11.24
SAIT Project Number: 2020-020
Scale: 3/16" = 1'-0" A1

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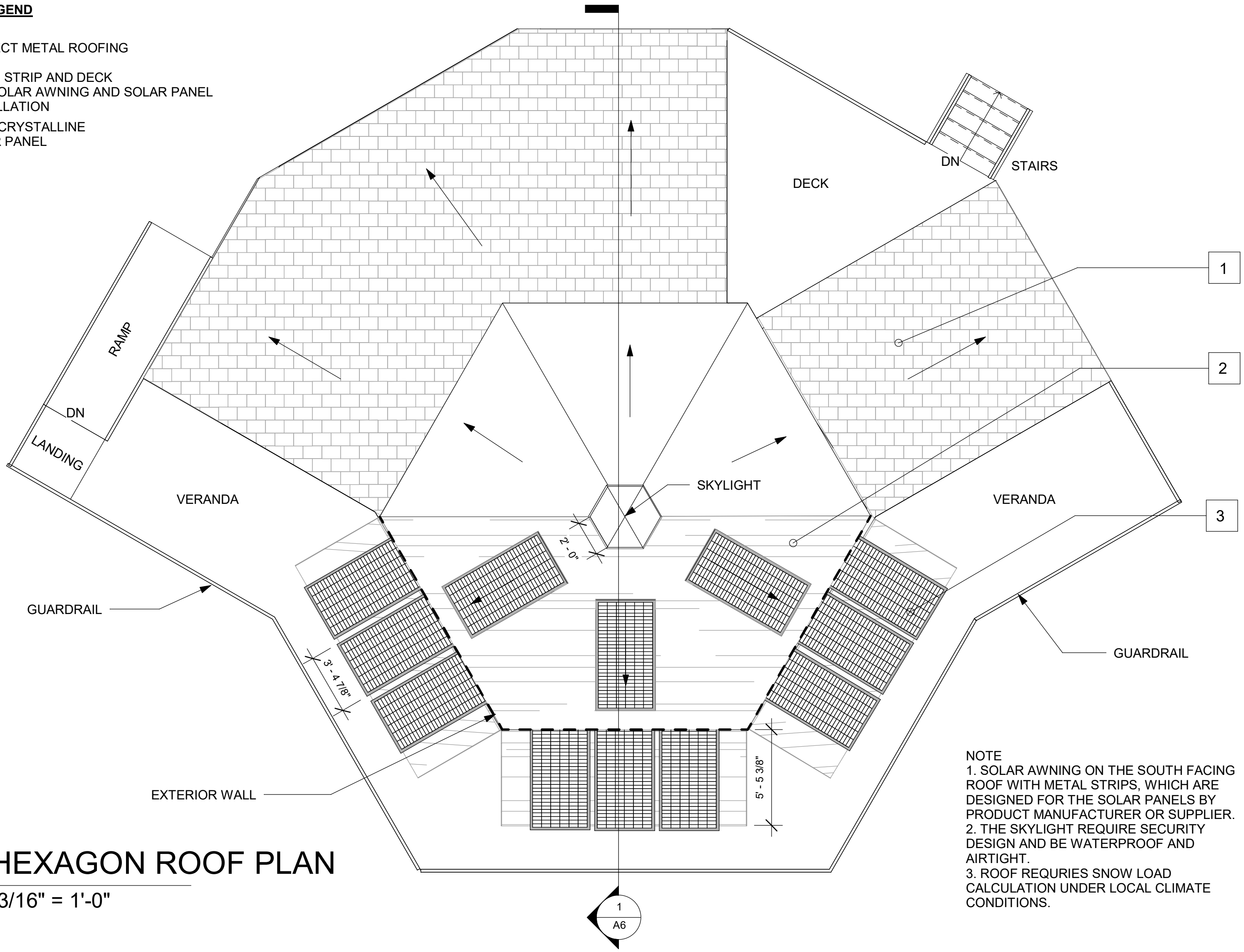
**MATERIAL LEGEND**

| | |
|---|---|
| 1 | PROJECT METAL ROOFING |
| 2 | METAL STRIP AND DECK FOR SOLAR AWNING AND SOLAR PANEL INSTALLATION |
| 3 | MONOCRYSTALLINE SOLAR PANEL |




# 1 HEXAGON ROOF PLAN

3/16" = 1'-0"

NOTE

1. SOLAR AWNING ON THE SOUTH FACING ROOF WITH METAL STRIPS, WHICH ARE DESIGNED FOR THE SOLAR PANELS BY PRODUCT MANUFACTURER OR SUPPLIER.
2. THE SKYLIGHT REQUIRE SECURITY DESIGN AND BE WATERPROOF AND AIRTIGHT.
3. ROOF REQURIES SNOW LOAD CALCULATION UNDER LOCAL CLIMATE CONDITIONS.



THE CONTRACTOR SHALL CHECK AND VERIFY ALL COMPONENTS AND DIMENSIONS WITH MECHANICAL ENGINEER PRIOR TO CONSTRUCTION

**APPROVALS:**

Name Signature/Stamp Date

| | | |
|---|---|---|
| Client | | |
| Contractor | | |
| Architect/ Engineer | | |

NOT FOR CONSTRUCTION

ISSUED FOR/REVISION:

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KHS CAMBRIDGE BAY WORKSHOP

ROOF PLAN

Contact: SAIT GBT
Phone: 403-774-5327

Drawn: TS Checked: ___
Date: 2021.11.24
SAIT Project Number: 2020-020
Scale: As indicated A2

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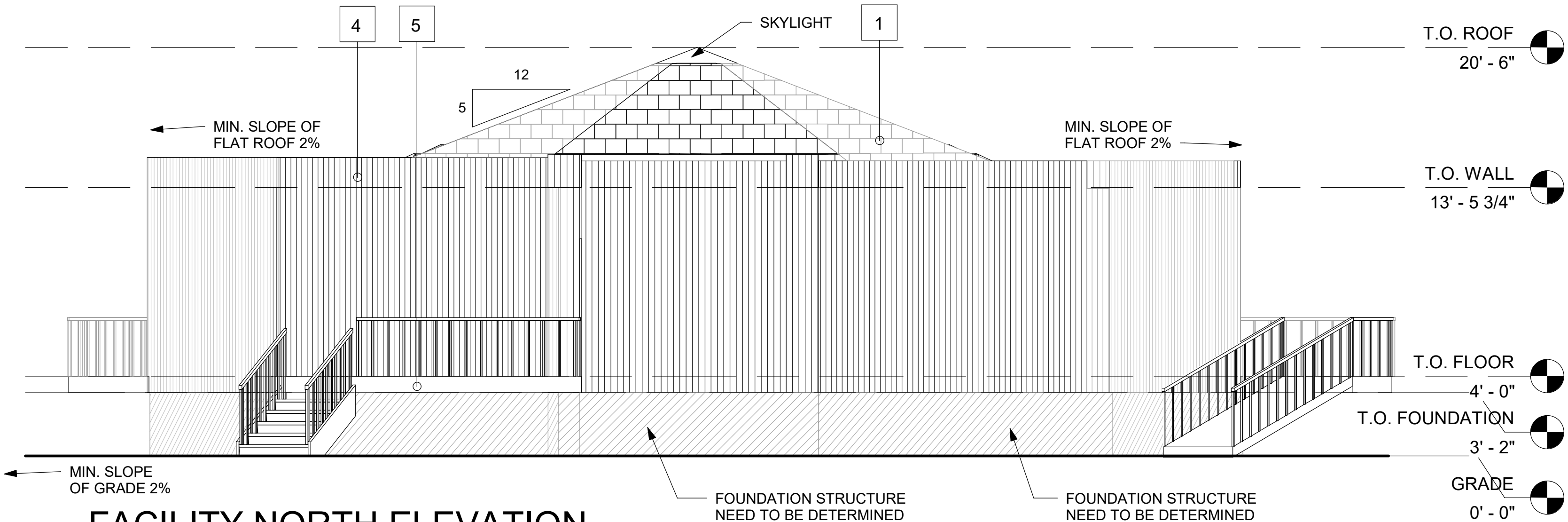



1 FACILITY NORTH ELEVATION

3/16" = 1'-0"

**MATERIAL LEGEND**

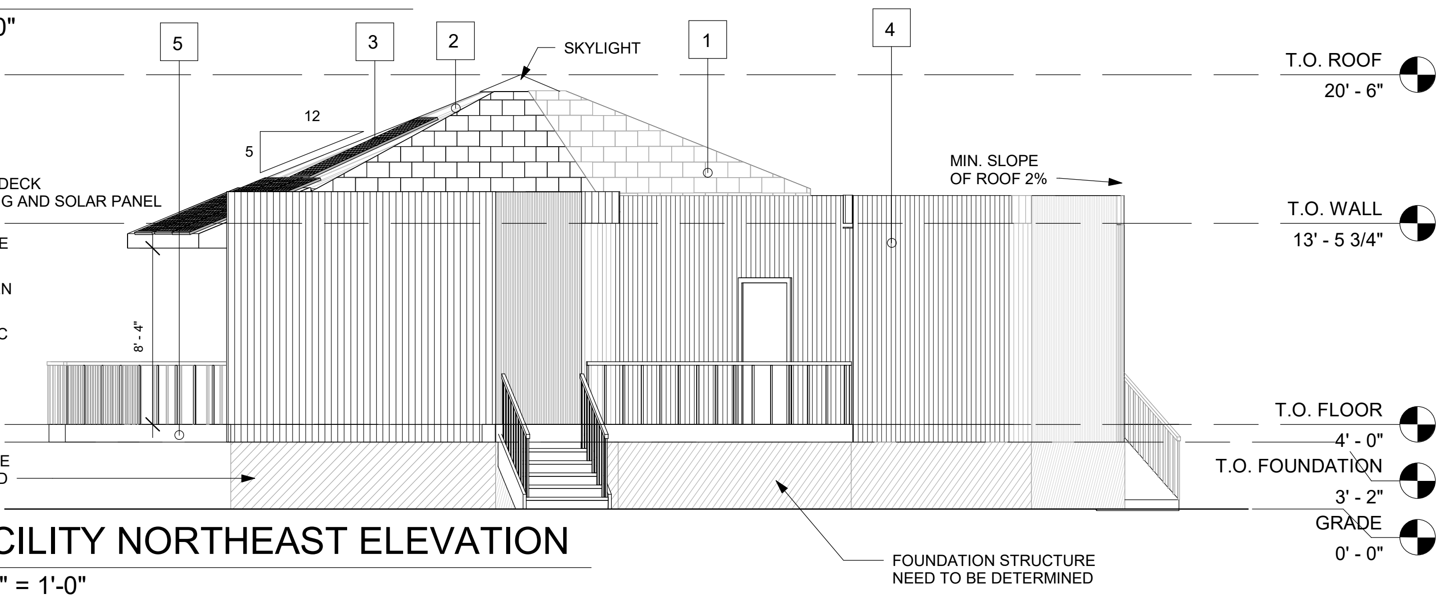
1 METAL ROOFING

2 METAL STRIP AND DECK FOR SOLAR AWNING AND SOLAR PANEL INSTALLATION

3 MONOCRYSTALLINE SOLAR PANEL

4 METAL RAINSCREEN CLADDING

5 RECYCLED PLASTIC COMPOSITE DECK




2 FACILITY NORTHEAST ELEVATION

3/16" = 1'-0"



THE CONTRACTOR SHALL CHECK AND VERIFY ALL COMPONENTS AND DIMENSIONS WITH MECHANICAL ENGINEER PRIOR TO CONSTRUCTION

**APPROVALS:**

Name Signature/Stamp Date

Client

Contractor

Architect/ Engineer

NOT FOR CONSTRUCTION

ISSUED FOR/REVISION:

| No. | Date | Comments |
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SAIT

KHS CAMBRIDGE BAY WORKSHOP

ELEVATION 1

Contact: SAIT GBT
Phone: 403-774-5327
Drawn: TS Checked: ____
Date: 2021.11.24
SAIT Project Number: 2020-020
Scale: As indicated A3

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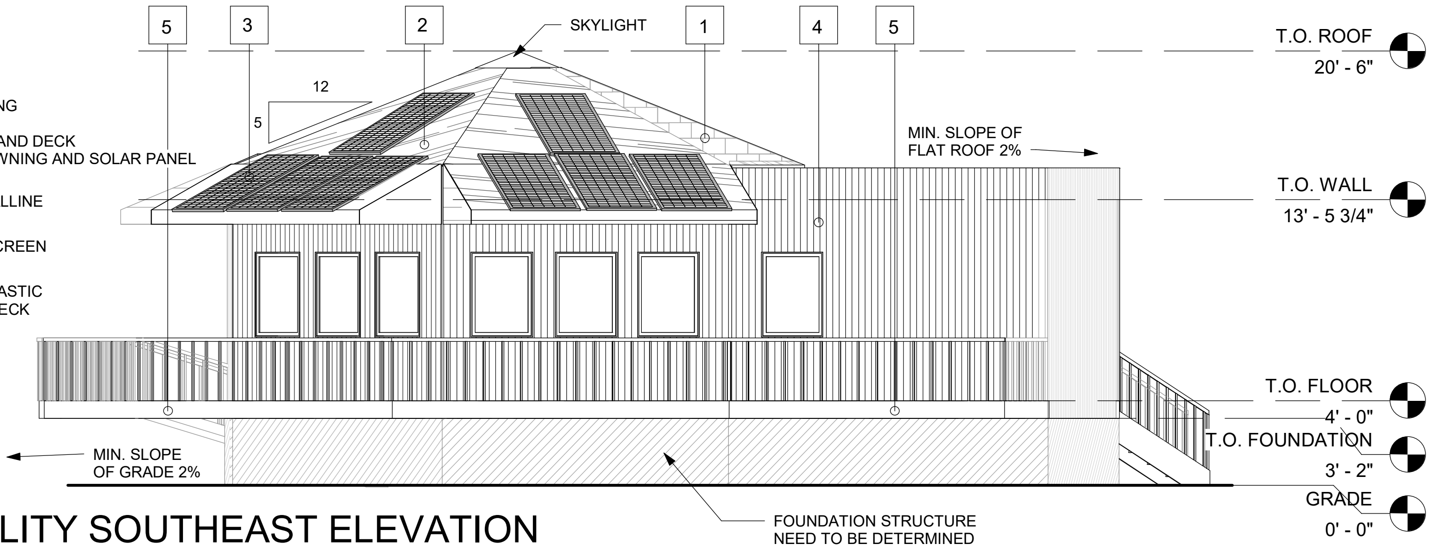
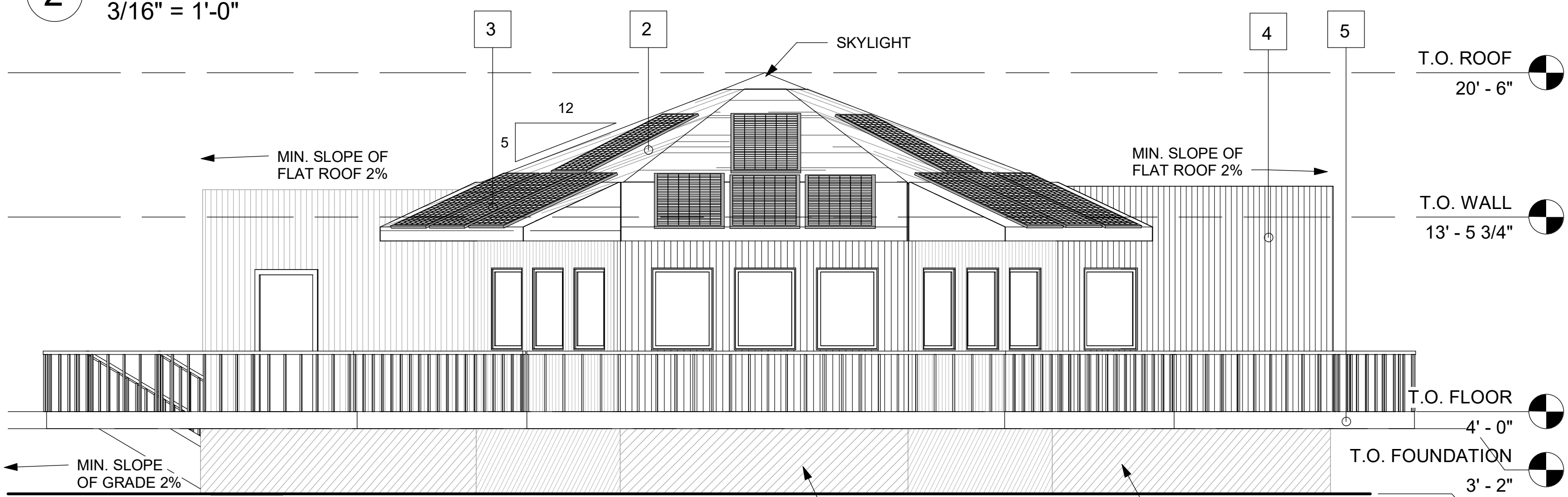
**MATERIAL LEGEND**

| | |
|---|---|
| 1 | METAL ROOFING |
| 2 | METAL STRIP AND DECK FOR SOLAR AWNING AND SOLAR PANEL INSTALLATION |
| 3 | MONOCRYSTALLINE SOLAR PANEL |
| 4 | METAL RAINSCREEN CLADDING |
| 5 | RECYCLED PLASTIC COMPOSITE DECK |




## 2 FACILITY SOUTHEAST ELEVATION

3/16" = 1'-0"




## 1 FACILITY SOUTH ELEVATION

3/16" = 1'-0"



THE CONTRACTOR SHALL CHECK AND VERIFY ALL COMPONENTS AND DIMENSIONS WITH MECHANICAL ENGINEER PRIOR TO CONSTRUCTION

**APPROVALS:**

Name Signature/Stamp Date

Client

Contractor

Architect/Engineer

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| No. | Date | Comments |
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KHS CAMBRIDGE BAY WORKSHOP

ELEVATION 2

Contact: SAIT GBT
Phone: 403-774-5327
Drawn: TS Checked: ____
Date: 2021.11.24
SAIT Project Number: 2020-020
Scale: As indicated A4

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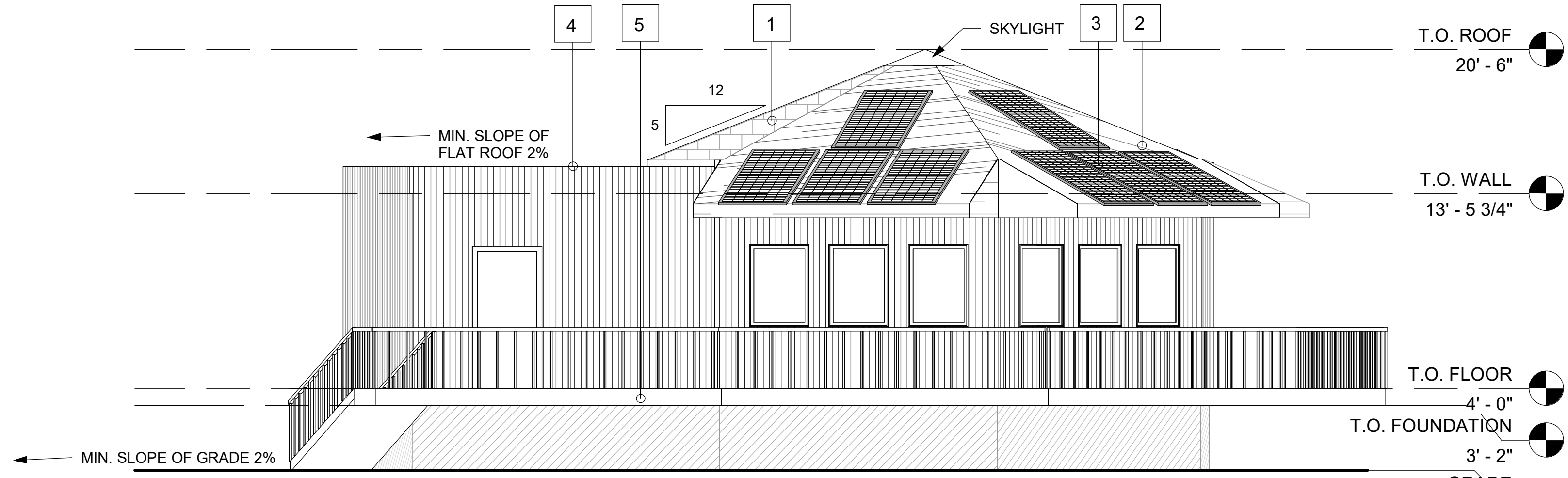
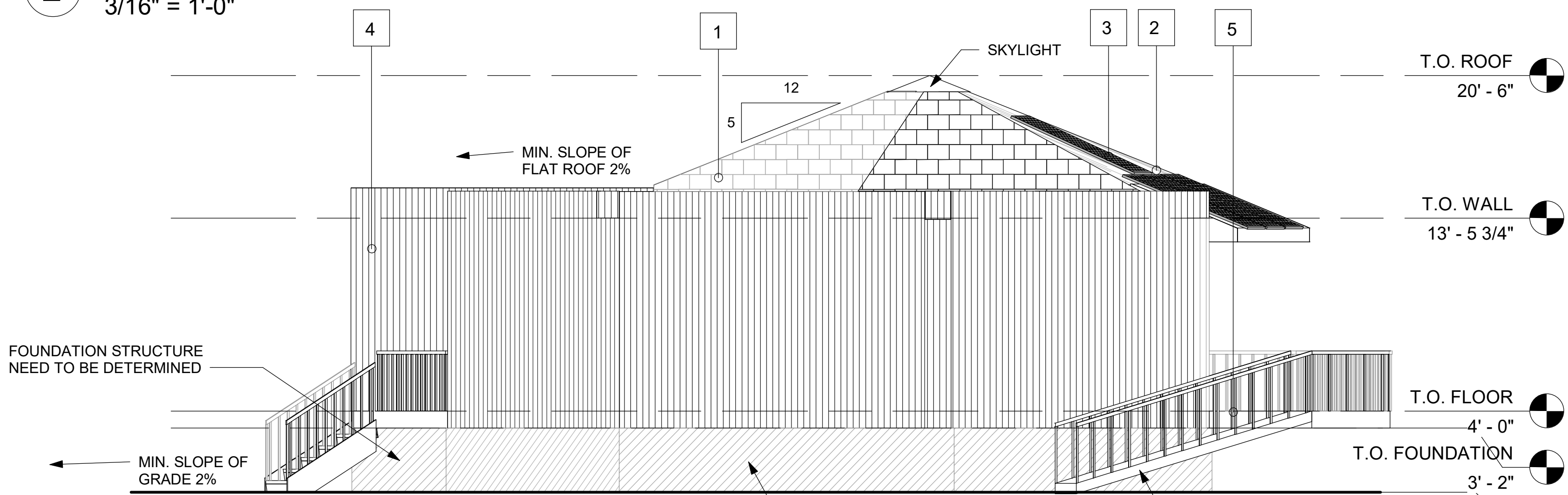



2 FACILTIY SOUTHWEST ELEVATION

3/16" = 1'-0"




1 FACILITY NORTHWEST ELEVATION

3/16" = 1'-0"



THE CONTRACTOR SHALL CHECK AND VERIFY ALL COMPONENTS AND DIMENSIONS WITH MECHANICAL ENGINEER PRIOR TO CONSTRUCTION

**APPROVALS:**

Name Signature/Stamp Date

Client

Contractor

Architect/Engineer

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KHS CAMBRIDGE BAY WORKSHOP

ELEVATION 3

Contact: SAIT GBT
Phone: 403-774-5327
Drawn: TS Checked: ____
Date: 2021.11.24
SAIT Project Number: 2020-020
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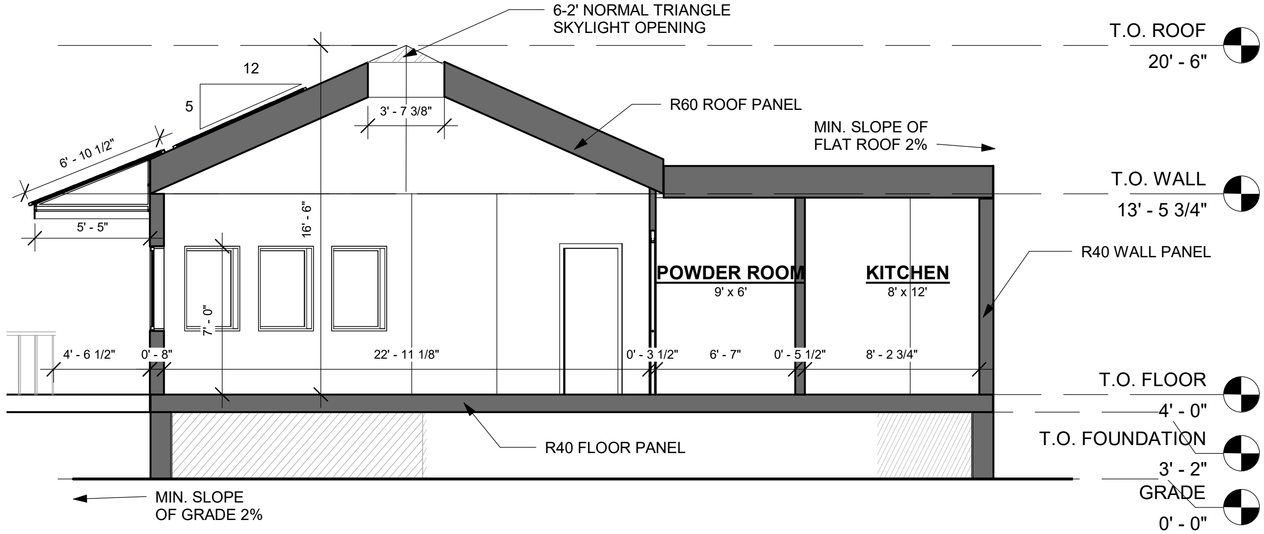


1 FACILTIY SECTION 1
3/16" = 1'-0"



THE CONTRACTOR SHALL CHECK AND VERIFY ALL COMPONENTS AND DIMENSIONS WITH MECHANICAL ENGINEER PRIOR TO CONSTRUCTION

**APPROVALS:**

Name Signature/Stamp Date

| | | |
|---|---|---|
| Client | | |
| Contractor | | |
| Architect/ Engineer | | |

NOT FOR CONSTRUCTION

ISSUED FOR/REVISION:

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KHS CAMBRIDGE BAY WORKSHOP

FACILITY SECTION 1

Contact: SAIT GBT
Phone: 403-774-5327
Drawn: TS Checked: ____
Date: 2021.11.24
SAIT Project Number: 2020-020
Scale: 3/16" = 1'-0" A6

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## APPENDIX F – ENERGY MODEL REPORT

The following is a summary table and the energy model reports conducted by SAIT in RETScreen for the workshop space.

# Table of Workshop Performance Comparisons for the Base Case and Proposals 1-3.

| Legends | Base Case (NECB Prescriptive Prediction) | | | Proposed Case 1 | | | Proposed Case 2 | | | Proposed Case 3 | | | Estimated Budget Include | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Modelling Description | | | | All Electrical Supply | | | Electric Grid/ Diesel Heating | | | Max Renewable from Case 2 | | | | |
| No Budget Request | > 0: Required Energy; <0 Generated Energy | | | > 0: Required Energy; <0 Generated Energy | | | > 0: Required Energy; <0 Generated Energy | | | > 0: Required Energy; <0 Generated Energy | | | | |
| Budget for Porposal | Heating kWh | Cooling kWh | Electricity kWh | Heating kWh | Cooling kWh | Electricity kWh | Heating kWh | Cooling kWh | Electricity kWh | Heating kWh | Cooling kWh | Electricity kWh | | |
| Heating Equipment | | | | | | | | | | | | | | |
| HVAC Furnace | | | | | | | | | | | | | Electrical Drived Furnace Replacement | **Assumed Efficiency** \|80% of heating oil fueled furnace; 95% of Electrical Powered Furnace |
| Water Heater | | | | | | | | | | | | | Electrical Drived Boiler Replacement | **Assumed Efficiency** \|66% of heating oil fueled boiler; 95% of Electrical Powered boiler |
| Cooling Equipment | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | No Budget Request | No requirement for cooling |
| Building envelope (NECB infiltration rate = 0.25 L/s·m² @ 5 Pa; Target infilration rate = 0.1875 L/s·m² @ 5 Pa) | | | | | | | | | | | | | | |
| Zone A Main Lodge Workshop | 20,284.05 | | | 14,001.48 | | | 16,626.76 | | | 16,626.76 | | | Insulation and Airtightness Upgrades, Additioned Thermal Hydronic Tube design | NECB Zone 8 Requirement for base case; R40 SIP Wall, R60 SIP Roof Panels, R40 Heated Floor Panels for proposed case |
| Zone B Utility Complex | 10,389.16 | | | 7,000.10 | | | 8,312.61 | | | 8,312.61 | | | Insulation and Airtightness Upgrades | NECB Zone 8 Requirement for base case; R40 SIP Wall, R60 SIP Roof Panels, R40 Heated Floor Panels for proposed case |
| Zone C Office/ Meeting Room | 5,554.11 | | | 3,548.29 | | | 4,213.59 | | | 4,213.59 | | | Insulation and Airtightness Upgrades, Additioned Thermal Hydronic Tube design | NECB Zone 8 Requirement for base case; R40 SIP Wall, R60 SIP Roof Panels, R40 Heated Floor Panels for proposed case |
| Zone D Cold Side Vesituble (Buffer Zone) | 0.00 | | | 0.00 | | | 0.00 | | | 0.00 | | | Insulation and Airtightness Upgrades, Additioned Thermal Hydronic Tube design | NECB Zone 8 Requirement for base case; R40 SIP Wall, R60 SIP Roof Panels, R40 Heated Floor Panels for proposed case, Warm side only |
| Ventilation (Assumption \| Under optimization for schedule, the whole building ventilation = 80% of Base case) | | | | | | | | | | | | | | |
| Ventilation-Whole Building | 7,551.06 | | | 2,034.69 | | | 2,416.20 | | | 2,416.20 | | | Ducting System Sealling Improvement | **Assumed Heat Recovery Rate** \| 50% for base case (261.93L/s, fresh air rate = 57%); 80% for proposed case (209.54 L/s, fresh air rate = 57%) |
| Ventilation-Kitchen Exhaust Air | | | | | | | | | | | | | Heat Recovered Exhaust Path Design | **Assumed Heat Recovery Rate** \| 50% for base case; 80% for proposed case |
| Ventilation-Washroom Exhaust Air | | | | | | | | | | | | | Heat Recovered Exhaust Path Design | **Assumed Heat Recovery Rate** \| 50% for base case; 80% for proposed case |
| Lighting | | | | | | | | | | | | | | |
| Zone A | | | 752.43 | | | 564.32 | | | 564.32 | | | 564.32 | Lighting unit and fixture selection to be determined | **Assumed Lighting Power Density** \| 8.5 W/m² for base case; 6.375 W/m² for proposed case |
| Zone B | | | 92.35 | | | 69.26 | | | 69.26 | | | 69.26 | Lighting unit and fixture selection to be determined | **Assumed Lighting Power Density** \| 4.6 W/m² for base case; 3 W/m² for proposed case |
| Zone C | | | 296.31 | | | 222.23 | | | 222.23 | | | 222.23 | Lighting unit and fixture selection to be determined | **Assumed Lighting Power Density** \| 8.5 W/m² for base case; 6 W/m² for proposed case |
| Zone D | | | 78.50 | | | 58.87 | | | 58.87 | | | 58.87 | Lighting unit and fixture selection to be determined | **Assumed Lighting Power Density** \| 5.2 W/m² for base case; 4 W/m² for proposed case |
| Electrical equipment | | | | | | | | | | | | | | |
| Arctic Living Requirement | | | 6,651.00 | | | 7,131.00 | | | 7,131.00 | | | 7,131.00 | Procurement list need to be determined | Generic equipment for office, kitchen stuff and heat recovery units |
| Hot water | | | | | | | | | | | | | | |
| Hot Water - Hydronic Thermal Tubes | 0.00 | | | 10,834.75 | | | 15,267.15 | | | 15,267.15 | | | Floor Embodied Thermal Hydronic Tube Materials and Component | For proposed case, the estimated length of the 9 mm tube is 135 meters. Heating up 4320 L/day from 71 to 87°C |
| Hot water - DHW Regular Hour | 109.79 | | | 77.91 | | | 109.79 | | | 109.79 | | | Electrical Drived Boiler Replacement | **Assumed Efficiency** \|66% of heating oil fueled boiler; 95% of Electrical Powered boiler |
| Hot water - DHW Workshop Hour | 40.78 | | | 28.94 | | | 40.78 | | | 40.78 | | | Electrical Drived Boiler Replacement | **Assumed Efficiency** \|66% of heating oil fueled boiler; 95% of Electrical Powered boiler |
| Hot water - DHW Activity Hour | 6.27 | | | 4.45 | | | 6.27 | | | 6.27 | | | Electrical Drived Boiler Replacement | **Assumed Efficiency** \|66% of heating oil fueled boiler; 95% of Electrical Powered boiler |
| Pumps | | | | | | | | | | | | | | |
| Circulating pump | | | 364.32 | | | 222.24 | | | 222.00 | | | 222.00 | Extra Circulation Pumps for Thermal Hydronic Tubes | **Assumed Required Power** \| 66W/ pump; 2 for base case, 4 for proposed case |
| Fans | | | | | | | | | | | | | | |
| HVAC Fans | | | 547.50 | | | 271.63 | | | 271.63 | | | 271.63 | Procurement list need to be determined | **Assumed Type** \| 149.2 W, Efficiency = 78.5%, 2 CAV units for base case, 608.2W, Efficiency = 88.5%, 4 VAV units for proposed case |
| Exhaust Fans - Kitchen | | | 50.84 | | | 45.70 | | | 45.70 | | | 45.70 | Procurement list need to be determined | **Assumed Type** \| 81.66 W, Efficiency = 77.1%, 1 CAV units for base case, 81.66 W, Efficiency = 85.5%, 1 CAV units for proposed case |
| Exhaust Fans - Washroom | | | 17.44 | | | 15.41 | | | 15.41 | | | 15.41 | Procurement list need to be determined | **Assumed Type** \| 24 W, Efficiency = 74.3%, 1 CAV units for base case, 24 W, Efficiency = 84.1%, 1 CAV units for proposed case |
| Renewable Source for Power | | | | | | | | | | | | | | |
| Solar Awing with Solar Panels | | | 0.00 | | | 0.00 | | | 0.00 | | | -6,297.00 | 12 LONGi mono-Si-LR4-72HPH-450M, 450W Model | The solar panels are designed as solar awing integrated structure; therefore, it could provide renewable energy and solar shading |
| Wind Power | | | 0.00 | | | 0.00 | | | 0.00 | | | -16,118.00 | To be determined | |
| Total (kWh) | 43,935.22 | 0.00 | 8,850.69 | 37,530.61 | 0.00 | 8,600.66 | 46,993.14 | 0.00 | 8,600.42 | 46,993.14 | 0.00 | -13,814.58 | | initial cost before tax would be only spent in the 0th year (construction year) |

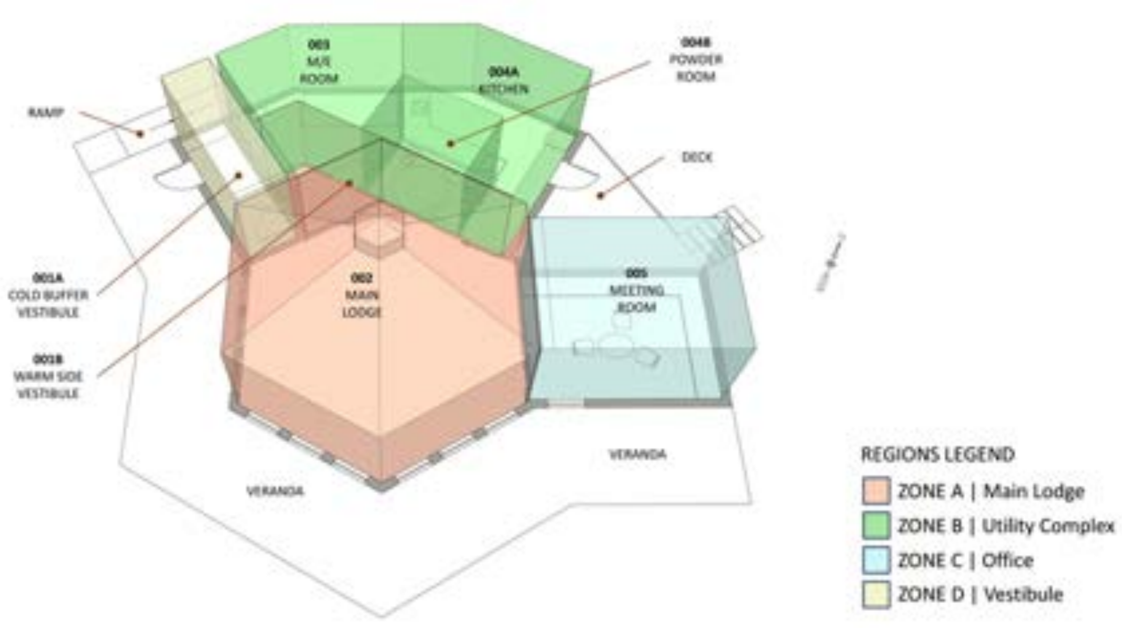
| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| To Base Case | 0.00% | #DIV/0! | 0.00% | 14.58% | #DIV/0! | 2.82% | -6.96% | #DIV/0! | 2.83% | -6.96% | #DIV/0! | 256.08% |
| To Proposed Case 1 | -17.07% | #DIV/0! | -2.91% | 0.00% | #DIV/0! | 0.00% | -25.21% | #DIV/0! | 0.00% | -25.21% | #DIV/0! | 260.62% |

| Energy/ Carbon Footprint | kg-C/kWh | kWh | GJ | $tCO_2$ | kWh | GJ | $tCO_2$ | kWh | GJ | $tCO_2$ | kWh | GJ | $tCO_2$ | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electricity (Cambridge Bay Specific) | 0.795 | 8,850.69 | 31.86 | 7.04 | 46,131.26 | 166.07 | 36.67 | 8,600.42 | 30.96 | 6.84 | -13,814.58 | -49.73 | 0.00 | Local Plant Generation Efficiency = 34.2%, On-site Transfer efficiency = 95% |
| Fuel (Diesel) | 0.253 | 43,935.22 | 158.17 | 11.12 | 0 | 0.00 | 0.00 | 46,993.14 | 169.18 | 11.89 | 46,993.14 | 169.18 | 11.89 | On-site combusion and energy conversion rate = 80% for Furnace; 66% for Boiler |
| Total | | 52,785.91 | 190.03 | 18.15 | 46,131.26 | 166.07 | 36.67 | 55,593.56 | 200.14 | 18.73 | 33,178.56 | 119.44 | 11.89 | |
| Renewable Eletricity Generation | 0.795 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -22,415.00 | -80.69 | -17.82 | 12X450W Solar Panel = 5.4 kW; Assumed 4.6 kW Wind Turbines |

# Energy management report

## KHS-Cambridge Bay Workshop

### Workshop




### Commercial/Institutional - Other

Prepared for:

Kitikmeot Heritage Society


Prepared by:

Leo Lu, Laboratory Technician
SAIT Green Building Technologies
1301 16 Ave NW
Calgary, Alberta, T2M 0L4
Canada
E-mail: leo.lu@sait.ca

# Executive summary

This report was prepared using the RETScreen Clean Energy Management Software. The key findings and recommendations of this analysis are presented below:

## Target

| | Fuel consumption MWh | Fuel cost $ | GHG emission $tCO_2$ |
|---|---|---|---|
| Base case | 52.8 | 10,225 | 18.1 |
| Proposed case | 46.1 | 30,908 | 36.7 |
| Savings | 6.7 | -20,683 | -18.5 |
| % | 12.6% | -202% | -102% |

The main results are as follows:

# Location | Climate data

## Location

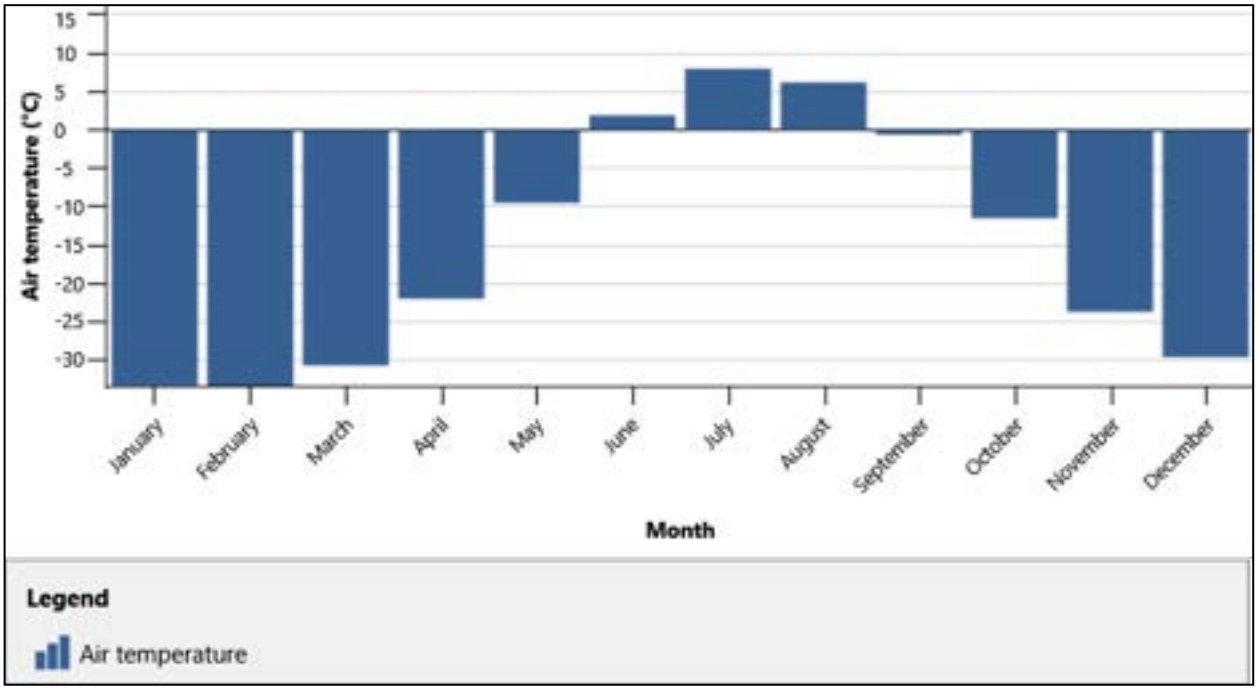
Legend

Facility location

Climate data location

| | Unit | Climate data location | Facility location |
|---|---|---|---|
| Name | | Canada - Nunavut - Cambridge Bay Airport | Canada - NU - Cambridge Bay |
| Latitude | ˚N | 69.1 | 69.1 |
| Longitude | ˚E | -105.1 | -105.0 |
| Climate zone | | 8 - Subarctic | 8 - Subarctic |
| Elevation | m | 27 | 2 |

Climate data

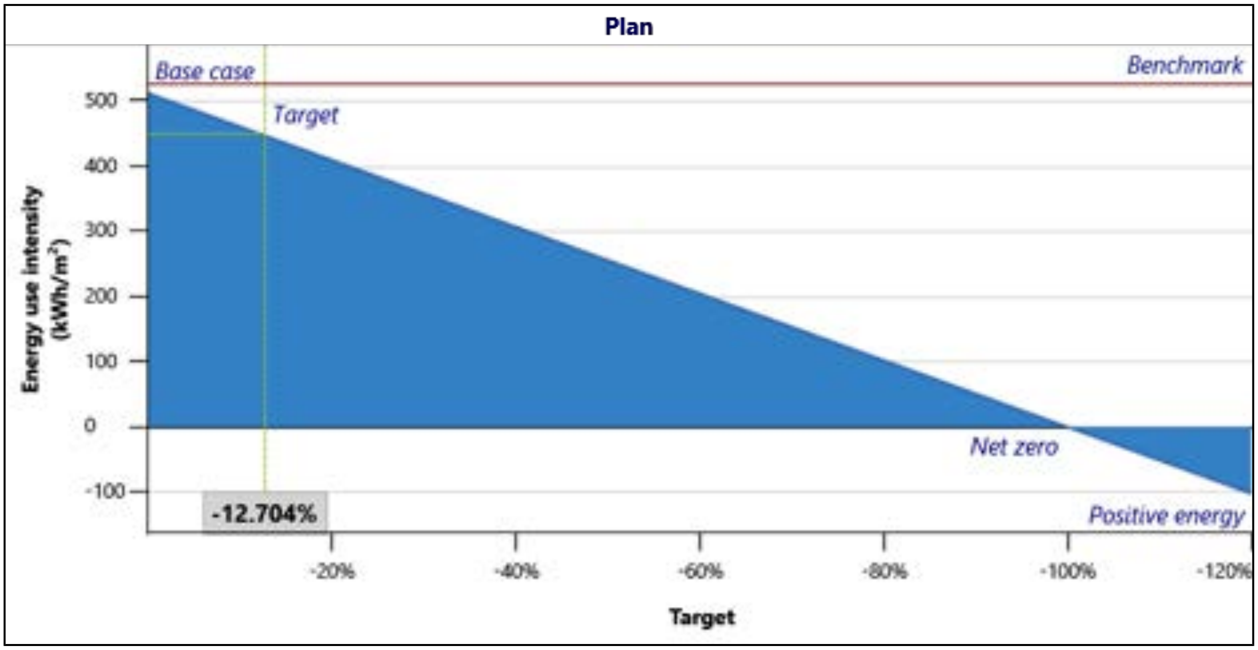



| | | |
|---|---|---|
| | Heating design temperature | -41.1 |
| | Cooling design temperature | 14.8 |
| | Earth temperature amplitude | 28.8 |

| Month | Air temperature | Relative humidity | Precipitation | Daily solar radiation - horizontal | Atmospheric pressure | Wind speed | Earth temperature | Heating degree-days | Cooling degree-days |
|---|---|---|---|---|---|---|---|---|---|
| | °C | % | mm | kWh/m²/d | kPa | m/s | °C | °C-d | °C-d |
| January | -33.4 | 66.3% | 15.81 | 0.04 | 101.4 | 6.4 | -28.5 | 1,593 | 0 |
| February | -33.5 | 66.3% | 14.28 | 0.49 | 101.5 | 6.1 | -27.5 | 1,442 | 0 |
| March | -30.7 | 68.2% | 19.22 | 2.06 | 101.7 | 5.8 | -22.8 | 1,510 | 0 |
| April | -22.0 | 72.9% | 21.60 | 4.42 | 101.7 | 5.6 | -13.7 | 1,200 | 0 |
| May | -9.5 | 84.3% | 28.83 | 6.05 | 101.5 | 5.8 | -4.8 | 853 | 0 |
| June | 1.9 | 83.1% | 41.40 | 6.44 | 101.2 | 5.6 | 4.7 | 483 | 0 |
| July | 8.0 | 77.6% | 46.19 | 5.13 | 100.9 | 5.6 | 8.7 | 310 | 0 |
| August | 6.2 | 81.9% | 47.12 | 3.31 | 100.8 | 6.1 | 6.0 | 366 | 0 |
| September | -0.6 | 86.4% | 38.40 | 1.64 | 101.0 | 6.4 | -0.1 | 558 | 0 |
| October | -11.5 | 85.2% | 31.31 | 0.70 | 101.0 | 6.4 | -10.5 | 915 | 0 |
| November | -23.7 | 74.2% | 18.30 | 0.10 | 101.2 | 5.8 | -21.7 | 1,251 | 0 |
| December | -29.6 | 68.7% | 15.81 | 0.00 | 101.3 | 5.8 | -26.4 | 1,476 | 0 |
| Annual | -14.8 | 76.3% | 338.27 | 2.54 | 101.3 | 5.9 | -11.3 | 11,956 | 0 |

# Benchmark

## Fuel consumption




| | | |
|---|---|---|
| Facility size | 103 | m² |
| Benchmark | 523 | kWh/m² |
| Minimum - average | 200 | kWh/m² |
| Maximum - average | 800 | kWh/m² |
| Base case | 513 | kWh/m² |
| Reference year | | |
| Set target | Target | |
| Year | | |
| Target | -12.7% | |
| Proposed case | 448 | kWh/m² |
| Facility - Plan | | |
| Fuel consumption | Annual | |
| Base case | 52,786 | kWh |
| Proposed case | 46,080 | kWh |
| Fuel saved | 6,706 | kWh |

# Notes

**Modelling Assumption**

1. Benchmark: 600 kWh/m² for 63.19 m² office or workshop area; 400 kWh/m² for 39.75 m² for unoccupied area. Average EUI performance of the building = 522.77 kWh/m² for subarctic climate zone

2. Regular Occupants = 4-6 Persons; Maximum Occupants =15-20 Persons

3. The parameters for base case setup are based on NECB 2017 in the aspect of assembly, lighting and mechanical performance.

4. The parameters for Proposed case are based on SAIT Green Building Technologies archiectural drawing package and envelope panel supplier.

5. The wall surface are is equivlent area to the normal orientation, not actural orientation, for RETScreen Energy Modelling.

6. Minimum air exchange rate in L/s is obtained by the required value in ASHREA 62.1-2019 for office, laboratory, and warehouase as room types in the project.

7. The proposed case is supposed to have 75% lighting energy requirement of NECB request.

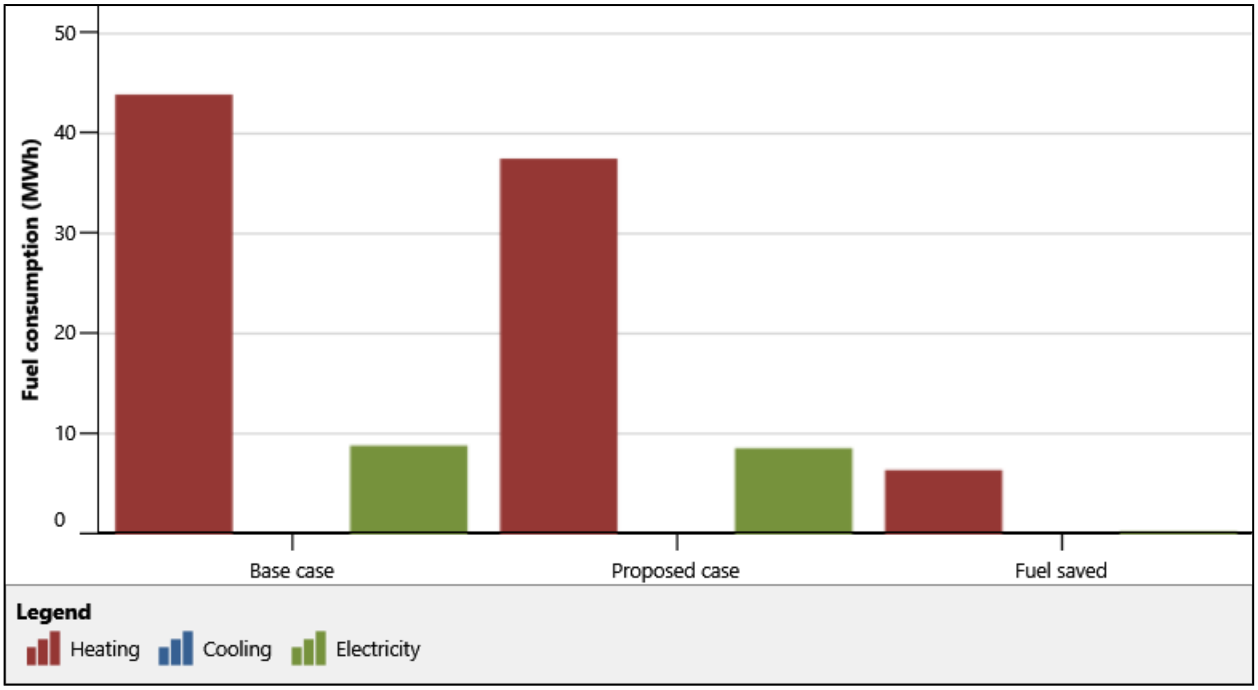
8. The performance of solar panel is improved by 15% due to bifacial gains.

9. The proposed wind turbine and solar panel can have 10 kW as maximum power capacity of renewable energy by local regulation.

10. Solar awing is simulated by Revit model. The solar gains in Spring, Summer and Fall may affect essential heating loads.

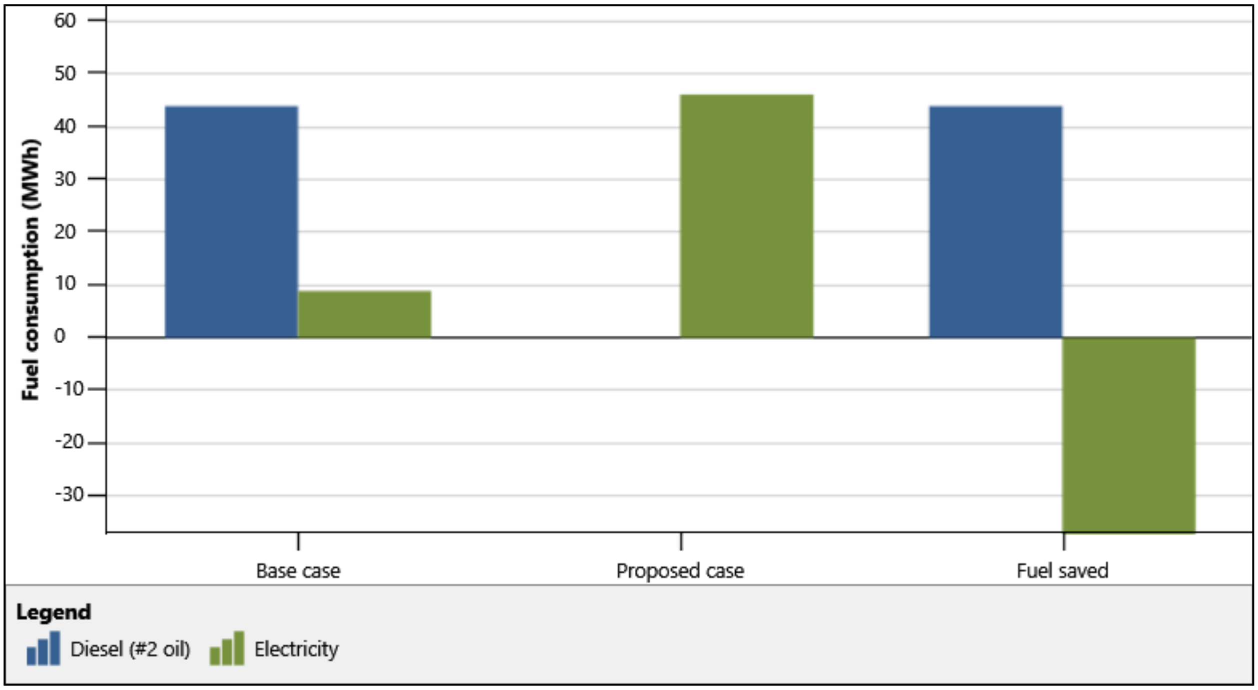
# Energy savings | Fuel summary

Energy savings




| Fuel consumption | Heating kWh | Cooling kWh | Electricity kWh | Total kWh |
|---|---|---|---|---|
| Base case | 43,935 | 0 | 8,851 | 52,786 |
| Proposed case | 37,531 | 0 | 8,601 | 46,131 |
| Fuel saved | 6,405 | 0 | 250 | 6,655 |
| Fuel saved - percent | 14.6% | 0% | 2.8% | 12.6% |

Fuel summary




| Fuel type | Fuel<br>Unit | Base case<br>Fuel consumption | Proposed case<br>Fuel consumption | Savings<br>Fuel saved |
|---|---|---|---|---|
| Diesel (#2 oil) | L | 4,130 | 0 | 4,130 |
| Electricity | kWh | 8,851 | 46,131 | -37,281 |

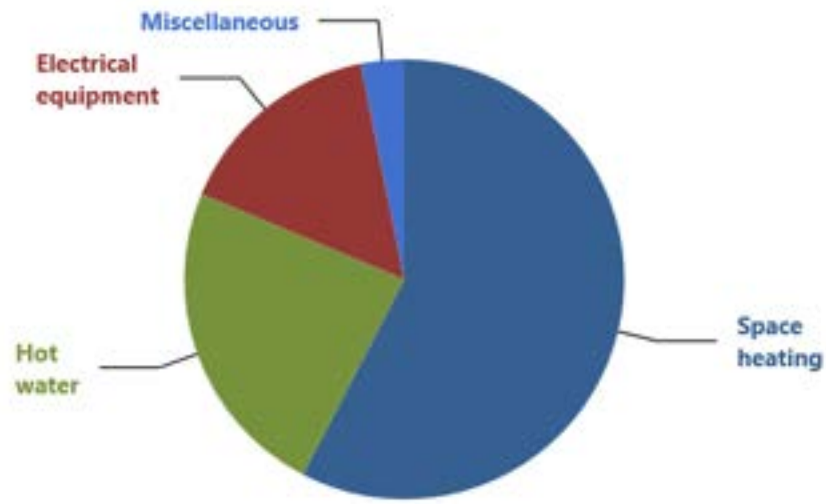
| Fuel type | Fuel<br>Fuel rate | Base case<br>Fuel cost | Proposed case<br>Fuel cost | Savings<br>Savings |
|---|---|---|---|---|
| Diesel (#2 oil) | 1.04 $/L | $ 4,295 | $ 0 | $ 4,295 |
| Electricity | 0.67 $/kWh | $ 5,930 | $ 30,908 | $ -24,978 |
| Total | | $ 10,225 | $ 30,908 | $ -20,683 |

## Notes

In this proposal (Proposal 1), All energy consumption for the building are powered by electricity.

# End-use

Fuel consumption - proposed case




| | Fuel consumption - proposed case | |
|---|---|---|
| Section | kWh | % |
| Space heating | 26,585 | 57.6% |
| Hot water | 10,946 | 23.7% |
| Electrical equipment | 7,131 | 15.5% |
| Miscellaneous | 1,470 | 3.2% |
| Lights | 915 | 2% |
| Mechanical equipment | 555 | 1.2% |

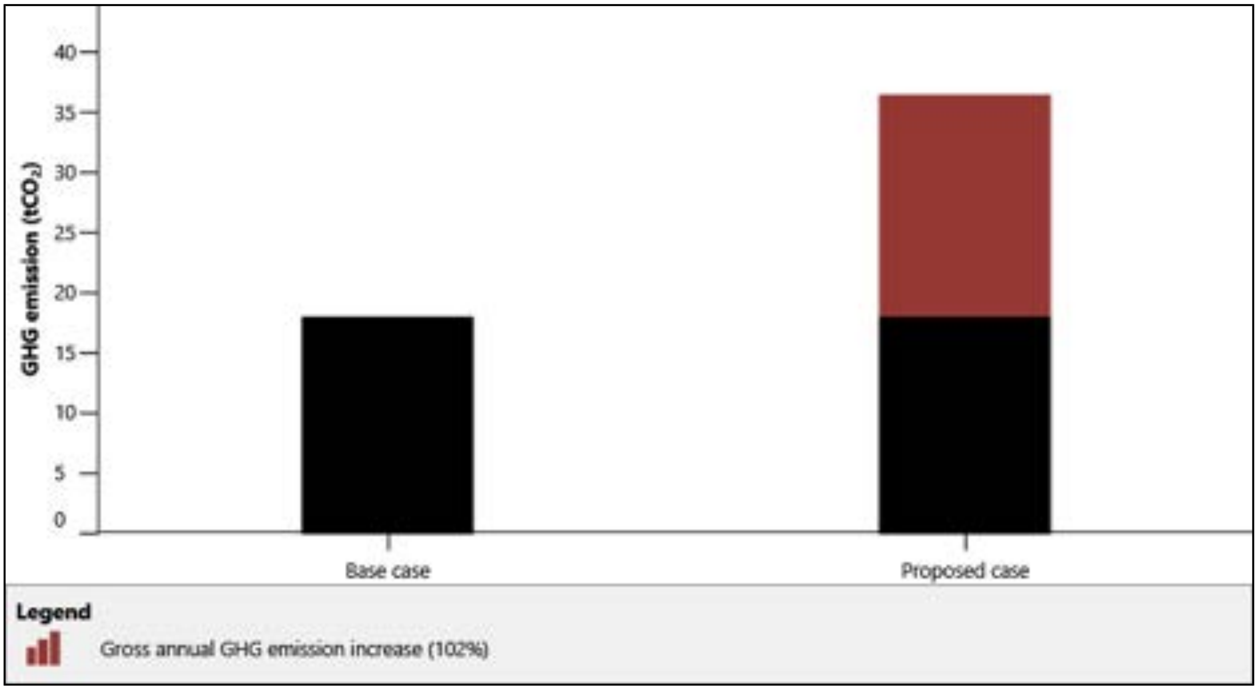
# Target

Summary

| | Fuel consumption MWh | Fuel cost $ | GHG emission $tCO_2$ |
|---|---|---|---|
| Base case | 52.8 | 10,225 | 18.1 |
| Proposed case | 46.1 | 30,908 | 36.7 |
| Savings | 6.7 | -20,683 | -18.5 |
| % | 12.6% | -202% | -102% |

# GHG emission

## GHG emission




## GHG equivalence

-18.5 $tCO_2$ is equivalent to -3.4

Cars & light trucks not used

| GHG emission | | |
|---|---|---|
| Base case | 18.1 | $tCO_2$ |
| Proposed case | 36.7 | $tCO_2$ |
| Gross annual GHG emission reduction | -18.5 | $tCO_2$ |

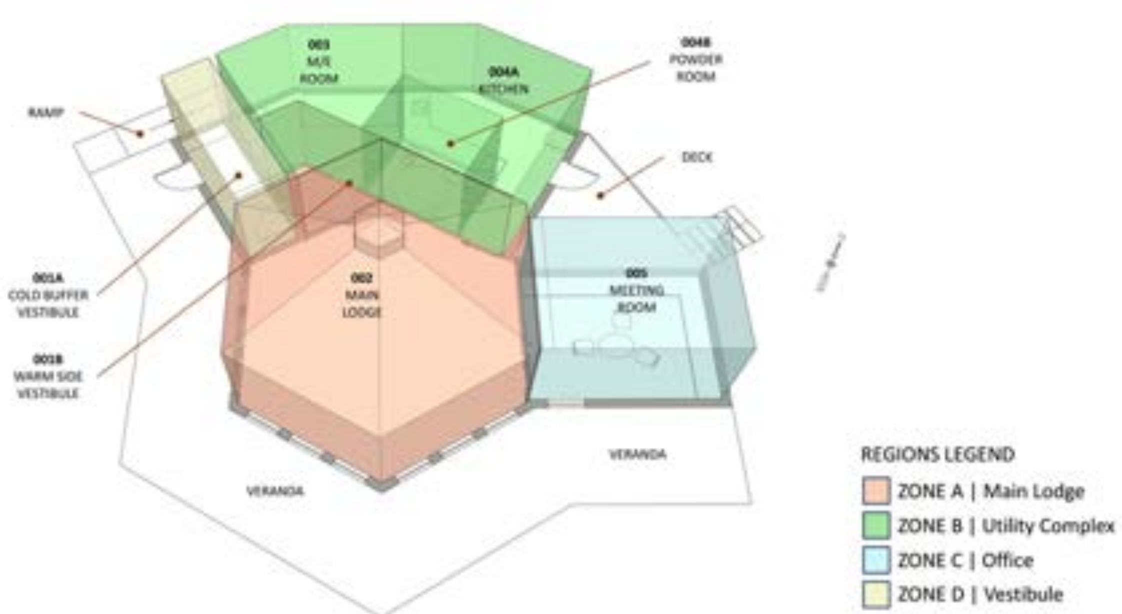
# Analysis type

Project life

# Energy management report

## KHS-Cambridge Bay Workshop

### Workshop




### Commercial/Institutional - Other

Prepared for:

Kitikmeot Heritage Society

Prepared by:

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Calgary, Alberta, T2M 0L4
Canada
E-mail: leo.lu@sait.ca

# Executive summary

This report was prepared using the RETScreen Clean Energy Management Software. The key findings and recommendations of this analysis are presented below:

## Target

| | Fuel consumption MWh | Fuel cost $ | GHG emission $tCO_2$ |
|---|---|---|---|
| Base case | 52.8 | 10,225 | 18.1 |
| Proposed case | 55.6 | 10,356 | 18.7 |
| Savings | -2.8 | -131 | -0.57 |
| % | -5.3% | -1.3% | -3.2% |

The main results are as follows:

# Location | Climate data

## Location

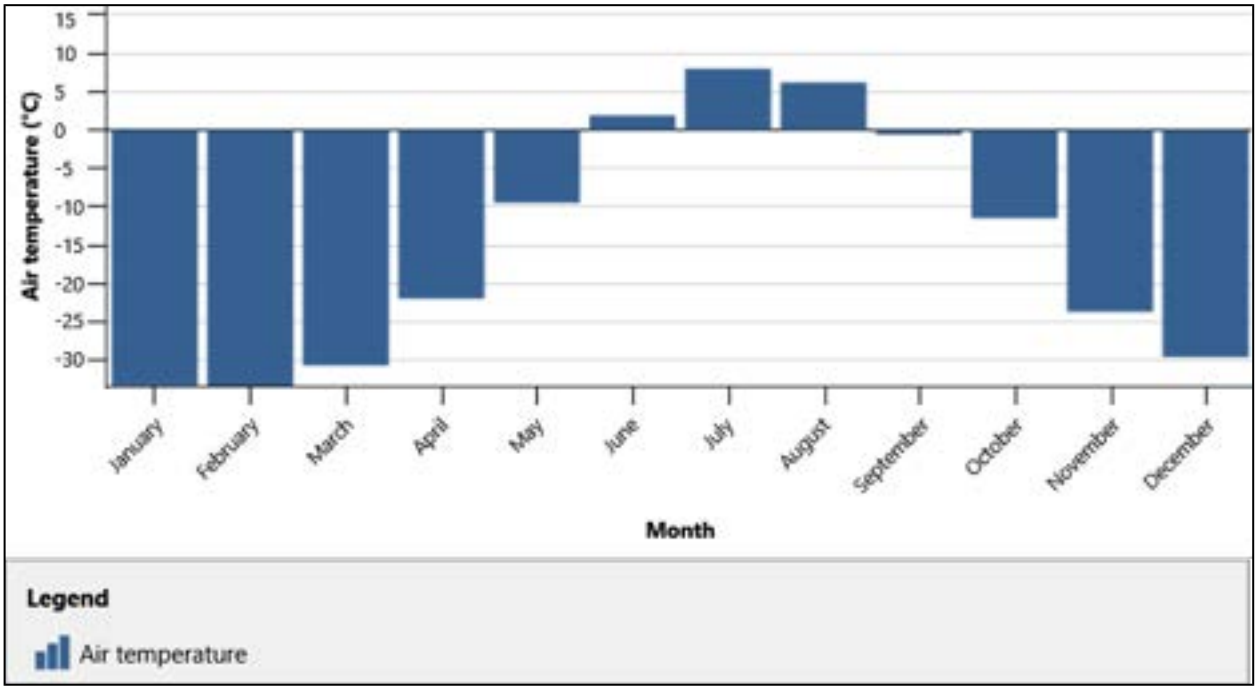
Legend

Facility location

Climate data location

| | Unit | Climate data location | Facility location |
|---|---|---|---|
| Name | | Canada - Nunavut - Cambridge Bay Airport | Canada - NU - Cambridge Bay |
| Latitude | ˚N | 69.1 | 69.1 |
| Longitude | ˚E | -105.1 | -105.0 |
| Climate zone | | 8 - Subarctic | 8 - Subarctic |
| Elevation | m | 27 | 2 |

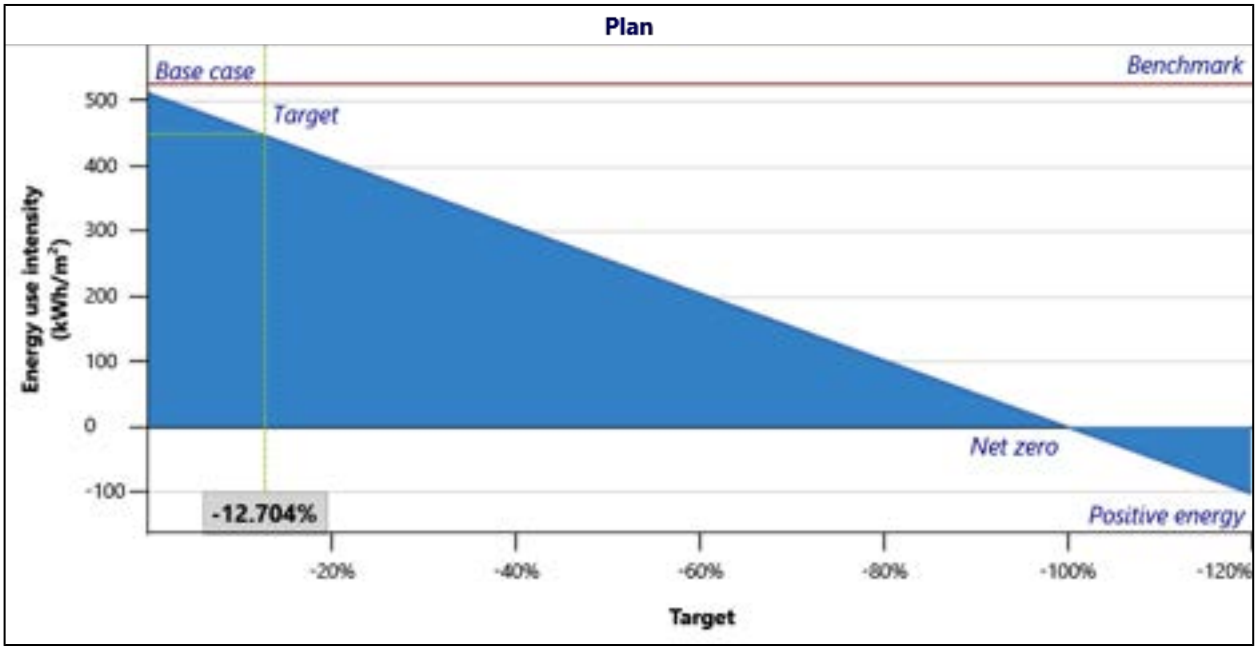
Climate data




| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Heating design temperature | | -41.1 | | | | | | |
| | Cooling design temperature | | 14.8 | | | | | | |
| | Earth temperature amplitude | | 28.8 | | | | | | |
| Month | Air temperature | Relative humidity | Precipitation | Daily solar radiation - horizontal | Atmospheric pressure | Wind speed | Earth temperature | Heating degree-days | Cooling degree-days |
| | °C | % | mm | kWh/m²/d | kPa | m/s | °C | °C-d | °C-d |
| January | -33.4 | 66.3% | 15.81 | 0.04 | 101.4 | 6.4 | -28.5 | 1,593 | 0 |
| February | -33.5 | 66.3% | 14.28 | 0.49 | 101.5 | 6.1 | -27.5 | 1,442 | 0 |
| March | -30.7 | 68.2% | 19.22 | 2.06 | 101.7 | 5.8 | -22.8 | 1,510 | 0 |
| April | -22.0 | 72.9% | 21.60 | 4.42 | 101.7 | 5.6 | -13.7 | 1,200 | 0 |
| May | -9.5 | 84.3% | 28.83 | 6.05 | 101.5 | 5.8 | -4.8 | 853 | 0 |
| June | 1.9 | 83.1% | 41.40 | 6.44 | 101.2 | 5.6 | 4.7 | 483 | 0 |
| July | 8.0 | 77.6% | 46.19 | 5.13 | 100.9 | 5.6 | 8.7 | 310 | 0 |
| August | 6.2 | 81.9% | 47.12 | 3.31 | 100.8 | 6.1 | 6.0 | 366 | 0 |
| September | -0.6 | 86.4% | 38.40 | 1.64 | 101.0 | 6.4 | -0.1 | 558 | 0 |
| October | -11.5 | 85.2% | 31.31 | 0.70 | 101.0 | 6.4 | -10.5 | 915 | 0 |
| November | -23.7 | 74.2% | 18.30 | 0.10 | 101.2 | 5.8 | -21.7 | 1,251 | 0 |
| December | -29.6 | 68.7% | 15.81 | 0.00 | 101.3 | 5.8 | -26.4 | 1,476 | 0 |
| Annual | -14.8 | 76.3% | 338.27 | 2.54 | 101.3 | 5.9 | -11.3 | 11,956 | 0 |

# Benchmark

## Fuel consumption




| | | |
|---|---|---|
| Facility size | 103 | m² |
| Benchmark | 523 | kWh/m² |
| Minimum - average | 200 | kWh/m² |
| Maximum - average | 800 | kWh/m² |
| Base case | 513 | kWh/m² |
| Reference year | | |
| Set target | Target | |
| Year | | |
| Target | -12.7% | |
| Proposed case | 448 | kWh/m² |

Facility - Plan

| Fuel consumption | Annual | |
|---|---|---|
| Base case | 52,786 | kWh |
| Proposed case | 46,080 | kWh |
| Fuel saved | 6,706 | kWh |

# Notes

**Modelling Assumption**

1. Benchmark: 600 kWh/m² for 63.19 m² office or workshop area; 400 kWh/m² for 39.75 m² for unoccupied area. Average EUI performance of the building = 522.77 kWh/m² for subarctic climate zone

2. Regular Occupants = 4-6 Persons; Maximum Occupants =15-20 Persons

3. The parameters for base case setup are based on NECB 2017 in the aspect of assembly, lighting and mechanical performance.

4. The parameters for Proposed case are based on SAIT Green Building Technologies archiectural drawing package and envelope panel supplier.

5. The wall surface are is equivlent area to the normal orientation, not actural orientation, for RETScreen Energy Modelling.

6. Minimum air exchange rate in L/s is obtained by the required value in ASHREA 62.1-2019 for office, laboratory, and warehouase as room types in the project.

7. The proposed case is supposed to have 75% lighting energy requirement of NECB request.

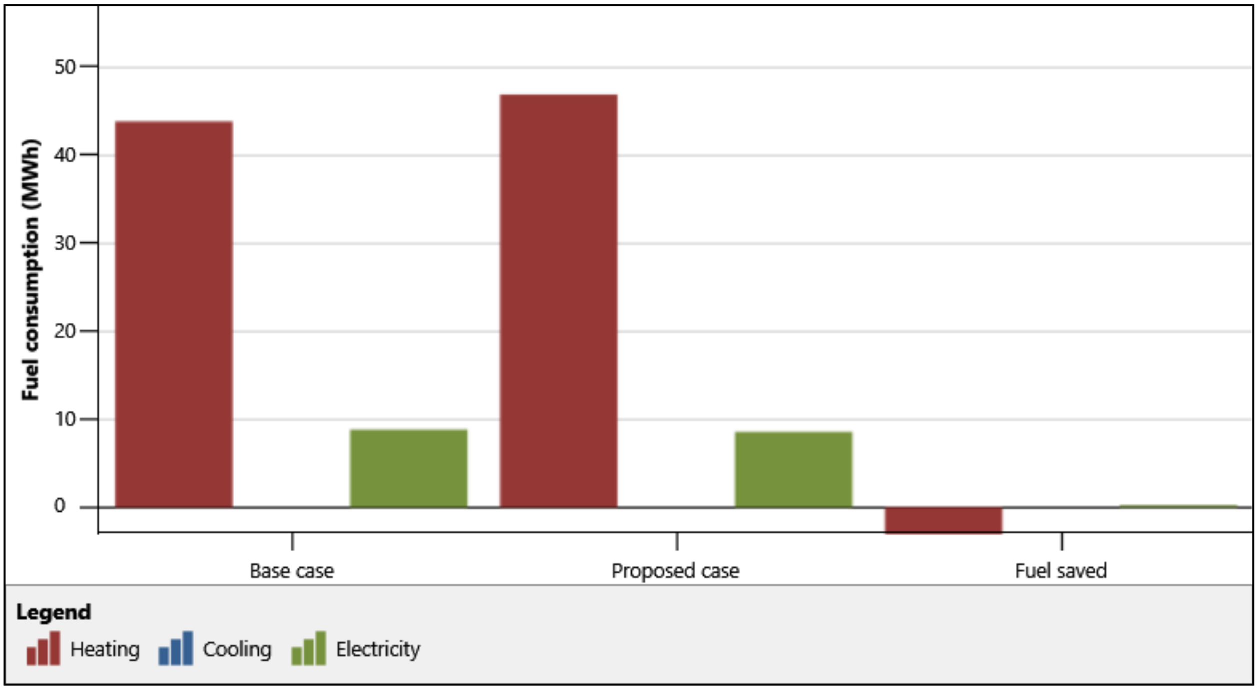
8. The performance of solar panel is improved by 15% due to bifacial gains.

9. The proposed wind turbine and solar panel can have 10 kW as maximum power capacity of renewable energy by local regulation.

10. Solar awing is simulated by Revit model. The solar gains in Spring, Summer and Fall may affect essential heating loads.

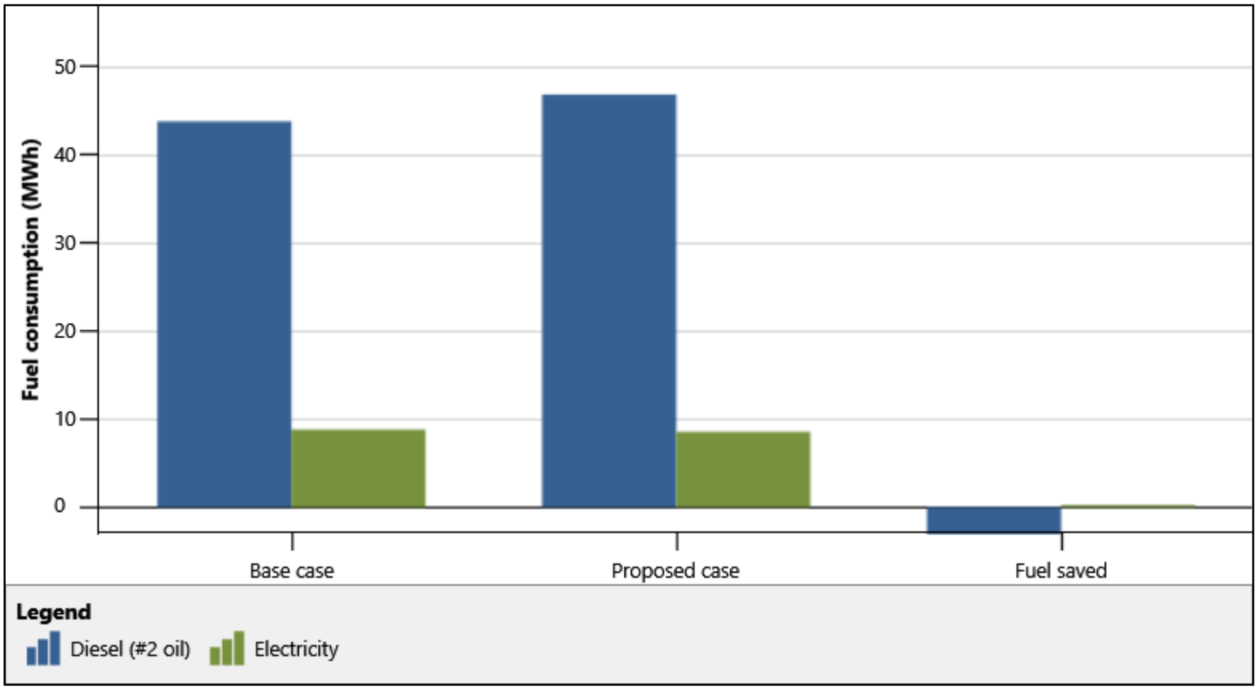
# Energy savings | Fuel summary

Energy savings




| Fuel consumption | Heating kWh | Cooling kWh | Electricity kWh | Total kWh |
|---|---|---|---|---|
| Base case | 43,935 | 0 | 8,851 | 52,786 |
| Proposed case | 46,993 | 0 | 8,601 | 55,594 |
| Fuel saved | -3,058 | 0 | 250 | -2,808 |
| Fuel saved - percent | -7% | 0% | 2.8% | -5.3% |

## Fuel summary




| Fuel type | Fuel<br>Unit | Base case<br>Fuel consumption | Proposed case<br>Fuel consumption | Savings<br>Fuel saved |
|---|---|---|---|---|
| Diesel (#2 oil) | L | 4,130 | 4,417 | -287 |
| Electricity | kWh | 8,851 | 8,601 | 250 |

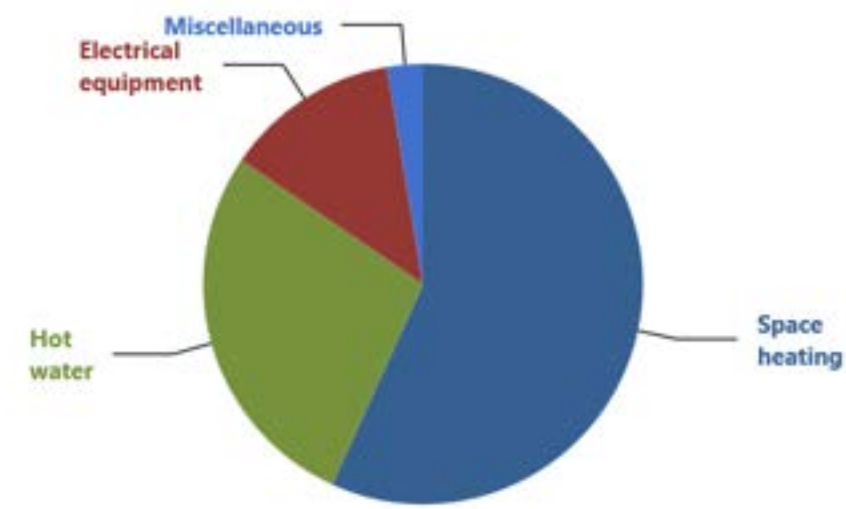
| Fuel type | Fuel<br>Fuel rate | Base case<br>Fuel cost | Proposed case<br>Fuel cost | Savings<br>Savings |
|---|---|---|---|---|
| Diesel (#2 oil) | 1.04 $/L | $ 4,295 | $ 4,594 | $ -299 |
| Electricity | 0.67 $/kWh | $ 5,930 | $ 5,762 | $ 168 |
| Total | | $ 10,225 | $ 10,356 | $ -131 |

## Notes

In this proposal (Proposal 1), All energy consumption for the building are powered by electricity.

# End-use

Fuel consumption - proposed case




| | Fuel consumption - proposed case | |
|---|---|---|
| Section | kWh | % |
| Space heating | 31,569 | 56.8% |
| Hot water | 15,424 | 27.7% |
| Electrical equipment | 7,131 | 12.8% |
| Miscellaneous | 1,470 | 2.6% |
| Lights | 915 | 1.6% |
| Mechanical equipment | 555 | 1% |

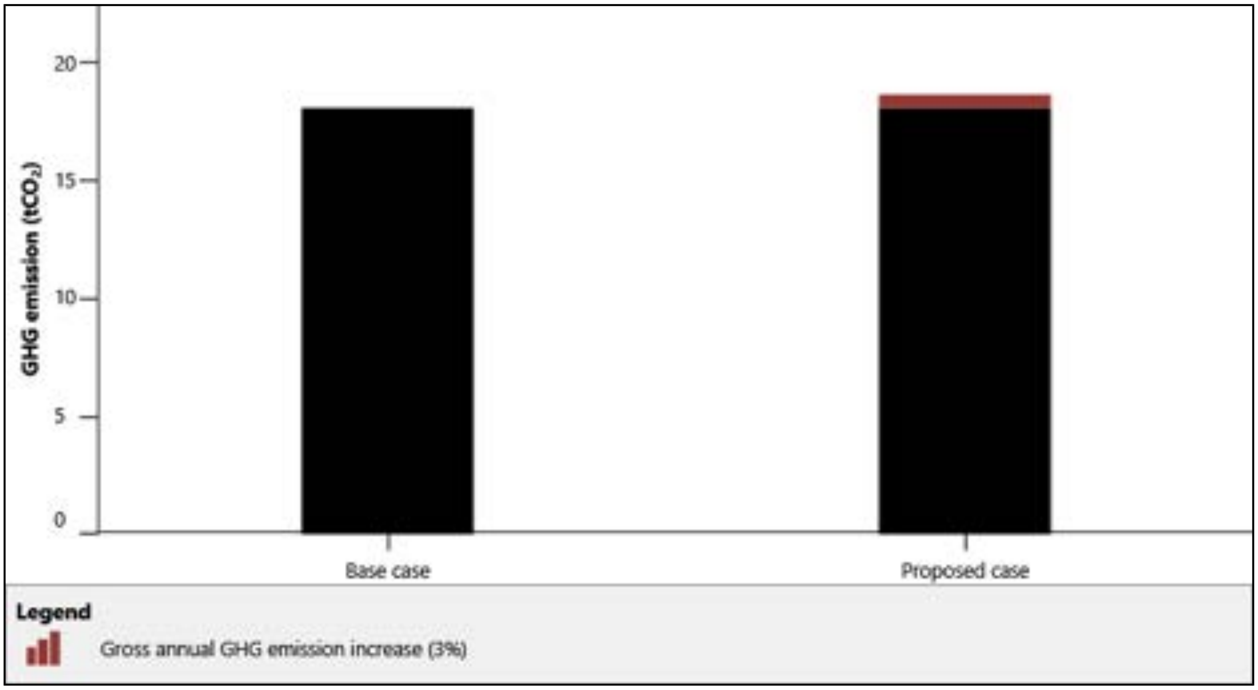
# Target

Summary

| | Fuel consumption MWh | Fuel cost $ | GHG emission $tCO_2$ |
|---|---|---|---|
| Base case | 52.8 | 10,225 | 18.1 |
| Proposed case | 55.6 | 10,356 | 18.7 |
| Savings | -2.8 | -131 | -0.57 |
| % | -5.3% | -1.3% | -3.2% |

# GHG emission

## GHG emission




## GHG equivalence

-0.6 $tCO_2$ is equivalent to -0.1

Cars & light trucks not used

| GHG emission | | |
|---|---|---|
| Base case | 18.1 | $tCO_2$ |
| Proposed case | 18.7 | $tCO_2$ |
| Gross annual GHG emission reduction | -0.6 | $tCO_2$ |

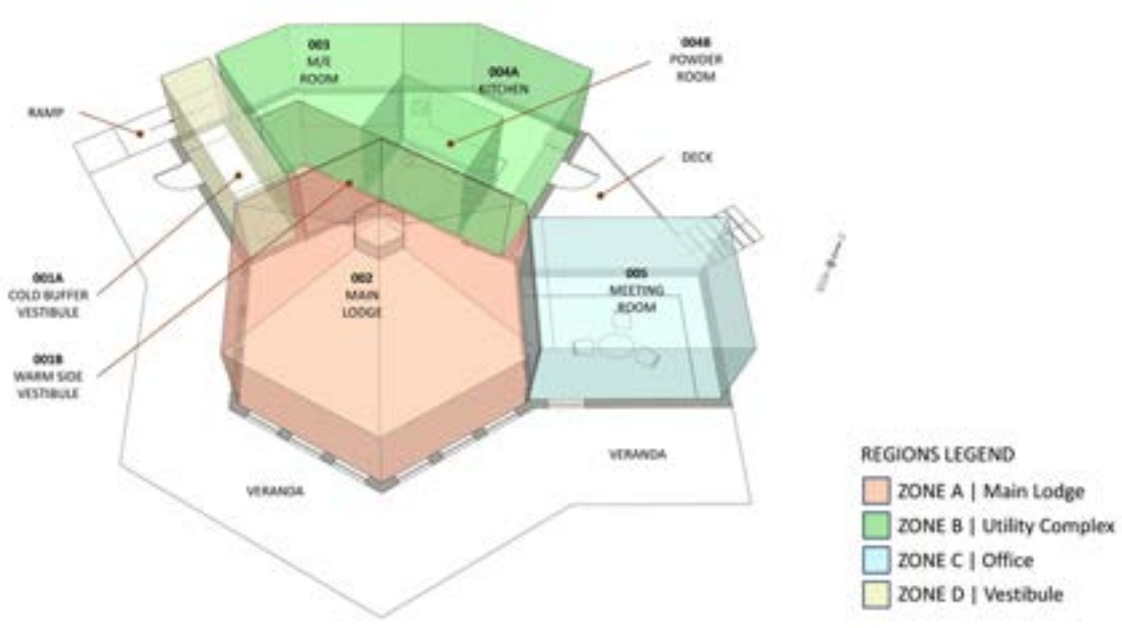
# Analysis type

Project life

# Energy management report

## KHS-Cambridge Bay Workshop

### Workshop




### Commercial/Institutional - Other

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# Executive summary

This report was prepared using the RETScreen Clean Energy Management Software. The key findings and recommendations of this analysis are presented below:

## Target

| | Fuel consumption MWh | Fuel cost $ | GHG emission $tCO_2$ |
|---|---|---|---|
| Base case | 52.8 | 10,225 | 29.1 |
| Proposed case | 33.2 | -4,662 | 12.6 |
| Savings | 19.6 | 14,887 | 16.5 |
| % | 37.1% | 146% | 56.6% |

The main results are as follows:

# Location | Climate data

## Location

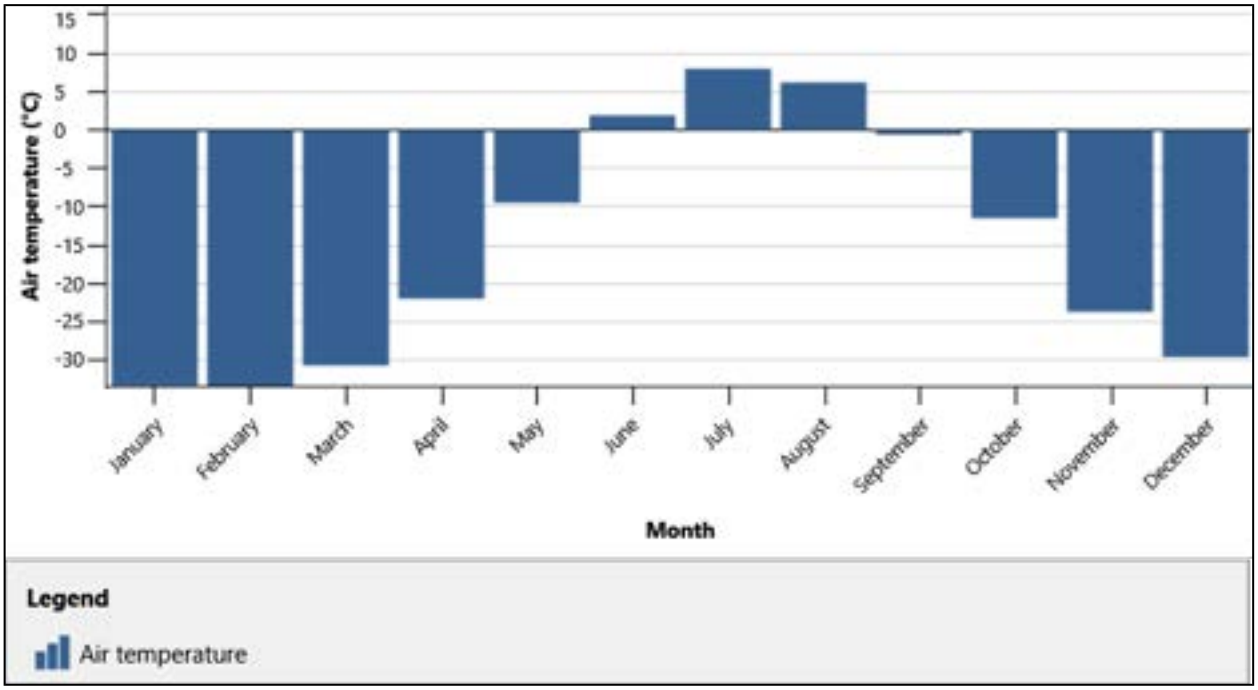
Legend

Facility location

Climate data location

| | Unit | Climate data location | Facility location |
|---|---|---|---|
| Name | | Canada - Nunavut - Cambridge Bay Airport | Canada - NU - Cambridge Bay |
| Latitude | ˚N | 69.1 | 69.1 |
| Longitude | ˚E | -105.1 | -105.0 |
| Climate zone | | 8 - Subarctic | 8 - Subarctic |
| Elevation | m | 27 | 2 |

## Climate data

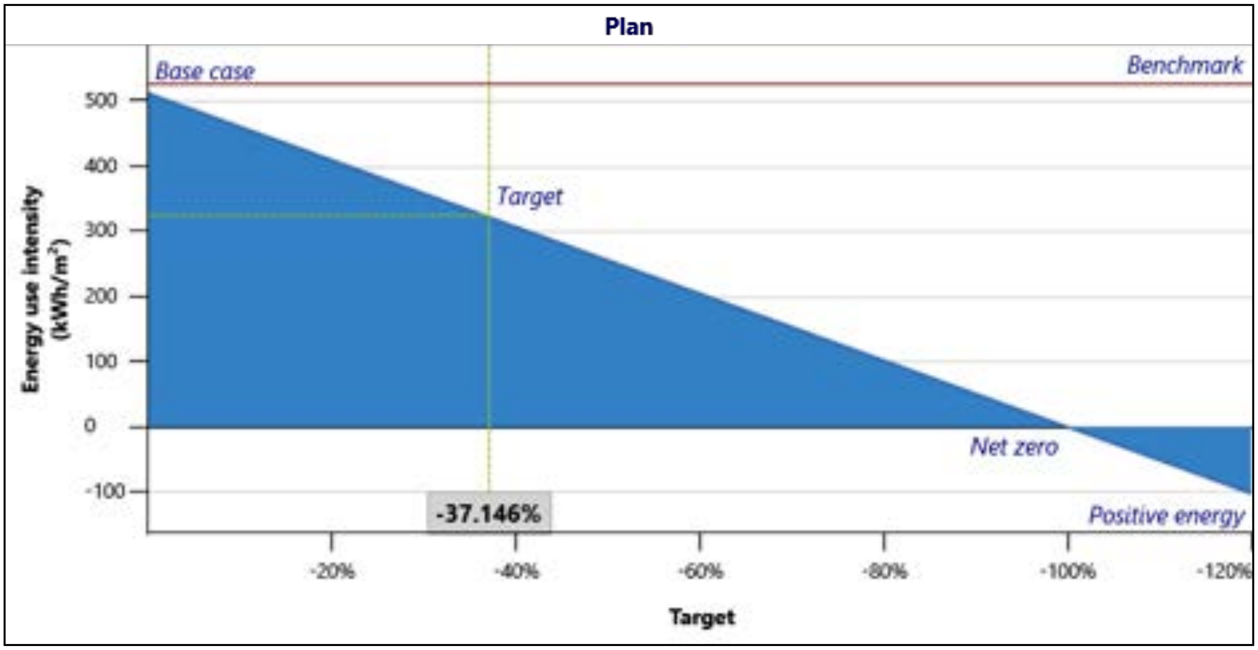



| | |
|---|---|
| Heating design temperature | -41.1 |
| Cooling design temperature | 14.8 |
| Earth temperature amplitude | 28.8 |

| Month | Air temperature | Relative humidity | Precipitation | Daily solar radiation - horizontal | Atmospheric pressure | Wind speed | Earth temperature | Heating degree-days | Cooling degree-days |
|---|---|---|---|---|---|---|---|---|---|
| | °C | % | mm | kWh/m²/d | kPa | m/s | °C | °C-d | °C-d |
| January | -33.4 | 66.3% | 15.81 | 0.04 | 101.4 | 6.4 | -28.5 | 1,593 | 0 |
| February | -33.5 | 66.3% | 14.28 | 0.49 | 101.5 | 6.1 | -27.5 | 1,442 | 0 |
| March | -30.7 | 68.2% | 19.22 | 2.06 | 101.7 | 5.8 | -22.8 | 1,510 | 0 |
| April | -22.0 | 72.9% | 21.60 | 4.42 | 101.7 | 5.6 | -13.7 | 1,200 | 0 |
| May | -9.5 | 84.3% | 28.83 | 6.05 | 101.5 | 5.8 | -4.8 | 853 | 0 |
| June | 1.9 | 83.1% | 41.40 | 6.44 | 101.2 | 5.6 | 4.7 | 483 | 0 |
| July | 8.0 | 77.6% | 46.19 | 5.13 | 100.9 | 5.6 | 8.7 | 310 | 0 |
| August | 6.2 | 81.9% | 47.12 | 3.31 | 100.8 | 6.1 | 6.0 | 366 | 0 |
| September | -0.6 | 86.4% | 38.40 | 1.64 | 101.0 | 6.4 | -0.1 | 558 | 0 |
| October | -11.5 | 85.2% | 31.31 | 0.70 | 101.0 | 6.4 | -10.5 | 915 | 0 |
| November | -23.7 | 74.2% | 18.30 | 0.10 | 101.2 | 5.8 | -21.7 | 1,251 | 0 |
| December | -29.6 | 68.7% | 15.81 | 0.00 | 101.3 | 5.8 | -26.4 | 1,476 | 0 |
| Annual | -14.8 | 76.3% | 338.27 | 2.54 | 101.3 | 5.9 | -11.3 | 11,956 | 0 |

# Benchmark

## Fuel consumption




| | | |
|---|---|---|
| Facility size | 103 | m² |
| Benchmark | 523 | kWh/m² |
| Minimum - average | 200 | kWh/m² |
| Maximum - average | 800 | kWh/m² |
| Base case | 513 | kWh/m² |
| Reference year | | |
| Set target | Target | |
| Year | | |
| Target | -37.1% | |
| Proposed case | 322 | kWh/m² |
| Facility - Plan | | |
| Fuel consumption | Annual | |
| Base case | 52,786 | kWh |
| Proposed case | 33,178 | kWh |
| Fuel saved | 19,608 | kWh |

# Notes

**Modelling Assumption**

1. Benchmark: 600 kWh/m² for 63.19 m² office or workshop area; 400 kWh/m² for 39.75 m² for unoccupied area. Average EUI performance of the building = 522.77 kWh/m² for subarctic climate zone

2. Regular Occupants = 4-6 Persons; Maximum Occupants =15-20 Persons

3. The parameters for base case setup are based on NECB 2017 in the aspect of assembly, lighting and mechanical performance.

4. The parameters for Proposed case are based on SAIT Green Building Technologies archiectural drawing package and envelope panel supplier.

5. The wall surface are is equivlent area to the normal orientation, not actural orientation, for RETScreen Energy Modelling.

6. Minimum air exchange rate in L/s is obtained by the required value in ASHREA 62.1-2019 for office, laboratory, and warehouase as room types in the project.

7. The proposed case is supposed to have 75% lighting energy requirement of NECB request.

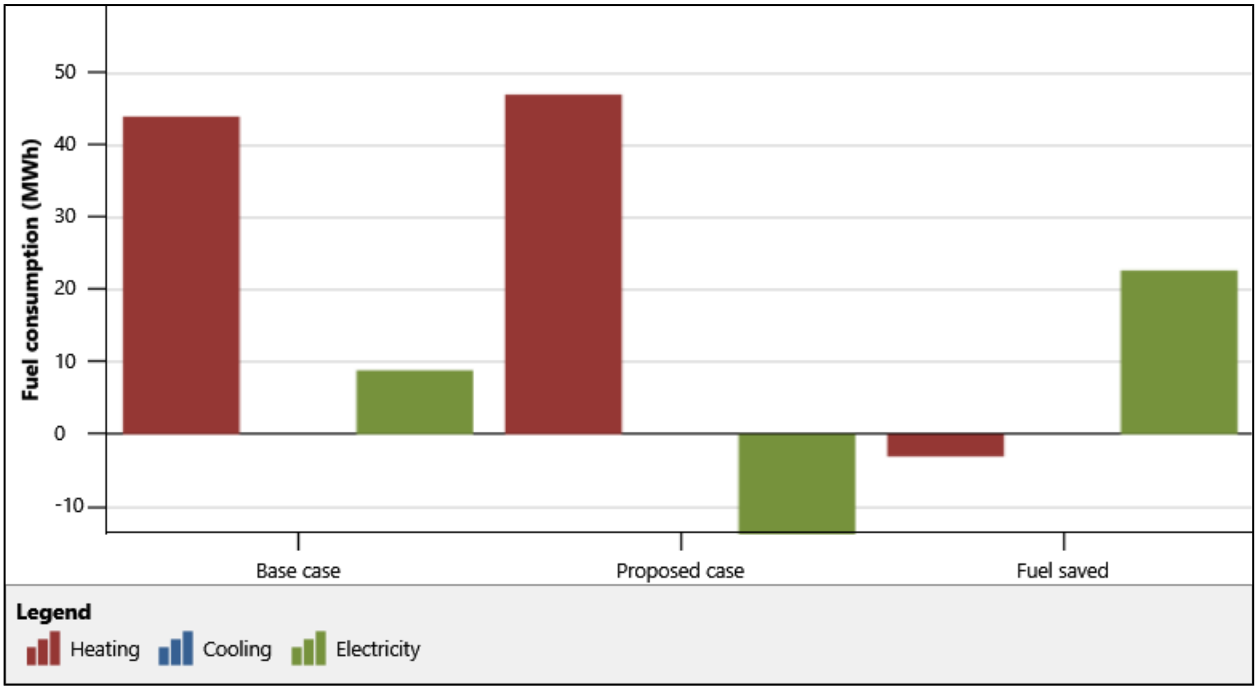
8. The performance of solar panel is improved by 15% due to bifacial gains.

9. The proposed wind turbine and solar panel can have 10 kW as maximum power capacity of renewable energy by local regulation.

10. Solar awing is simulated by Revit model. The solar gains in Spring, Summer and Fall may affect essential heating loads.

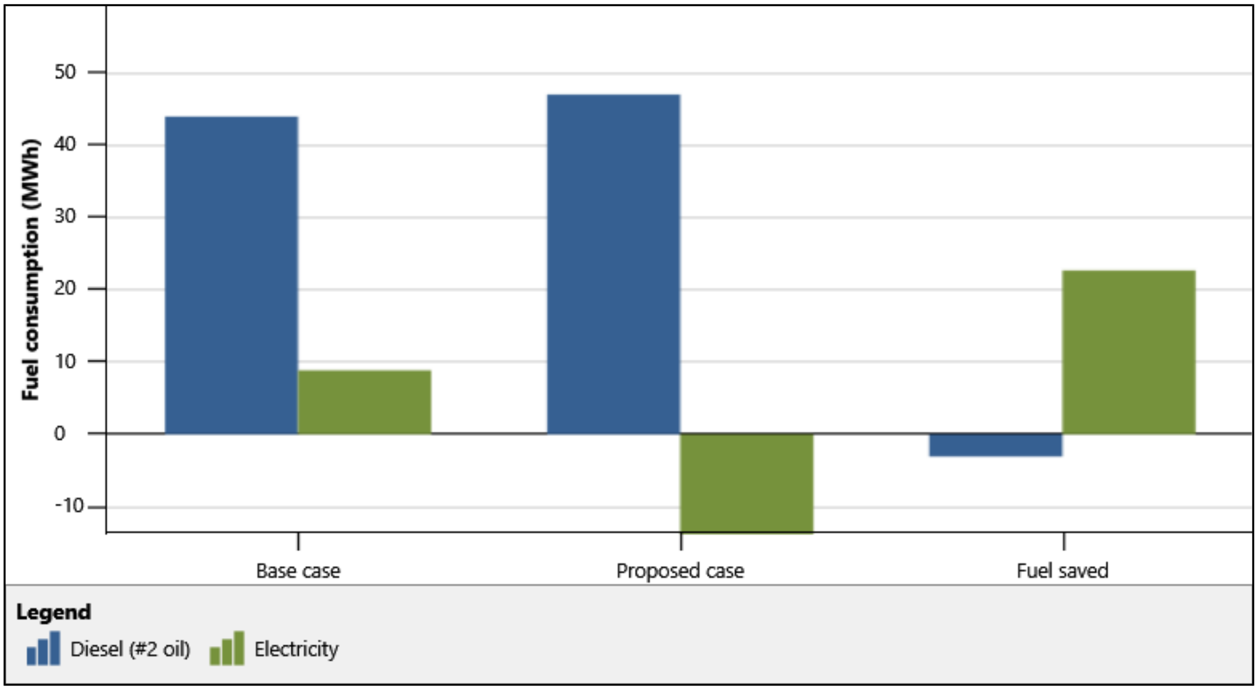
# Energy savings | Fuel summary

Energy savings




| Fuel consumption | Heating kWh | Cooling kWh | Electricity kWh | Total kWh |
|---|---|---|---|---|
| Base case | 43,935 | 0 | 8,851 | 52,786 |
| Proposed case | 46,993 | 0 | -13,815 | 33,178 |
| Fuel saved | -3,058 | 0 | 22,666 | 19,608 |
| Fuel saved - percent | -7% | 0% | 256% | 37.1% |

Fuel summary




| Fuel type | Fuel<br>Unit | Base case<br>Fuel consumption | Proposed case<br>Fuel consumption | Savings<br>Fuel saved |
|---|---|---|---|---|
| Diesel (#2 oil) | L | 4,130 | 4,417 | -287 |
| Electricity | kWh | 8,851 | -13,815 | 22,666 |

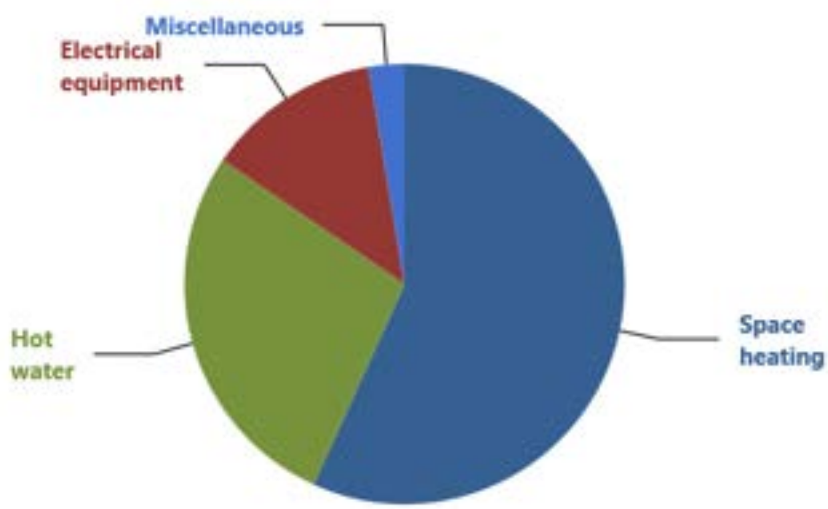
| Fuel type | Fuel<br>Fuel rate | Base case<br>Fuel cost | Proposed case<br>Fuel cost | Savings<br>Savings |
|---|---|---|---|---|
| Diesel (#2 oil) | 1.04 $/L | $ 4,295 | $ 4,594 | $ -299 |
| Electricity | 0.67 $/kWh | $ 5,930 | $ -9,256 | $ 15,186 |
| Total | | $ 10,225 | $ -4,662 | $ 14,887 |

## Notes

In this proposal (Proposal 1), All energy consumption for the building are powered by electricity.

# End-use

Fuel consumption - proposed case




| Section | Fuel consumption - proposed case kWh | % |
|---|---|---|
| Space heating | 31,569 | 56.8% |
| Hot water | 15,424 | 27.7% |
| Electrical equipment | 7,131 | 12.8% |
| Miscellaneous | 1,470 | 2.6% |
| Lights | 915 | 1.6% |
| Mechanical equipment | 555 | 1% |
| Power | -22,416 | - |

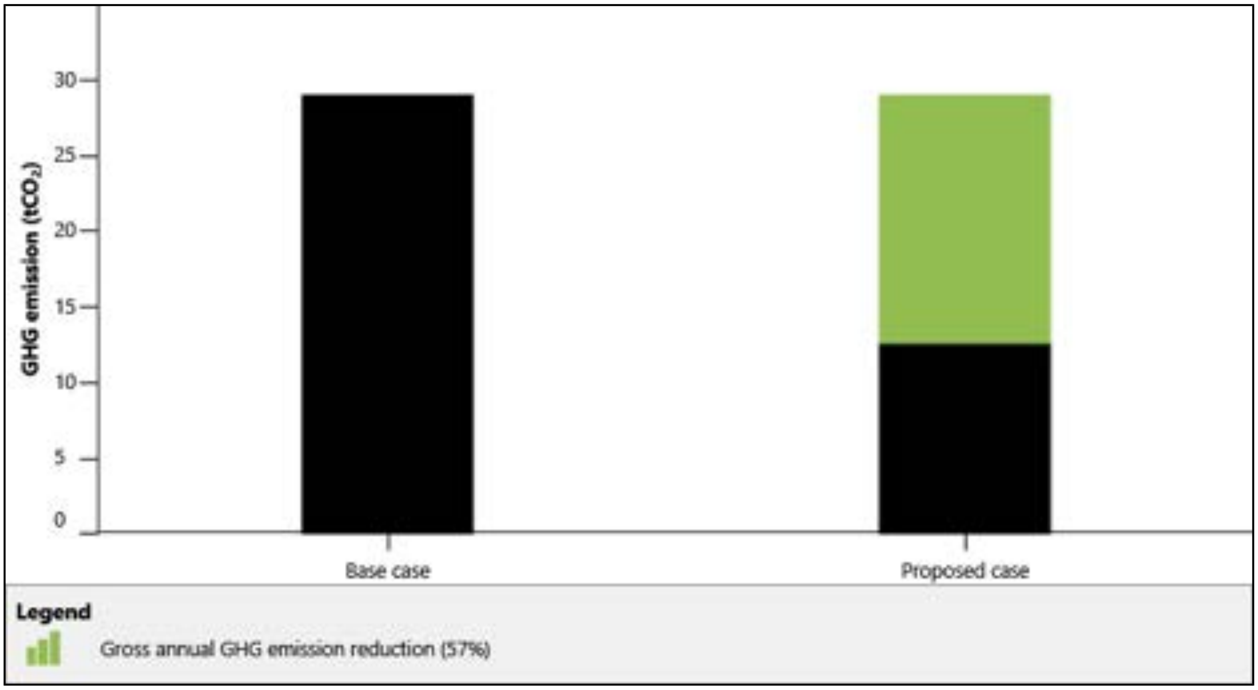
# Target

## Summary

| | Fuel consumption MWh | Fuel cost $ | GHG emission $tCO_2$ |
|---|---|---|---|
| Base case | 52.8 | 10,225 | 29.1 |
| Proposed case | 33.2 | -4,662 | 12.6 |
| Savings | 19.6 | 14,887 | 16.5 |
| % | 37.1% | 146% | 56.6% |

# GHG emission

GHG emission




GHG equivalence

16.5 $tCO_2$ is equivalent to 3

Cars & light trucks not used

GHG emission

| | | |
|---|---|---|
| Base case | 29.1 | $tCO_2$ |
| Proposed case | 12.6 | $tCO_2$ |
| Gross annual GHG emission reduction | 16.5 | $tCO_2$ |

# Analysis type

Project life

## APPENDIX G – FINANCIAL FEASIBILITY

The following appendix shows the budget breakdown and funding sources for the workshop and final building over the next three years.

*Table 1 Class C Construction Cost Estimate for Kitikmeot Knowledge Centre - Workshop Area*

| Element | Element Square Footage | Cost /sf | Element Quantity | Cost/item | Total cost | Percentage of total construction cost | Comments | Assumptions |
|---|---|---|---|---|---|---|---|---|
| **A SHELL** | | | | | **$231,710.00** | **23.5%** | | |
| **A1 SUBSTRUCTURE** | | | | | **$56,550.00** | **5.7%** | | |
| A11 Foundation | 1131 | $ 50.00 | | | $56,550.00 | | Foundation of the building is sitting on the ground, will require screw piles and built-up beam structure for building floor to sit on | |
| A12 Basement Excavation | 0 | $ - | | | $0.00 | | None | |
| **A2 STRUCTURE** | | | | | **$69,680.00** | **7.1%** | | |
| A21 Main Floor Construction | 2262 | $ 20.00 | | | $45,240.00 | | Floor plus structural posts and beams, includes a 'double floor' | ZS2 Panel cost ($12-20/ft2), plus structural posts, beams, trusses. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| A22 Second Floor Construction | | 0 | $ - | | | $0.00 | | No second floor | ZS2 Panel cost ($12-20/ft2), plus structural posts, beams, trusses. |
| A23 Roof Construction | | 1222 | $ 20.00 | | | $24,440.00 | | Panels only plus waste Allowance | Includes waste when cutting the triangular shapes for the roof |
| **A3 EXTERIOR ENCLOSURE** | | | | | | **$105,480.00** | **10.7%** | | |
| A31 Walls Below Grade | | 0 | $ - | | | $0.00 | | No walls below grade | |
| A32 Walls Above Grade - Insulated Panels | | 2360 | $ 20.00 | | | $47,200.00 | | Main building is two stories, Workshop is one storey. Wall assembly: board, insulation | ZS2 cost ($12-20/ft2) |
| A32 Walls Above Grade - Cladding | | 2360 | $ 10.00 | | | $23,600.00 | | Membranes, exterior cladding | $3-10/ft2 - https://homeguide.com/costs/siding-cost#metal |
| A33 Windows | | 180 | $ 70.00 | | | $12,600.00 | | Windows, skylights Inlcudes Installation | $50-70/ft2 for triple-pane high-performance glazing units |
| A34 Entry Doors | | | | 3 | $1250.00 | $3,750.00 | | Prefinished Value Series Pricing • Initial Pricing is based on a Solid Door (6- | https://doorsmith.ca/wp-content/uploads/2020/12/Doorsmith-Exterior-Price-Book-REF_DRPB_03_web1.pdf |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Panel) • 24 Ga. Prefinished White Steel • Doors do not come standard with Brickmould | |
| A34 Roof Covering | | 1222 | $ 15.00 | | | $18,330.00 | | Roof assembly: board, insulation, membranes, exterior cladding finish | Metal clad roof costs - https://homeguide.com/costs/siding-cost#metal |
| A35 Projections | | | | 1 | $10000.00 | $10,000.00 | | Pipes, vents, overhangs, soffits, trim, etc. | 10% estimate of exterior enclosure costs |
| **B INTERIORS** | | | | | | **$65,100.00** | **6.6%** | | |
| **B1 PARTITIONS & DOORS** | | | | | | **$8,750.00** | **0.9%** | | |
| B11 Partitions | | 250 | $ 20.00 | | | $5,000.00 | | Interior walls: pod connections, vestibule wall | ZS2 cost ($12-20/ft2), estimate 20% of the total sq footage of the building |
| B12 Doors | | | | 5 | $750.00 | $3,750.00 | | Interior doors | Standard pricing |
| **B2 FINISHES** | | | | | | **$22,350.00** | **2.3%** | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| B21 Floor Finishes | | 1131 | $ 4.00 | | | $4,524.00 | | Flooring: vinyl | https://www.homeadvisor.com/r/vinyl-vs-laminate-flooring/#cost |
| B22 Ceiling Finishes | | 1222 | $ 3.00 | | | $3,666.00 | | Paint only | https://homeguide.com/costs/cost-to-paint-interior-of-house |
| B23 Wall Finishes | | 4720 | $ 3.00 | | | $14,160.00 | | Paint only | https://homeguide.com/costs/cost-to-paint-interior-of-house |
| **B3 FITTINGS & EQUIPMENT** | | | | | | **$9,000.00** | **0.9%** | | |
| B31 Fittings & Fixtures | | | | 5 | $600.00 | $3,000.00 | | Toilets, sinks, faucets, utility sinks, shower. Consider outdoor sink for summer use. | Standard pricing |
| B32 Equipment | | | | 3 | $2000.00 | $6,000.00 | | Stove, fridge, dishwasher | Standard pricing |
| B33 Conveying Systems | | | | 0 | | $0.00 | | None | https://www.ameriglide-toronto-aurora.ca/platform-lifts-alternative-to-elevator.htm, Standard pricing for stairs |
| **B4 MILLWORK** | | | | | | **$25,000.00** | **2.5%** | | |
| B41 Millwork | | 50 | $ 300.00 | | | $15,000.00 | | Kitchen cupboards, utility area cupboards, shelving and outdoor freezer box in | https://homeguide.com/costs/kitchen-cabinets-cost |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | vestibule, other shelving in building ie: in vaulted ceiling | |
| B42 Furniture | | | | 1 | $10000.00 | $10,000.00 | | Chairs, tables, etc. | Estimate based on current furniture prices |
| **C SERVICES** | | | | | | **$205,141.00** | **20.8%** | | |
| **C1 MECHANICAL** | | | | | | **$47,841.00** | **4.9%** | | |
| C11 Plumbing & Drainage | | 1131 | $ 5.00 | | | $5,655.00 | | Pipes, drains, water tank, sewage tank, exterior piping and hookups for tanks | https://homeguide.com/costs/install-new-house-plumbing-pipes-cost |
| C12 Water Heater | | | | 3 | $1800.00 | $5,400.00 | | Water Heater, water tank, sewage tanks | https://homeguide.com/costs/water-heater-installation-cost |
| C12 Fire Protection | | 1131 | $ 6.00 | | | $6,786.00 | | Fire proofing: spray on fire damping, fire-rated doors and walls treatment where required, | https://www.ecostarinsulation.ca/blog/spray-foam-insulation-cost |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | extinguishers, alarms | |
| C13 H.V.A.C. | | | | 1 | $15,000.00 | $15,000.00 | | Heat recovery ventilator, furnace, ducts, fans | Based on current GBT projects |
| C14 Controls | | | | 1 | $15,000.00 | $15,000.00 | | Lighting, heating, ventilation, humidity controls. Monitoring equipment. | Based on current GBT projects |
| **C2 ELECTRICAL** | | | | | | **$157,300.00** | **16.0%** | | |
| C21 Service & Distribution | | 0 | | 1 | $10,000.00 | $10,000.00 | | Wiring, electrical panels, power connections (interior and exterior) | Based on current GBT projects |
| C22 Lighting, Devices & Heating | | 0 | | 1 | $10,000.00 | $10,000.00 | | Lights, heating panels, electrical outlets, other devices | Based on current GBT projects |
| C23 Systems & Ancillaries | | 0 | | 1 | $137,300.00 | $137,300.00 | | Renewables: solar PV, | Based on current GBT projects |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | thermal, wind turbine, battery storage | |
| **NET BUILDING COST (Excluding Site)** | | | | | | **$501,951.00** | **51.0%** | | |
| **D SITE & ANCILLARY WORK** | | | | | | **$63,400.00** | **6.4%** | | |
| **D1 SITE WORK** | | | | | | **$30,000.00** | **3.0%** | | |
| D11 Site Development | | 2000 | $ 10.00 | | | $20,000.00 | | Site preparation to place buildings on level surfaces | Qillaq provided this estimate |
| D12 Mechanical Site Services | | | | 1 | $5000.00 | $5,000.00 | | Minimal - no municipal water or sewage connections required | Estimate only |
| D13 Electrical Site Services | | | | 1 | $5000.00 | $5,000.00 | | Connect to municipal power system | Estimate only |
| **D2 ANCILLARY WORK** | | | | | | **$0.00** | **0.0%** | | |
| D21 Demolition | | 0 | $ - | | | $0.00 | | None | |
| D22 Alterations | | 0 | $ - | | | $0.00 | | None | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **G1 LANDSCAPING** | | | | | | **$33,400.00** | **3.4%** | | |
| G11 Outdoor Decks and Ramps | | 835 | $ 40.00 | | | $33,400.00 | | Main decks on each building plus wheelchair accessible ramps | https://www.renoassistance.ca/en/deck-and-balcony/cost-to-build-a-deck/ |
| G12 Walkways and Gathering Pads | | | $ - | | | $0.00 | | None | $55 per cubic metre - 2000 sq ft x 3ft deep - 170 cubic Metres. - Qillaq provided this estimate |
| G13 Parking | | | $ - | | | $0.00 | | None | $55 per cubic metre - 2000 sq ft x 3ft deep - 170 cubic Metres. - Qillaq provided this estimate |
| **NET BUILDING COST (Including Site)** | | | | | | **$565,351.00** | **57.5%** | | |
| **Z GENERAL REQUIREMENTS & ALLOWANCES** | | | | | | **$191,535.10** | **19.5%** | | |
| **Z1 GEN. REQ. & FEE** | **10%** | | | | | **$56,535.10** | **5.7%** | | |
| Z11 General Requirements | 7% | | | | | $39,574.57 | | Cost for construction overhead (power, tools, equipment, etc.) | |
| Z12 Fee | 3% | | | | | $16,960.53 | | Cost to coordinate | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | construction activities | |
| **ZX PERMITS & FEES** | | | | | | **$135,000.00** | **13.7%** | | |
| Insurance | | | | | | $10,000.00 | | | Estimate only |
| Development/Building Permits | | | | | | $15,000.00 | | | Based on a $1 Million value building in Calgary |
| Legal | | | | | | $10,000.00 | | | Estimate only |
| Logistics Costs | | | | | | $100,000.00 | | Cost for shipping and storage of construction materials + Seacans | Based on current pricing |
| **TOTAL CONSTRUCTION ESTIMATE (Excluding Allowances)** | | | | | | **$756,886.10** | **76.9%** | | |
| **Z2 ALLOWANCES** | **30%** | | | | | **$227,065.83** | **23.1%** | | |
| Z21 Estimating Allowance | 10% | | | | | $75,688.61 | | Contingency for high-level estimating errors | |
| Z22 Escalation Allowance | 10% | | | | | $75,688.61 | | Contingency for cost increases by the time construction | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | occurs in 1 year | |
| Z23 Construction Allowance | 10% | | | | | $75,688.61 | | Contingency for construction cost overruns | |
| **TOTAL CONSTRUCTION ESTIMATE (Including Allowances)** | | | | | | **$983,951.93** | **100.0%** | | |

| **OTHER ACTIVITIES - POST CONSTRUCTION** | **Total Cost** |
|---|---|
| Travel Costs (1 trip) | **$ 18,750.00** |
| Embodied Carbon Analysis | **$ 10,000.00** |
| Monitoring and Analysis (1 year) | **$ 41,200.00** |
| Marketing and Communications | **$ 11,500.00** |
| **TOTAL** | **$81,450.00** |

**Grand Total : $1,065,401.93**

*Table 2 Overview of Class C Costs per Year*

| Year 1- 2021/22 | Schedule | Costs |
|---|---|---|
| Capital Costs + contigency(1/2) | Q4 | $ 364,508 |
| | | |
| | | **$ 364,508** |
| Year 2 - 2022/23 | | |
| Travel Cost | Q2 | $ 18,750 |
| Capital Costs + contigency (2/2) | Q1 | $ 364,508 |
| Marketing & Comms (1/2) | Q1-Q4 | $ 5,750 |
| Monitoring (1/2) | Q3-Q4 | $ 20,600 |
| Permitting | Q2 | $ 91,535 |
| Freight | Q2 | $ 100,000 |
| Site prep | Q2 | $ 63,400 |
| | | |
| | | **$ 664,544** |
| Year 3 - 2023/24 | | |
| Marketing & Comms (2/2) | | $ 5,750 |
| Embodied carbon analysis | | $ 10,000 |
| Monitoring (2/2) | | $ 20,600 |
| | | **$ 36,350** |
| | **Total (3 years)** | **$ 1,065,402** |

## APPENDIX H – MITIGATING OVERHEATING WHEN PASSIVELY HEATING REPORT

The following is a report conducted by SAIT on the design of the windows, shade control, and solar awnings that the recommendations in the feasibility report are based on.

Applied Research
and Innovation Services
**Green Building
Technologies**

Southern Alberta Institute of Technology
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Calgary, Alberta, Canada
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# Cambridge Bay Community Centre

## Mitigating Overheating when Passively Heating

## Introduction

The community of Cambridge Bay, Nunavut, is seeking a new community centre to create an adaptable space that can be used for many different communal uses. The purpose of this report is to assess the unique solar path and conditions experienced in this area. Due to their extreme northern location, sunlight trends vary greatly from the southern areas of Canada, with no sunlight around winter solstice to 24-hour sunlight around the summer solstice. The community is seeking an efficient building that utilizes passive heating in cohesion with high-efficiency HVAC systems. The possibility of overheating could be higher due to the area's unique solar path.

When designing for passive solar heating, the 3 methods of heat transfer must be considered: conduction, convection, and radiation.

The first, conduction, is the process of heat being directly transmitted through a material when a difference in temperature is present. An example of this would be the thermal loss (or leakage) through walls due to the various materials connected within the wall. The second, convection, is the movement of air due to a difference in temperatures. An example of this would include warm air rising to the top most area of an interior space, as cool air would sink. The third and final transfer, radiation, is the movement of heat through a space. An example of this would be in-floor radiant heating, where pipes with a warm liquid transfer heat to the floor's concrete mass to warm a space.

These three methods of heat transfer will be important in identifying over-heating potential and mitigation methods. Passive heating utilizes the heat of the sun to naturally heat a space. Buildings can be designed and built to optimize passive heating potential to reduce the need of other heating sources that may require the consumption of fuel or electricity to function, thus reducing the building's resource consumption and waste production.

However, as the sun can't be turned off, the potential for over-heating can occur if not planned for. The following report will investigate methods of over-heating prevention for a space that not only utilizes passive heating, but also one that is situated in the Northern Canadian territory of Nunavut where sunlight patterns can cause long periods of sunlight exposure.

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and Innovation Services
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## Research Methodology

For the context of this report, benchmark or theoretical buildings have been designed and modeled in the architectural software Revit. All benchmark buildings are a single storey with minimum 9-foot ceilings as is typical in commercial design. Windows have been added to all faces of each building to demonstrate interior daylighting. Roof design varies between flat to angled depending on the building.

The buildings will be located in the general area of Cambridge Bay, Nunavut, Canada, and two time periods have been modelled. The first scenario demonstrates June 21st, the Summer Solstice, where residents experience 24 hours of daylight with the sun providing light from all directions through the course of the day. One issue presented here stems from the height of the sun on the horizon: a low-laying sun cannot be easily obstructed by traditional roof-overhang design. The second scenario explored is set during the Equinox, March or September, to illustrate daylighting that spans from 9:00 AM to 9:00 PM and sunlight coming from the south as is typical for southern Canada. For both scenarios, the time periods of 9:00 AM, 3:00 PM (15:00), 9:00 PM (21:00), and 3:00 AM have been captured. Sun path coordinates have been gathered from the website Gaisma[1], an online resource that details solar paths in great depth including azimuth and elevation of the sun. The website has a set number of locations with data and the closest and most similar point on the website to Cambridge Bay is Inuvik, Northwest Territories. We acknowledge that this solar path data is not exact to Cambridge Bay but illustrates similar patterns very closely.

In passive heating design, roof over-hangs are utilized to provide shading to windows, and thus the interior of the building, at peak hours of the day where heat from the sun is strongest. Morning and evening light will still enter the home, typically providing enough heat to maintain a comfortable interior temperature. The same cannot be said for low-laying sun conditions presented in Northern Canada.

Furthermore, vegetation in this climate is limited. Deciduous trees are used in passive heating design to obstruct some sunlight in the summertime, when these trees are in leaf. In the winter, when they are bare, more heating is required and thus the lack of obstruction is welcomed. Coniferous trees and shrubs inhabit the majority of Nunavut, with some areas even lacking the presence of small coniferous tress, leaving only the occasional shrub or lichen.

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[1] Gaisma, *Inuvik, Canada* [website], https://www.gaisma.com/en/location/inuvik.html, (accessed 14 June 2021).

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# Benchmark Scenarios

**Benchmark Scenario: Rectangular Building**

To begin, the first building to be modelled was a basic rectangular, single-storey building. The following images display the amount of sunlight that enters an interior space when slab-to-ceiling windows are installed. In this scenario, a typical roof overhang of two-feet has been designed, and the interior space has been designed to a height of nine-feet which is typical for commercial spaces. This scenario demonstrates the extended amount of sun exposure under these conditions. This will lead to over-heating if mitigation measures are not applied.

The yellow arrows indicate the light direction and the teal circles inside the building represent two adults for scale. The green symbols on the exterior of the building indicate landscaping in the form of shrubs and small conifer trees. Coordinates are true to the images, meaning North is the top of an image.

**Figure 1:** plan view at 9:00 AM on June 21st (Summer Solstice) with slab-to-slab windows and two-foot roof overhang. Source: primary.

**Figure 2:** plan view at 3:00 PM (15:00) on June 21st (Summer Solstice) with slab-to-slab windows and two-foot roof overhang. Source: primary.

**Figure 3:** plan view at 9:00 PM (21:00) on June 21st (Summer Solstice) with slab-to-slab windows and two-foot roof overhang. Source: primary.

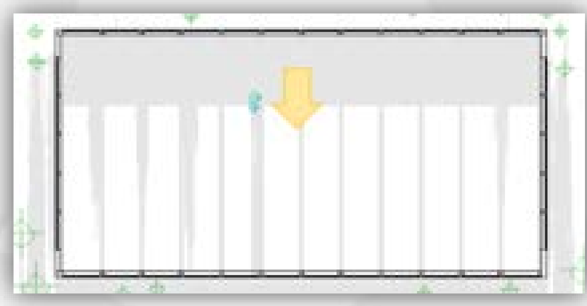

**Figure 4:** plan view at 3:00 AM on June 21st (Summer Solstice) with slab-to-slab windows and two-foot roof overhang. Source: primary.

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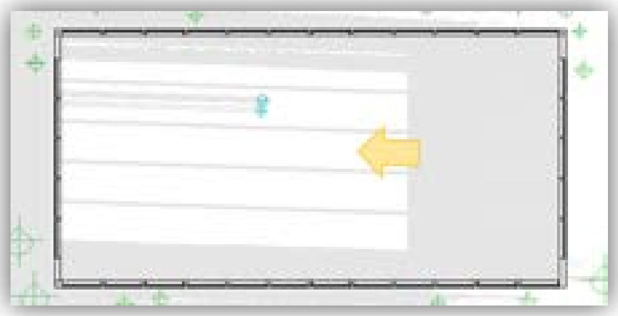

**Figure 5:** plan view at 9:00 AM during an Equinox (March or September) with slab-to-slab windows and two-foot roof overhang. Source: primary.

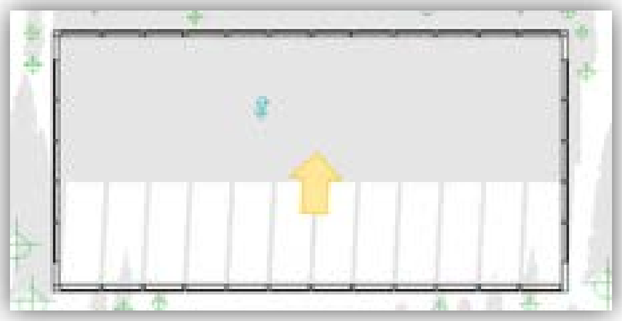

**Figure 6:** plan view at 3:00 PM (15:00) during an Equinox (March or September) with slab-to-slab windows and two-foot roof overhang. Source: primary.

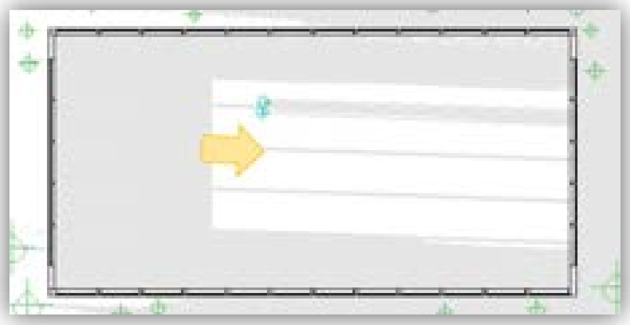

**Figure 7:** plan view at 9:00 PM (21:00) during an Equinox (March or September) with slab-to-slab windows and two-foot roof overhang. Source: primary.

**Note:** there is no image for 3:00 AM during an Equinox as the sun has set at that time.

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**Benchmark Scenario: Hexagonal Building**

The second scenario transforms the building shape to a hexagon. This design was introduced to the project shortly after the initial solar modelling was completed above. Similar to the first scenario, this is a single-storey building with nine-foot ceilings. One difference is that the roof is sloped at 25%. Slab-to-slab windows have also been installed for this scenario to illustrate maximum interior sunlight.

Again, the yellow arrows indicate the light direction and the green symbols on the exterior of the building indicate landscaping in the form of shrubs and small conifer trees. The areas circled in yellow indicate where light is reaching the opposite wall and is not visible in the image due to the angle.

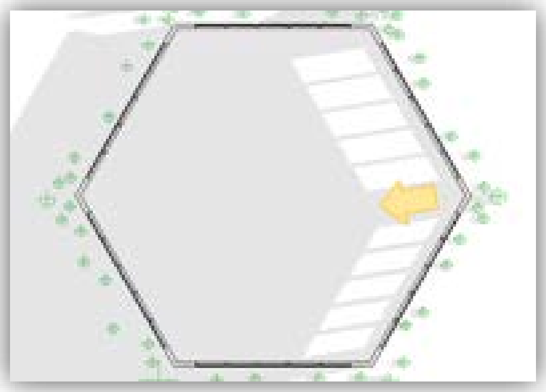

**Figure 8:** plan view at 9:00 AM on June 21st (Summer Solstice) with slab-to-slab windows and two-foot roof overhang. Source: primary.

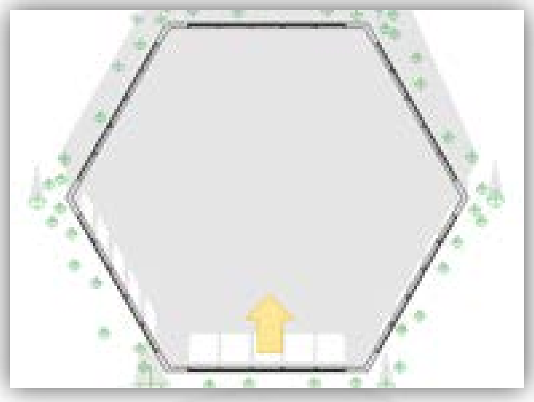

**Figure 9:** plan view at 3:00 PM (15:00) on June 21st (Summer Solstice) with slab-to-slab windows and two-foot roof overhang. Source: primary.

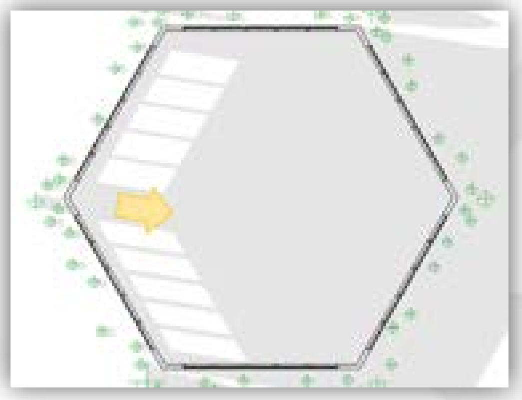

**Figure 10:** plan view at 9:00 PM (21:00) on June 21st (Summer Solstice) with slab-to-slab windows and two-foot roof overhang. Source: primary.

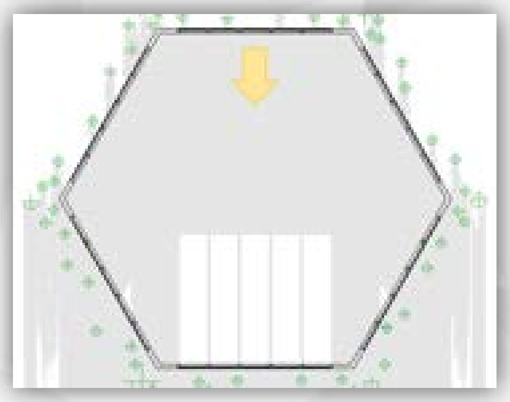

**Figure 11:** plan view at 3:00 AM on June 21st (Summer Solstice) with slab-to-slab windows and two-foot roof overhang. Source: primary.

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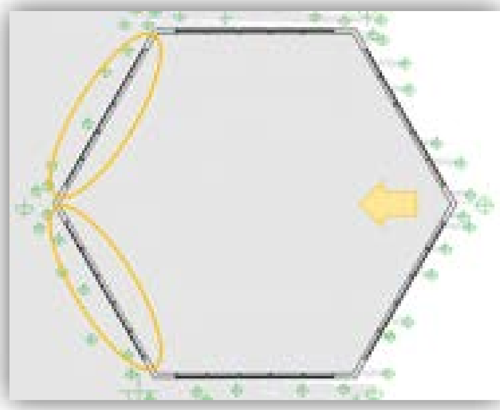

**Figure 12:** plan view at 9:00 AM on an Equinox (March or September) with slab-to-slab windows and two-foot roof overhang. Source: primary.

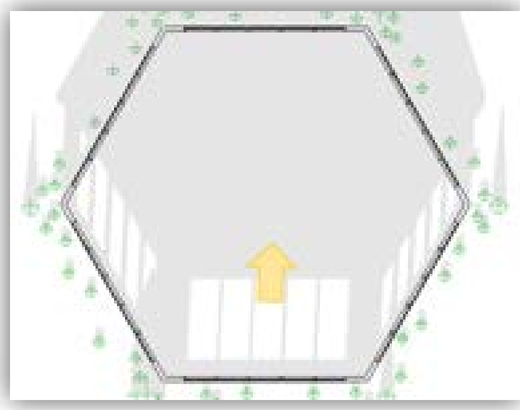

**Figure 13:** plan view at 3:00 PM (15:00) on an Equinox (March or September) with slab-to-slab windows and two-foot roof overhang. Source: primary.

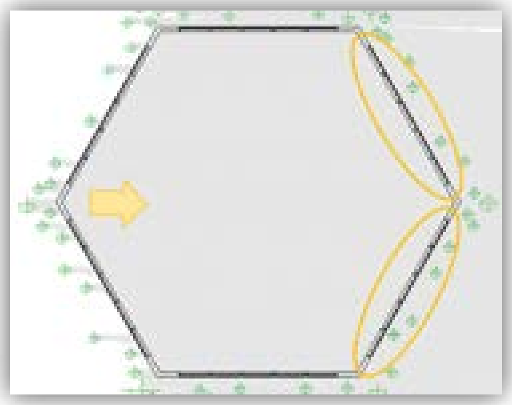

**Figure 14:** plan view at 9:00 PM (21:00) on an Equinox (March or September) with slab-to-slab windows and two-foot roof overhang. Source: primary.

**Note:** there is no image for 3:00 AM during an Equinox as the sun has set at that time.

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## Overheating Mitigation Strategies

### Roof Overhang Shading

To demonstrate roof overhang shading, this scenario has the same slab-to-slab windows however the roof overhang has been extended as far as needed to provide shading at peak sunlight heating periods. As shown in *Figure 15, Figure 16, and Figure 17* the overhang had to extend to an extreme of nine feet; this design is highly unrealistic as this amount of overhang will not only require a substantial amount of building materials, but it will also lead to snow and wind load concerns and will like not be structurally feasible.

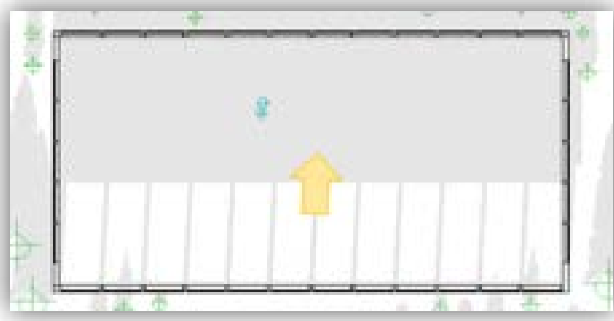

**Figure 15:** plan view at 3:00 PM (15:00) during an Equinox (March or September) with slab-to-slab windows and two-foot roof overhang. Source: primary.

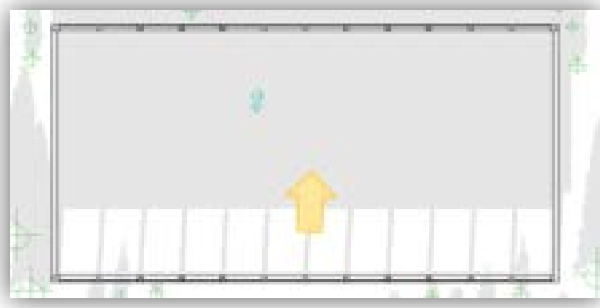

**Figure 16:** plan view at 3:00 PM (15:00) during an Equinox (March or September) with slab-to-slab windows and **nine-foot roof overhang**. Source: primary.

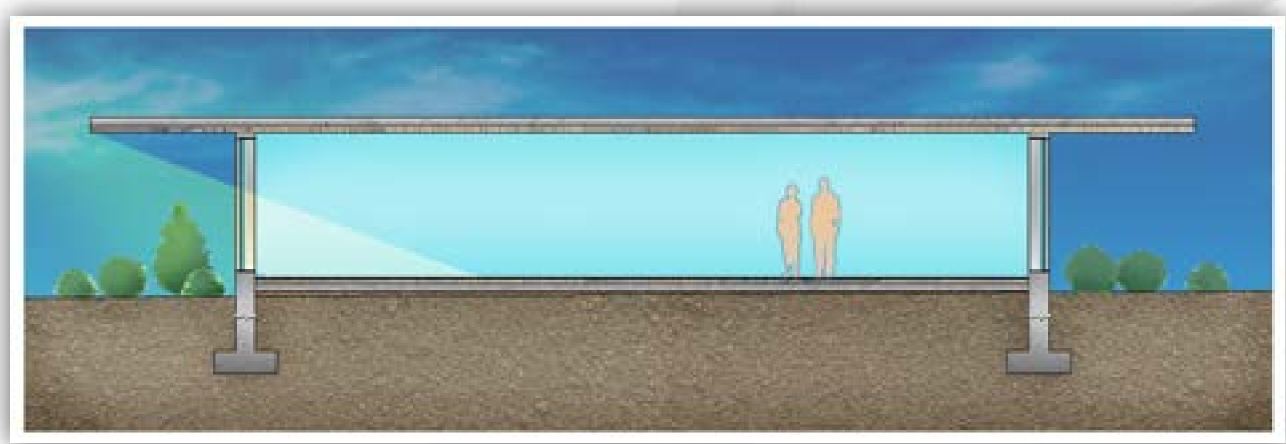

**Figure 17:** section view at 3:00 PM (15:00) during an Equinox (March or September) with slab-to-slab windows and **nine foot roof overhang**. Even the hyper-extended overhang does not block out the majority of the sunlight at a peak sunlight period. This is due to how low the sun lays on the horizon at 21° elevation. Source: primary.

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### Adjusted Window Sizes

The solar heat-gain coefficient (SHGC) of a window defines the level of heat it allows to pass through its glass. This is an example of radiation heat transfer as the energy is directly coming from a source emitting energy (the sun.) The lower SHGC of a window, the less heat it will allow into the interior space; the value is measured between 0 and 1.

Two methods of lowering a window's SHGC are directly shading light from accessing it (i.e.: roof overhang), and applying low-e films to the window which reduce UV and infrared light from passing through the glass. A window's size and orientation can also contribute to its SHGC. For example, a short but long window located near the top of wall could have a 0 SHGC as the roof overhang could prevent any directly light form entering. It still serves a purpose by providing ambient light, however,

When designing with large window-to-wall ratios (WWR), such as slab-to-slab windows that span the full height of a wall or curtain walls, the lowest quarter or $1/3^{rd}$ of a window does nothing but increase its SHGC. The reason for this is that access to nice views is not required at such a low level; views to the exterior for comfort can be achieved even if the bottom two feet of the window are cut off. However, what this section does do is transmit heat if unobscured.

*Figure 18, Figure 19,* and *Figure 20* illustrate the added amount of light exposure a slab-to-slab window adds. Figure 7 demonstrates that even a window half the size of the original still provide adequate visual access to the exterior, while still utilizing the small shaded area provided at the top of the window by the roof overhang.

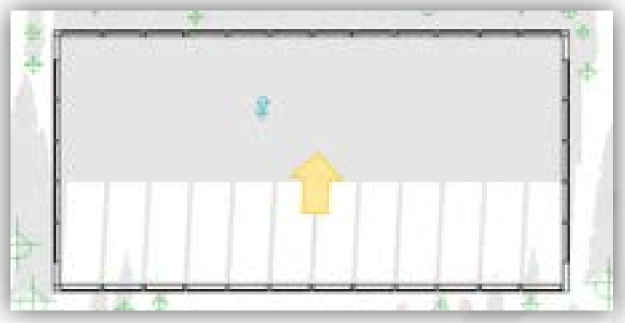

**Figure 18:** plan view at 3:00 PM (15:00) during an Equinox (March or September) with slab-to-slab windows and two-foot roof overhang. Source: primary.

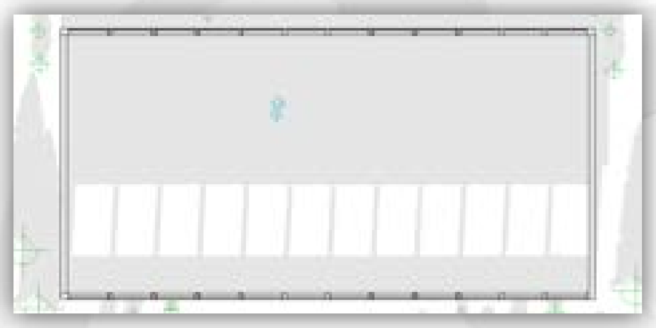

**Figure 19:** plan view at 3:00 PM (15:00) during an Equinox (March or September) with half-sized windows two feet above slab and two-foot roof overhang. Source: primary.

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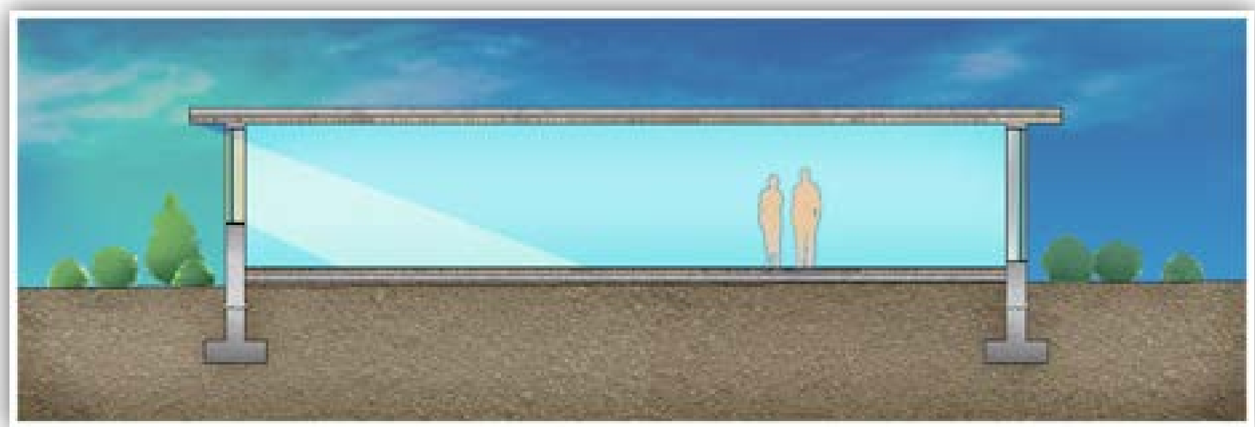

**Figure 20:** section view at 3:00 PM (15:00) during an Equinox (March or September) with raised windows and two-foot roof overhang. Raised windows that lay a minimum of two feet above the floor still provide excellent views to the outside while reducing internal sunlight exposure near the bottom of the window. Source: primary.

**Transitional Glass Films**

Also know as photochromatic film, transitional films shift glass from clear to a darker opaque as they absorb UV from the sun. The most widely known example of this are outdoor/indoor transitional glasses that eliminate the need to change into sunglasses when exposed to the sun. This technology works by adjusting the visual light transmittance (VLT) through the window's pane of glass. VLT, as the term suggests, is the amount of visible light (and UV) that passes through a window. Films are available in a range of VLT levels from as low as 5 to as high as 70 and above. The higher the VLT value, the darker the film becomes when exposed to UV. A major benefit to this is that heat is reduced on sunny days but windows remain clear on cloudy days, leading to no compromise in thermal and visual comfort.

Newer systems have taken transitional film even further and have developed methods of fully controlling the level of tint manually. These systems can typically function in either automatic or manual modes, allowing occupants more control over how much solar heat and light can enter the interior space. These systems offer wall panel and mobile phone apps which allow for the manual adjustment of the window tinting as well as predetermined programming. Certain systems can also be integrated into the building management system (BMS) to allow the transitional tinting of the windows to be connected to other systems within the building, such as in-floor radiant and other heating and cooling systems. SageGlass[2] is one company which offers highly controllable and manual transitional film systems.

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[2] SageGlass, *Resources Sustainability* [website], https://www.sageglass.com/en/resources?category=30&field_resource_term_tid=31, (accessed 1 July 2021).

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**Exterior Shading Elements**

The largest benefit of utilizing exterior shading elements is that any heat they collect remains outside and away from the interior thermally controlled space. In other words, if interior shading elements such as blinds are installed on the interior of a window, the heat they collect is slowly released on the interior of the building which is counterintuitive to their purpose.

The *extended roof overhang* explored in an earlier section of this report is technically an external shading element. This section will explore other design methods or options that utilize exterior shading.

**Perforated Façades**

Perforated façades have been utilized globally across a wide range of applications. As their name implies, their perforated surface allows for partial screening making them ideal for applications concerned with controlling light and air. For example, many commercial buildings will utilize these panels as their exterior cladding as the panels, often made of metal or other durable materials, will protect the building's walls from exterior harm (i.e.: hail and debris) while also allowing the wall system to breath and dry reducing the possibility for mould and mildew to build-up. Similarly, windows can sometimes be partially or completely covered by these panels to reduce heat and light exposure to the interior, as well as protect the windows themselves.

Adjustable exterior elements also exist as either manual and automated systems. Similar to window shutters on hinges or blinds, these elements can be rotated and adjusted to meet environmental conditions and allow for greater occupant comfort on the interior. Aluminum sunshades are most common given the durability of the material. Italian company Feal[3] offer manual and automated aluminium blade systems that act as exterior blinds.

**Stationary Horizontal and Vertical Elements**

The orientation of external sun shading elements will determine which direction of sunlight is being shaded. Vertically oriented elements, for example, are ideal in shading light from the left and right which is most typically the east and west sunlight. Contrarily, horizontal sunshades are most effective against high orientated sunlight such as at noon when the sun is at its peak.

Exterior elements have limitless design capabilities and can allow a building to become more visual appealing and eye-catching. Vertical, horizontal, and angled elements can be utilized, and these can take the form of beams, panels, spheres, and virtually any shapes. Illustrations or images have been cut into panels to create dynamic imagery across a building's exterior while also providing function in the form of light, wind, and rain shading.

[3] FEAL, *FEAL Sun 55* [website], https://feal.ba/en/feal-sun-55/ (accessed 14 June 2021).

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**Solar PV Awning: Combining Shading Methods**

This final section will explore a design which incorporates several of the above mentioned shading methods. This design incorporates solar PV panels on the three southern building faces: south-east, south, and south-west.

Windows have been divided into three separate units to increase wall structural integrality by allowing vertical wall beams to be added between windows. This also contributes to increasing the efficiency of wall prefabrication as each wall panel is identical. One wall face is made of three pre-fabricated panels.

Not only do these panels generate electricity for the building, they also act as shading elements. The bottom row of three panels act as a 7-foot roof overhang, extended from the roof at the same 25° angle as the roof. An additional single panel was added to each roof-face as there was enough space and more panels will contribute to more energy generation.

Vertical wooden furring, or beams, have been added in-between the panels to create a more aesthetically pleasing design while further adding to solar shading. Any material can be used here based on aesthetic preference.

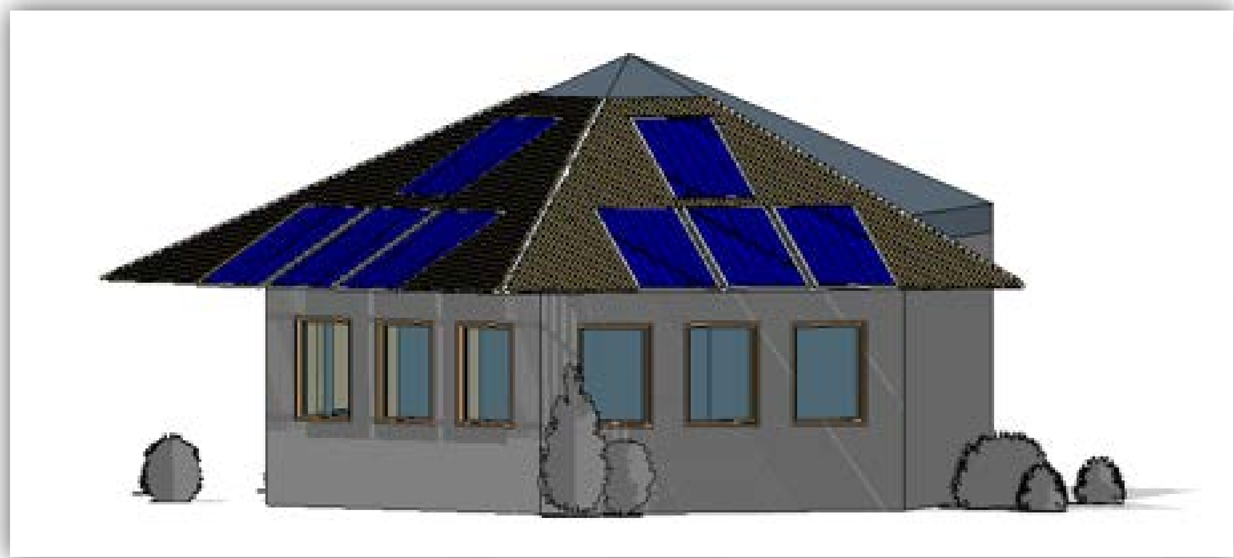

**Figure 21:** view at 3:00 PM (15:00) during an Summer Solstice (June 21) with 4-foot tall windows raised 2.5 feet above slab and no roof overhang. Solar PV awning extends 7-feet past roof edge to create a roof overhang that shades windows and interior. Additional elements are fitted over the rest of the awning system for aesthetic and shading purposes. Source: primary.

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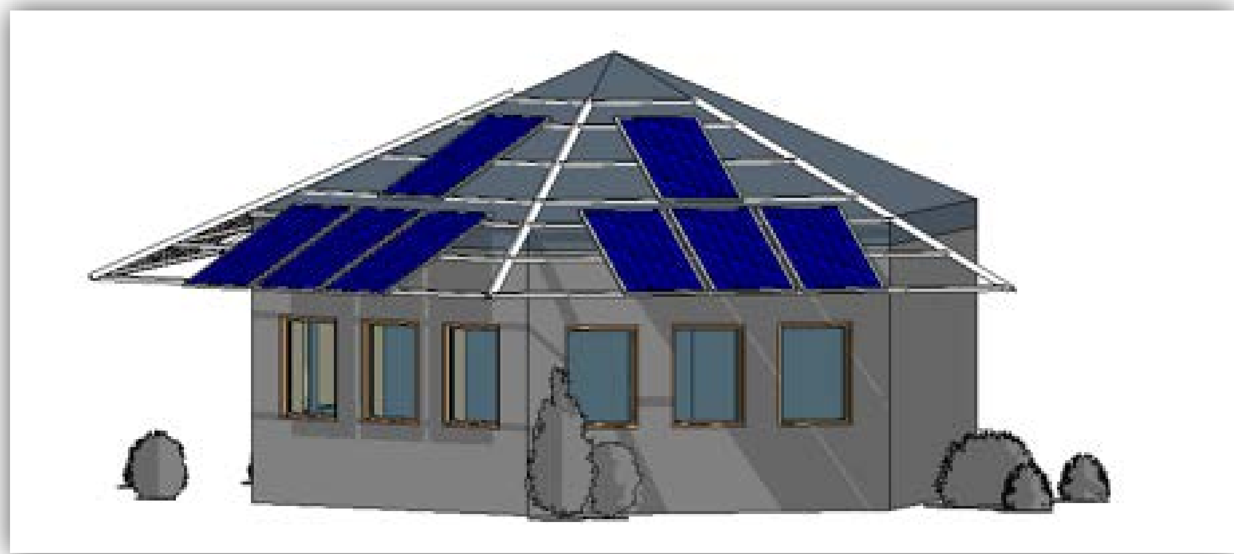

**Figure 22:** view at 3:00 PM (15:00) during an Summer Solstice (June 21) with 4-foot tall windows raised 2.5 feet above slab and no roof overhang. Illustration of the structural skeleton of the solar awning without additional cladding finish (i.e.: the elements seen above.) Source: primary.

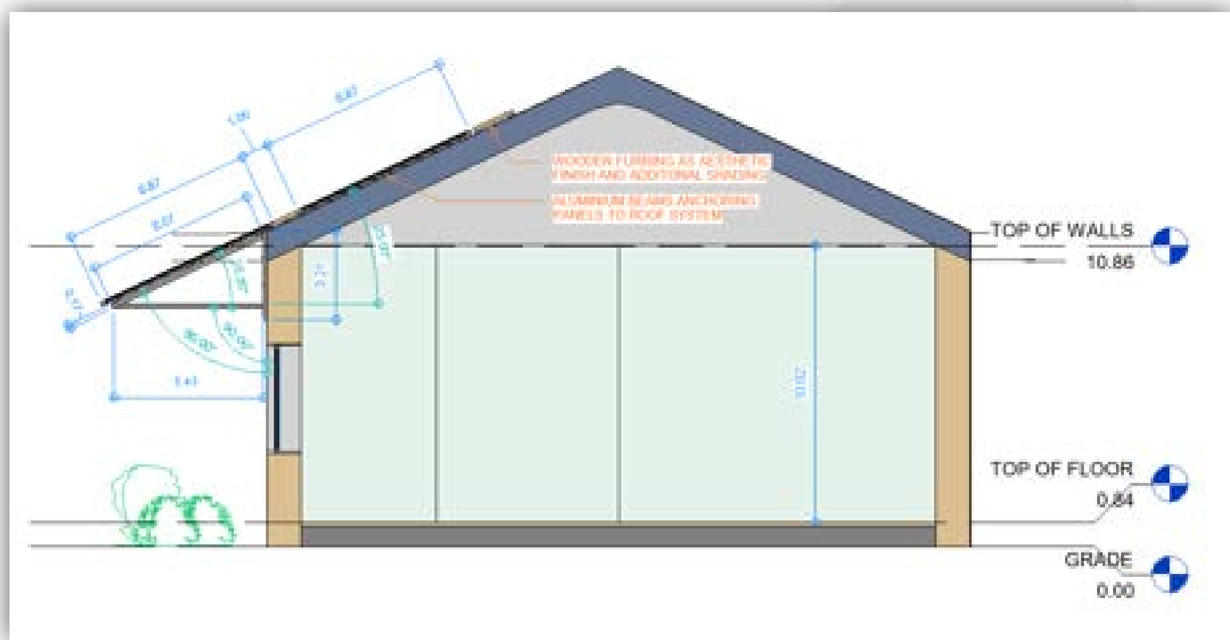


**Figure 23:** a simplified section view of the solar awning connection to the building.