INSULATING HERITAGE MASS MASONRY BUILDINGS FROM THE INTERIOR

A Condensed Best Practice Guide to Mitigate Risk of Freeze-Thaw Damage

November 2022

Public Services and Procurement Canada
Services publics et Approvisionnement Canada

Canada

Figure 1: A photo of the interior masonary work being done for Centre Block

Également disponible en français sous le titre : Isolation par l'intérieur des édifices patrimoniaux en maçonnerie massive: Un guide condensé des pratiques exemplaires pour réduire les risques de dommages causés par le gel et le dégel - 2022

Published by Public Services and Procurement Canada (PSPC) 2023.

For additional information, contact:
Science and Parliamentary Infrastructure Branch
TPSGC.DGSIPEngagement-SPIBEngagement.PWGSC@tpsgc-pwgsc.gc.ca

Cat.: P4-117/2023E-PDF
ISBN: 978-0-660-48443-3

Figure 2: The rehibilitation of Centre Block

ACKNOWLEDGMENTS

This guide was developed at the Science and Parliamentary Infrastructure Branch (SPIB) of Public Services and Procurement Canada (PSPC) with financial support from the Greening Government Fund. This guide is a condensed version of the technical guide entitled *Insulating Heritage Mass Masonry Buildings from the Interior: Best Practice Guide to Mitigate Risk of Freeze-Thaw Damage* published by the National Research Council (2022). Both the technical and condensed versions of the guide have been developed in collaboration with the following groups:

- National Research Council of Canada (NRC)
- PSPC Real Property Services (RPS)
- Canadian Museum of Nature
- Global Centre for Pluralism
- Morrison Hershfield
- Crosier Kilgour & Partners

TABLE OF CONTENTS

INTRODUCTION

CONTEXT

The Government of Canada, through the Greening Government Strategy, has introduced increasingly ambitious greenhouse gas (GHG) emissions reduction targets for its real property portfolio. Introduced in 2017 and updated in 2020, the Greening Government Strategy commits the Government of Canada to reducing GHG emissions by 40% below 2005 levels by 2025, and by at least 90% below 2005 levels by 2050. Federal departments are expected to ensure that all major building retrofits, including heritage rehabilitation projects, prioritize low-carbon and resiliency to climate change.

For heritage buildings where the unique architectural features of the façade are character defining elements, achieving these ambitious GHG reduction requirements, and meeting modern thermal comfort requirements for building occupants typically implies that the addition of insulation to the interior of walls and roofs is required.

It has been widely identified that, for a heritage mass masonry building, the addition of insulation to the interior of the building risks the exterior masonry being colder and wetter during the winter season. This can increase the risk of freeze-thaw damage to the exterior, thus potentially risking the long-term durability to heritage-defining characteristics. Because of this, it has been a long-held principle to avoid adding insulation to the interior of heritage mass masonry buildings.

However, recent innovations in laboratory methods to predict freeze-thaŵ risk, numerical simulations, and future climate projections combine to make now an opportune time to explore a method to achieve an optimum balance between heritage conservation and GHG emission reduction goals for heritage building rehabilitations. Through an increased thermal performance of the building envelope, operational GHG emissions can be reduced while maintaining durability and respecting the character-defining elements of the heritage building.

Figure 3: The east elevation of West Block before rehabilitation [1]

Figure 4: The east elevation of West Block after rehabilitation [1]

PURPOSE

The Condensed Heritage Envelope Thermal Retrofit Guide (hereafter referred to as "this guide") provides a methodology on how to approach insulating exterior masonry walls of heritage buildings from the interior while minimizing the risk of freeze-thaw damage. Often, the exterior elevations of designated heritage buildings are character-defining elements, eliminating the option of adding insulation from the building's exterior.

If a heritage masonry building does not have insulation, the interior temperature of the building keeps the masonry at a relatively warm temperature and aids in drying. Adding insulation on the interior side of an exterior masonry wall prevents the warm interior condition from warming this masonry during cold months. This effect can lead to a greater risk of damage due to an increased number of freeze-thaw cycles experienced by the colder masonry. The decreased temperature can lead to ice formation in the masonry pores (critical freeze-thaw cycles) which can lead to spalling and cracking (freeze-thaw damage), jeopardizing the long-term durability of the building. The risks of freeze-thaw cycles can be minimized by limiting the amount of insulation based on detailed analysis, in conjunction with other measures.

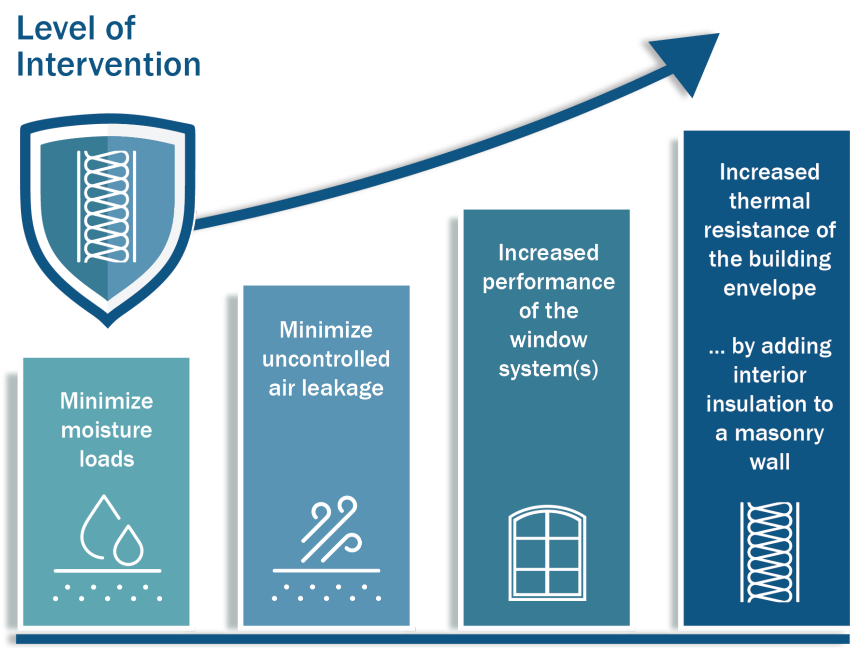
Best practices can be continually updated, revised, and added to this guide as they are developed. This condensed guide builds upon knowledge obtained through ever-evolving sources, including case studies, private sector consultation, and work done in Canada's Parliamentary Precinct and other buildings in the National Capital Region. The target audience for this condensed Guide is project managers working on heritage rehabilitation projects that involve improving the thermal performance of a heritage building envelope. This guide is a condensed companion to the more detailed guide entitled Insulating Heritage Mass Masonry Buildings from the Interior: Best Practice Guide to Mitigate Risk of Freeze-Thaw Damage, authored by the National Research Council (NRC).

Important terminology is defined in the glossary at the end of this guide, and the first occurrence of each term is italicized in the text. For a visual representation of common building assembly deficiencies, please refer to the illustrated glossary at the end of the document.

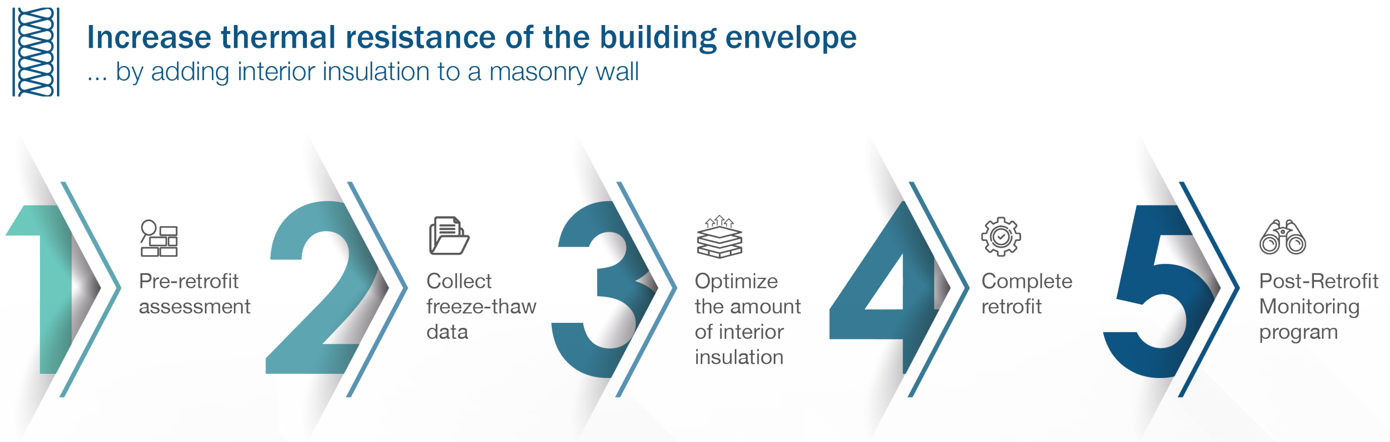
Figure 5: A photo of the Peace Tower

OVERVIEW

There are three recommended improvements to consider before adding insulation: reduce the exterior moisture loads, decrease the whole building air leakage, and upgrade the windows.



This guide focuses only on the last step: increasing the thermal resistance of the building envelope. It provides a methodology for assessing the potential to increase the thermal performance of a heritage masonry building envelope by adding interior thermal insulation. The outlined methodology ensures minimum risk to the long-term durability of the exterior masonry heritage elements and can generally be applied to any building envelope retrofit of a masonry building located in a cold climate and subject to freeze-thaw conditions. The methodology is outlined in the graphic below.



STEP 1: PRE-RETROFIT ASSESSMENT

A pre-retrofit assessment of the building must be completed to determine the condition and energy consumption of the building. The pre-retrofit inspection process is critical – it forms the basis of all future modelling and retrofit decisions. The information collected from the site inspection, testing, and building drawings will be used for the building model, which is discussed in step 3.

The pre-retrofit assessment is divided into three categories: pre-inspection information review, site inspections, and site performance tests.

PRE-INSPECTION BUILDING INFORMATION REVIEW

The objective of the pre-inspection building information review is to acquire information through drawings and historical records about building geometries, past performance, and areas to investigate on-site.

- ❑ Identify the building envelope construction and cross-section details
  - Determine assemblies of exterior walls, roofs, foundations, and window systems, including thicknesses of each component.
  - Determine termination/transition details and cross-sections at interfaces in the building envelope.
  - Determine existing roof layout and geometry. Identify potential for bulk roof drainage to affect wall/foundation/window construction. Assess during site inspections.
- ❑ Identify a timeline of the history of retrofits/ renovations
- ❑ Identify the building foundation type and layout
- ❑ Identify window types and locations using building drawings
  - Prepare a window schedule, mapped to the elevation drawings, for use in the on-site inspection of the window systems.
- ❑ Identify existing mechanical systems
- ❑ Identify typical framing materials, span directions, lengths, and interface to the exterior walls
- ❑ Identify the building orientation
- ❑ Identify potential limitations or constraints of the retrofit due to post-rehabilitation use or other factors

SITE INSPECTIONS

Site inspections establish the pre-retrofit building envelope condition and identify damaged or problematic areas that need to be addressed.

- ❑ Conduct site interviews with building operators to collect information:
  - Complaints from occupants regarding comfort, temperature, drafts.
  - Occurrence of air or moisture infiltration.
  - Presence of condensation at varying times of the year.
- ❑ Conduct a preliminary site review
  - Complete a designated substance review to gain a general understanding of the building
  - Plan the detailed site review
- ❑ Conduct a detailed site review
  - Gather in-depth information about the building condition
  - Identify causes of envelope deterioration
  - Confirm the building assemblies
  - Plan material sampling locations

STEP 1

SITE PERFORMANCE TESTS

Site performance tests provide qualitative and quantitative data for the development of the whole-building performance and hygrothermal models. Tests establish existing wall conditions as a baseline for a pre-retrofit monitoring program.

- ❑ On-site monitoring to establish pre-retrofit exposure conditions and envelope performance
  - Create a data collection plan and verification process to provide accurate results.
  - Install through-the-wall monitoring sensors to establish a pre-retrofit conditions.
  - Ensure system sensors are calibrated and have an accompanying calibration certificate.
- ❑ Whole-building air leakage testing
- ❑ Thermographic inspection of the building envelope
- ❑ Material sample harvesting for laboratory testing to establish hygrothermal modelling inputs
  - Develop a field sampling plan to identify the number of samples and removal locations.
  - Document the sample locations thoroughly with photos before, during, and after the sample has been removed. Ensure sample locations are mapped on an elevation drawing.

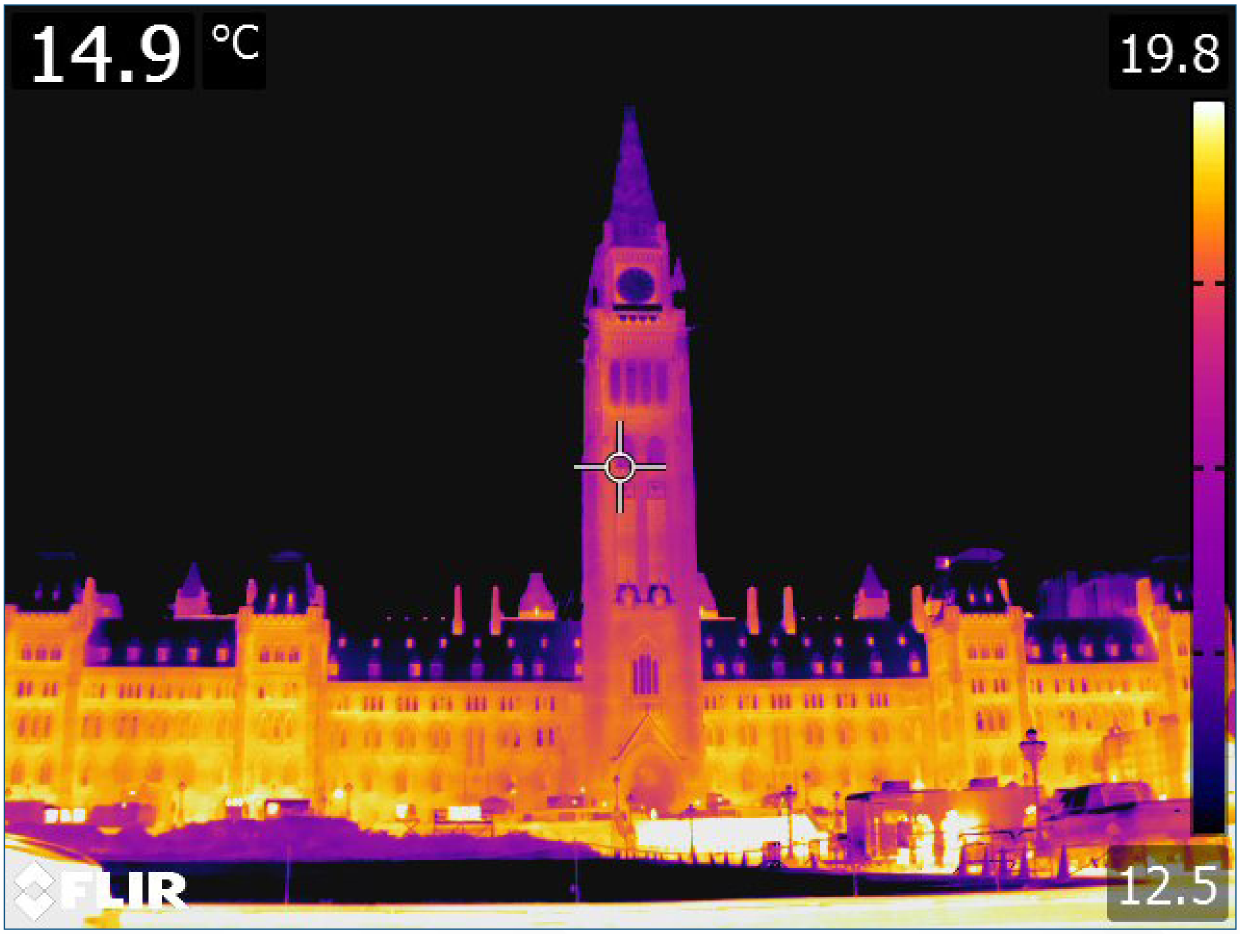


Figure 6: Thermography scan of Centre Block [2]

Figure 7: Victoria Memorial Museum Building [3]

STEP 1

CASE STUDY

VICTORIA MEMORIAL MUSEUM BUILDING

How the Victoria Memorial Museum Building rehabilitation project exemplifies Step 1: Pre-Retrofit Assessment

Since the Victoria Memorial Museum Building is a museum, this rehabilitation project had very specific design constraints for the interior conditions. Completing a thorough pre-retrofit assessment was necessary to achieve a design with the specific interior conditions required for artifact storage and display. Specifically, the interior temperature and moisture of the building must be very closely monitored and controlled. Some of the pre-retrofit assessment that was completed included whole-building air leakage and thermography scanning. These assessments informed the energy model used in the design process.

BUILDING INFORMATION

Original Construction: 1911

Rehabilitation Date: 2010

Floor Area: 23,225 m2

No. of Storeys: 4

Owner: Canadian Museum of Nature

Heritage Designation: Classified Federal Heritage Building

STEP 2: COLLECT FREEZE-THAW DATA

Data required to complete hygrothermal modelling (freeze-thaw analysis of the masonry) is established through laboratory testing. Laboratory characterizations are used to identify, validate, and develop material characteristics for the hygrothermal and energy models. The material property characterization consists of several laboratory tests. Depending on the pre-existing knowledge of the building materials, the tests completed for input to the model can range from preliminary tests to validate materials to full characterization. It is recommended that a full characterization be completed as specific site elements and age of building can have an effect on the material properties.

In the future, masonry buildings in the National Capital Region are expected to experience an increase in freeze-thaw cycles and damage due to climate change.

Given the variance in heritage material properties, it is recommended that minimal validation tests be completed even if the material has been previously characterized in other retrofits. Measurements of material properties of the field samples should be done in a professional laboratory capable of measuring hygrothermal properties.

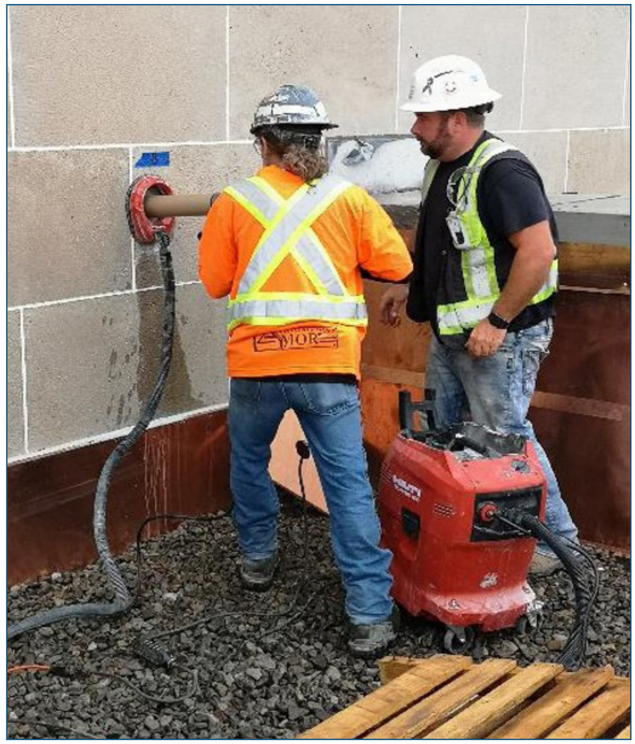


Figure 8: Material sampling being completed at West Memorial Building [4]

Figure 9: Material Core Samples from West Memorial Building [4]

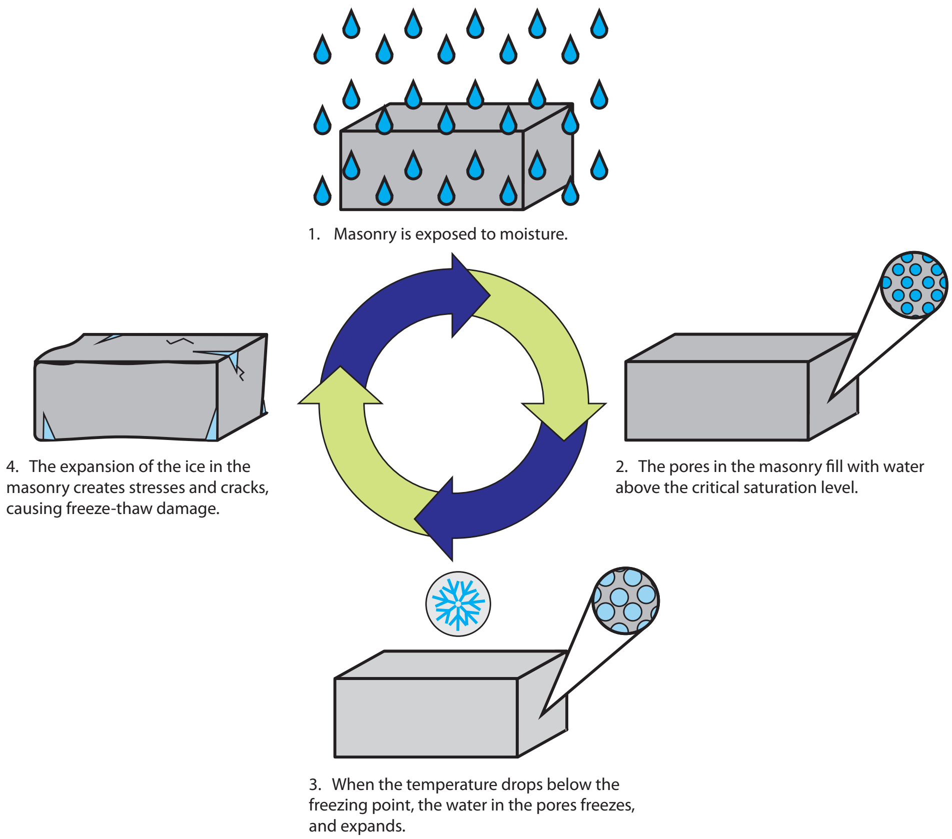


Figure 10: The freeze-thaw damage process

Some further tests are required to characterize the freeze-thaw durability of the masonry components. The laboratory data required to perform the freeze-thaw durability modelling analysis are listed below:

- Dry bulk density (ASTM C20)
- Thermal conductivity (ASTM C518, ASTM C177)
- Heat capacity (ASTM E1269)
- Water absorption coefficient (ASTM C1794)
- Permeability (ASTM E96 wet cup)
- 80% Relative humidity water content (ASTM C1498)
- Free water saturation (DIN12087)
- Vacuum saturation
- Calculated porosity (ASTM C20)
- Critical freeze-thaw saturation (S_{crit})

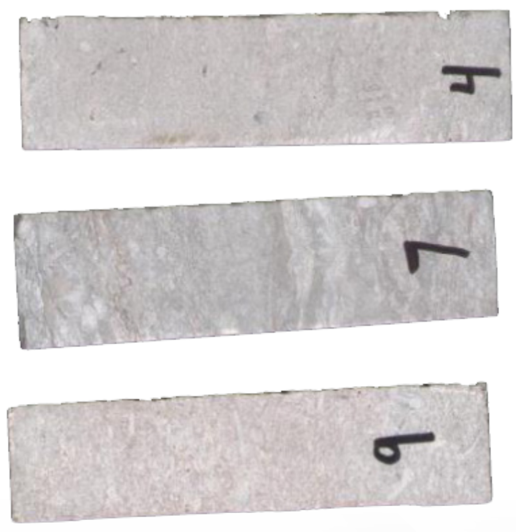


Figure 8: Limestone samples for laboratory testing [4]

Figure 11: West Memorial Building [5]

STEP 2

CASE STUDY

WEST MEMORIAL BUILDING

How the West Memorial Building rehabilitation project exemplifies Step 2: Collect Freeze-Thaw Data

Material sampling and testing was completed for the West Memorial Building rehabilitation project to create hygrothermal and energy models. 30 core samples of the limestone masonry with varying exposure conditions were harvested from 10 different locations throughout the building. The stone cores were sent to a laboratory where the stone's properties were established (see page 15 for an expatiation of these properties). The freeze-thaw data was used to inform the freeze-thaw durability of the cladding through hygrothermal modelling.

BUILDING INFORMATION

Original Construction: 1954

Rehabilitation Date: 2024 (projected)

Floor Area: 24,410 m2

No. of Storeys: 6

Owner: Federal Government

Heritage Designation: Classified Federal Heritage Building

Sample	Water Vapour Permeability ng/Pa•s•m	Water Uptake A-value $kg/m^2•s^{1/2}$	Free Water Saturation W_f kg/m^3	Critical Freeze-Thaw Saturation S_{crit} kg/m3
Stone 1	3.6	0.001	14	24
Stone 2	3.9	0.001	24	28
Stone 3	3.2	0.001	23	25
Stone 4	4.8	0.001	12	32
Stone 5	3.8	0.004	46	25
Stone 6	2.1	0.001	22	32
Stone 7	3.8	0.001	11	21
Stone 8	3.8	0.001	18	24
Stone 9	5.3	0.002	45	48
Stone 10	3.1	0.002	23	46

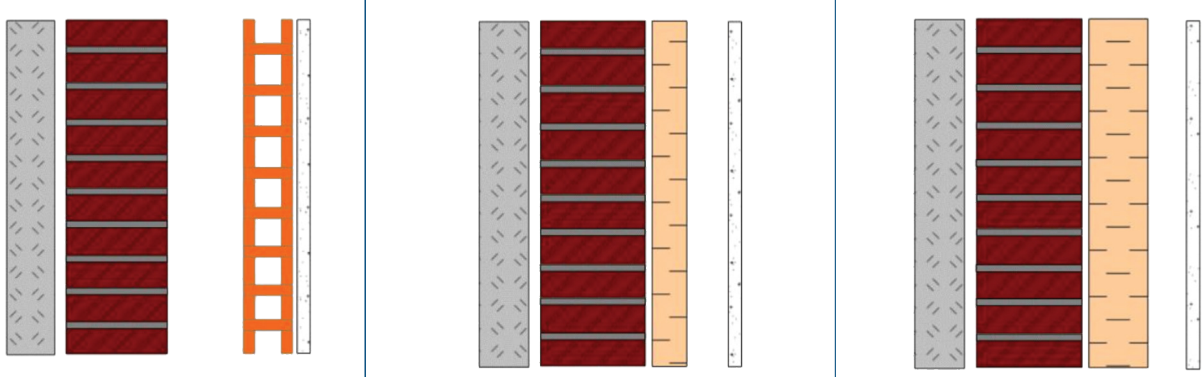
Figure 12: Extract of limestone material properties at West Memorial Building [4]

STEP 3: OPTIMIZE THE AMOUNT OF INTERIOR INSULATION

Once the building information and material properties have been established, whole-building energy modeling and hygrothermal modelling can be completed to determine the effects of adding interior insulation on the long-term durability. Determining if, and how much, interior insulation can be added is an iterative process involving both modelling methods. Each model type informs the other until an optimized design for the thermal retrofit of the building envelope is determined. After establishing a design, if any aspects are changed or altered before or during construction, the energy and hygrothermal models should be updated to confirm that the design goals will still be met.

The following section details the assumptions and requirements for the whole-building and hygrothermal modelling. It does not provide enough context to teach an individual how to complete the models.

It should be noted this guide focuses on the building envelope. A whole-building energy model and a hygrothermal model considers other inputs from the building highlighting the holistic modelling approach. A building envelope retrofit needs to be considered within the overall building rehabilitation as it interacts with other rehabilitation decisions.



Scenario C1	Scenario C2	Scenario C3
▪ 100mm limestone ▪ 200mm brick ▪ 150mm air space ▪ 100mm terracotta tile ▪ 15mm plaster	▪ 100mm limestone ▪ 200mm brick ▪ 50mm medium density, closed cell spray polyurethane foam (R-12) ▪ 92mm stud cavity ▪ 13mm gypsum drywall	▪ 100mm limestone ▪ 200mm brick ▪ 100mm medium density, closed cell spray polyurethane foam (R-24) ▪ 92mm stud cavity ▪ 13mm gypsum drywall

Figure 13: Example - Three wall retrofit scenarios with varying levels of interior insulation to be considered using hygrothermal analysis for the West Memorial Rehabilitation Project [4]

WHOLE-BUILDING ENERGY MODELLING

In the specific context of the building envelope and whole-building energy modelling tools, there are two main inputs:

i. The effective thermal resistance of the building envelope

ii. The air leakage rate through the envelope

The design team will be required to calculate the situation-specific effective thermal resistance of all envelope assemblies in the heritage envelope. The effective thermal transmittance is calculated for the pre-retrofit building and is compared to the effective thermal transmittance calculated for the designed post-retrofit building. Thermal bridges have a more significant effect on the effective thermal transmittance when a building is insulated from the interior. An accurate calculation of the effective thermal resistance of the envelope, given the assumed addition of interior insulation, can help determine the point at which the risk of freeze thaw damage becomes significant.

The air leakage rate refers to the convective transfer of air across the building envelope between the interior and exterior environments. While the National Building Code of Canada provides airtightness limits for new construction, there is little guidance on a realistic or achievable value for heritage buildings in either a pre- or post-retrofit scenario. Therefore, test values are needed for the specific heritage retrofit project for accurate model development.

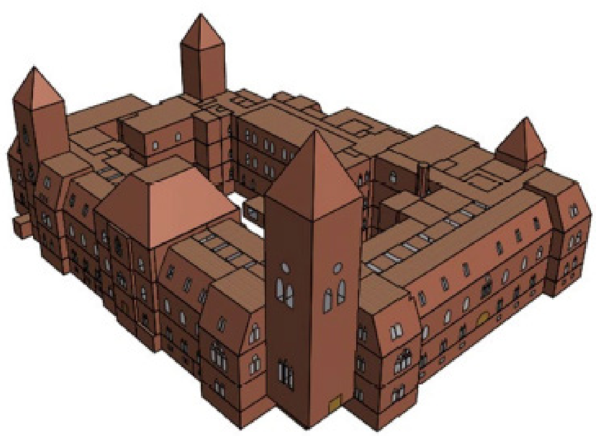


Figure 14: 3D model of East Block used for calibration of energy model [6]

Effective thermal resistance refers to the overall thermal resistance accounting for thermal bridges. The effective thermal resistance is not the same as the traditional 'nominal' thermal resistance value. The nominal insulation thermal resistance is a simplistic value that must not be used as an input to a whole building simulation as it could result in an overestimation of the envelope thermal resistance.

Models should be calibrated against the energy performance (heating and cooling loads, energy use intensity, etc.) of an existing building, in real conditions. Actual conditions should not differ significantly from the modelled use.

The information necessary for proper model calibration includes:

- Monthly gas consumption for a whole year (ideally several years to see fluctuations)
- Monthly electricity consumption for a whole year (ideally several years to see fluctuations)

ESTABLISH PERFORMANCE CRITERIA: FREEZE-THAW DURABILITY METHODOLOGY

The overall intent of the analysis of the impact on freeze-thaw durability for the exterior walls is to provide evidence-based information that can be used to assess the potential risks. The process employed follows ASTM E3069-19: Standard Guide for Evaluation an Rehabilitation of Mass Masonry Walls for Changes to Thermal and Moisture Properties of the Wall (ASTM E3069) which outlines the process and key steps that must be followed for the results to be consistent and comparable. The combination of the source information and the output of the hygrothermal simulations are used to make a judgement on freeze-thaw risk. Simply completing the referenced tests is not enough – the designer must demonstrate traceable results between the simulation output and empirical evidence gathered from the previous investigations.

Hygrothermal modelling has three main variables: the critical degree of saturation (S_{crit}), the free water saturation moisture content (W_f), and the water absorption coefficient (A-value). These factors are further described in the table on page 18.

Materials with a W_f higher than their S_{crit} have the potential to experience freeze-thaw damage. In this case, the material can achieve a moisture content under the normal field conditions, which could cause damage in a freeze-thaw cycle.

Figure 15: Cracked masonry unit due to freeze-thaw damage [2]

Main Variables for Hygrothermal Modelling

Name	Material Property	Relevance to Freeze-Thaw
S_{crit}	Critical Degree of Saturation	Moisture content at risk to damage the material from freeze-thaw action
W_f	Free Water Saturation	Highest moisture content the material is expected to experience under typical field conditions
A-value	Water Uptake Coefficient	Rate at which liquid water can be absorbed or drained out of the material

Furthermore, the rate at which a masonry component will absorb or desorb moisture (A-value) predicts if the saturation level in the material is greater than the *critical saturation level* (S_{crit}).

A hygrothermal model determines the interaction between these attributes and predicts the process depending on the local moisture loads to the material (wind-driven rain, drainage from the material above, interior condensation loads, etc.), the drying potential of the material, the local temperature fluctuations, and the assumed freeze point depression.

The number of hygrothermal simulation runs can be reduced if sample materials have similar S_{crit}, W_f, and A-values. The interaction of these parameters during hygrothermal simulations governs the number of critical freeze-thaw cycles. Justification is required for the material grouping, including an explanation of how inter-group variability is accounted for in the model results.

The freeze-thaw evaluation's second step is establishing the freeze-thaw risk criteria. The uncertainty of the freezing temperature of water within a pore must be determined. The freezing temperature of water within pore spaces of porous materials varies depending on the material pore size. There is a direct relationship; as pore size decreases, the freezing point of water decreases, commonly to values below 0°C. Depending on the material, there may be a wide range of pore sizes, and the water within these pores may freeze at different temperatures.

A range of freeze-thaw benchmarks should be considered, with the freezing temperature thresholds adjusted based on the expected pore-size range of the material. The freezing-point value or range must be carefully considered and assessed. The selection of the critical freezing point temperature is to be made based upon experience, knowledge of the materials, and historical performance. Research on the potential pore-size distribution and range within the materials is often required to support the assumption of an appropriate freezing point within the sample's pores (based upon laboratory testing). The assumed freeze-thaw temperature should be documented and justified in the freeze thaw analysis report.

The number of cycles that the material can withstand before damage occurs is determined by establishing a baseline freeze-thaw cycle limit using the hygrothermal simulations of the existing building, with results corroborated from the site investigations. If there is no evidence of freeze-thaw damage on-site, the baseline freeze-thaw analysis using hygrothermal simulations indicates a design threshold. A threshold can be used to assess a potential risk increase when insulation is to be added.

HYGROTHERMAL (LONG-TERM DURABILITY) MODELLING

Hygrothermal modelling uses the laboratory test results from Step 2 to determine the effects of interior insulation on the long-term durability of the heritage masonry. Freeze-thaw performance of an assembly is based on the number of critical freeze-thaw cycles predicted by transient hygrothermal simulations over a specified period. The simulations determine an acceptable number of cycles that the masonry components can tolerate without sustaining significant damage, leading to a conclusion about how much interior insulation can safely be added.

The model is created using the previously gathered inputs and validated by comparing the model outputs to the baseline building conditions:

- Listing the materials used in the model and the material properties
- Defining the exterior boundary conditions
- Defining the interior boundary conditions
- Configuring the model building envelope geometry

Pre-retrofit monitoring results can be used for model calibration, verification and validation.

Figure 16: Cracked masonry unit due to freeze-thaw damage [2]

The environmental conditions used for the model should reflect previous conditions experienced by the existing building envelope and projected future conditions post-rehabilitation.

Finally, a report should be produced by the modelling team presenting the results and retrofit recommendations. The report provides confidence in the post-rehabilitation, long-term durability of the heritage character-defining elements. It ensures the information provided is sufficient for a different team to repeat the modelling.

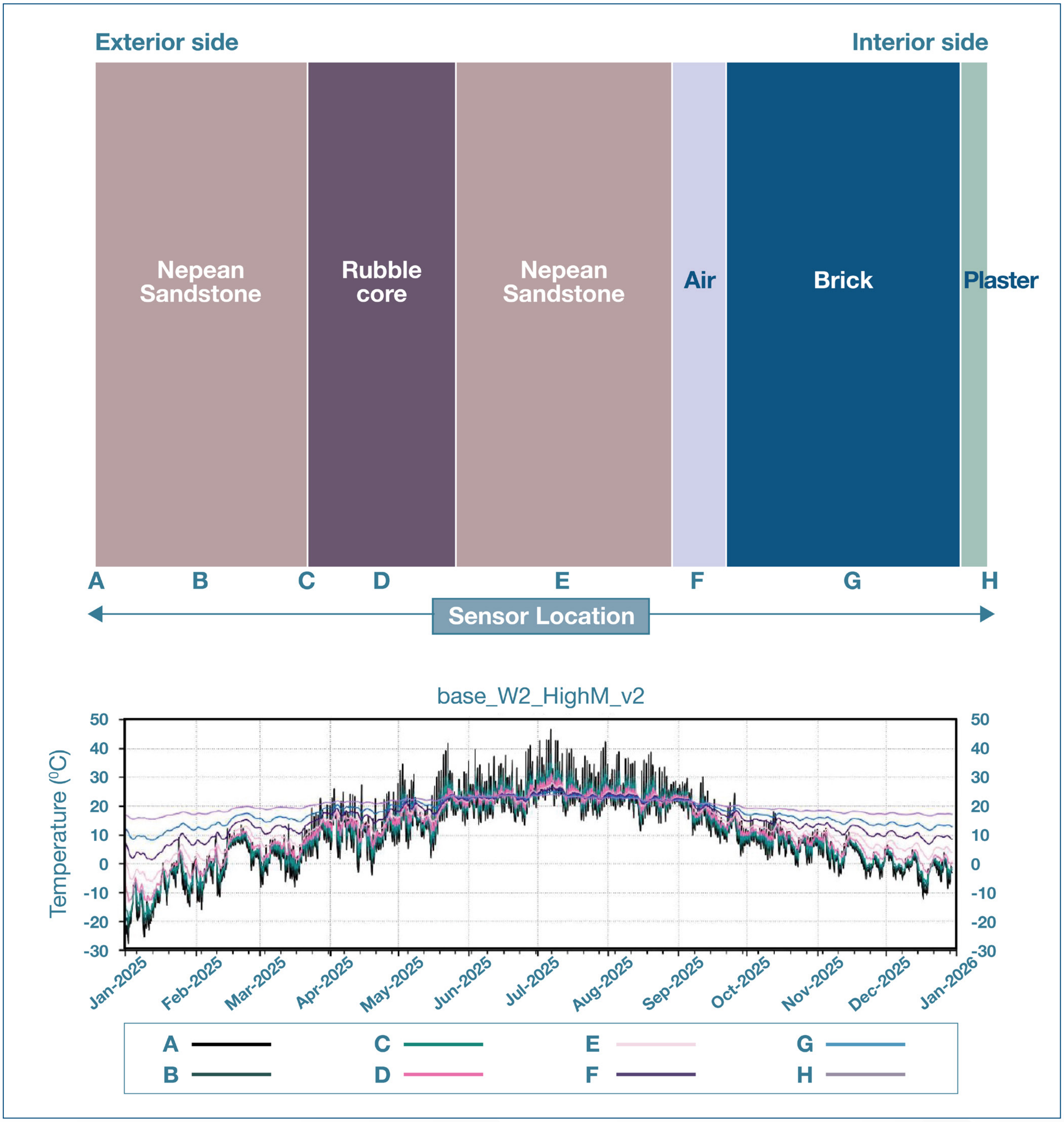


Figure 17: Example of the location of wall sensors in a hygrothermal model at East Block [6]

Figure 18: Postal Station B

STEP 4

STEP 4: COMPLETE RETROFIT

The information from Steps 1 through 3 informs the project's design. While the retrofit is being completed, it is possible that unknown building conditions could be revealed. If applicable, the modelling step should be revised to reflect these uncovered building conditions to ensure that the project outcomes remain on track. Furthermore, the construction phase may be an ideal time to install on-site monitoring packages outlined in Step 5.

CASE STUDY

POSTAL STATION B

How the Postal Station B rehabilitation project exemplifies Step 4: Complete Retrofit

During the rehabilitation of Postal Station B, the large areas of walls above the finished ceilings were found to be uninsulated, even though these areas of walls were indicated in the energy model as having been insulated. If the building is not fully understood, assumptions made in the energy models may be misinterpreted. The energy model was updated during construction as new information about the building was learned.

BUILDING INFORMATION

Original Construction: 1939

Rehabilitation Dates: 1975, 2018

Floor Area: 6,040 m2

No. of Storeys: 8

Owner: Federal Government

Heritage Designation: Classified Federal Heritage Building

STEP 5: POST-RETROFIT MONITORING PROGRAM

It is recommended that an on-site monitoring program be implemented to compare the design and actual outcomes from an energy and long-term durability perspective. The monitoring program validates the developed hygrothermal models to ensure the ongoing performance of the building envelope is within the range predicted during the design phase and to confirm that there is no risk of freeze-thaw damage. The post-retrofit monitoring program is very similar to the pre-retrofit monitoring program – however, it may be easier to install interstitial sensors in the envelope during the retrofit.

The ongoing monitoring program should be designed to track the performance of the locations used to develop hygrothermal models. The program consists of two concurrent steps:

1. The collection of measured data on the hygrothermal building envelope conditions

2. Regularly scheduled site inspections to assess the ongoing performance

Deviations from the modeled predictions and any potential damage must be determined as quickly as possible, before extended damage occurs. If the modelling does not reflect the real-world performance, further studies are needed. Further studies are critical if the trends of the model start to indicate increases in freeze-thaw cycling compared to the pre-retrofit assumptions.

For the collection of data, sensors should be shielded from solar radiation and be installed in a minimum of two locations:

1. At the interior air/interior wall interface

2. Near the exterior stone components (in a void space if present)

Figure 19: Monitoring sensors being installed in a masonry wall [2]

At minimum, sensors should detect the moisture content, relative humidity and temperature. Sensors should be installed on the interior and exterior of the wall and throughout the building envelope. At each location in the measurement site, three sensors of each type should be installed for increased reliability and verification. The data collected from these sensors is only reliable if the sensor has been calibrated to a calibration standard. Calibration should occur every year. Certifications for all sensors and data acquisition systems used for the monitoring should be provided as part of the program.

The collected data should be used to update the whole-building energy model and the hygrothermal model to reflect the as-built final design. The updated model should be compared with the data collected from the ongoing monitoring program. The best practice is to have the monitoring program in place for a minimum of 3 years post-rehabilitation to allow the building to settle into normalized performance.

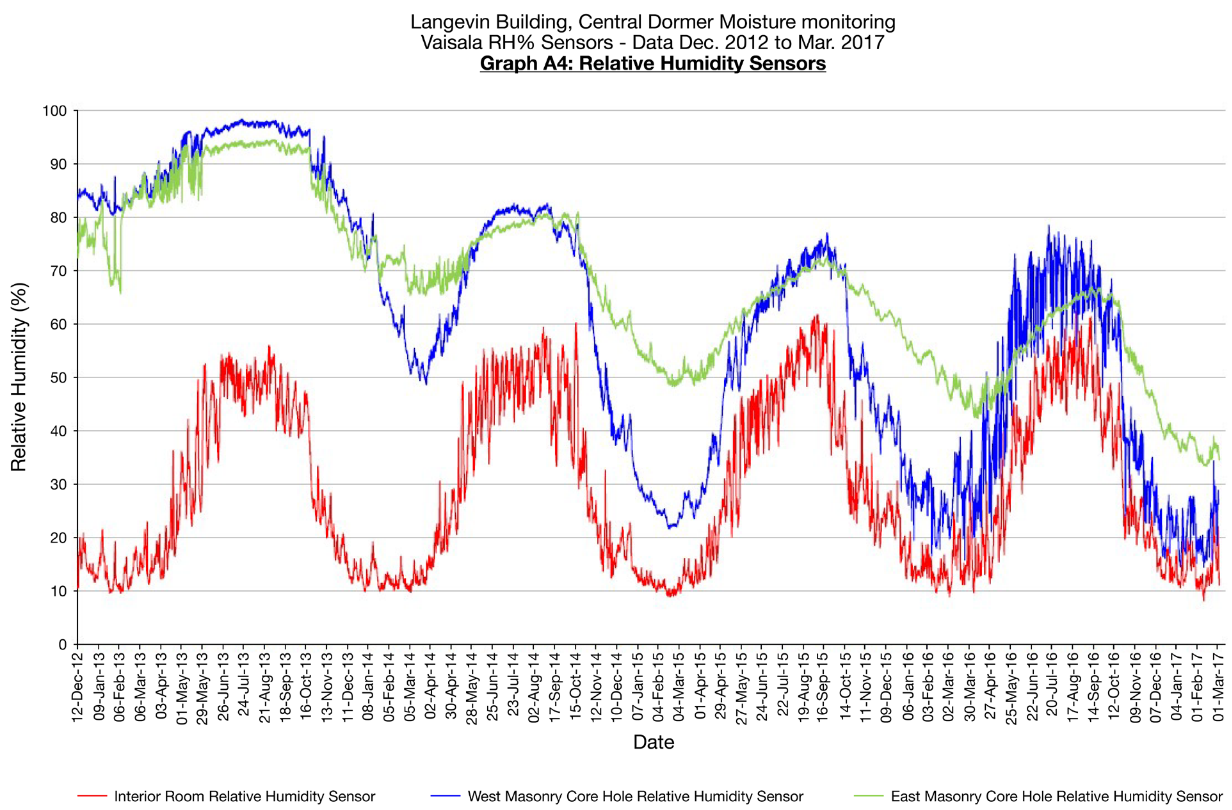


Figure 20: Graph monitoring the relative humidity sensors at 80 Wellington St, formerly known as the Langevin Building [7]

Figure 21: Global Centre for Pluralism [8]

STEP 5

CASE STUDY

GLOBAL CENTRE FOR PLURALISM

How the Global Centre for Pluralism Rehabilitation Project exemplifies Step 5: Post-Retrofit Monitoring Program

The design intervention at the Global Center for Pluralism involved a rigorous evaluation of the risks and benefits—material testing, hygrothermal modelling, and computational analysis—for approval by the Federal Heritage Buildings Review Office (FHBRO). The project incorporated a successful 3-year hygrothermal and corrosion post-monitoring program. The masonry was monitored in eight locations throughout the building, including both insulated and uninsulated wall assemblies. The temperature and relative humidity were tracked at these locations. Annually, the data was compiled, and recommendations regarding the state of the stone and any suggested repairs or adjustments were outlined. The program has indicated that the introduction of insulation has not increased risk to building durability to date.

BUILDING INFORMATION

Original Construction: 1865

Rehabilitation Date: 2019

Floor Area: 28,400 m2

No. of Storeys: 4

Owner: Federal Government

Heritage Designation: Classified Federal Heritage Building

CONCLUSION AND FUTURE OPPORTUNITIES

This condensed guide provides an approach to upgrading the thermal performance of heritage building envelopes by determining how much insulation can be added to the interior of a building while minimizing risk of freeze-thaw damage to the exterior masonry. This approach helps to optimize the energy efficiency of the building to meet sustainability targets while protecting heritage character-defining elements.

This condensed best-practice guide is built on inputs from literature reviews, normative standards, case studies, research, and private sector consultations. Rehabilitation of a heritage building needs to follow a holistic approach in which upgrades and repairs to all building components and systems should be evaluated concurrently. This guide is a tool to be used as part of an overall rehabilitation plan and should not be used in isolation from other rehabilitation considerations.

The proposed methodology uses on-site assessments, field sampling, and material property characterization to produce results in the modelling stage, such that freeze-thaw risk can be established. The modelling analysis dictates the amount of insulation to be added to the interior of the heritage wall.

For a more in-depth discussion of the topics discussed herein, refer to the *Insulating Heritage Mass Masonry Buildings from the Interior: Best Practice Guide to Mitigate Risk of Freeze-Thaw Damage in Heritage Rehabilitation Projects* guide authored by the NRC.

During the development of this best-practice guide, several opportunities for future development were revealed to aid in the thermal retrofit of heritage envelopes.

These consist of the following:

i. Air-tightness of heritage buildings

ii. Advanced wind-driven rain analysis using computational fluid dynamics

iii. 3D laser scanning when building drawings are not available

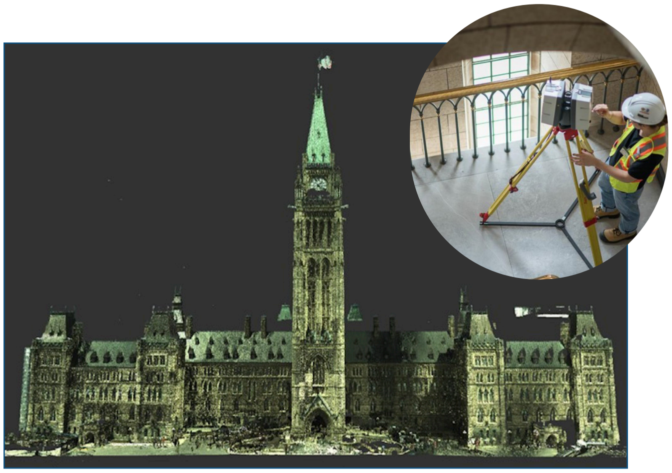


Figure 22: The Centre Block Building Information Model created from laser scans [9]

GLOSSARY

Air leakage	The uncontrolled transfer of air through the building envelope.
Building envelope	The combined layers that protect the interior space in a building from the exterior weather elements. Also referred to as the building enclosure.
Character-defining element	The materials, forms, location, spatial configurations, uses, and cultural associations or meaning that contribute to the heritage value of an historic place and that must be retained to preserve its heritage value.
Conservation	All actions or processes that are aimed at safeguarding the character-defining elements of an historic place to retain its heritage value and extend its physical life.
Critical freeze-thaw cycle	A freeze-thaw cycle in which the moisture saturation within the pore is above the critical saturation level. See critical saturation.
Critical saturation	The saturation level in which the freezing pore water and corresponding volume expansion due to ice crystal formation exceeds the ultimate tensile strength of the masonry material.
Effective thermal resistance	The thermal resistance that accounts for all thermal bridges through the insulation layer of the building envelope. See thermal bridge.
Field sampling	The act of collecting material samples from the building for laboratory characterization, including for designated substance analysis and removal of material on-site.
Freeze point depression	The phenomena that occur in porous media where the freezing point of water is dependent on the pore diameter and decreases with decreasing pore radius, in some cases well below 0°C.
Freeze-thaw cycle	A cycle in which the temperature of a porous media material descends from above to below the freeze-point temperature, indicating probable ice formation within the pores.
Hygrothermal model	A model which simulates the transfer of heat and moisture through building components. In the case where air transport phenomena are included, it is typically referred to as a heat, air, and moisture model (HAM).
Rehabilitation	The sensitive adaptation of an historic place or individual component for a continuing or compatible contemporary use, while protecting its heritage value.
Retrofit	A specific part of the rehabilitation process, specifically an alteration to increase the performance of a system or component beyond the original design.
Thermal bridge	Thermal bridge occurs when a material with higher relative thermal conductivity (or lower thermal resistance) dissects a material of lower relative thermal conductivity (or higher thermal resistance) in a direction parallel to the direction of heat transfer.

ILLUSTRATED GLOSSARY

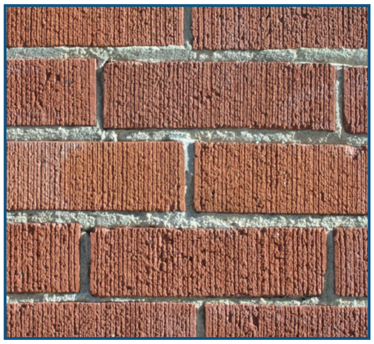

Contour Scaling [2]


De-bonded Mortar [2]


De-bonded Masonry Unit [2]


De-lamination [2]


Detachment [2]

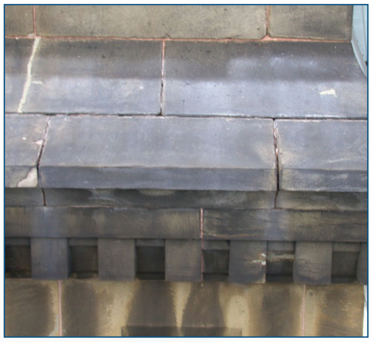

Deteriorated Mortar [2]


Efflorescence


Face-pointing Failure [2]


Fire Skin Damage


Friable Surface [2]


Open Masonry Joint [2]


Spall [2]

FIGURE REFERENCES

[1] Public Services and Procurement Canada, Government of Canada, "West Block photo gallery," Nov. 06, 2018. https://www.tpsgc-pwgsc.gc.ca/citeparlementaire-parliamentaryprecinct/rehabilitation/ouestgalerie-westgallery-eng.html.

[2] Public Services and Procurement Canada - Heritage Conservation Services

[3] Attractions Ontario, "Canadian Museum of Nature," https://attractionsontario.ca/attraction-listings/canadian-museum-of-nature/.

[4] Morrison Hershfield, "Freeze-Thaw and Thermal Analysis of West Memorial Rehabilitation Wall Assembly," Jan. 2019.

[5] Public Services and Procurement Canada, Government of Canada, "West Memorial Building: Rehabilitation," West Memorial Building: Rehabilitation, Aug. 14, 2017. https://www.tpsgc-pwgsc.gc.ca/biens-property/construction/eco-wmb-eng.html.

[6] Stantec and SHRMA, "East Block Phase 2 Technical Feasibility Study," Feb. 2022.

[7] R. Melanson and PSPC, Heritage Conservation Services, Installation of moisture and relative humidity sensors.

[8] R. Melanson, "Langevin Building Ottawa, Ontario Central Dormer Environmental Monitoring 2016-2017," PSPC, Heritage Conservation Services, Mar. 2017.

[9] Historic Places Days, "Global Centre for Pluralism," https://historicplacesdays.ca/places/global-centre-for-pluralism/.

[10] CENTRUS, BIM And Scanning examples from Centre Block Rehabilitation ASHRAE Presentation.

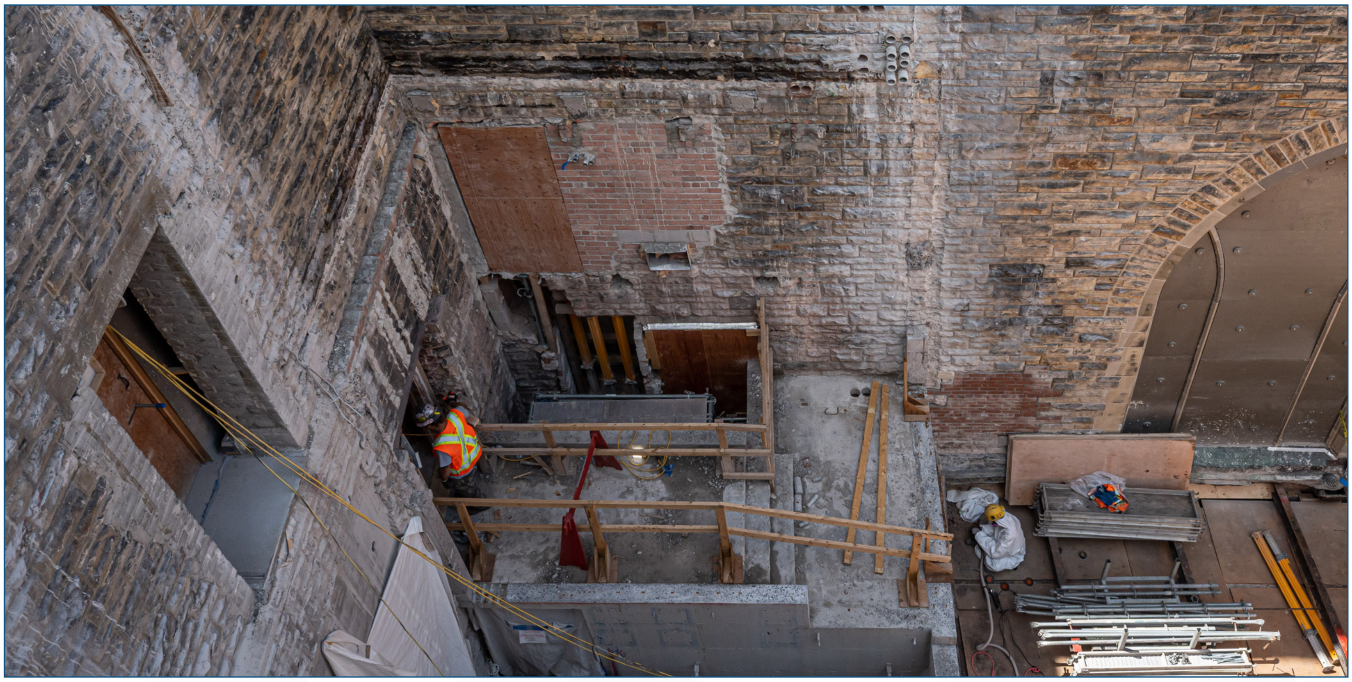


Figure 23: Masonry workers at Centre Block's excavation site