

ENVELOPE DURABILITY PROBLEMS IN HIGH-HUMIDITY BUILDINGS

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ABSTRACT

This paper examines envelope durability problems in high-humidity buildings such as museums and those containing swimming pools by presenting a series of brief case studies. All buildings are located in cold-climate areas within Canada.

Moisture damage found could, for the most part, be

attributed to the exfiltration of moist air into cavities outside the insulation layer of the envelope assemblies. The building envelope failures occurred due to problems in design and construction of the building envelope and operation of the building's mechanical systems.

INTRODUCTION

High-humidity buildings in cold Canadian climatic zones provide a serious challenge for building envelope design teams. Operating conditions for building humidity and the possible mechanical pressurization of the building during operation must be balanced against the cost of the building envelope, its constructability with average labor, and its serviceability over time. Often, too little emphasis is placed on critical transition details to provide a continuous, structurally supported air barrier.

CASE #1

The first example comes from a recreation facility, constructed in 1975 in central Canada, whose major feature is a swimming pool. The building is maintained at approximately 45% relative humidity (RH). Building operations staff attempt to maintain a slight positive interior pressure relative to the exterior to control cold drafts. The building has an upper roof deck and sections of lower-level roofs, some flat and some sloped.

Performance Problems

Two of the indications that there were serious envelope problems with this building were the observation of ice formation emanating from the back side of the steel cladding (photo 1), particularly at the base of walls between upper and lower roofs, and water dripping into a visitor's gallery at a location in line with clear-story glazing above. Figure 1 shows a schematic of the typical roof wall intersection of parapet and clear-story glazing. A conventional asphalt roof is seen meeting a metal wall system at the parapet.

Site Observations

Thermographic scanning provided evidence of air leakage along the upper parapet at the junction of the sloped roof to wall and at locations on the wall cladding.

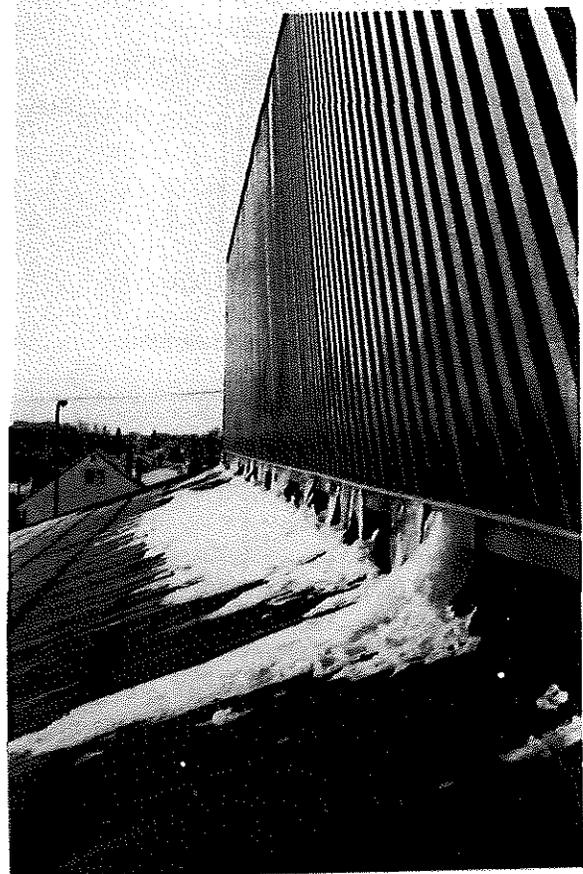


Photo 1 Ice formation emanating from the back of the steel cladding.

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A test opening (photo 2) was conducted, under early winter conditions, to determine the condition of materials within the wall and the parapet.

Inspectors noted that the wall insulation was frozen to the metal cladding. In reviewing the construction of the interior metal liner system (photo 3), the authors found that foam tape had been used in an attempt to seal the joint between the upper channel and the liner and that vertical liner joints were left unsealed. Insulation over the joints was blackened by dirt filtered out of

air moving through the joints. The material under the parapet cap flashing was saturated (photo 4), and at the base channel of the metal wall, water was trapped and soaking the insulation (photo 5). Some corrosion of metal elements was evident.

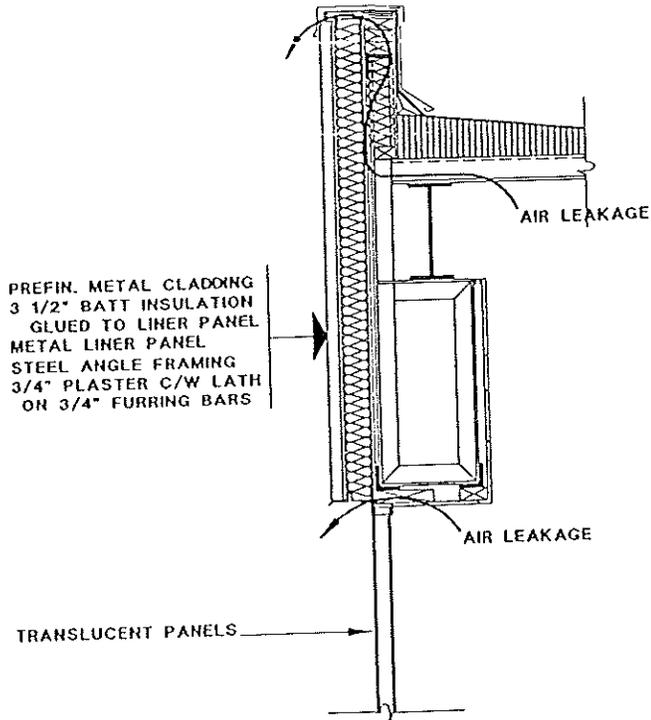


Figure 1 Roof wall schematic.



Photo 3 Unsealed linear joints.

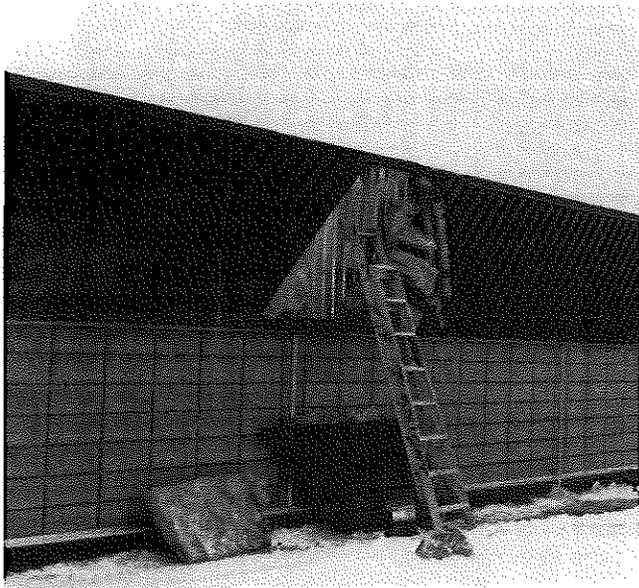


Photo 2 Test opening above spectators gallery.



Photo 4 Saturated materials and standing water at roof parapet.

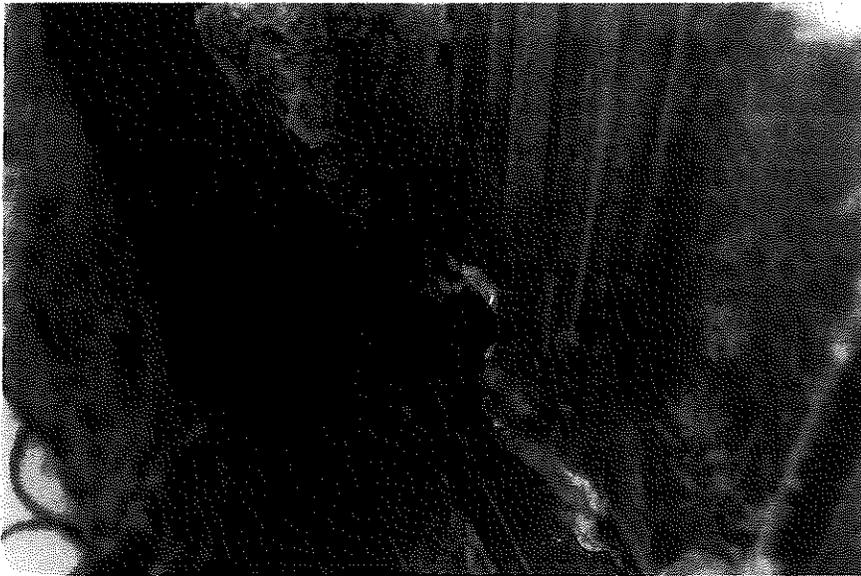


Photo 5 Saturated materials and standing water at roof/wal junction.

Analysis of Observations

The foregoing assembly provides a graphic illustration of the effects of air leakage from a high-humidity building. The inner liner was not adequately sealed to either itself, the roof membrane at the parapet, or the window assembly below. The exterior metal cladding provides an impervious cold surface upon which water vapor can condense and freeze. In this particular case, the large volumes of condensate were not drained from the assembly at the lower wall intersection. This provided the conditions for material failure through corrosion, the loss of R-value due to water-soaked insulation, and reduced functionality of the space due to water dripping.

Remedial measures are expensive because most involve complete disassembly of the system. Connecting an air barrier membrane to a V-ribbed liner sheet is difficult because of the profile. A combination of peel-and-stick membrane mechanically clamped with a strip of heavier gauge metal with the same profile may be successful. At the base, a positively drained flashing is required to redirect condensate or rain water to the exterior of the finished cladding.

Design lessons to be learned include the following.

- Metal cladding wall systems will collect condensation water on the back side of the cladding. Provision must be made to drain this water in a harmless manner.
- Metal-to-metal joints are not inherently airtight.
- It is difficult to design and construct a durable detail to seal a V-ribbed metal wall liner to the roof air barrier (the roof membrane).

CASE #2

The second example comes from the same city as the first. It is another recreation complex with a swimming pool being a major element. The building was constructed

in 1972 with an addition in 1978. The exterior walls are 200- and 250-mm (8- and 10-in.) concrete block, with a 90-mm (3.5-in.) cavity with semi-rigid fiberglass adhered to the exterior of the structural block with an asphalt air/vapor barrier. The exterior is 100-mm (4-in.) fluted concrete block. The design concept of the later addition was the same but the materials varied slightly. Expanded polystyrene insulation was used and a mastic-type adhesive was specified to form the air/vapor barrier, as well as attach the insulation.

The pool is operated at 24°C (75°F) and 67% relative humidity. At the time of the review, the indoor pressure at ground level was measured at 4 pascals (Pa) below exterior.

Performance Problems

The exterior concrete block cladding on this structure is experiencing significant displacement near corners and parapets where mortar is in very poor condition. At the upper pool roof/wall junction, mortar was found to be wet and friable. In some locations, upper courses had settled to contact the course below (photo 6). The block is

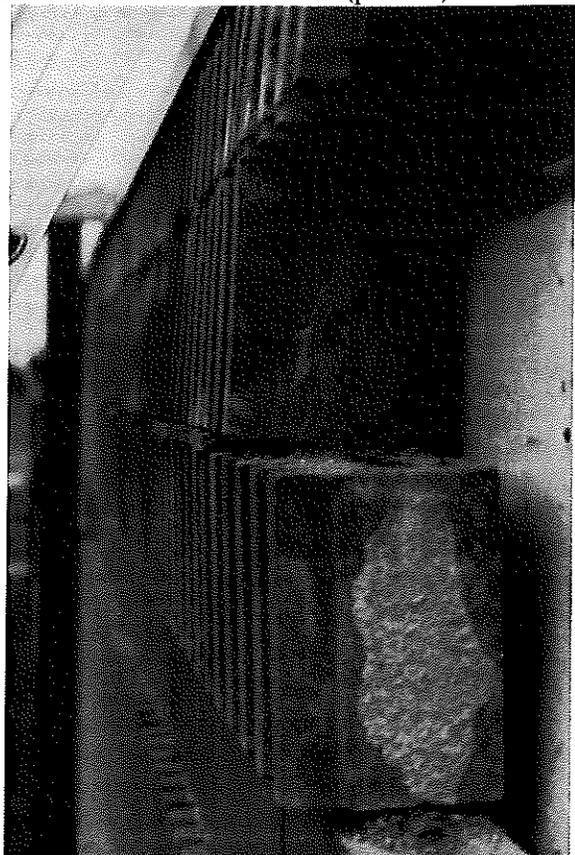


Photo 6 Deteriorated mortar leaves blockwork unstable.

visibly wet, fractured, and approaching an unstable condition in some areas (photo 7).

Site Observations

Once again, the authors conducted both a thermographic scan and test openings to establish the existing conditions. These were done in winter conditions.

The thermographic survey provided characteristic signatures of air leakage at the roof-to-wall junction of the main pool building and at connections between the pool and the administration area below. Smoke pencil testing confirmed these leakage sites. Observations from within the swimming pool included dust patterns on the interior acoustic insulation indicative of diffuse leakage through

the interior wythe of concrete block. Several test openings revealed serious masonry damage associated with air leakage paths.

Some attempt had been made to seal the roof/wall interface. Neoprene flute closures were observed in the lower flutes of the metal roof deck. Where the flutes were oriented parallel to the exterior walls, a mastic-type sealing strip was placed along the flute above the inner surface of the wall. Both these air-sealing elements were in line with the inner face of the block rather than the exterior surface, which was the surface treated to be an air barrier. There was no attempt to seal the upper flute openings above the deck. The authors found large quantities of warm air leaking out of the wall-to-deck interface (photo 8). The fiberglass insulation and wood elements of the parapet detail were wet. It was also noted that the coverage of the asphaltic and mastic air/vapor barriers was thin and incomplete.

Another test opening was conducted at the intersection of the lower administration and service area roof and the wall above (photo 9). At this location, mortar had no consolidation, the concrete block was fragmented, and the insulation was wet. In addition to air leakage at the roof-wall junction above, the authors found air leaking from behind the through-wall flashing, which was not sealed to the inner block wall. When the construction was reviewed from within the ceiling space of the administration area below, we found the heated space below was connected to the wall cavity above via a layer of fiberglass insulation (photo 10 and Figure 2).

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Analysis of Observations

Block and mortar damage observed in this building can be attributed to air leakage, condensation collection, and subsequent freeze/thaw damage. The deterioration is so great that structural failure of the facade is very likely. Certain design features intended to protect the envelope from high humidity were included in the original design (such as mastic-type vapor barriers and metal deck closures) but they have proven to be ineffective. The degree of air leakage at the roof/wall interfaces was significant at all test opening locations and appears to be the primary source of moist air in the cavity. Diffuse air leakage and vapor transmission through

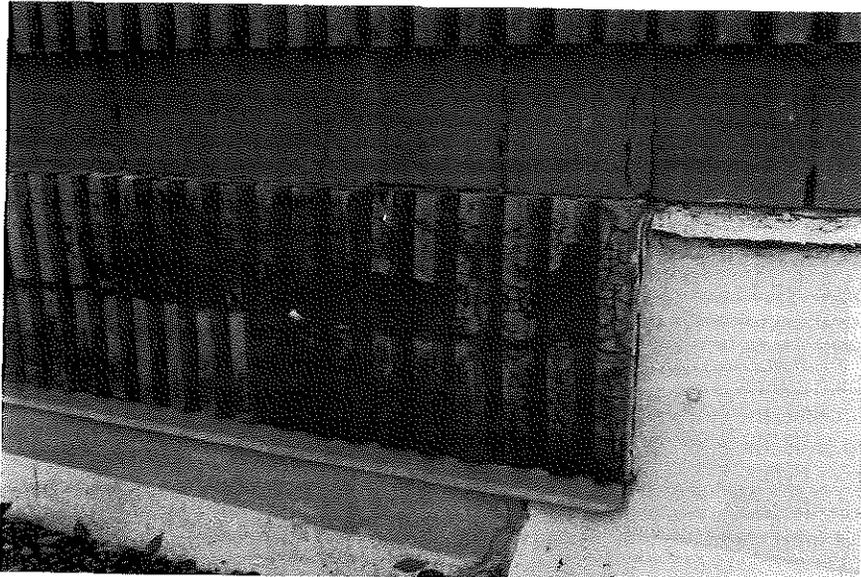


Photo 7 Badly fractured concrete block cladding.

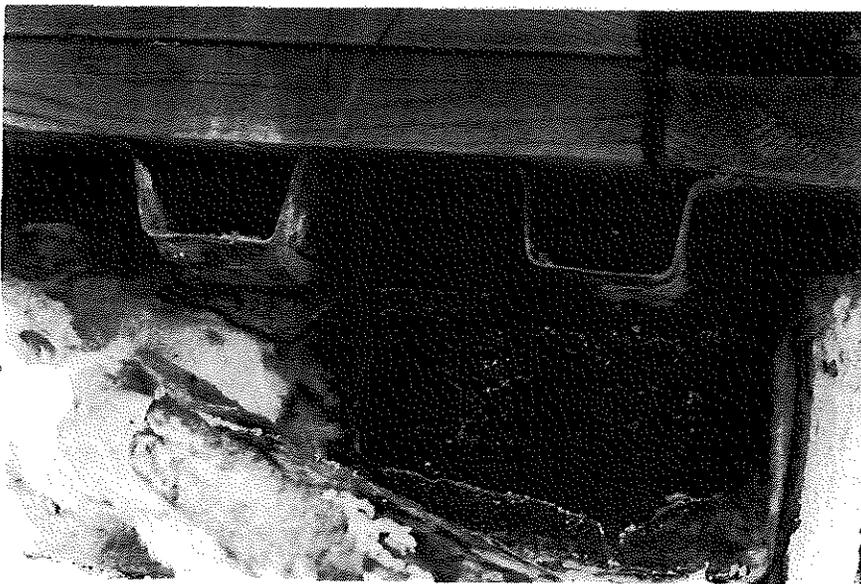


Photo 8 Roof wall connection.



Photo 9 Showing poor condition of masonry and air leakage from top of flashing.



Photo 10 Wall/lower roof intersection showing lack of air seal at junction.

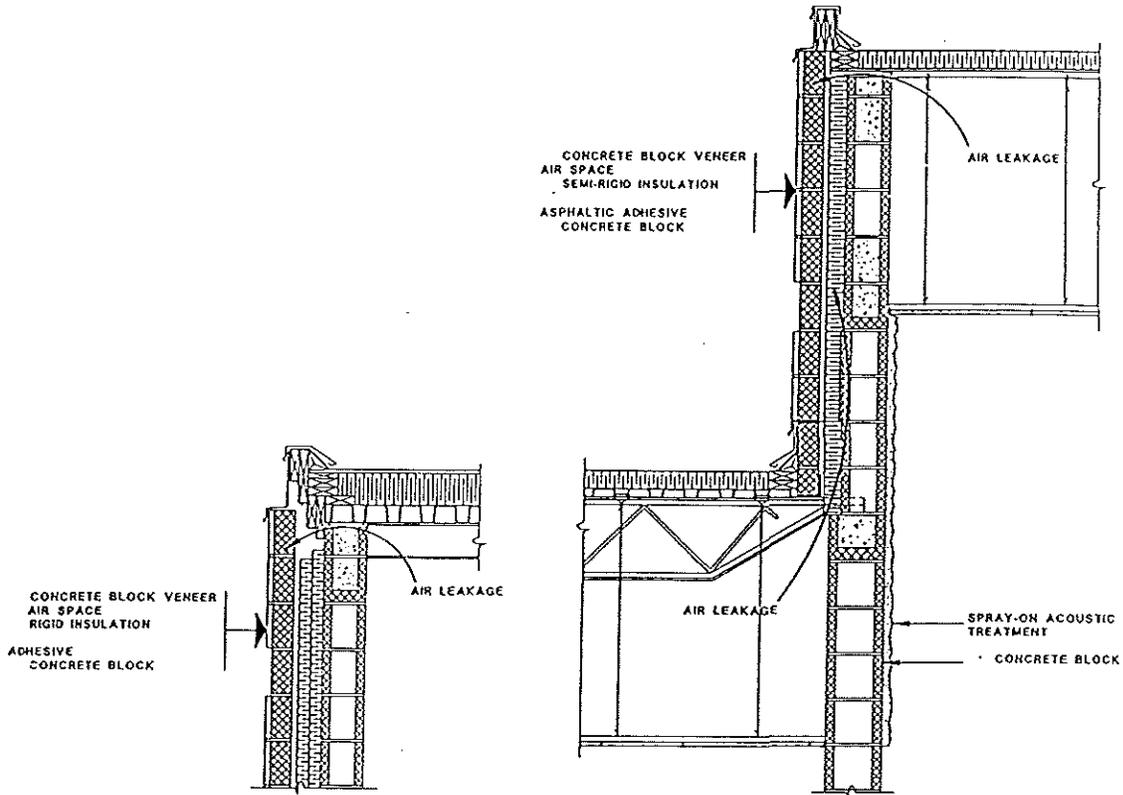


Figure 2 Test opening above spectators gallery.

the block interior walls and an incomplete mastic-type air/vapor barrier is a secondary, but possibly significant, source of moisture (Figure 2).

Because the exterior cladding has deteriorated to the point of failure, remedial plans include its removal and the installation of a complete air barrier on the outer surface of the structural block wall. The roof membranes can be directly connected to the new air barrier to make this connection continuous.

Design lessons to be learned include the following.

- The difficulty in providing continuity at joints and penetrations in fluted metal decking makes it an inappropriate material for consideration as an air barrier. Wall-roof interfaces should be based on providing continuity between the roof membrane and the wall air barrier. This requires addressing the flute troughs above the deck or, better still, carrying a membrane over the edge of the deck.
- Particular design attention has to be placed on providing continuity where a lower roof connects to a wall.
- Creating an acceptable air barrier with trowel- or spray-applied air/vapor barrier materials requires special attention to joint design and construction quality control. Membrane-type connections should be used at joints between adjacent structural materials, at intersections between walls and roofs, and at all penetrations. These require structural support and complete continuity to maintain airtightness under air pressure gradients. The thickness of trowel- or spray-applied mastics must be carefully monitored during construction to ensure the resulting membrane has both the required permeability and resistance to air leakage.

CASE #3

The third example deals with another common problem area—soffits or overhangs under heated space. This specific example is a recently constructed museum in central Canada. The indoor environment of the museum is tightly controlled at a temperature of 22°C and a stable humidity level of approximately 45%. The building is operated at a positive pressure relative to outdoors, primarily to eliminate the possibility that the infiltration of unconditioned outdoor air would affect the perimeter environment or bring in contaminants. The fact that air movement, condensation, and moisture collection could be a problem was recognized at the design stage and a continuous air barrier, made up primarily of a torch-on bituminous membrane, was specified for the entire building.

Performance Problems

In spite of the attention to providing an air barrier, there have been some areas where moisture collection problems with the building envelope have occurred. One that caused special concern is at a series of overhangs on the front facade of the building. Under winter conditions, icicles were found to be collecting at the inner and outer perimeters of the soffit and at potlight assemblies installed in the soffit (photo 11). The soffits are directly over pedestrian areas, thus raising safety concerns. The museum had to resort to using a worker in a manlift to remove the more significant icicles.

Site Observations

The construction of the soffit assembly and housing for the potlights is shown in Figures 3 and 4. In general the torch-on air barrier membrane is adhered to a cement board substrate. A high level of insulation is provided by

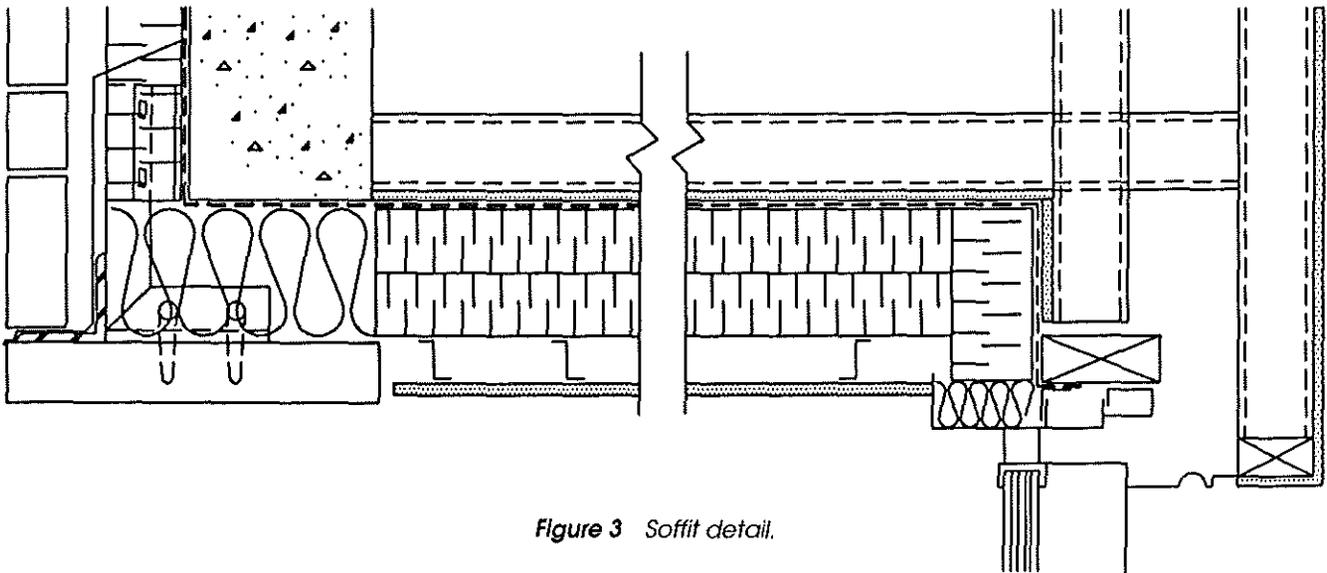
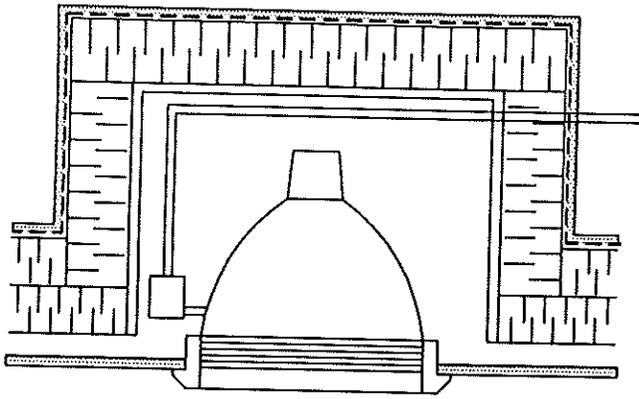


Figure 3 Soffit detail.



Note: Draft - to be redrawn for simplicity and clarity

Figure 4 Potlight housing.

3 inches of extruded polystyrene. The exterior finish is cement board exterior mounted on Z-girts, such that there is a 1-in. air space between the cement board and the insulation, which is vented to the exterior at the outer perimeter of the soffit. The potlight housing was fabricated from cement board lined with the torch-on membrane and insulated with 1½ inches of extruded polystyrene.

Investigation of the problem included removal of several soffit sections to determine the source of moisture to the ice collection points. It was found that the construction was in general conformance with the

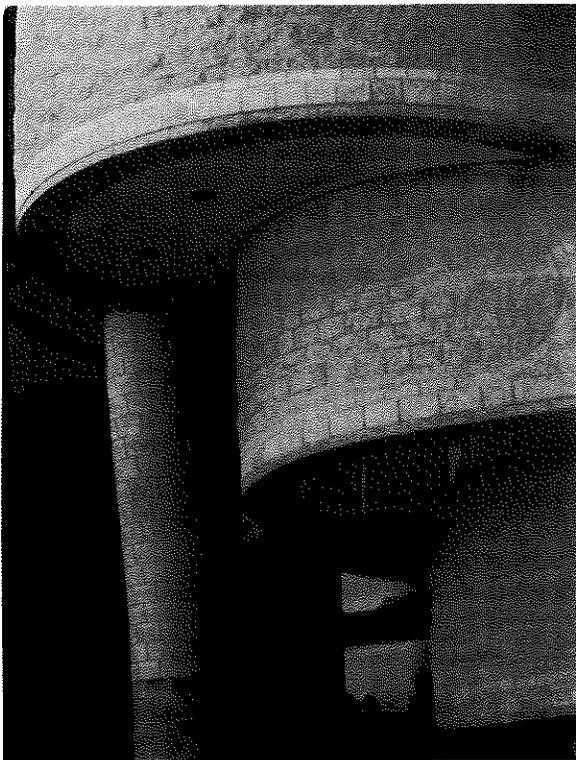


Photo 11 Icicle collection at soffits.

design details. There were, however, a number of imperfections in the air barrier assembly that were sources of exfiltration, as demonstrated by smoke testing. These included the following:

- At corners of the potlight housing assemblies (photo 12).
- Through and around the electrical conduit serving the potlights (photo 12).
- At the head end of the split mullions of the strip windows on the inner perimeter of the overhang. It was found that the membrane used to seal between the mullion sections was located on the inside of the mullion and no provision was made to transfer the plane of airtightness to outside the structure, where the wall and soffit air barriers were located.
- At unsealed screw holes, which appeared to have been drilled from above during construction to identify attachment locations for Z-girts supporting the exterior soffit finish (photo 13).
- Some poor seals at laps between adjacent sheets of air-seal membrane. In the test opening areas these did not appear to be major air leakage points but they could have been a problem in other locations.

The general condition of materials in the soffit was good except for the potlights themselves, which showed heavy corrosion considering their short service to date (photo 14).

It was also found that the level of pressurization across some soffits was higher than the average building pressurization, due to duct leakage in enclosed service spaces above the soffits. Some quantification of air leakage was done by using plastic bags to collect air leakage for a known time and pressure difference. This indicated that the most significant air leakage points were those at the corner of the potlight housing and the window head, which appear to be contributing approximately the same amount of air leakage and moisture load to the soffit.

Analysis of Observations

One of the most important lessons from this investigation is how important heat flow factors are in condensation-related problems. By virtually any normal standards, the overhang assembly used at this museum was "tight." However, the high levels of insulation meant that a very limited amount of heat flows into the vented space of the soffit. This increases potential for moisture collection in two ways. The soffit vent space is at or near outdoor temperatures, so any humidified air leaking out can find a condensing surface. The ability to remove water from the space by venting is also reduced because without the benefit of added heat, the drying capability of outdoor air is very limited.

In this particular case, the use of moisture-tolerant materials reduced the durability impact, but the prob-

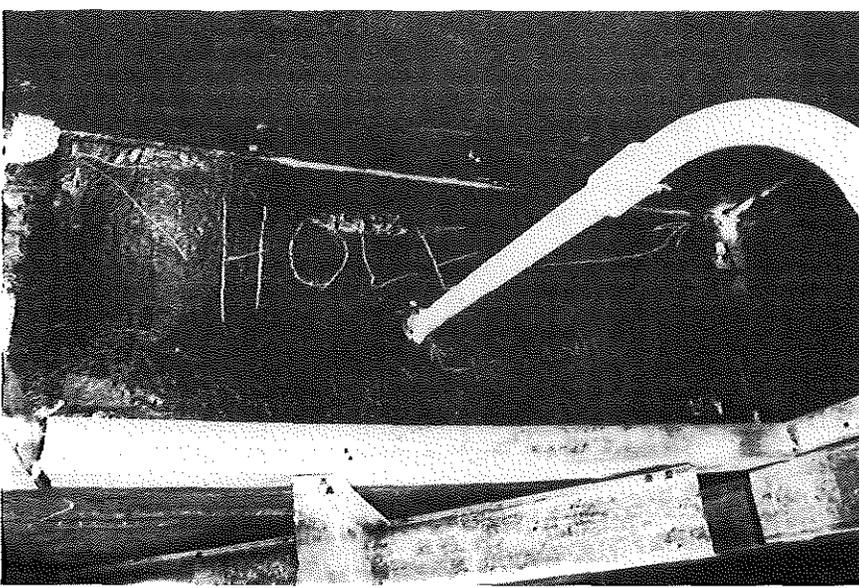


Photo 12 Opening in air barrier membrane at corners of potlight housing. Note that there is no seal at the PVC conduit penetrating the air barrier membrane.

lem manifested itself as a major liability concern with icicle collection over pedestrian areas...

- Museum authorities and mechanical engineers were not receptive to the suggestion of exploring the concept of operating the building at negative pressure to minimize or eliminate exfiltration. Measures have been taken to reduce the level of pressurization, particularly where duct leakage into enclosed spaces was elevating

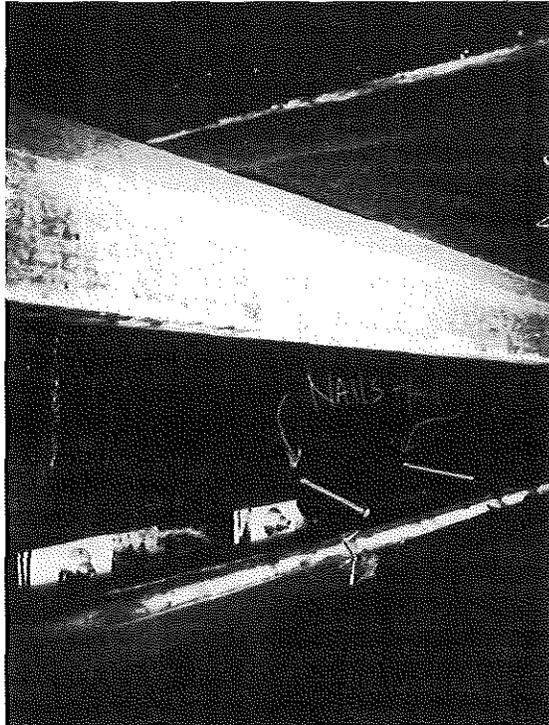


Photo 13 Air barrier leakage points included open screw holes and leakage from window vertical mullions and corners at potlight housing.

it. Remedial action plans also include removal of the exterior finish and insulation of all affected soffits and sealing all identified leakage points.

Design lessons to be learned include the following.

- The better the insulation, the more critical it is to control exfiltration, especially small concentrated leaks.
- Designers of air barrier details must think in three dimensions and provide methods of maintaining continuity between all elements that make up the air barrier.

CONCLUDING COMMENTS

In general, the materials used in the case studies presented here are available and commonly used in current construction. They are likely to meet current standards for material durability. The materials failed in service because the envelope systems of which they formed a part did not adequately control the leakage of moist air from the interior of the building to the cold exterior wall cavities. In all of the examples, the designers were cog-



Photo 14 Corrosion of potlight filter..

nizant that air leakage was an important design requirement and some air leakage control elements were provided in the design of the building envelopes. Obviously, the design and execution of key details was not adequate to control durability problems.

Some people would argue that the construction industry has improved its knowledge and methods. Indeed, the concept that high interior humidity, air leakage points, and exfiltrating pressures result in moisture and durability problems is hardly surprising. However, the authors would note that in practice we see very similar design details employed in current designs. The key difference in the example buildings presented here and many buildings being constructed today is simply the time it takes for the problems to appear. The industry has yet to find ways of addressing the concern in a consistent manner.

Some general conclusions to be drawn from these examples include the following.

- Mechanical pressurization of building envelopes that are required to maintain high relative humidity must be kept at an absolute minimum. We find that the conventional design and operating logic for mechanical systems in large buildings is to pressurize the building to avoid the cold drafts and perimeter-zone heating problems. This may avoid these important and immediate problems but at the expense of longer term durability problems.
- The lack of intentional pressurization did not negate the need for air barrier continuity. In example #2, the nor-

mal operating pressure is slightly negative at ground level. There was still air leakage at the wall roof interface, which would be at positive pressure under the influence of stack and wind forces.

- Operating buildings at higher negative pressures is contrary to the design thinking of most designers, and they will need convincing that it is a valid design approach. Negative-pressure operation still requires attention to airtightness to avoid cold drafts and perimeter-zone heating problems and may require special measures such as vestibules at entrances.
- A common factor in the examples was the lack of continuity of the air barriers at the interface between different assemblies and materials and, to a lesser extent, the joints between similar materials. Wall-roof interfaces were a common location of problems because of the potential for large leakage areas and high exfiltrating pressures.
- The specific problems discussed were related primarily to design, detailing, and material selection rather than poor construction.
- Early signs of damage, including mortar loss, wetting patterns, or efflorescence, should be investigated and remedial action taken before serious problems develop.

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