DILLON CONSULTING

75 YEARS

ᓄᓇᕗᒻᒥ ᐃᒡᓗᓕᕆᔨᕐᔪᐊᒃᑯᑦ
NUNAVUT HOUSING CORPORATION
LA SOCIÉTÉ D'HABITATION DU NUNAVUT
NUNAVUNMI IGLULIQIYIIRYUAT

NUNAVUT HOUSING CORPORATION

MOULD REMEDIATION AND MITIGATION PROGRAM

Category A: Buildings

CANADIAN CONSULTING engineer

ASSOCIATION OF CONSULTING ENGINEERING COMPANIES | CANADA
ASSOCIATION DES FIRMES DE GÉNIE-CONSEIL | CANADA

Key Players

Owner: Nunavut Housing Corporation

Primary Consultant: Dillon Consulting Limited

Sub-Consultant: RDH Building Science

Project Summary

Dillon was retained in December, 2017 by Nunavut Housing Corporation (NHC) to complete this Residential Units Mould Mitigation Program. This project is a culmination of approximately three years of work conducted by Dillon, in collaboration with NHC, Local Housing Organizations (LHOs), our sub-consultant RDH Building Science (RDH), and various Nunavut-based contractors in designing, building, and testing various design strategies aimed at mitigating potential mould impacts in NHC's existing stock.

As introduction to this project, it is important to first understand the context for why this project was required. Studies completed by Dillon on behalf of NHC have indicated that approximately 80% of NHC's existing housing stock have mould impacts, with approximately 20% of the units having greater than three square metres of mould on interior visible surfaces. Mould remediation work conducted by NHC since 2017 in various communities throughout Nunavut has indicated that it is not uncommon for the mould impacts to extend into the interior of the floor, wall and/or roof assemblies. In numerous cases the high moisture conditions within the building assembly structure has also resulted in wood rot ranging from minor to severe, including cases impacting the structural integrity of some wood members.

One of the common design features of residential units in Nunavut is the use of an unvented cathedral ceiling design, also called a "hot roof" design. It is unknown why this roof design was adopted decades ago; however, it is suspected that snow penetration into traditional vented roof assemblies prompted adopting the unvented roof assembly design. While this design has been successfully employed in other locations, it has been found to be problematic in many cases in Nunavut due to condensation formation within the unvented roof assembly leading to mould generation and in some cases severe rot. Although unconfirmed, it is suspected that high humidity conditions associated with overcrowding, combined with potential vapour barrier issues and extreme cold have led to the observed prevalence of condensation formation within the unvented roof assembly. As described in this summary, a key focus of this project included exploring methods to introduce ventilation into the cathedral roof assembly, while mitigating potential snow penetration through the roof vents.

The root-causes of mould impacts observed in the housing units were studied in detail as part of this project. In summary, there are multiple root causes of the mould observed in the housing units, including:

- Design, maintenance, and construction issues related to the building envelop;

Severe mould impacts in unit crawlspace.

Severe roof damage in existing "hot roof" design due to condensation formation, leading to mould and rot.

- Design, operation, and maintenance of building ventilation systems; and
- Tenant damage and negative behavior issues (e.g., disconnecting ventilation equipment).

It is not uncommon for multiple potential root causes of mould to be present in impacted units. In addition to these potential root causes, the impact of the current housing crisis on the prevalence of mould impacts observed in Nunavut should not be underestimated. The housing crisis is resulting in higher levels of occupancy in some homes, and thus elevated levels of humidity in the homes associated with human respiration. This is particular evident where existing building ventilation systems are not present or not operating effectively per the root causes noted above. In summary, the high levels of occupancy in the homes potentially exacerbates and increases the frequency of mould generation in the homes in combination with the other root causes noted above.

Dillon was commissioned by NHC to understand the root causes of mould generation in their existing housing stock, study and identify potential strategies for preventing mould generation, followed by detailed design of pilot test homes to investigate the performance of these design and operational changes.

The overall objective for this program was to develop new design recommendations for the building envelope and mechanical ventilations, as well as architectural features, to assist in mitigating future mould generation.

This project was executed in the following five phases:

Phase 1: Mould Root Cause Analysis

Phase 2: Problem Formulation, Gap Analysis, and Air Monitoring Program

Phase 3: Mould Mitigation Options Analysis

Phase 4: Mould Mitigation Pilot Testing Program

Phase 5: Mould Mitigation Design Recommendations

The strategy for this project was to adopt a holistic approach to addressing many of the potential root causes of mould in relation to building envelop and mechanical ventilation system design. In addition, this included strategies aimed at mitigating the impact of potential negative tenant behavior, such as negative impact to the building vapour barrier due to interior wall damage.

It is intended that the design recommendations from this project would inform the design of new builds regarding potential design strategies to assist in mitigating mould generation in newly constructed units. In addition, the design recommendations are intended to assist in the detailed design of retrofit requirements in current housing units impacted by mould and requiring remedial measures.

Example of mould formation under damaged windows.

Challenges and Innovative Engineering Solutions

As noted in the previous section, **the project was initiated with an assessment of the root causes of mould generation.** The results of this assessment in relation are summarized as follows:

Building Envelop Related Potential Root Causes:

- Cold being transmitted through wood members resulting in condensation/mould formation (i.e., "thermal bridging");
- Lack of ventilation/air circulation in interior roof cavities utilizing an unvented, cathedral roof design (i.e., "hot roof" design);
- Missing or damaged insulation in walls, ceilings, floors and/or around windows; and,
- Poor vapour barrier seal due to poor construction, wall damage, and/or maintenance work.

Example of "thermal bridging" through building wood framing.

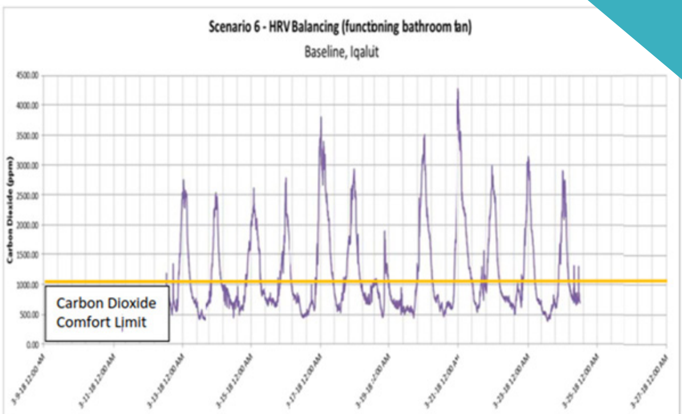
Mechanical Related Potential Root Causes:

- Inadequate ventilation systems in some units and/or lack of ventilation of high humidity areas such as building crawlspaces;
- Some Heat Recovery Ventilators (HRVs) undersized due to high occupancy/over-crowding;
- Lack of regular maintenance and cleaning of HRV filters resulting in poor air exchange;
- HRV core freezing resulting in periods of continuous operation in recirculation mode, thus not providing ventilation during these periods;
- Leaking plumbing fixtures; and,
- Leaking water and sewage tanks.

Phase 2 of the project included indoor air monitoring testing on a number of occupied residential units throughout Nunavut.

The testing included monitoring of CO_2, temperature, and relative humidity (RH) levels in the homes throughout the day over an approximate two week period. The results of this testing indicated the following:

- A direct correlation between RH and CO_2 levels was observed suggesting that the primary driver for elevated relative humidity was due to human occupancy, particularly in overcrowded units;
- The CO_2 levels measured in the housing units assessed were typically elevated above comfort levels which is considered above 1,000 ppm; and
- Relative humidity ranged from excessively low to high.



Example of elevated CO_2 concentrations observed in a residential unit in Iqaluit. Note regular spikes in CO_2 on a daily basis associated with increased occupancy in evenings (Dillon, July 2018).

The **options analysis** was completed during **Phase 3** and included research into best practices for residential unit building envelop and mechanical ventilation system design for arctic conditions. In summary, although some research was available in Canada and internationally, limited data was publically available regarding performance of various design concepts for residential applications. Furthermore, the unique arctic conditions, combined with high occupancy levels associated with the current housing shortage, required design and field testing of full scale pilot testing units to confirm the performance characteristics.

Phase 4 of the project encompassed design, construction, and monitoring of the pilot test units. The units selected were located in Arviat, Igloolik, and Baker Lake and included a total of five existing buildings comprised of single family dwellings and multiplex units, ranging in age from over 40 years old to less than 10 years old. All test units had existing mould, and in some cases wood rot due to frequent condensation in internal wall and/or roof cavities. Remediation of existing mould impacts and/or structural repairs to the buildings were incorporated into the program.

The following provides a summary of the building envelope and mechanical system designs adopted for testing purposes.

1) Building Envelop Testing:

Designs tested to mitigate thermal bridging, condensation in wall/roof cavities and vapour barrier damage:

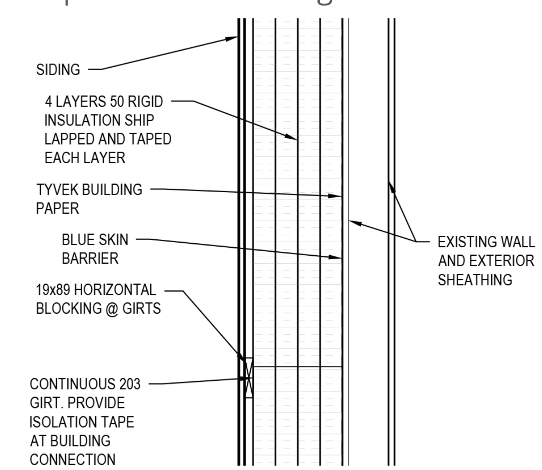
a) Exterior applied rigid foam board insulation:

This design has been applied for commercial/ institutional building in Nunavut; however, it had not been applied to public housing stock prior to this project. The design for exterior walls included the removal of the existing batt insulation and replacement with four layers of 50 mm rigid insulation, providing an estimated R value of 40.

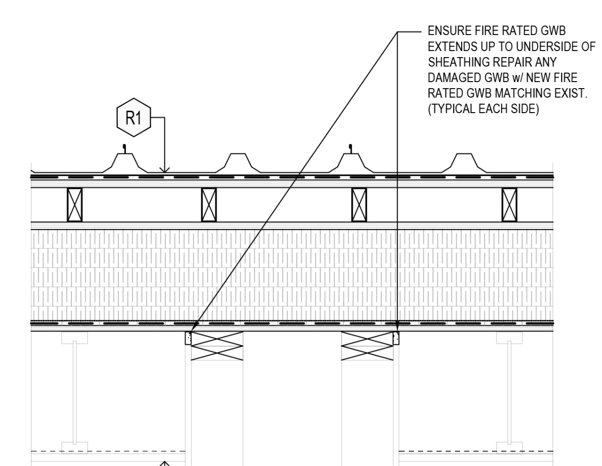
A similar test design was employed for the roof assembly. This design utilized five layers of 50 mm rigid insulation, with existing insulation between the trusses removed. In addition, a venting cavity was created to equalize temperatures between the exterior and underside of the new roof sheathing. This venting cavity was ventilated utilizing the unique roof assembly venting systems described in the following sections.

Installation of rigid insulation to the exterior walls and roofs aimed to achieve the pilot testing objectives through:

- Mitigating the risk of thermal bridging;
- Relocating the dew point from the existing wall and roof cavities to the outside of the wall and roof sheathing thus mitigating the risk of condensation; and
- Eliminating the need for a vapour barrier, thus eliminating the risk of vapour barrier damage.



Exterior wall detail utilizing exterior applied rigid insultation - Arviat pilot test unit.



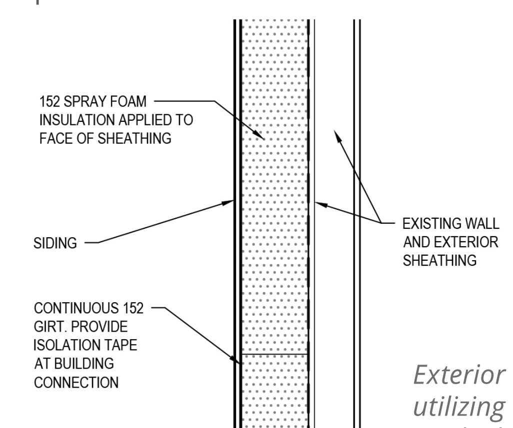
Rigid insulation applied to roof assembly - Baker Lake pilot test unit.

Exterior retrofit near completion - Pilot test unit in Arviat.

b) Exterior applied spray polyurethane foam (SPF) insulation:

This pilot test employed a similar strategy as the previous test through replacing the existing insulation with insulation added to the exterior to address thermal bridging, internal wall and roof cavity condensation, and potential vapour barrier damage. However, this design employed the use of closed cell SPF insulation applied to form a 152 mm thick layer on the exterior side of the wall sheathing. Like the previous test, this design aimed to achieve an estimated R value of 40. For the roof assembly testing, a 230 mm thick layer was applied to achieve an estimated R value of 60.

SPF has numerous advantages with respect to moisture mitigation (and hence mould mitigation); however, it is not commonly used in Nunavut due to temperature limitations for application and a limited number of qualified installers.



Exterior wall detail utilizing exterior applied SPF.

Pilot test unit in Arviat under construction following application of SPF insulation on exterior walls.

Designs tested to introduce ventilation into the roof assembly, while mitigating potential snow intrusion:

a) Soffit vent with filter media:

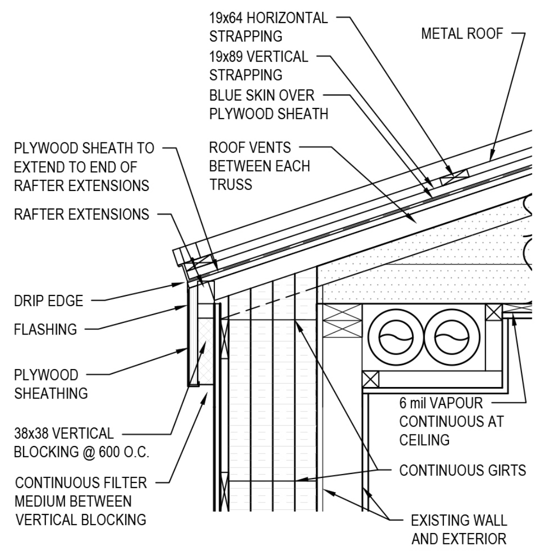
To test the ability to introduce ventilation into the roof assembly, while mitigating potential snow intrusion, several pilot test units were equipped with a unique soffit vent designs employing a filter media. In addition to the custom designed soffit vents, commercially available gable end vents and ridge vents were employed that also utilize either filter media or snow trap chambers to mitigate potential snow penetration.

This unique soffit vent design was a modification of a previously designed soffit vent by Guy Architects (Yellowknife, NT) for another NHC residential unit; however, no performance data was available for that design.

b) Soffit vent with "snow knock-out" chamber

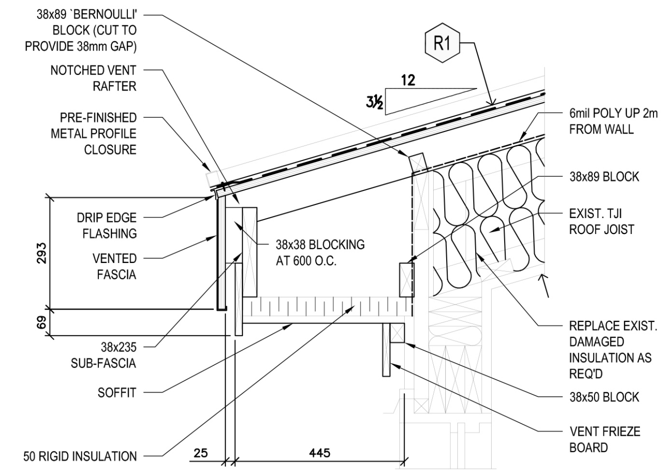
A second soffit vent design assessed utilized a "snow knockout chamber". This design was developed conceptually by Building Science Corp (BSC, 2010); however, no actual field performance data was available. This design includes use of a "Bernoulli" block to create a pressure differential as proposed by BSC.

This design was incorporated into the pilot test units in Igloolik that maintained the existing batt insulation between the trusses. However, a venting cavity was introduced to facilitate ventilation on the underside of the roof sheathing. This design was combined with commercially available ridge stack vents equipped with filter media.



Soffit vent design with filter media

Replacement of damaged roof trusses and installation of new roof assembly.



Detail of "snow knock-out" soffit vent design - Igloolike pilot test unit.

2) Mechanical Systems Testing:

Pilot testing objectives:

- Test methods to improve Heat Recovery Ventilation (HRV) system's ability to monitor and adapt to periods of high occupancy; and
- Mitigate risk of HRV core freezing, while also improving the temperature comfort of the fresh air supply.

The design of the ventilation system for the pilot testing units included a two speed HRV equipped with a hydronic pre-heat coil to prevent core freezing, combined with a hydronic reheat coil to improve the temperature comfort of the fresh air supply.

The testing also focused on the controls for the HRV system to establish whether better HRV response to high occupancy levels could be achieved through CO_2 monitoring as opposed to traditional RH monitoring for residential applications. The testing program included multiple CO_2 and RH sensors located throughout the unit to not only assess CO_2 versus RH, but also assess preferential locations for the sensors within the home.

3) Pilot Testing Performance Monitoring

Performance monitoring of the pilot test units in Arviat, Baker Lake, and Igloolik was conducted from September 2019 to June 2020, thus providing 10 months of monitoring data that included the winter season. Monitoring of the performance of the pilot testing units will continue beyond this project to facilitate collection of longer term data.

Monitoring the building envelope and mechanical ventilation system performance was completed utilizing the following instrumentation and equipment:

Moisture content, relative humidity, and temperature sensors in wall and roof assemblies:
Dillon retained the services of RDH Building Science (RDH) to assist with instrumentation and monitoring of the building envelop performance. This included electrical low voltage sensors located in multiple areas of the wall and roof assemblies to monitor moisture content, RH and/or temperature.

Roof ventilation snow intrusion monitoring:
In developing the roof ventilation pilot testing program it was recognized that a method would be needed to visually monitor potential snow intrusion through the various venting systems, rather than rely on indirect data such as moisture content. To address this requirement, remote video cameras were strategically located within the roof assembly to facilitate visual monitoring and capture of photographic records of the performance of the venting systems in preventing snow intrusion. In addition, the cameras provide a means of monitoring potential frosting of the roof sheathing over the winter months.

Ventilation (HRV) performance monitoring:
In addition to the building envelop sensors, monitoring the performance of the HRV ventilation performance was completed through monitoring room-specific air quality throughout the units. Data collection was completed using HOBO™ MX1102 Loggers providing air quality monitoring of CO_2,

temperature, relative humidity, and dew point. All MX1102 Loggers were factory certified calibrated prior to field deployment.

Summary of Pilot Testing Program

In summary, the pilot testing program was successful. Insulation strategies for exterior wall and roof assemblies demonstrated effective condensation and thermal bridging control over the winter months. The roof assembly venting strategies also proved effective in controlling moisture content and humidity levels in the roofs. The testing further demonstrated that the unique soffit vent designs were effective in mitigating potential snow intrusion through the vents.

In addition to the building envelop testing, the mechanical ventilation test results were also positive. Relative humidity levels were maintained below 30% over the winter months, and CO_2 levels were maintained around 1,000 ppm.

The pilot testing results were used to develop a "tool box" of design strategies for the building envelop and mechanical ventilation systems for future review and application during mould remediation and retrofit work, as well as assist in informing future new build designs. In addition, the pilot test units remain fully occupied and the monitoring systems remain in place and operational to facilitate long-term monitoring of the building envelop and mechanical systems performance.

Innovation

In addition to the engineering solutions identified previously, this project revisited and tested long established norms and standard practices for residential building design and construction in Nunavut. Furthermore, past mould impacts were simply addressed by removing the mould, only to find it return over time. This project aimed to address root causes of mould generation to facilitate long term mould mitigation in the homes.

In executing this project, it was recognized that the negative impact of the housing crisis in Nunavut was obviously beyond our ability to control. Therefore the design strategy was to accept the potential for this condition and aim to adapt the home to accommodate high occupancy levels, while maintaining healthy indoor air environments.

Finally, prior to this work, there was limited available research data on residential building envelop and mechanical ventilation performance for arctic conditions in Nunavut. Furthermore, the negative impact of the Nunavut housing crisis had never been studied nor addressed from an indoor air quality perspective. In working with our sub-consultant on this project (RDH Building Science), this project represents the first full-scale study of residential building envelop and mechanical ventilation performance for multiple residential units in Nunavut under real-life, tenant occupied conditions.

Complexity

This project was highly complex from a number of technical, logistical, and operational perspectives. The following provides a summary of key challenges with respect to this project:

- Identify and design holistic solutions aimed at mitigating multiple root-causes of potential mould formation related to building envelop, mechanical ventilation, and tenant behavior related issues.
- Design solutions suitable for unique arctic conditions, with little to no past full scale design and performance data available for residential applications.
- Adapt designs to accommodate potential negative impacts associated with overcrowding in the homes due to ongoing housing shortage in Nunavut.
- Engineer around potential negative tenant behaviour, such as damage to vapour barrier.
- Design and test an HRV system that can accommodate periods of high occupancy in the housing units through maintaining RH and CO_2 levels.
- Design an HRV pre-heat and re-heat system to optimize the temperature settings to prevent core-freezing, while maintaining heat transfer efficiency of the HRV and temperature comfort of fresh air supply.
- Identify a means to monitor roof ventilation performance visually and remotely through the use of roof assembly camera monitoring systems, combined with moisture content, RH, and temperature sensors.
- Design the pilot testing program to enable full, undisturbed use of the home while maintaining remote data collection.
- Design a system that would enable both short-term and long-term performance monitoring.

Top: *Roof assembly camera image pointed toward soffit vent for snow intrusion monitoring - January, 2020.*

Bottom: *Camera mounted within "snow knockout" soffit vent showing snow accumulation. January, 2020.*

Ridge cap vents complete with media filter (supplied by Maximum Ventilation Ltd.).

Social and Economic Benefits

Approximately 52% of Nunavut's population live in public housing, with a total NHC public housing stock of approximately 5,600 units. It is widely known that NHC requires approximately 3,000 additional housing units to meet current demands. This housing shortage results in overcrowding, which is contributing to the high frequency of mould. This negatively impacts not only the building structure, but also indoor air quality.

The significant impact of housing on low-income people with respect to social well-being and general health is well researched and documented. Health professionals agree that living or working in an environment where mould is present could cause an increased risk of respiratory illness, especially in susceptible individuals.

Generally, people considered more susceptible to mould include (but not limited to) infants and small children, the elderly, people with respiratory illness, and those who are immunosuppressed (sometimes referred to as immunocompromised individuals).

The economic benefits from this project are related to the building life-cycle costs relative to not implementing these measures. As noted previously, approximately 80% of NHC housing stock has visible mould impacts. If left unaddressed, mould impacts can continue to grow, as well as result in rot of the building structure over time. Surveys conducted by Dillon have confirmed that even relatively new homes in Nunavut (i.e., less than 10 years old) can become impacted by mould and experience wood rot due to repeated wetting from condensation. Note that the costs for new build residential construction in Nunavut is currently in excess of $500,000 per unit.

Environmental Benefits

This project has many environment benefits related to not only improved energy efficiency, but also improving the potential lifespan of the building, thus reducing the carbon footprint related to future building replacement at remote, high-arctic locations.

In regards to energy efficiency, the design recommendations are applicable both to retrofits and new build construction. With respect to retrofits, many homes impacted by mould were originally constructed in the 1970s (and in some cases 1960s). Most of these older homes would benefit from improved building envelop and insulation strategies developed from this project, thus reducing heating requirements for arctic conditions. All residential heating in Nunavut is supplied through fuel oil fired boilers/furnaces, thus improved energy efficiency of the homes not only reduces fuel consumption, but also CO_2 emissions.

The project included design strategies to improve the operation of existing Heat Recovery Ventilators (HRVs) through design and testing of pre-heat and re-heat coils to prevent HRV core freezing, as well as improve tenant comfort of the fresh air supply. In some cases, tenants would turn off the HRV due to the cold temperature of the fresh air supply into the homes, thus negating the benefits of the HRV.

Carbon footprint reductions would be anticipated through extending the lifespan of the buildings impacted by mould. It is anticipated that these reductions would not only be related to manufacturing of the materials required for new construction, but also related to greenhouse gas reductions associated with material transportation to remote, arctic communities.

DILLON CONSULTING

75 YEARS

CANADIAN CONSULTING engineer

ASSOCIATION OF CONSULTING ENGINEERING COMPANIES | CANADA

ASSOCIATION DES FIRMES DE GÉNIE-CONSEIL | CANADA