Decision Making on the Indoor Environment and Building Envelope of Canada's Library of Parliament

Stéphane P. Hoffman, P.Eng.

Mark D. Lawton, P.Eng.
Member ASHRAE

ABSTRACT

A year-long monitoring program was undertaken at Canada's Library of Parliament to answer the following:

- *What indoor environmental conditions are currently being maintained in the library with its existing temperature and humidity control systems?*
- *What seasonal indoor environmental conditions can the existing building envelope support without distress or long-term durability problems?*
- *What improvements could be gained with various levels of intervention?*

The goal of the monitoring program was to provide specific recommendations for indoor temperature and humidity conditions and required interventions that would provide for the long-term durability of the building envelope and functional, archival, and heritage conservation needs.
The work included monitoring of

- *hydrothermal conditions at key indoor locations and interstitial spaces in the envelope,*
- *indoor/outdoor pressure differences,*
- *surface condensation and moisture content of building assemblies including stone walls, and*
- *surface temperatures to establish the condensation resistance of the existing window systems.*

This paper focuses on how monitoring data, visual observations, and assessment of moisture collection potential by analysis and simulation were used to define recommendations for the conservation of both the library and its collection.

INTRODUCTION

The Library of Parliament is one of the most important federal heritage structures in Canada. Originally constructed in the 1860s and preserved from a 1916 fire that destroyed the original Centre Block of Parliament, the Library of Parliament remains as one of the three original buildings of the Parliamentary Hill Precinct. It continues to operate as the main parliamentary library and has a large and diverse collection of important artifacts. Although most of the collection is stored off site, the library acts as the primary access point and houses important archival artifacts. Conservation of these materials and the elaborate interior finishes requires a stable indoor environment. The library currently has an HVAC system providing heating, humidification, and air conditioning in an attempt to maintain a stable 20°C, 35%-40% relative humidity (RH).

As part of the conservation plan for the Parliamentary Hill Precinct, the library is scheduled for restoration in the near future, providing an opportunity to improve its functions as a library and archive. This includes addressing the issues of indoor environmental control. A study into functional requirements (LAA 1995) has identified several options for indoor humidity and temperature conditions specific to the preservation of the collection ranked by functional desirability (in which stability of relative humidity was the primary criteria). In order of preference, these were as follows (all assumed an indoor temperature of 20°C±2°C):

- 40% RH year-round

Stéphane P. Hoffman is a building science specialist at Morrison Hershfield Ltd. in Vancouver, British Columbia. **Mark D. Lawton** is technical director of building engineering for Morrison Hershfield Ltd. in Ottawa, Ontario.

- 30% RH in winter and 40% RH in summer with gradual adjustments through the shoulder periods
- 40% RH in winter and 50% RH in summer with gradual adjustments through the shoulder periods
- 30% RH in winter and 50% RH in summer with gradual adjustments through the shoulder periods

These options did not address the ability of the existing or future mechanical system to provide and maintain these conditions nor the impact these operating conditions would have on the long-term durability of the building envelope. A previous condition survey (SHA 1994) •f the building envelope of the library had already revealed that certain elements had experienced significant deterioration. In some cases, these appeared to be directly linked to the effects of operating in a humidified space. A major question was what could the building envelope withstand, assuming a minimum intervention strategy appropriate for a significant heritage building. The needs of the building envelope would have to be resolved with functional, archival, and heritage conservation needs.

A monitoring program was therefore undertaken to establish the existing environmental conditions throughout the library and determine their impact on the building envelo The mandate for this study was to

1. determine the current indoor environmental operat conditions in the library and their impact on the build envelope,
2. evaluate the different indoor environmental operat conditions established for the collection in relation to tl impact on the existing building envelope,
3. establish the improvements required to implement different indoor environmental operating conditions w out creating distress or durability problems for the build envelope.

BUILDING DESCRIPTION

Of gothic design, the Library of Parliament is a 16-si polyhedron with twin masonry ringwalls supporting the s truss of the conical metal clad roof. The roof is intersected two clerestories braced by flying buttresses. Figure 1 ill trates a cross section through the building. The main cham rises 49 m from the main floor to an inner plaster dome an

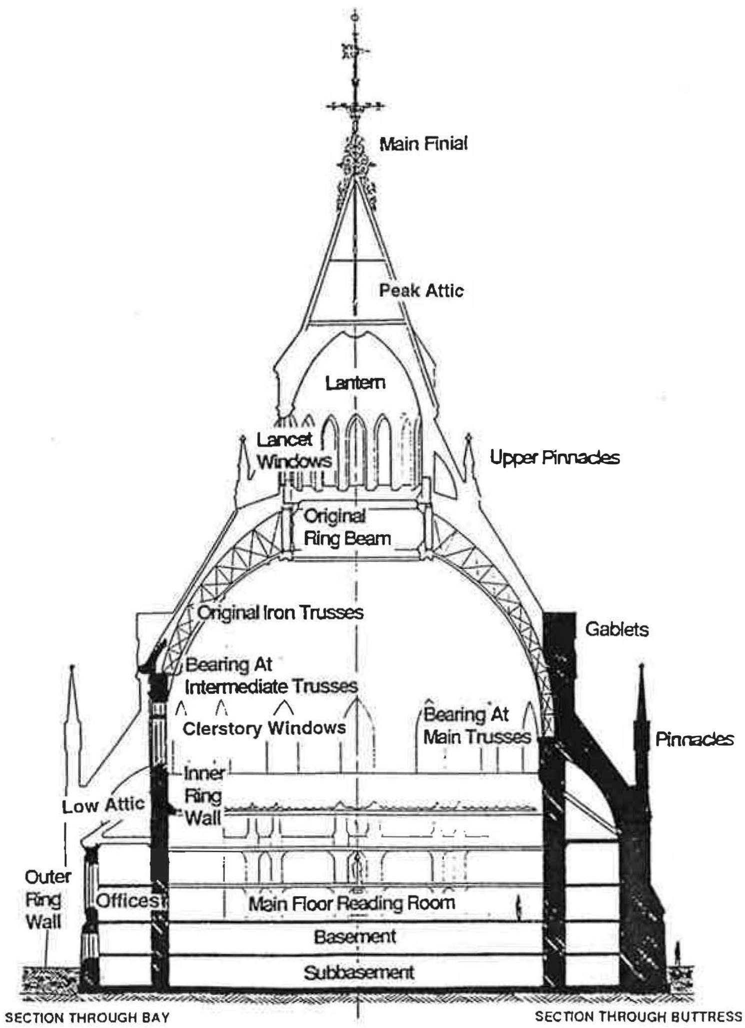

Figure 1 *Cross section of Library of Parliament.*

surrounded by three levels of ornately decorated wooden walkways housing book stacks. Under the main chamber are two levels of stacks and service areas referred to as the basement and sub-basement levels. The lower perimeter rooms of the building are utilized as office accommodation and storage areas. Four staircases that provide internal circulation are located around the perimeter. One of these stairways leads up to an exterior tower, providing access to the interstitial dome space and the roof.

In 1952, the library was badly damaged by fire and water. In the subsequent renovation, the internal wood structure and roof truss system were replaced with fire-resistant construction. This included a new insulated roof and lantern wall assembly, as illustrated in Figure 2, which incorporated an air space between the interior plaster and steel deck. At that time, the original lantern windows were replaced with double-glazed insulated units, as were the smaller perimeter office wood windows. The single-glazed clerestory windows with their exterior lead glazed storm windows were reinstated as were the matching stairwell windows. The existing mechanical system installed during the 1952 renovation was subsequently modified in 1975 with the installation of fan-coil air-conditioning units.

METHODOLOGY

Preliminary Work

Prior to developing the monitoring plan, both the original construction drawings and the extensive record of the existing construction prepared by the Public Works' Heritage Conservation Program were reviewed to gain an understanding of how the various building envelope assemblies and the division of the interior spaces were likely to influence the interior environmental conditions or be affected by them. Previous studies

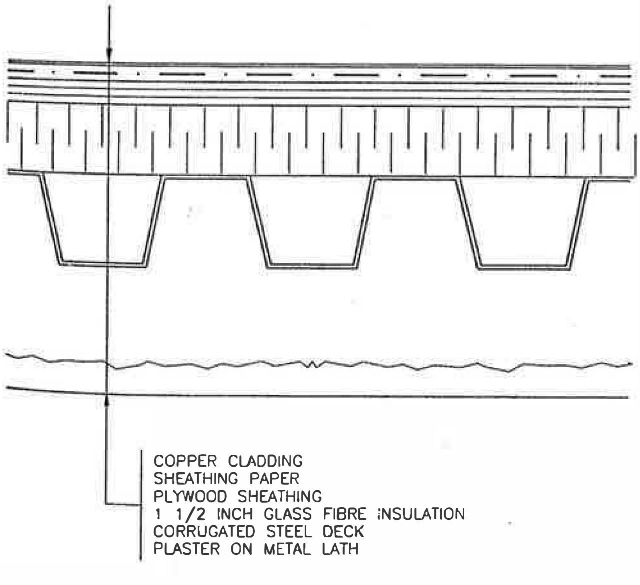

Figure 2 *Cross section of roof and lantern wall*

on the library were also reviewed to establish the existing condition of the building envelope and to identify past performance problems. These studies included detailed condition surveys of the various building elements (SHA 1994), which were helpful in identifying existing problems, and evaluations of the existing mechanical system (CEM 1994), which provided an overview of how the various areas of the building were mechanically served. Using this information, a preliminary analysis was undertaken.

Thermal and moisture gradients were calculated and simulations with a software program, which estimates the amount of moisture accumulation resulting from air leakage and vapor diffusion (Handergord and Trow 1994), were carried out to gain insight as to the condensation potential of various building envelope assemblies. The analysis of the basic thermal and moisture gradients indicated that, in the absence of air leakage, condensation could be avoided in most assemblies where the elements were exposed to the regular indoor temperature. However, where shielding reduced the ambient air temperature, condensation could be a problem. This was expected to occur at the top of the ringwalls in the low attic and dome space. The software program simulations indicated that the expected exfiltration would lead to condensation during the period between September and May. The calculated amount of condensation during the winter period was sufficient to saturate the sheathing materials in the cavity assemblies of the dome space and lantern walls.

Monitoring

The monitoring program was developed based on the use of small self-contained data loggers. This allowed flexibility of deployment as insight was gained into the variation of the environmental conditions throughout the library. Monthly site visits to download these instruments would also provide an opportunity to undertake a visual survey of specific building elements. These observations could be used to evaluate the results of the monitoring program and, hopefully, confirm established trends in the data.

Data were recorded at ten-minute intervals, and the downloaded data processed to provide hourly averages in a spreadsheet format. These data were plotted in two-week periods with the exterior temperature and dew-point temperature used as a guide to evaluate the response of the interior conditions to changes in the exterior conditions.

Interior Hydrothermal Conditions. Data loggers measuring local temperature and relative humidity were installed in the central area of the library at different heights, the adjacent perimeter areas, and the interstitial regions such as the attic areas as shown in Figure 3. In addition, the exterior temperature and relative humidity at the level of the lantern were also monitored. Measurements of the dry-bulb and wet-bulb temperatures were taken with a psychrometer at each location during each site visit to verify the accuracy of the relative humidity sensors. The psychrometer readings typically indicated a slightly lower relative humidity than that recorded

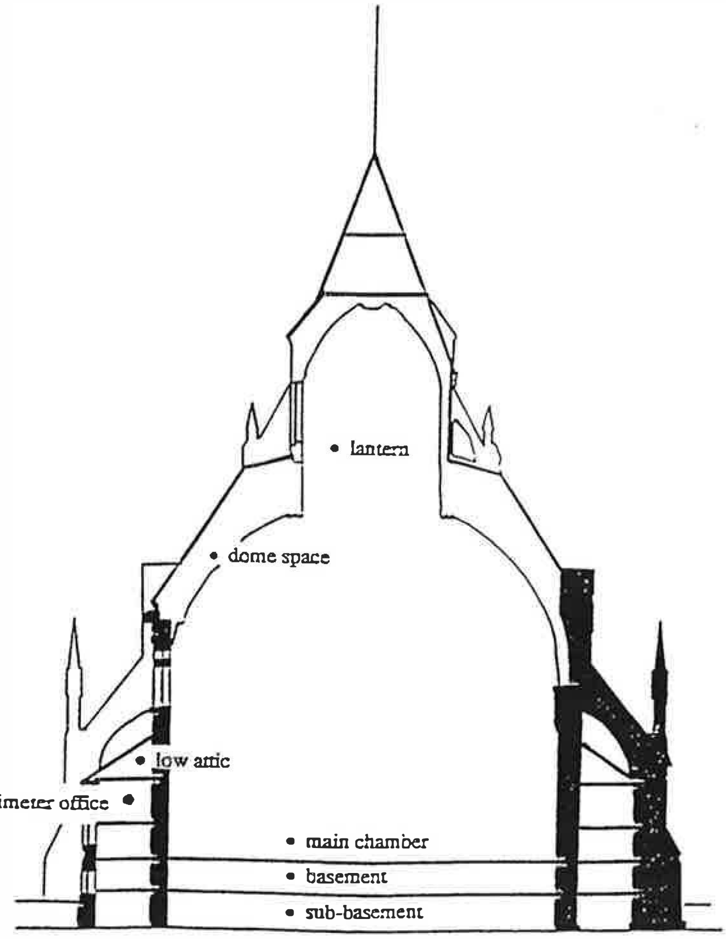

Figure 3 *Location of temperature and relative humidity sensors.*

by the sensors. This difference was typically within 5%, which can be considered fairly typical for this type of instrument.

Temperature and humidity readings were used to calculate the interior dew-point temperature at measured locations.

Pressure Differential. Three data acquisition packages incorporating two pressure transducers and a data logger were installed. The first two packages were installed in the dome space to measure the pressure difference from lantern to peak, lantern to exterior, and lantern to dome space, as illustrated in Figure 4. The third one was installed in a ground floor perimeter office to measure the pressure difference from perimeter office to exterior. The pressure transducers were disconnected and zero pressure readings were taken during each site visit to calibrate the readings.

Window Condensation. Two data collection packages, each capable of measuring seven thermistors, were used to monitor the microclimate in the general area of the window and record the surface temperatures of the glass, the frame, and the surrounding wall surfaces. The instrumentation packages were moved to different windows to obtain two or three weeks of data under winter conditions for each type of window.

Surface Condensation. To monitor assemblies susceptible to condensation, data acquisition packages connected to moisture sensors were installed to detect surface wetting on potential condensation planes. Initially, these instrumentation packages were installed on the inside face of the steel deck in the peak attic roof and lantern wall cavity (refer to Figure 2). When no condensation events were recorded after the initial winter period, the sensors were relocated to the inside face of the wood sheathing.

In addition, remote temperature and relative humidity probes were installed in the cavities of the main roof and the low attic roof.

An instrument package identical to those used on the windows and a remote temperature and humidity probe were also subsequently installed in the cavity housing the base of an iron roof truss. This measured surface temperatures on the iron truss and the adjacent masonry.

Stone Moisture Content. Moisture sensors were installed at two locations in the stone masonry at the base of the dome and at the base of the low attic. These consisted of a pair of brass pins installed in the masonry or stone. The resistance across these pins was measured with a standard resistance meter during each site visit. The lower the resistance, the

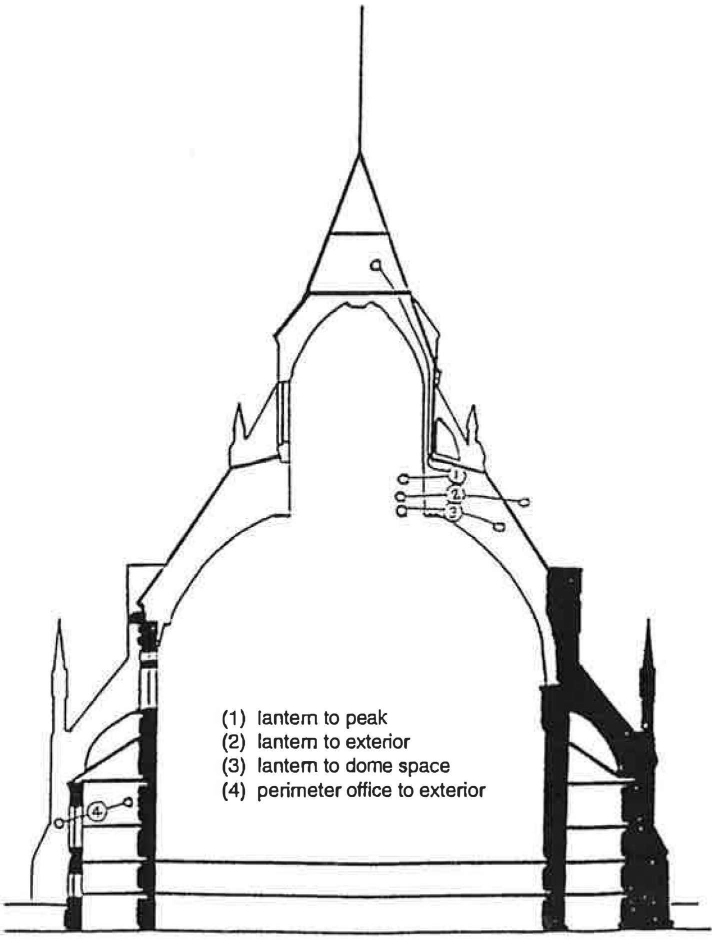

Figure 4 Location of pressure transducers.

higher the moisture level in the stone. The surface temperatures were also measured and compared to the dew point of the local ambient air.

FINDINGS

Existing Operating Conditions

The existing mechanical systems were set to maintain a stable indoor humidity of 35%-40% RH year-round. This was not being achieved, and the dominating factor appeared to be air leakage.

Interior temperature in the main chamber and stacks was relatively stable at 22°C. There was some daily cycling, but this was generally within the desired ±2°C range. Higher variations were noted in the lantern, which could be expected from solar effects through the lantern windows and temperature stratification. Relative humidity and dew point showed considerable cycling related to exterior temperature, especially during the winter months. In winter, when the exterior temperature was above −10°C, the relative humidity in the main chamber was relatively stable at approximately 35%. Below −10°C, the relative humidity in the main chamber fell, and at −20°C, it reached about 25% (Figure 5). Daily cycling in the main chamber and the perimeter was in the order of ±10%, whereas the basement stack areas were within the recommended ±5%.

During the summer period, when the exterior dew-point temperature was between 10°C and 20°C, the relative humidity in the main chamber was relatively stable at approximately 45%. Above 20°C outdoor dew point, the relative humidity in the main chamber rose to approximately 50%, and below 10°C, it fell to about 40% (Figure 6). Diurnal cycling of the relative humidity in the central areas of the library and the adjacent perimeter areas directly served by the HVAC system was generally within the recommended ±5%.

The pattern of variation was characteristic of a building with significant air leakage for which the existing mechanical system could not compensate.

- Indoor temperatures were relatively stable; however, fluctuations directly tracked changes in exterior temperature, especially at lower levels in the building. While the existing mechanical system could control temperatures most of the time, the occasional period of extreme cold caused a noticeable drop in the interior temperatures as the mechanical system struggled to compensate.
- The dew-point temperature of the indoor air remained

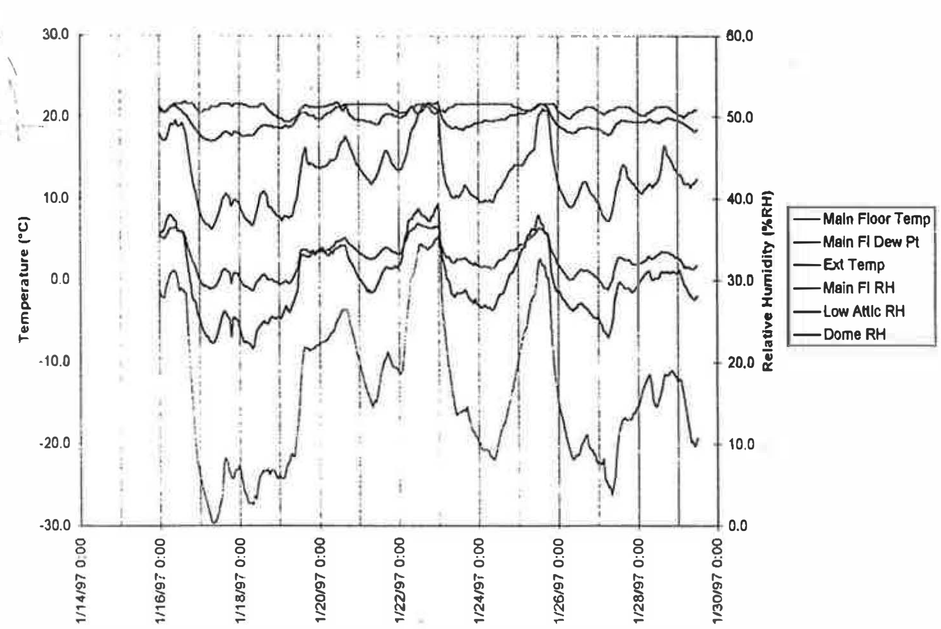

***Figure 5** Interior relative humidity during period of January 16 to 29, 1997.*

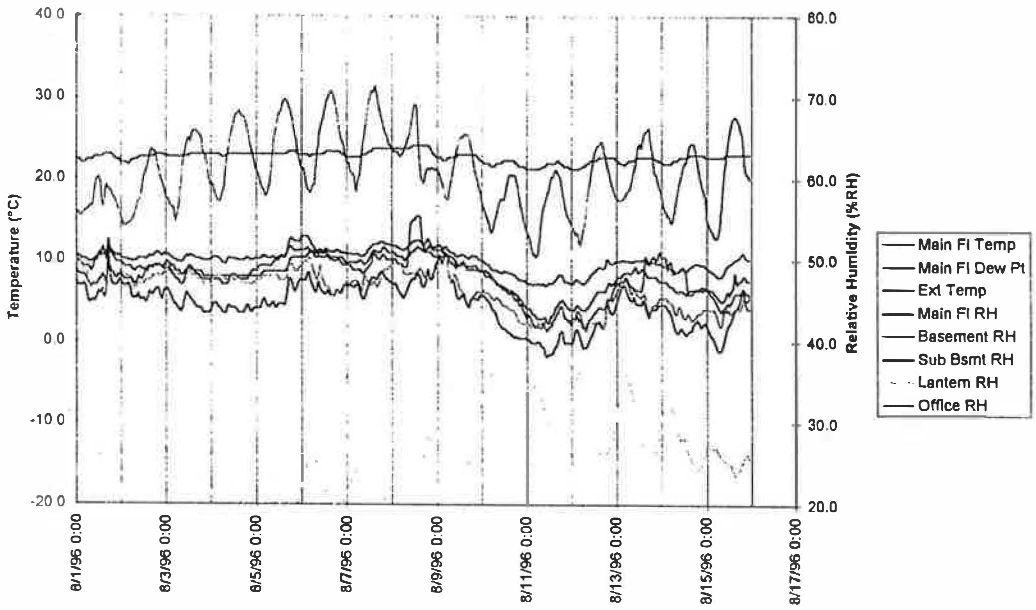

***Figure 6** Interior relative humidity during period of August 1 to 15, 1996.*

relatively constant throughout the library under moderate exterior conditions, but relative humidity and the dew-point temperature decreased sharply whenever the exterior temperature dropped below −10°C. This pattern was more pronounced in the main chamber and perimeter offices and more gradual in the low attic and the dome space. This suggests infiltration of dry cold air at the base of the building and the exfiltration of warm moist air in the upper sections and that the existing humidification system could not compensate for the moisture loss through exfiltration.

- The indoor relative humidity levels also varied in summer, and the pattern of change was very closely related to the outdoor dew-point temperature. This indicated that indoor conditions were also being driven by the entry of warm moist air in the summer and that the dehumidification systems could not maintain the desired relative humidity level.

Condensation Resistance of Windows

The existing glazing systems used for the main clerestory windows and the lantern windows appeared to be performing adequately. The combination of an interior single-pane window and an exterior lead glazed storm window on the clerestory windows performed as well as the double-glazed insulated units of the lantern windows despite the large air space between the storm unit and the interior glazing. Comparison of the surface temperatures of these windows with the dew-point lines for 30% and 40% relative humidity (Figure 7) showed that these windows could support 30% RH with only occasional periods of condensation but would experience frequent periods of condensation at 40% RH. This was supported by the fact that surface condensation on these units was observed on only one occasion during the winter period, which coincided with a site visit carried out during a period of sustained cold weather.

The wood frame perimeter office and basement windows were of similar construction, and comparison of the surface temperatures of these windows with the dew-point lines for 30% and 40% relative humidity indicates that they can support 30% RH with occasional periods of condensation but would experience frequent periods of condensation at 40% RH. The absence of surface condensation during the monitoring period may, in large part, be attributed to the air leakage observed between the sash and frame of these units. Infiltration of cold dry air around these units would have chilled the frames, but it also reduced the local relative humidity and dew point. There is some concern that if these units were sealed to reduce air leakage, higher local humidity might lead to an increase in the occurrence of condensation.

The data on the perimeter window that had been retrofitted with a vinyl frame interior insert showed that it could support 40% RH with only occasional periods of condensation.

The units that were the most susceptible to condensation were the stairwell windows in the perimeter areas of the library. These consist of a single-pane window with both an exterior lead storm window and an interior storm sash. Almost constant condensation was observed during the winter period on the central single pane and on the adjacent stone frame as a result of a loose-fitting interior storm sash. The interior sash reduced the temperature but did not prevent the infiltration of moist air. If the interior insert was made airtight, the occurrence of condensation could be greatly reduced.

Condensation Potential on Interior Surfaces

In general, there was limited evidence of condensation formation on the mass stone masonry exterior walls exposed to indoor temperatures. However, we did observe some frost formation on exposed buttresses in the low attic and interstitial dome space, as well as the stone mullions and window trim of the stairwell windows, which represented a direct thermal bridge to the exterior.

Interstitial Condensation

Preliminary computer simulations had indicated that air leakage during the winter months would result in condensation in the outer elements of building envelope assemblies that incorporated a cavity or were protected from interior heat. One such large interstitial space was the area between the interior dome and the exterior roof assembly. The plaster dome provided little vapor diffusion resistance but did restrict heat flow to the dome space and peak attic. After factoring out the wind effects, a 10 Pa pressure difference measured across the dome ceiling indicated that it had significant resistance to airflow. Furthermore, this pressure difference indicated that stack forces across the main roof were depressurizing the dome space relative to the interior.

The monitoring of the stone moisture content indicated that the exposed masonry at the top of the ring walls inside the dome space was consistently near saturation during the winter

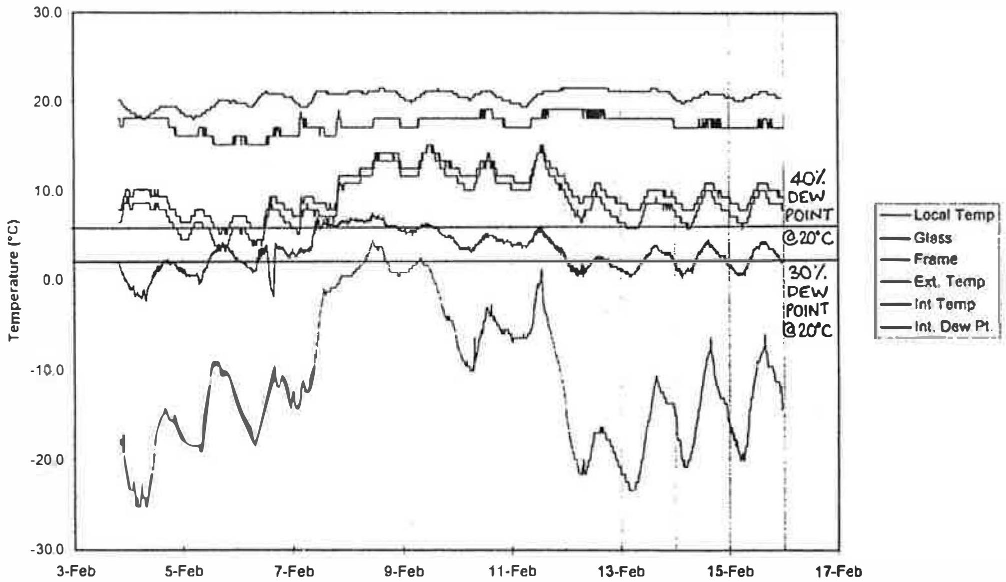

Figure 7 *Surface temperature of clerestory windows during period of February 1 to 15, 1996.*

period. Together with measurements of surface temperatures below the dew point of the ambient air, visual observations of surface water and frost in cold weather presented strong evidence that the current indoor environmental conditions can be linked to high moisture contents and surface condensation in localized areas of the masonry walls.

The cavities in the main roof, low attic roof, and lantern wall assemblies were also instrumented. The cavity temperature and dew-point temperature in both the main roof and low attic roof assemblies were generally very close to the ambient interior air temperature. The calculated temperature index of the main and low attic roof cavity, a normalized ratio of the cavity temperature and the interior and exterior temperatures, showed a gradual rise with respect to the pressure differential across the envelope, as illustrated in Figure 8. This can be interpreted as an indication of air leakage across these assemblies. The cavity temperature is raised by exfiltration of warm indoor air across the envelope. Furthermore, judging from the slope of the trend line, the amount of air leakage was substantial.

There was visual evidence of damage caused by condensation in the envelope assemblies containing cavities. Ice formation was observed in the insulation of the roof and lantern wall assemblies. The bases of the main and low roofs are areas of noted stone deterioration, which could be attributed to wetting from water exiting the roof assemblies. Localized moisture damage was also observed in the interior fireproofing of the peak attic and dome space, where condensation runoff from the roof assemblies had found its way through perforations in the steel deck.

IMPLICATIONS

The monitoring program has revealed that stack force-driven air leakage exceeded the humidification capacity of the existing system. To maintain a constant humidity at the desired levels, it would be necessary to either add humidification capacity or control air leakage.

However, despite the reduced relative humidity levels during periods of extreme cold, there was evidence that the current environment was having a detrimental effect on localized elements of the building envelope. Condensation problems were occurring on interior surfaces of the ringwalls where heat flow was restricted as well as within the roof and lantern wall assemblies as a result of air leakage through the envelope. These conditions have caused localized problems in the upper part of the masonry ringwalls and the roof and lantern wall assemblies. In the sheltered interior environment, the deterioration was currently limited to minor surface deterioration of the exposed masonry with the potential for corrosion at the base of the iron truss. However, in the harsher exterior environment, condensation runoff from the roof assemblies likely played a significant role in the accelerated deterioration of the masonry at the eaves and may also adversely affect the stability of the core of the ringwalls.

In the short term, continued operation under these conditions should have only minor implications for the building envelope. However, condensation in the roof and lantern wall will continue to be problematic and, in the long term, the slow but gradual deterioration observed at the top of the ringwalls will eventually result in irreversible damage. Increasing the humidity during the winter period without addressing air leakage issues would only exacerbate these problems as well as increase the occurrence of surface condensation problems on the various window assemblies.

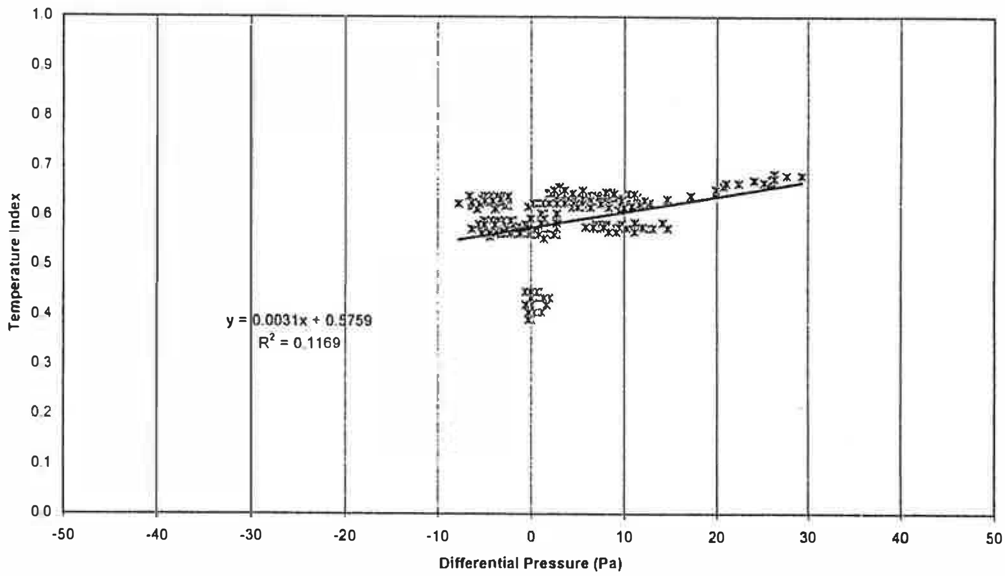

Figure 8 *Nightly temperature index as a function of pressure differential across the low attic roof assembly during period of February 16 to 27, 1996.*

To operate under these conditions without adversely affecting the long-term durability of the building envelope would require the following interventions:

- Undertaking measures to control or reduce air leakage through the roof and lantern wall assemblies or, at a minimum, carefully review the design and existing condition of the waterproofing and flashing details in the roof assemblies to ensure condensation runoff from the roof assembly is drained away from the top of the masonry ringwalls and the numerous projections such as buttresses and pinnacles. While some reduction of air leakage and condensation in the roofs could be achieved by sealing interior surfaces, elimination of condensation will probably require removal of the copper roof and installation of a membrane at the roof deck plane.
- Providing additional heat and/or insulation to exposed envelope elements susceptible to surface condensation. The area of greatest difficulty to address is the top of the ringwall at the base of the dome space. In all probability, this could be easily addressed by providing perimeter heat in this area. The heat source could be entirely hidden in the dome space.
- Undertaking basic window repairs but without major intervention.

The assessment explored the various physical interventions that would be required to operate with a variety of more severe environments.

Operating at 20°C and 30%-50% RH Adjusted Seasonally

The current operating conditions in the library are very close to the least restrictive of the environments proposed for archival conservation, 20°C and humidity of 30%±5% in winter and 50%±5% in summer with gradual adjustments through the shoulder periods.

It is possible that the measures outlined in the previous section and a program of limiting air infiltration and exfiltration (weatherization) could reduce stack force-driven air changes to the point that existing humidification capacity could achieve this condition. However, it is anticipated that some modification of the HVAC system to increase humidification capacity in the coldest weather would be required. In milder winter weather, the system could be set to reduce humidification to maintain a stable 30% relative humidity level. Without an upgrade in capacity, the relative humidity levels would have a tendency to move down toward 25% as the exterior temperature fell below −20°C. However, these conditions represent only a small percentage of the total hours during the winter months and are not generally sustained for a long period.

Some upgrade of the air-conditioning/dehumidification system would also be required to stabilize summer humidity levels. The existing systems allowed variation from about 40% to 50% depending on the outdoor dew-point temperature. The higher value occurred when outdoor dew-point temperature rose above 20°C, which, once again, represents only a small percentage of the total hours during the summer months and is unlikely to be sustained for long periods.

The higher humidity in conditions of extreme cold would exacerbate the condensation-related envelope problems occurring under the existing operating conditions. It is our opinion that if this environment were specified, the measures outlined in the previous section would become mandatory but no further major interventions would be needed. It would be advisable to accommodate additional window condensation by providing simple measures such as condensation gutters.

Operating at 30%-40% RH Adjusted Seasonally

A stable relative humidity of 30%±5% in winter and 40% ±5% in summer with gradual adjustments through the shoulder periods was identified as the second most desirable option for archival preservation. The winter condition is the same as described above, and the measures outlined in the previous sections would be required. In addition, a substantial modification to air-conditioning/dehumidification systems would be required to increase the dehumidification capacity of the system in order to maintain 40% relative humidity during the summer period.

An alternative worth examining is to maintain the relative humidity at a stable 35%±5% during the winter period and operate at 45% during the summer. This keeps the same 10% annual range in humidity set points and reduces summer dehumidification requirements. The data indicate that operating at 35% is practical if the air leakage across the roof and lantern wall assemblies is addressed and envelope elements susceptible to surface condensation have been properly addressed. An increase to 35% relative humidity in winter should not adversely affect the exterior masonry walls. A 35% relative humidity winter condition appears to be the upper boundary of what the existing window systems could handle after basic rehabilitation.

Operating at 40% RH Year-Round

To achieve the optimal operating conditions, identified for archival artifact preservation as 40%±5% year-round, would require more intensive physical interventions than outlined in the previous sections. In addition, the retrofitting of the existing HVAC system to increase both the humidification and dehumidification capacity would be required.

The data indicated that above 35% relative humidity, frequent periods of condensation would be expected on windows and would likely exceed the capacity of a simple condensation gutter. A substantial upgrade to the existing window systems or providing direct heat to the windows would be required to operate at 40%. This would be a major intervention.

Operating at 40% relative humidity during the winter would also greatly increase the risk of localized problems. The retrofit of the existing interior air barrier of the exterior wall would be crucial and, in some locations, this may require the removal of existing finishes. Special attention would have to be given to the connection of the retrofitted interior air barrier of the exterior walls and the new exterior applied air barrier of the roof and lantern assemblies.

SUMMARY

The monitoring program found that the envelope of this complex mass stone masonry heritage building was supporting a humidified environment with few major problems. Air leakage was limiting the ability of mechanical systems to maintain the desired level and stability of relative humidity, and the relative humidity was causing some long-term deterioration. If measures required to protect the envelope from existing operating conditions were implemented, it could sustain a slight increase in the severity in the indoor hydrothermal environmental conditions to levels that were considered desirable, if not optimal, for archival artifact preservation.

REFERENCES

CEM (Chiarelli Engineering Management Ltd.). 1994. HVAC study of perimeter offices, Library of Parliament.

Handergord and Company Inc. and Trow Engineers. 1994. *EMPTIED.*

LAA (Lundholm Associates Architects). 1995. Technical standards for library accommodation.

SHA (Spencer Higgins Architect Inc.). 1994. Report on the conservation of the exterior facade and related work.

BIBLIOGRAPHY

Brook, M.S., Morrison Hershfield Ltd. 1992. Infrared thermographic survey, Parliamentary Precinct, Library of Parliament.

Kerr, G., L.C. Nguyen, and A. Edge. 1995. Productive Working Environment Division, Technology Services, Architectural and Engineering Services, PWGSC. Indoor Air Quality Survey, Library of Parliament, Ottawa, Jan.-Feb.

Michalski, S., Canadian Conservation Institute. 1985. EDR. Report No. 1512, Tour of the Library of Parliament.

Spencer Higgins Architect Inc. 1990. Inspection report on the condition of the exterior fabric of the Library of Parliament, Ottawa.

Spencer Higgins Architect Inc. 1992 Library of Parliament, conservation of exterior facade, Vol. 2.

Wong, J., and R. Allard. 1995. Maintenance Engineering, Technical Services Division, PWGSC Air Quality Testing Report, Centre Block Library Area.