SOCIÉTÉ D'HABITATION DU QUÉBEC

REPORT

NORTHERN HOUSING PROTOTYPE IN QUAQTAQ

DESIGN AND IMPLEMENTATION OF A HOUSING MODEL WITH HIGH ENERGY EFFICIENCY, SUITED TO THE NORTHERN LIFESTYLE

Votre gouvernement

Québec

Report – Northern Housing Prototype in Quaqtaq

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Summary

Climate change is raising major challenges for the development of northern communities. In addition, these communities largely depend on fossil fuels to produce electricity and to heat homes. With the goal of designing a housing model that meets current requirements and anticipated challenges for housing in Nunavik, a prototype was built in Quaqtaq in 2015. A “semi-detached”-type dwelling, was designed by experienced architects and engineers who were inspired by the Passive House standard and included specific measures to adapt its design to the northern lifestyle. The reflection process was initiated by a design charrette (intensive collaborative workshop) and the design of the plans was carried out in conjunction with energy simulations. During construction, monitoring equipment was concealed in the prototype to allow analysis of energy consumption and validation of design choices. Although lessons can be learned from these first steps, the longer-term study of the energy data collected combined with the occupants’ practices will make it possible to judge the sustainability and efficiency of the prototype in future work.

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Acknowledgements

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1. Introduction

For nearly 40 years, the Société d'habitation du Québec (SHQ) has helped thousands of families find accommodation in homes adapted to northern climatic conditions. In this territory, there are many challenges in terms of sustainable construction. Costly and limited energy resources, climate change and intense weather conditions, as well as the scarcity of materials and skilled labour are just a few examples.

To face these challenges while responding to the specifics of the northern way of life, a housing prototype was built in Quaqtaq in 2015. The project was undertaken by the SHQ and funded by the Société du Plan Nord (SPN) and the SHQ, and many stakeholders from various backgrounds participated in its development. Construction of the prototype was carried out by the Makivik Corporation and, since its inception, it has been rented as low-rental housing. The Kativik Municipal Housing Bureau (KMHB) acts as the manager of these two dwellings, as it does for all other low-rental housing in Nunavik.

This report describes how the prototype meets today's imperatives while testing unique design elements and innovative energy efficiency technologies.

2. Findings relating to northern construction

According to the most recent surveys[1], the population of Nunavik is 13,777. Population growth is steady, with the population having more than doubled in the past 35 years—it was 5,860 in 1986. In addition, the population is very young, with 50% under 25 years old. A strong expansion of the housing stock has therefore been necessary over the last decades and it is foreseeable that this trend will continue.

Nunavik's low-rental housing stock has 3,144 rental units, representing 90% of all dwellings in the territory[2]. Construction, operation and renovation of this inventory are subsidized by various agreements and programs with Quebec and Canada. Since the turn of the year 2000, construction of social housing has been carried out by the Makivik Corporation while management of the real estate stock is under the responsibility of the KMHB.

It should be noted that planning for construction and renovations in Nunavik has to be rigorous since it is subject to specific constraints. The allocation of housing to each village is generally determined and announced in the spring of the year preceding construction, at the general assembly of the Kativik Regional Government (KRG). The villages where construction will take place vary from year to year depending on the most pressing rental needs. In general[3], construction planning is done by the Makivik Corporation and allows some materials to be ordered in the fall and others in the spring. Construction schedules are then planned according to the delivery of materials. Since there is no land link between the villages of Nunavik, the materials are loaded onto the sea carriers (departing from the Port of Valleyfield) from June until the end of the summer, then delivered to the designated villages a few weeks later. It is also possible, but very expensive, to transport certain materials by air. Note that despite this, perishable food intended for workers must necessarily be transported by air cargo.

Other constraints must also be considered in the planning, execution and implementation of the work. Almost all of the northern villages of Nunavik have no underground water supply or municipal sewer system. Each dwelling is therefore provided with a mechanical room equipped with drinking water and wastewater tanks which are regularly filled or emptied by tank trucks. Depending on the type of building, there may be a mechanical room for several dwellings. This is particularly the case for the prototype, where a mechanical room supplies both sides of the semi-detached dwelling. In addition, in all northern villages, electricity is produced by power stations that run on diesel. Due to high production costs and the limited production capacity of power plants, this electricity is used only to power household appliances and lighting. Fuel oil is used to supply heating for homes and domestic water. Finally, all construction work in Nunavik must preserve the permafrost on which the constructions are built. Most often, gravel beds are used to raise the level of permafrost under dwellings. However, several villages face a lack of granular materials, and other foundation techniques should therefore be considered. In these villages, the scarcity of granular materials is likely to have a significant effect on the construction costs of the foundations and non-structural backfill required for access to services and for various storage equipment.

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1. www.stat.gouv.qc.ca/statistiques/profils/region_10/region_10_00.htm.
2. www.omhkativikmhb.qc.ca/en/. November 2019.
3. It was different for the prototype, as described in section 3.

3. The prototype

3.1 The main stages

The prototype aimed to test different technologies, new building materials and innovative design details to meet energy goals and adaptation to the northern lifestyle. It also had to allow data collection by monitoring.

Four years elapsed between the start of the design process for a new northern housing model and construction of the prototype. Many stakeholders participated in the process and made it possible to develop and implement this innovative project, the first of its kind in Nunavik.

- **2012:** A design charrette allows Inuit participants to explore housing concepts suited to their cultural, modern and traditional practices.
- **2014:** The site is chosen, the architectural specifications and technical drawings are produced. The piles and the drill are delivered by boat.
- **2015:** Drilling is done and the piles are anchored in the ground in April, materials are delivered in June and construction work begins in August and continues for 17 weeks. Engineers test the monitoring devices.
- **2016:** Two families move into the prototype in January and energy data has been collected since.

3.2 Design factors

As mentioned previously, the objectives of the prototype were to improve adaptation to the northern lifestyle and the energy efficiency of the building. More specifically, the prototype had to be adapted to the harsh climate, meet the expectations of the Inuit community, be inspired by the Passive House standard and use foundation techniques adapted to the site. The prototype also had to take climate change into account while integrating aerodynamic performance strategies such as shape, roof slopes and railing details that minimize snow accumulation, or even an elevation of the construction to reduce snowdrifts, etc.

To meet the objective of adapting to the northern way of life, a design charrette was held in Kuujjuaq in the spring of 2012. It brought together 20 stakeholders. Seven Inuit from different communities collaborated with representatives of the SHQ, the KMHB, the Makivik Corporation, the KRG and the École de technologie supérieure, as well as with an independent architect, an architecture student and a postdoctoral researcher from the CHU de Québec-Université Laval Research Centre. On the theme of sustainable housing, the design charrette aimed to reflect on and discuss needs by type of activity, the definition of spaces, and aesthetic, practical and building expectations on the site. By means of sketches and diagrams (Figure 1), the participants' reflections led to potential avenues for improvement of the building. Following the design charrette, a report[4] was produced which led to the development of plans for the prototype housing.

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4. Charrette report, Kuujjuaq, 2012 - sharing on request (available in French only).

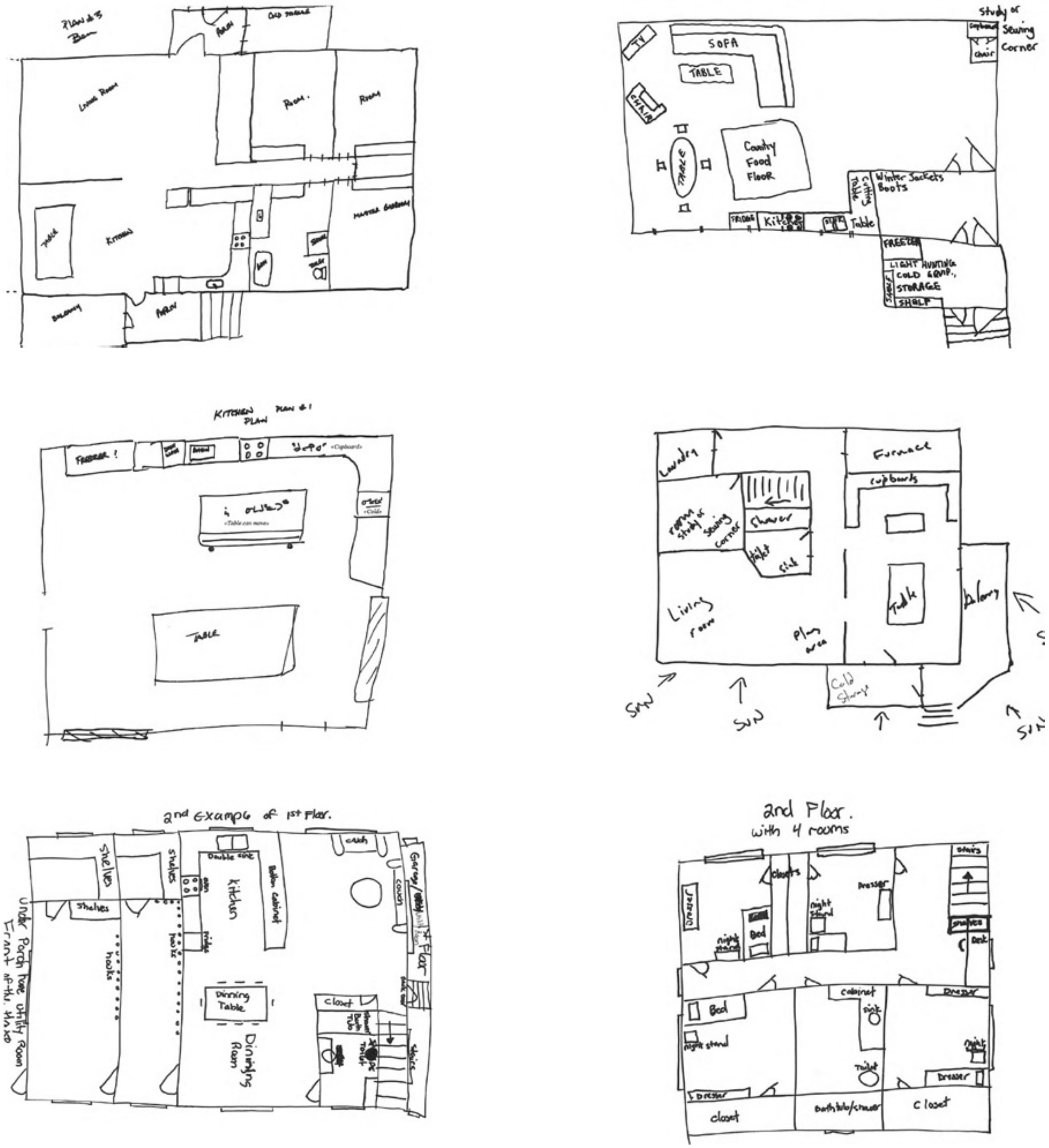

Figure 1: Sketches made during the design charrette, Kuujjuaq, 2012

Source: Charrette report, Kuujjuaq, 2012

In response to the goal of achieving better energy efficiency, the selected design team and the northern organizations involved received a one-day training course in July 2013 by the Canadian Passive House Institute (CanPhi). This training covered the general and fundamental design conditions for the prototype to meet the standards of the Passive House standard and the desired performances in a northern climate (including waterproofing materials, ventilation systems, simulations with the Passive House Planning Package software, thermal bridges and windows). In addition, CanPhi was mandated to support and advise architects and engineers during the design.

3.3 Choice of Site

In May 2014, the northern village of Quaqtaq was selected for construction of the prototype. The topography, geomorphology and possible orientation of the prototype on the site were determining factors of this choice of location (Figures 2 and 3). Based on this site choice, a preliminary study and preliminary plans were produced.

Figure 2: Northern village of Quaqtaq
Source: Government of Quebec, 2016

Figure 3: Site of the prototype, Quaqtaq
Source: Government of Quebec, 2016

The prototype site has a steep slope, is mainly composed of rock, and is covered with active layer (the surface layer of permafrost soil) of varying composition and thickness of more or less one metre. The site favours a foundation on piles and allows optimal orientation in relation to the sun's path.

3.4 Description of the prototype

When the Makivik Corporation took charge of housing construction in the early 2000s, it designed single-family and J2.2 semi-detached houses (J2.2 for "two-bedroom semi-detached"). The semi-detached model alone now represents around 50% of housing units in the region[5]. Thus, the design team proposed that the prototype (Figure 4) be a semi-detached house similar to the standard model (Figure 5), although larger[6] and with certain specific features.

Figure 4: South face of the prototype

Source: SHQ, 2016

Figure 5: Front face of a J2.2 built by the Makivik Corporation

Source: SHQ, 2014

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[5] Semi-detached dwellings built since 1980, units of 2 or 4 bedrooms, according to data provided by the KMHB, 2016.

[6] During the pre-project studies, the design team proposed that the prototype have an area 13% larger than that of a standard semi-detached dwelling. However, in order to reduce construction and operating costs, the prototype as built has a surface area 6% larger than a standard semi-detached house.

3.4.1 Adaptation to the northern way of life

In response to the design charrette, the interior spaces were redesigned and design details were added (Figure 6). As with the semi-detached houses designed by the SHQ in the 1980s, entry to the dwelling is via a cold porch that leads to a heated vestibule. However, at the request of the participants in the design charrette, the spaces are more spacious and the cold porch of the prototype is equipped with a storage cabinet with a stainless steel work surface. The heated vestibule accommodates a full-size freezer and contains built-in storage for outerwear and a lockable cabinet for storing hunting weapons. It opens to the living room.

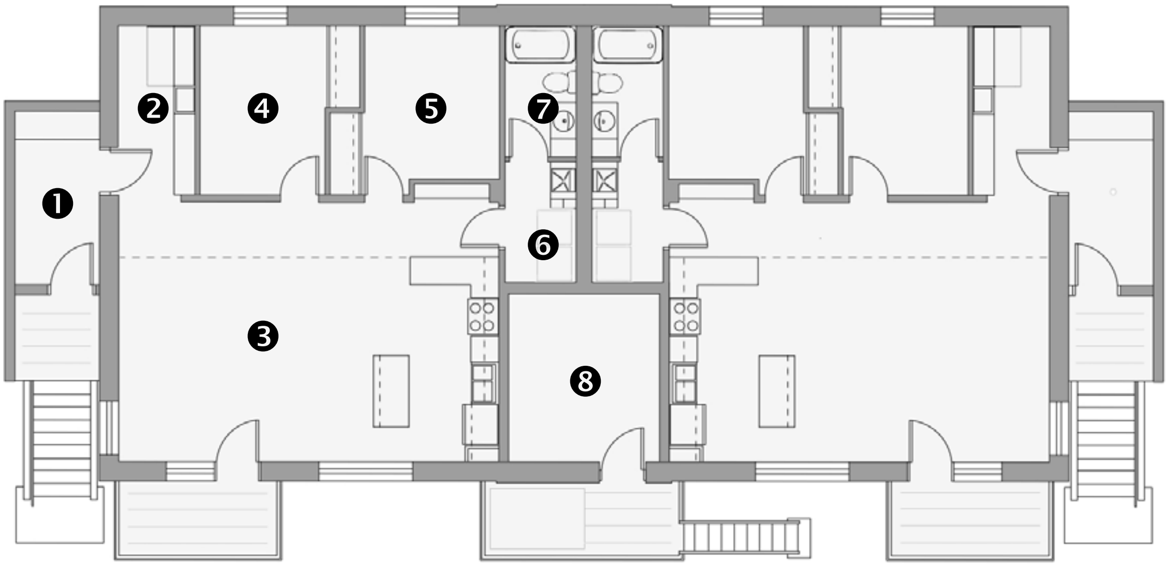

Figure 6: Prototype layout plan

❶ Cold porch ❷ Heated vestibule ❸ Living room and kitchen ❹ Bedroom 1 ❺ Bedroom 2 ❻ Laundry room ❼ Bathroom ❽ Mechanical room

Source: Makivik Corporation

In accordance with the improvements suggested by the stakeholders, the kitchen, dining room and living room make up a larger open area, with a mobile island that offers the occupants flexibility in layout. A removable work surface in polyethylene panels, resistant to cutting hunting and fishing products, is also provided in the kitchen. The ceilings of the prototype are higher, and a mezzanine storage space overhangs the entire length of this open area (Figure 7). This area benefits from wide windows that maximize the natural lighting from the south and allows significant winter solar gains. From the living room, a door gives access to the front balcony and also serves as an emergency exit[7]; in the standard J2.2 dwelling, a hinged window at the back of the building plays this role. To limit noise, the washer and dryer are in a closed laundry room, adjacent to the bathroom. A sink and storage, including a second lockable cabinet for storing hunting ammunition, are included in this space.

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[7] In the case of construction on piles, installing a rear emergency exit is a challenge, given the slope of the terrain.

Figure 7 : Interior views of the prototype
❶ Open concept kitchen and living room. ❷ Mobile work surface. ❸ Storage in the heated vestibule. ❹ Stainless steel counter in the cold porch.
Source: Société d'habitation du Québec, 2015

3.4.2 Foundation and structural system

With the aim of testing a type of foundation that is little used in Nunavik, the semi-detached dwelling rests on steel piles welded to a steel base structure (Figure 8). In the case of the prototype, the rental of the drilling equipment and the lack of economies of scale meant that the pile foundation turned out to be more expensive than a cylinder jack foundation. However, piles have many advantages since they allow construction on uneven terrain, offer great stability, limit the amount of aggregate required and ensure good wind circulation under buildings to prevent snow accumulation.

The piles reach a minimum depth of two metres in the rock (Figure 9). To facilitate drilling, their installation took place in April 2015, while the active layer was still frozen. The piles are steel pipes 141 mm in diameter in which holes have been made in the buried section, every 600 mm (Figure 10). Cement is poured inside the piles and overflows through these holes to ensure better adhesion with the rock. Metal rings 15 mm thick were welded to each pile, alternating with the holes, allowing better adhesion between the piles, rock and grout. Two steel plates, 12 mm and 19 mm thick, were welded to the head of the piles in order to bolt them to the steel foundation structure under the dwelling.

Figure 8: North face of the prototype

Source: Société d'habitation du Québec, 2015

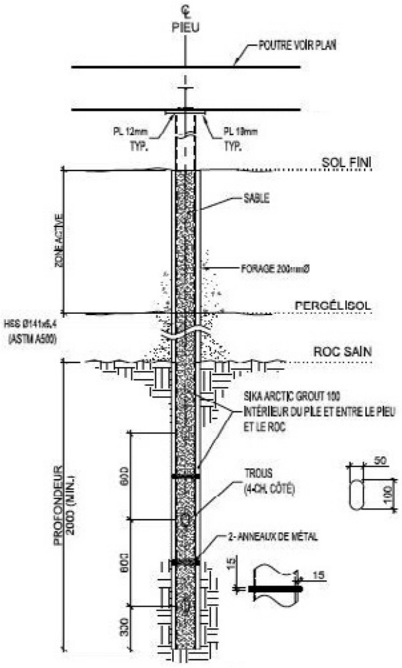

Figure 9: Section of a pile anchored in the ground

Source: Makivik Corporation, as-built plan 2015

Figure 10: Delivery of piles to the construction site

Source: Société d'habitation du Québec, 2015

3.4.3 Envelope and floor system

To achieve an energy efficiency higher than that of the standard J2.2, the composition of the building's thermal envelope had to be improved (Table 1). Thus, the windows of the high-efficiency prototype are triple-glazed and the walls were constructed of light wood framing in order to enhance the level of thermal insulation.

Since the floor of the prototype is a 6th face, its composition had to reach a level of thermal resistance comparable to that of the exterior walls (Figures 11 and 12).

Composition of exterior walls	
Standard J2.2	**Prototype**
Exterior finish board Vertical wood furring strip –- 19 x 64 mm Air barrier Rigid extruded polystyrene insulation – 50 mm OSB panel – 11 mm Timber stud – 38 x 140 mm Full cavity insulating mineral wool Vapour barrier – 0.15 mm Furring strip – 19 mm Gypsum board – 13 mm	Exterior finish board Vertical wood furring strip – 19 x 64 mm Rigid extruded polystyrene insulation – 50 mm Self-adhesive air barrier Plywood – 13 mm Timber stud – 38 x 140 mm Air space – 50 mm Timber stud – 38 x 89 mm Blown high density fibreglass insulation Full cavity Optima membrane Vapour barrier Horizontal wood furring strip – 19 x 64 mm Gypsum board – 13 mm
Total RSI value of 5.1 / R 29	**Total RSI value of 10.04 / R 56.25**

Table 1: Composition of exterior walls

Source: J2.2 standard 2014 by EVOQ (FGMDA) and "as-built" plans Prototype 2016 by EVOQ (FGMDA)

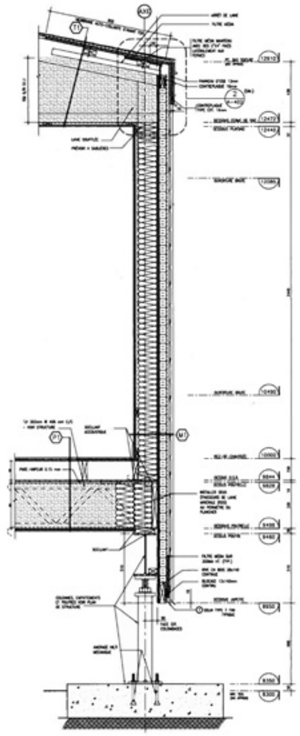

Figure 11: J2.2 Standard – Typical wall section

Source: Makivik Corporation

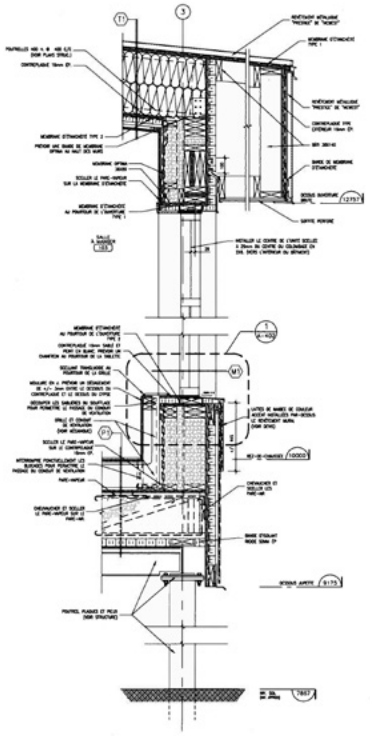

Figure 12: Prototype – Front facade wall section of the prototype

Source: Makivik Corporation

As with the exterior walls, the insulation used for the floor is high-density cellulose wool. For the roof, two layers of mineral wool batts were used, in addition to extruded polystyrene. The floor composition of the prototype dwellings thus reaches an RSI[8] value of 10.155 and the roof has an RSI value of 10.341 (Table 2).

The exterior cladding of the prototype is made of wood composite, a material widely used in Nunavik, which requires little maintenance and is easy to repair. A metal exterior cladding covers the width of the mechanical room from the front to the rear of the prototype as well as the walls of the crawl space. The prototype also has a metal roof covering, which is more durable than conventional asphalt shingles. A slight roof overhang on the south side of the prototype makes it possible to reduce solar gains in summer, without obstructing solar gains in winter.

3.4.4 Heating system

The hybrid system (hot air – hot water) installed in this prototype is an innovation. Oil is fed to the heating system boiler and the heat produced by the boiler is then transferred to a double coil hot water tank. These coils supply the dwellings with domestic hot water and also provide heat to the ventilation and heating system (Figure 13). In the standard J2.2 semi-detached dwellings, the mechanical room is equipped with two hot-air furnaces and an independent water heater, all requiring oil burners.

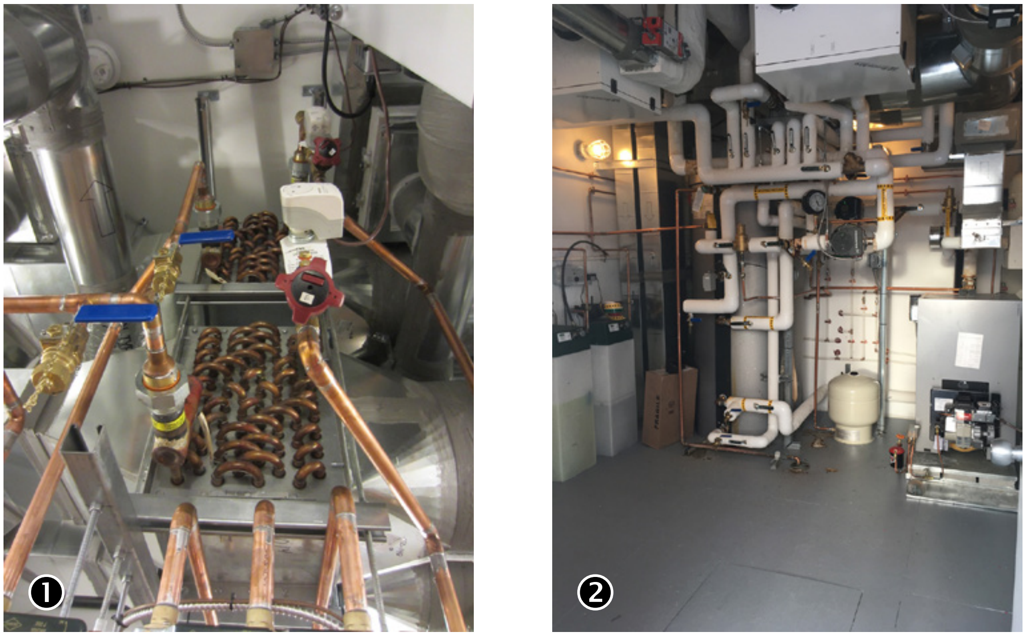

Figure 13: Mechanical room equipment

❶ Coils for heating the air. ❷ Mechanical room.

Sources: SHQ and SNC-Lavalin, 2017

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[8] R-value of the international system (thermal resistance of materials).

Another innovation is an energy recovery ventilator (ERV) which recovers part of the residual heat from the stale air discharged to the outside. This heat is used to heat the fresh air before it reaches the ventilation system. The hot air is then distributed in the dwellings through ventilation ducts which circulate in the subfloor space (Figure 14). The air outlets are located under the windows and are divided into two distribution zones per dwelling, one north, the other south.

Figure 14: Ventilation ducts in the subfloor space
Source: Makivik Corporation, 2015

4. Energy targets

The designers performed detailed pre-project energy studies to compare the expected performance of the prototype with that of a reference J2.2 model. Note, however, that in order to reduce construction and operating costs, the prototype built has a smaller surface area (+6% than the reference J2.2) than that of the prototype used in these simulations (+13% than the reference J2.2).

4.1 Energy simulations

During the design phase, the design team used the Passive House Planning Package (PHPP) support tool to assess the energy efficiency of the prototype and compare it to a reference J2.2 (Table 2). PHPP is a spreadsheet-based design software tool created by the Passivhaus Institute, which assesses the energy demand of a project. The Passive House standard aims for energy savings through factors such as insulation, airtightness and mechanical systems.

In addition, EnergyPlus™ software, which also makes it possible to simulate energy consumption and water use, was used to cross-validate the results obtained with PHPP, as well as to establish the construction parameters of the prototype.

It turned out that the Passive House standard could not be reached in Nunavik because there were too many barriers to certification. In this regard, note the double challenge of the winter capture (reduced sun duration and path), exposure to cold of a 6th facade, energy losses relating to delivery of water in the tanks, incompatibility between the level of insulation required and the realities of northern construction, etc. The designers therefore proposed an optimized system responding to the realities of Nunavik which provided for a 60% reduction in the energy bill.

Comparative study of the theoretical energy performance of the systems

Parameters	Reference J2.2 *	Passive House Building **	Prototype (simulations)
Net area (two dwellings)	181 m²	181 m²	181 m²
Thermal resistance of exterior walls	RSI 5.332	RSI 18.56	RSI 9.556
Thermal resistance of the floor	RSI 8.206	RSI 14.398	RSI 10.155
Thermal resistance of the roof	RSI 9.043	RSI 15.051	RSI 10.341
Annual energy consumption for heating	310 kWh/m² (i.e. 20.6 times the Passive House standard)	95 kWh/m² (i.e. 6.3 times the Passive House standard)	128 kWh/m² *** (i.e. 8.5 times the Passive House standard)
Maximum heating load	122 W/m²	34 W/m²	42 W/m² ***

Table 2: Comparative study of the theoretical energy performance of the systems

* *Theoretical housing model serving as a reference basis for the comparative study of energy performance.*
Plan and volume used equivalent to the prototype.
Envelope equivalent to the standard J2.2 of the Makivik Corporation.

** *Residential model attempting to achieve the Passive House standard.*
Plan and volume used equivalent to the prototype.

*** *Data analyzed in section 5.3.*

Source: Unified report, December 2014, EVOQ (FGMDA) and SNC-Lavalin, pp. 3-5

4.2 Infiltrometry test

An airtightness optimization test took place during a site visit in November 2015. At the time of the test, the wall interiors were only covered with a vapour barrier. The roof, windows and siding were in place but the ventilation system, wastewater and clean water tanks, and plumbing were not yet installed. Given the condition at the time of this first test, the objective was not to measure the rate of air change per hour, but rather to target the places where airtightness could be improved. This sealing optimization test made it possible to seal around fifteen air infiltration points.

An infiltrometry test carried out in August 2018 measured that the prototype performed an air change of 1,152 ft^3/min at 50 Pascal for an estimated volume of 22,685 ft^3. This measurement is equivalent to 3.05 air changes per hour, which results in less air infiltration than in the standard J2.2[9] located in Quaqtaq, which corresponds rather to 4.50 air changes per hour.

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[9] Type J2.2-2012 buildings located in Quaqtaq, having an average of 1,054 ft^3/m at 50 Pa with an interior volume of 14,019 ft^3.

5. Monitoring

5.1 Monitoring equipment

Monitoring equipment requirements were determined during the prototype design phase by the SHQ team in collaboration with a firm specializing in automation; they were then incorporated into the construction (Table 3). Independently of the composition of the tenant households, the main objectives of the monitoring equipment were to validate the design choices, compare energy consumption of the two dwellings of the prototype, offer the possibility of adding or removing measurement points and devices, and assess the energy performance of the prototype. Thus, sensors and meters were installed in specific places during construction, so that they would be imperceptible to the occupants.

Data and frequency of measurements in each dwelling and in the mechanical room		
Every 15 minutes	**Every 60 minutes**	**Over 24 hrs**
On return air from the hybrid ventilation-heating system: 1. CO^2 level 2. temperature 3. relative humidity **Ambient temperature:** 4. bedroom 1 5. bedroom 2 6. cold porch 7. living room-kitchen 8. ERV exit	**Water level:** 9. drinking water tank 10. wastewater tank **Water temperature:** 11. in the drinking water tank 12. at the outlet of the hot water tank 13. in the wastewater tank 14. Exterior temperature	15. Electricity consumption 16. Fuel oil consumption **Usage time of:** 17. kitchen hood 18. bathroom ventilation 19. dryer 20. HRV **Open time of:** 21. exterior door 22. door between porch and vestibule 23. balcony door 24. mechanical room door 25. bedroom 1 window 26. bedroom 2 window 27. kitchen window 28. living room window 29. balcony window

Table 3: Data and frequency of measurements in each dwelling and in the mechanical room

5.2 Data collection

Depending on the device, data are recorded daily every 15 minutes, every 60 minutes or once every 24 hours. In addition, some sensors measure operating time, for example the use of the kitchen hood or the frequency of opening windows.

Data has been collected since the tenants moved in in January 2016. However, corrective work was carried out in the fall of 2016 to replace the fuel oil meter. Some analysis data are therefore from after this replacement. In addition, given the intermittence of the satellite internet connection, the data are recorded on a computer installed in the mechanical room, between times when communication was re-established. Since then, they have been saved locally, then transmitted to an FTP site, which also experienced slight reception problems. In April 2019, an IT technician went to Quaqtaq to adjust the measuring devices, collect the database and stabilize the transmission system. Saving the data over the years will allow a more informed analysis of the energy efficiency of the prototype.

5.3 Preliminary energy analysis

The preliminary analyzes carried out at the SHQ made it possible to validate the measurement points, their locations and the correct functioning of the devices. However, there are some factors that limit further analysis, including the time factor. It is still early to judge the durability and efficiency of the prototype. In addition, for a precise analysis of the building's energy efficiency, consumption data must be associated with the occupants' practices, according to each dwelling, since they largely influence the forecasts (see section 8.1). Finally, it should be noted that the volume of the prototype as built (718 m^3) is much greater than that of a standard J2.2 (335 m^3); their actual energy comparison is therefore less significant than during simulations.

Nonetheless, it is possible to raise some convincing elements and to make the comparison between the real data and the simulated data of the northern housing prototype.

First, energy consumption is higher than expected. For heating the dwellings and producing domestic hot water, in 2018, the prototype consumed a quantity of 5,774 litres of fuel oil (Figure 15). Based on a theoretical efficiency of 80%, this is equivalent to 237 kWh/m^2, while the anticipated consumption was 170 kWh/m^2 (10).

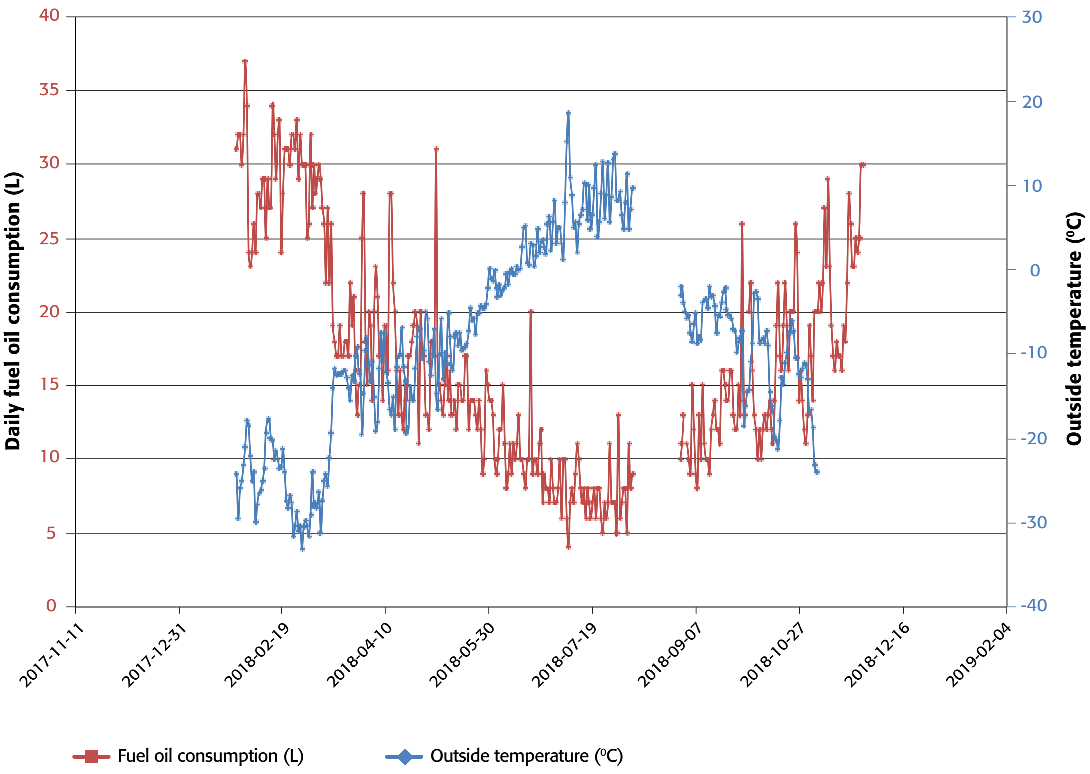

Figure 15: Daily fuel oil consumption of the residential prototype in 2018

Source: Société d'habitation du Québec, 2019

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10. This data is equivalent to the sum of the anticipated energy consumption for heating the dwellings (128 kWh/m^2) and the anticipated energy consumption for domestic hot water production (42 kWh/m^2).

During the same year, the prototype consumed 16,501 kWh of electricity (Figure 16), while the anticipated consumption was 12,183 kWh for the total of three electricity meters (dwelling unit 1, dwelling unit 2 and mechanical room).

In 2018, the heating energy consumption was 178 kWh/m² (11), while the anticipated heating energy consumption (air only) was 128 kWh/m².

The difference between the projected and actual results could be explained by the lack of consideration of human practices in the energy simulation software.

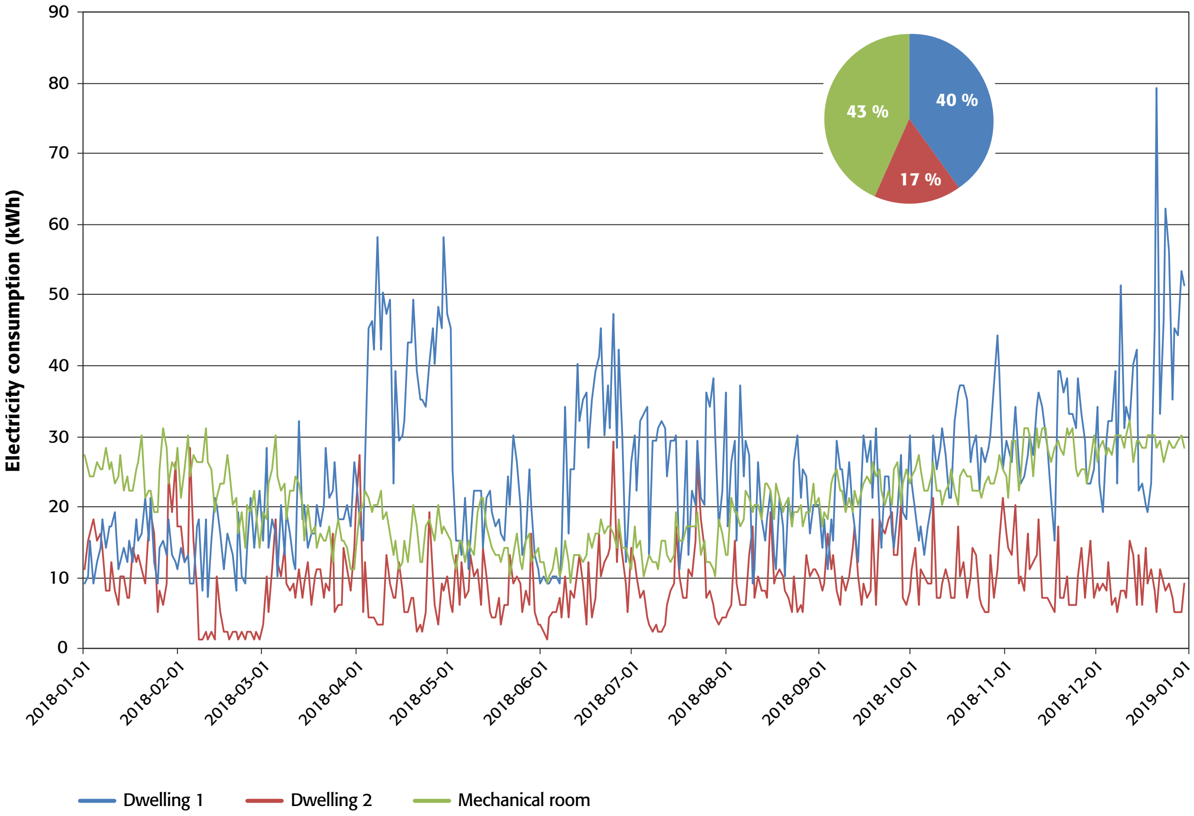

Figure 16: Daily electricity consumption of the residential prototype in 2018

Source: Société d'habitation du Québec, 2019

Another analysis shows that in the prototype, as in the standard semi-detached dwellings, the average consumption of domestic hot water is 46 litres per day and per dwelling. This consumption data is excellent, if we compare it to the average daily individual water consumption (hot and cold) of a Quebecer, which is around 570 litres per day[12].

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[11] This data results from monitoring domestic hot water consumption and is based on a hypothetical temperature differential of 56°C.

[12] www.environnement.gouv.qc.ca/eau/strategie-quebecoise/strategie2018-2030.pdf, p. 40.

6. Costs

The project is an initiative of the SHQ. It was funded by the SPN as part of the Plan Nord 2015-2020 Action Plan and by the SHQ.

Depending on the technological specifics, it was expected that construction of the prototype would be more expensive than a standard J2.2. The anticipated additional costs were related to the monitoring equipment as well as the choice of materials, windows, foundation and ventilation system. Note that the economic benefits of the prototype can be assessed in the longer term, based on improvements related to energy efficiency.

Having said that, there have still been cost overruns. This can largely be explained by the additional time relating to the innovative construction techniques and the use of new materials, as well as indirect costs, including the rental of machinery, site supervision and delays caused by the harsh climate.

7. Lessons learned

At all stages of the project, an integrated design approach was anticipated. However, apart from the design charrette, the process rather followed a conventional linear implementation approach, as initiated by the design team.

7.1 Design phase

The design charrette proved to be essential to the design process and the incorporation of measures to adapt to the northern lifestyle in the dwelling. The participants' feedback and proposals were used to reflect on the subject of housing, and to discuss their wishes and needs. The challenge posed by this type of initiative remains the reconciliation between aspirations and the economic and construction realities of the projects. In this exercise, the discussions were able to guide the choices of the design team. Thus, certain design details were reproduced[13] in the subsequently built dwellings in order to better respond to the occupants' practices and, by the same token, to ensure the sustainability of the building.

In the event of a future charrette, a larger number of participants would be desirable. Ideally, it would bring together as many stakeholders as possible and a variety of local citizens for a better representativeness and translation of the issues specific to the northern village where the project is located. Feedback to participants should also be ensured.

7.2 Construction phase

In order to protect the permafrost and ensure the sustainability of the building, it was understood that the type of foundation should be chosen according to the typology of the site and the characteristics of the soil. In the case of the prototype, in addition to fulfilling these conditions and offering greater stability and sustainability, the piles have contributed to significant savings in gravel (40% to 50% savings in gravel compared to a foundation on jack cylinders). However, a large backfill was built for the installation of the side sheds and for the front parking space, also necessary for access to services. The development of this backfill reduced the economic benefits linked to the use of the piles. In addition, drilling and anchoring of the piles was to take place while the ground was still frozen (in the spring of 2015). For this reason, the drill had to be delivered by the last boat of the previous year, in November 2014. The rental costs of the drill were therefore increased by these months of waiting.

In addition, the installation of the new design details turned out to be more complex than expected. In this regard, we can identify the mezzanine storage space, the large triple-glazed windows and the hybrid heating system of the prototype. These new construction elements took more time than expected by the workers. The installation of the metal roof and the imposing rear scaffolding were also unusual. Note that the need to install such a scaffolding for any maintenance work raises questions about the maintenance work that will have to take place over time on the back of the building.

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[13] The concept of building reversibility, expansion joints between walls and ceilings, improvement of window membranes are concepts that have been taken from the prototype and reproduced in the field of social housing.

7.3 Tracking – monitoring phase

The installation of monitoring devices during the construction of the prototype ensures better durability of the equipment and also contributes to its proper functioning. When they are integrated, they are imperceptible to the occupants. Since the acquisition of monitoring data in January 2016, however, connection problems have generated issues in the transmission of data over the internet. Despite attempts to correct it, the connection was often lost. There are many possible explanations: the location of the antenna in relation to the village dish, the location of the modem inside the mechanical room, power outages in the village, FTP site errors, etc. In order to help the telecommunications equipment intended for the transmission of data function correctly, a battery of the UPS type has therefore been added.

During the monitoring phase, a problem occurred with the sensor designed to measure the electrical consumption of the kitchen hood in one of the dwellings. It could not distinguish the electric current used for ventilation from that used for the lights in the hood. In response to this observation, and to decrease the amount of electricity associated with the hood bulbs, the original bulbs were replaced with low-energy bulbs. Despite this change, the power consumption data remained similar. To clearly distinguish the two uses of the hood, the sensor could have been placed in a more selective manner.

Again, in relation to this kitchen hood, when the lights are used, a command mistakenly activates the make-up air system in the mechanical room. This triggers the operation of an outside fresh air preheating coil while the building is not under negative pressure. Unnecessary operation of this coil generates excess heat in the duct, which contributes to overheating of the mechanical room and is a waste of energy. Manual adjustment should be made to optimize the use of the hood.

7.4 Post-occupation phase

It is the occupants who really test the functionality of the home. The sustainability and efficiency of the prototype therefore largely depend on its adaptation to the northern way of life over time, the different households that will occupy the dwellings, and the level of maintenance that will be continuously carried out. In future work, qualitative and quantitative analyses will be able to teach us more about the use of the buildings and it will then be possible to draw more accurate lessons about their efficiency. For now, we can only make assumptions about the monitoring data for each dwelling.

In this regard, we note that the windows are open regularly during the heating season. Does this imply that tenants wish to manually control the temperature of the dwelling? Do they just want a supply of fresh air? Is the use of mechanical systems adequate? Does the superior airtightness of the building envelope constitute a limit to its performance?

Opening windows during the heating season significantly increases the building's natural air change rate, which dries out the indoor air (because outdoor air contains very little water in the form of vapour). On a regular basis, relative humidity levels of 10% and less were measured in both dwellings, despite the energy recovery ventilation system which should help to maintain an adequate indoor relative humidity level[14]. Moreover, since the ceilings of the prototype are higher than those of the standard J2.2, the volume of interior air to be heated is greater (reference J2.2 = 14,019 ft^3, prototype = 22,685 ft^3). Each change of natural air in the building therefore has a very significant energy impact because the replacement air must be heated.

In general, although many mechanical system options have been considered by designers, it must be admitted that the chosen hybrid heating system includes subsystems and equipment requiring more maintenance than a standard J2.2 to ensure optimal operation. The various options for checking the system also make repairs more complex. It should be noted that start-up training was offered to the maintenance team on the specific features of the prototype mechanical room and that the development of a maintenance sheet, in consultation with the KMHB, is being considered.

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[14] According to Health Canada, humidity should be around 30% during the heating season.

8. Next steps

8.1 Qualitative monitoring

In November 2016, a doctoral candidate from Memorial University travelled to Quaqtaq to speak with tenants of the prototype. The structured interviews addressed the structural conditions and “psychosocial factors” associated with the dwelling (perception of control, identity, satisfaction). Interviews were also conducted with the people involved in the prototype project in order to document the facilitating factors and barriers encountered in the design and construction processes. Analysis of these interviews is in progress and should be the subject of a report in order to determine whether the tenants are using the spaces as intended and whether the design choices meet their needs.

8.2 Quantitative monitoring

A study of the energy profile of the prototype and its comparison with efficiency targets is planned in partnership with Université Laval. This study will be able to explain the expected and real differences in terms of performance. The behaviour of the occupants, linked to the monitoring data, will also be studied with a view to reducing energy demand. In this regard, an energy demand prediction model is planned to be developed and lead to a broader reflection on the development of solutions and concepts to better deal with the issue of energy needs in Nunavik.

Conclusion

More time will be needed to measure the improvement in the livability and efficiency of the prototype. Along the same lines, its sustainability remains dependent on the magnitude of internal and external factors that will test it over time.

We can recognize, however, that the design and implementation of the prototype reflect advances and best practices that allow us to believe in its sustainability. From a cultural point of view, reflection in the form of an intensive design workshop made it possible to orient the conceptual choices and to better adapt the building to the needs and practices of its occupants. In this sense, the chosen development solutions suggest a better use of spaces and their components. From an energy point of view, simulations have led to technological innovations and automation that allow us to hope for the good efficiency and resilience of the building. The extent and nature of climate change remains unpredictable, but efforts have been made to reduce the building vulnerabilities associated with it. Finally, the collaboration between the stakeholders, their common desire to improve northern homes and their diligent work to achieve this will hopefully lead to better living conditions for the communities.

As presented, preliminary analysis of the monitoring data indicates discrepancies between the expected results and the actual results of energy consumption. Here again, the time factor must be considered, and the energy portrait could not be complete without its connection with qualitative and quantitative analyses planned in future work.

In any case, the prototype is a unique research vehicle in the Canadian North and its follow-up will lead to continuous reflection which will hopefully guide the principles of northern construction in Nunavik as elsewhere.

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