Feature

Best Practices for a Successful Natatorium Enclosure

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INTRODUCTION

The indoor environment of a natatorium (indoor pool) presents one of the greatest moisture-related durability challenges to enclosures in cold climates. Temperature and relative humidity levels are elevated compared to typical commercial indoor environments (for example, living spaces and offices), resulting in a high indoor dew point. In high-humidity environments, the building enclosure is often subjected to interstitial condensation and moisture accumulation on indoor surfaces. These conditions often result in premature enclosure failures and, in serious cases, structural damage. This paper reviews strategies for successful natatorium enclosure design and construction as well as high-level design considerations for HVAC equipment. Other challenges and considerations for indoor pool environments, such as indoor air quality and corrosion of metals in the pool space as a result of chlorine exposure, are also important to the operation of a pool building, but these are not the focus of this paper.

Over the last two decades, we have participated in over two dozen projects involving the design or forensic investigation of pool buildings and other spaces that are characterized by high indoor temperatures and high relative humidity, resulting in high dew points. In most cases, moisture issues could have been reduced or entirely eliminated using best-practice design and construction details.

Our objective in this paper is to provide guidance on the key design criteria based on building science principles, field experience, and industry documents. This guidance is suited to both architects and general contractors.

INTERIOR ENVIRONMENT

The American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE's) HVAC applications guide[1] recommends design conditions for different types of pool environments. The ASHRAE recommendations, reproduced in **Table 1,** consider different pool uses and recommend ranges for indoor air temperature, water temperature, and relative humidity. The different classifications of use suggest climate condition ranges appropriate for each expected activity level. The reader will note that this guidance provided by ASHRAE is not based on climate zones.

Relative humidity is not a measure of the absolute amount of moisture in the air. By definition, it is relative to the temperature of the air, so on its own, it cannot be used to assess moisture risks. Dew point does provide a measure of the absolute amount of moisture available. Dew point is the temperature at which water vapor in the air reaches the saturation limit of the air and has the capability to condense on a surface. Hence, dew point is a convenient, more meaningful, and tangible parameter to use when comparing the interior moisture loads.

Typical industry standard and building code recommended indoor conditions for "normal" buildings in a cold climate are 20 to 22°C (68 to 71.6°F) and approximately 35% relative humidity (and lower in the far north). These indoor conditions result in a dew point of approximately 5°C (41°F). This is consistent with dew point values we measure in winter months in typical cold-climate commercial buildings with relatively high air leakage and ventilation requirements. As shown in Table 1, the indoor conditions for a pool are necessarily much warmer (to match the activity and clothing level) and at a higher relative humidity (owing to moisture from the pool). Table 1 shows a range in relative humidity for all pools between 50% and 60%, although in cold climates we recommend keeping the relative humidity as close to 50% as possible. If a typical pool environment were considered to have an air temperature of 28°C (82.4°F) and a relative humidity of 50%, the dew point would be approximately 17°C (62.6°F), which is 12°C (21.6°F) higher than that of a typical building. This means that in a natatorium, surfaces that

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TABLE 1. Typical pool design conditions[1]

Type of Pool	Air Temperature		Water Temperature		Relative Humidity
	°C	°F	°C	°F	%
Recreational	24 to 29	75.2 to 84.2	24 to 29	75.2 to 84.2	50 to 60
Therapeutic	27 to 29	80.6 to 84.2	29 to 35	84.2 to 95	50 to 60
Competition	26 to 29	78.8 to 84.2	24 to 28	75.2 to 82.4	50 to 60
Diving	27 to 29	80.6 to 84.2	27 to 32	80.6 to 89.6	50 to 60
Elderly Swimmers	29 to 32	84.2 to 89.6	29 to 32	84.2 to 89.6	50 to 60
Hotel	28 to 29	82.4 to 84.2	28 to 30	82.4 to 86	50 to 60
Whirlpool/Spa	27 to 29	80.6 to 84.2	36 to 40	96.8 to 104	50 to 60

are below 17°C (62.6°F) will have a high risk of condensation. Buildings exposed to cold-climate winters or having long periods of cold weather require best-practice design, material selection, and construction to prevent the humid indoor air from reaching surfaces that are near or below the dew point. The enclosure design is critical for all pool enclosures, both residential and commercial, to minimize the risk of condensation of the interior air on interior surfaces and within the enclosure. It is also critical to point out that to limit the rate of evaporation of the pool, which adds available moisture to the air and can exacerbate condensation in the enclosure, the pool should be maintained at a temperature 2–3°C (3.6–5.4°F) below the air temperature. If the pool is maintained at a temperature above the air temperature, it will evaporate and increase the relative humidity of the space substantially or add significant latent load to the HVAC system to meet the design relative humidity requirements.

BEST-PRACTICE ENCLOSURE DESIGN

Continuous Exterior Insulation

Residential and commercial pool buildings can successfully use a range of enclosure materials (cladding, insulation, control layers, and structure). Typical structural systems include wood, concrete, steel, and mass timber. However, we recommend that pool enclosures in cool to cold climates employ a layer of continuous exterior insulation (i.e., the thermal-control layer) and that this be installed over the other control layers (i.e., water and air control) and the structure. The use of continuous exterior insulation keeps the structure and all other materials inboard of the insulation warm, reducing the potential for condensation. This stands in contrast to the numerous cold spots that are presented when insulation is installed between the structural members as a result of thermal bridging. Further, the application of insulation in the stud cavities and other framing spaces serves to insulate the sheathing from the interior, making it colder and increasing the relative humidity and potential for condensation and moisture accumulation at the interior face of the sheathing.

Construction with continuous exterior insulation over the structure has been studied exhaustively over the past several decades. In 1964, Neil Hutcheon[2] showed how installing the insulation on the exterior of the structure kept the interior surfaces warmer, reducing the risk of condensation. This concept was further refined by others. Alberta Infrastructure's Chris Makepeace[3] promoted the idea of the PERSIST (Pressure Equalized Rain Screen Insulated Structure Technique) wall assembly in 1998. In Alaska, similar exterior insulation strategies have been referred to as the REMOTE (Residential Exterior Membrane Outside-Insulation Technique) wall.[4] Building Science Corporation's Building Science Insight 001[5] employs the same principles in describing "the perfect wall" strategy. Many others have documented research and summarized theory and guidance to maximize the benefits of this construction strategy.[6,7,8,9]

A conceptual representation of an ideal exterior insulation strategy is illustrated in **Fig. 1.** The image shows a schematic identifying the structural, finish, and control layers in the enclosure. The structure (concrete masonry unit [CMU], steel, wood, insulated concrete form, mass timber, etc.) is covered with continuous water, air, and vapor control layers, which are all covered by continuous exterior insulation. The insulation could be rigid foam, semi-rigid stone wool, or medium-density (i.e., 32 kg/m^3 or 2 pcf) closed-cell spray polyurethane foam (ccSPF). This strategy ensures the air barrier system is well supported by the structure and protected from temperature fluctuations and ultraviolet light. When this strategy is used in design and the structure is well constructed, issues with the wall assembly are rare because of the continuity of the control layers. However, as is typical with enclosure issues, the problems often occur at penetrations and transitions, which is why it is critical for the designer to provide clear, constructible details for all penetrations and transitions within the enclosure.

Air Barrier System

One of the most critical components of a natatorium's enclosure design and construction is a continuous air barrier system. The air barrier system must be continuous on all

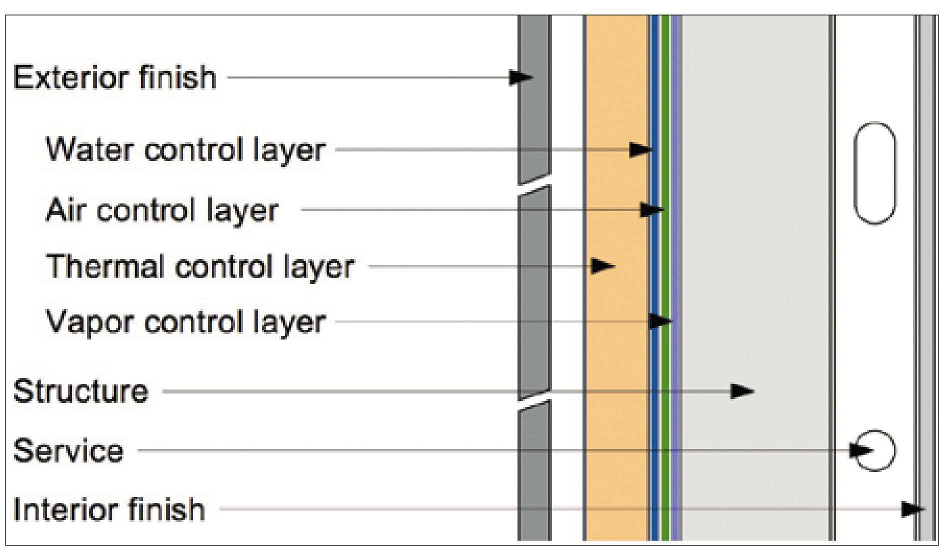

Figure 1. *Schematic for an exterior insulated enclosure wall assembly.*

enclosure surfaces around the pool, including the roof, the exterior walls, and any interior partition walls that separate the pool space(s) from adjoining spaces having different uses (e.g., offices, community room, gymnasiums, and especially ice rinks). The design and construction of the air barrier system in a pool building in a cold climate demands a higher standard of care than typical construction, as even small imperfections can result in substantial failures. Designers and builders frequently struggle to achieve the required airtightness. Many in the industry remain confused regarding the roles of air and vapor barriers, and this confusion is propagated in manufacturers' literature, industry guidance documents, construction drawings, etcetera. An air barrier is always needed, must be continuous, and, in a cold climate, must be located on the warmer side of the enclosure to avoid re-entrant looping condensation. A vapor barrier is usually required for pool buildings and can be the same material as the air barrier, but it does not necessarily have to be.

As an example of the confusion in literature and guidance documents, consider the *2011 ASHRAE Handbook–HVAC Applications*,[1] which states that "failure to install an effective vapor retarder will result in condensation forming in the structure, and potentially serious envelope damage," but it does not make any statements regarding the need for a continuous air barrier system within the enclosure, which is even more critical than vapor control.

Fig. 2 illustrates how much more water vapor can be moved by air movement than by vapor diffusion, further emphasizing the need for a continuous air barrier membrane in the enclosure. Depending on the height of the space, stack effect can be substantial and cause continuous air leakage through the roof system.

In 1966, Kirby Garden wrote *Canadian Building Digest 83* on the topic of indoor swimming pools.[10] Garden wrote, "Air leakage, a very prominent mechanism operating in most buildings, transports water vapour into walls and roofs, producing interstitial condensation." Garden also discussed the importance of preventing air movement from the swimming pool space to other adjoining spaces in the building.

Other publications have also emphasized how critical the air barrier system is. In 1990, Madeleine Rousseau of the National Research Council published an article in *Home Builder Magazine*[11] regarding design and construction solutions to problems with indoor swimming pools. Rousseau stated correctly that an airtight assembly, or air barrier system, is required to control condensation. She expanded further on that, writing, "To obtain an airtight assembly over the enclosure, connect wall or roof air barrier materials to other air barrier materials in floors, windows, and skylights and seal the joints with sealants, adhesive membranes or gaskets." She provided a simplified cross-section view of a house with a pool that identified an airtight compartment around the pool space with a continuous air barrier system and separate mechanical system from the rest of the building.

Paul Totten, in 2007,[12] also wrote on the importance of properly designed and constructed air barrier systems in pool enclosures as well as the need for review and oversight of the construction of the air barrier system.

POOL AIR LEAKAGE CASE STUDIES

We offer the following case studies to further consider the importance of thermal and air control in the building enclosure assemblies of natatoriums and pool buildings.

Case Study 1: Wood-Framed Resort Pool in the Northeastern US

Case Study 1 is a wood-framed pool building within a ski resort located in the northeastern US. The owners had observed some dripping and staining from the roof assembly onto the glulam structural beams of the building (**Fig. 3**), and the exterior roof surface on the north side of the building appeared to be uneven. The key issue related to enclosure durability was air leakage condensation that led to moisture accumulation in the roof and, to a lesser extent, in the walls. The panelized wood-framed roof construction was assembled on the ground as panels adjacent to the building and lifted into place onto the glulam beams. The panels themselves were constructed to be quite airtight: they were constructed with 10 in. (254 mm) engineered wood joists (e.g., TJIs) and were nearly full of ccSPF insulation. ccSPF insulation is an air and vapor barrier; however, at any joints where there is no insulation, such as panel joints, air control must be maintained. Continuity of the control layers between panels can be a challenge. In this case, when the panels were set on the glulam structure, the air barrier was not made continuous between the panels. This allowed the slow movement of moisture-laden air through the gap between the panels, which reached the cooler roof surface and then condensed. The moist conditions resulted in rot and decay of the wood materials in the roof assembly at the joints between the panels (**Fig. 4**), which slowly spread to the rest of the panel. The deterioration was greatest on the north orientation, which is to be expected due to the lower amount of solar energy available for drying. The deterioration was so widespread that there was some concern about the roof collapsing. Dark drips stained the sides of the glulam beams due to the condensate that eventually started rotting out the wood in the roof and turned the condensate a dark brown color when it drained back into the building. The glulam beams were structurally sound, just stained, so the remediation involved replacing the roof with panelized wood-framed construction. The replacement required careful air barrier continuity detail at the joints, as shown in **Fig. 5,** and a completely exterior insulated roof assembly.

Case Study 2: Commercial Pool Building in Southwestern Ontario

Case Study 2 was a project completed in 2019. Situated in southwestern Ontario, this project reminded us that even before the completion

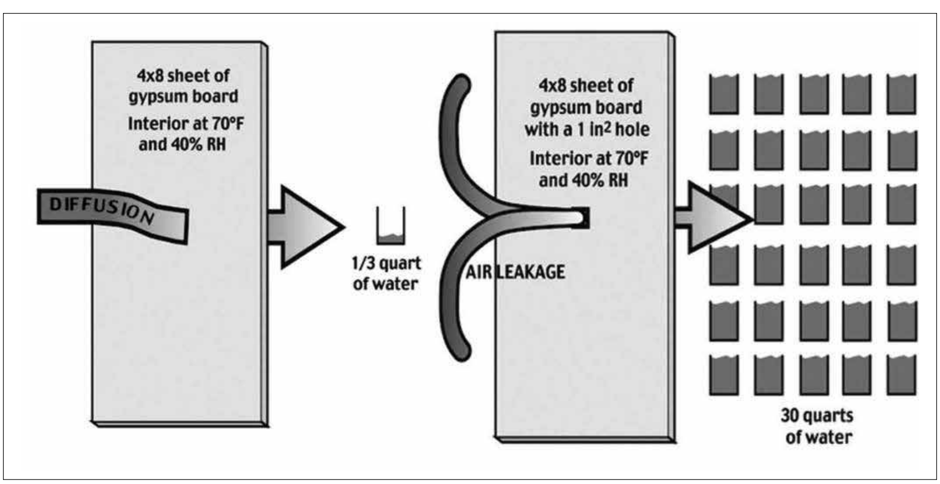

Figure 2. *Illustration explaining the relative water vapor movement from vapor diffusion and air leakage. Source: buildingscience.com.*

Figure 3. *Staining from the roof on the interior structure.*

Figure 4. *Rotting of the wood at the exterior of the roof assembly.*

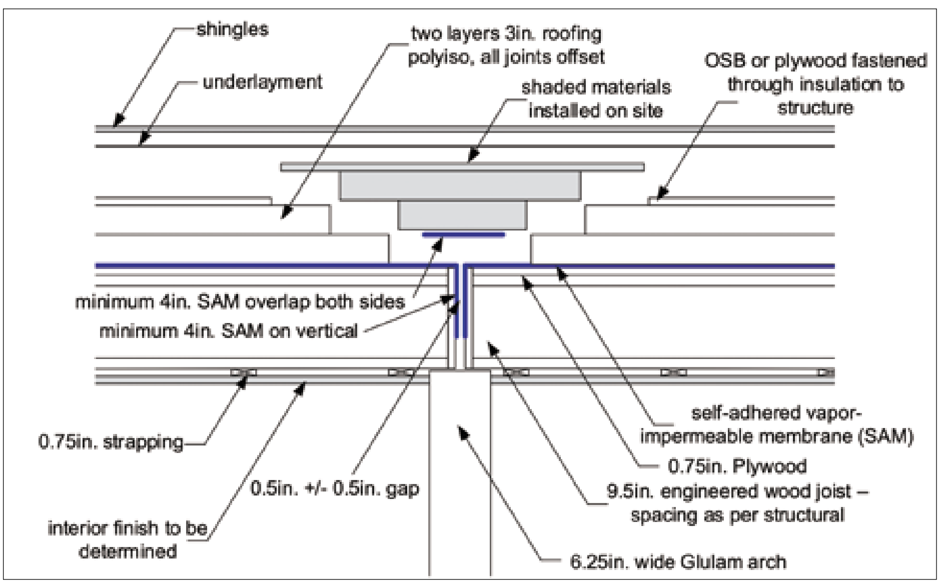

Figure 5. *Schematic of the roof repair ensuring the air barrier continuity on the warm side of the insulation.*

of the project and the operation of the building, care is required during construction. The structure was constructed, and the windows and membranes were installed. In many locations, exterior insulation was also installed. The pool had been mostly filled with water to ensure there were no issues with the pool systems, although the mechanical systems were not fully installed and functional. One of the exterior walls of a lower roof area had a self-adhered air/vapor barrier installed on the exterior of the gypsum sheathing and the steel stud to the exterior of a CMU structural wall. We observed that the self-adhered membrane had become loose over the entire wall surface and was no longer supported by the gypsum. Further investigation identified that it was not the membrane that had released, but the facer on the gypsum sheathing, and the gypsum core was wet. This failure occurred because the self-adhered membrane was a cold-sided vapor barrier during the winter. Air leakage pathways around the CMU wall extended into the void space, and since the continuous exterior insulation had not been fully installed, it resulted in failure of the wall assembly. Water was accumulating within the exterior gypsum, causing the facing to separate from the core. The repair involved a combination of strategies. First, ccSPF was installed into the void from the exterior, improving the thermal control, reducing the air leakage, and significantly reducing the void space. New gypsum was installed, and a vapor-permeable air/water barrier was installed in this area of the wall to increase the future safety factor of the assembly, particularly to take advantage of the vapor-permeable stone wool continuous exterior insulation. A more comprehensive quality control process using building pressurization and thermal imaging was conducted to assess and improve the air barrier system in other areas of the building while the air barrier system was exposed.

The requirement for airtightness of the interior partition walls surrounding a pool is important in buildings with adjacent spaces to limit the transport of odors, chloramines, and moisture.

Case Study 3: Community Center Pool Space Adjacent to Ice Rink Near Toronto, ON

Case Study 3 was a project in 2006 at a community center north of Toronto that included a pool and ice rinks in the same building, separated by a foyer space. The issue at this building was mounding on the rink ice overnight (**Fig. 6**). The ice mounding was greatest at the end of the rink closest to the foyer and pool and diminished with distance from the foyer. Our investigation determined that air leakage pathways were created on the interior near the roof of the building where the partition walls were not air-sealed to the underside of the roof. These pathways allowed

Figure 6. *Mounding on ice formed when air leaked from the common areas and the pool leaked into the ceiling above the ice rink, condensed, and dripped onto the ice.*

moisture from the pool space and foyer area to pass through the common space and into the roof assembly above the ice rink. It condensed and dripped onto the ice through the joints of the interior finish, resulting in mounds that formed every night.

Case Study 4: Community Center Pool in Southwestern Ontario

Case Study 4 is a pool in southwestern Ontario that had condensation drainage coming out of the roof assembly at the lower portions of the roof. The architectural design for the roof and the roof-to-wall transition looked adequate: a self-adhered membrane transition from the wall to the roof, underneath the parapet, creating continuity between the roof and wall. However, when the parapet and adjacent roof were opened, it was discovered that the backer had not been peeled from the self-adhered membrane (**Fig. 7**). The membrane was not adhered, and further, there were structural penetrations through the membrane that were not sealed. This resulted in air leakage pathways into the parapet from the interior space. The schematic in **Fig. 9** shows the air leakage pathway along the structural connection to the parapet. Condensation on the underside of the roof membrane was guiding water directly to the roofing assembly and saturating the coverboard and roofing insulation. Condensation was also draining back to the interior of the building, staining window mullions and the pool deck (**Fig. 8**).

THERMAL BRIDGING

Thermal bridging is another important consideration for the design and performance of pool enclosure assemblies. Ideally, thermal bridges are addressed in the design phase of a project, when they are easiest to remedy. They become difficult to manage once they are constructed. Often, the structure will pass through the insulation layer of the enclosure to support components of the building on the exterior, such as soffits, or other architectural details. In some cases, structural thermal breaks can be integrated into the structural design to reduce thermal bridging through the enclosure early in the design phase.

POOL THERMAL BRIDGING CASE STUDIES

We offer the following case studies to further consider the impact of thermal bridging on building enclosure assemblies of natatoriums and pool buildings.

Case Study 5: Community Center Pool in Chicago, IL

Case Study 5 is a pool in Chicago that had issues with both air leakage and thermal bridging from the hollow structural section (HSS) that connected to the structure on the interior of the enclosure while also supporting the soffit. Significant condensation and dripping on the interior of the enclosure at this HSS was a result of a combination of thermal bridging and air infiltration. The infiltrating air combined with thermal bridging cooled the interior steel surfaces sufficiently in the wintertime that interior air condensed on the surfaces. The initial design was for the entire soffit to be wrapped airtight in self-adhered membrane

Figure 7. *Water accumulation and damage in the parapet, and the backer observed on the Blueskin air barrier.*

Figure 8. *Staining inside the pool area running down steel columns from the parapet.*

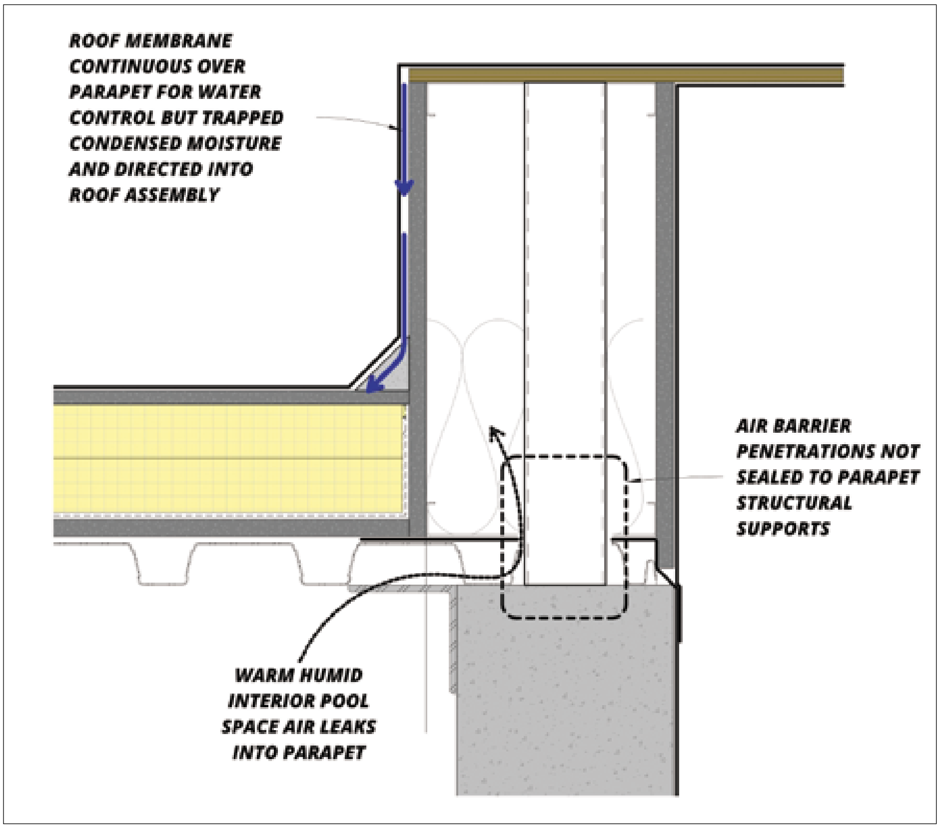

Figure 9. *Schematic of the air leakage pathway and condensation that saturated a large percentage of the roofing insulation in the roof assembly.*

and connected to both the roof and the wall, but the air barrier layer was not continuous. Air flowed into the soffit through deficiencies in the air barrier, and then into the building through the hollow HSS. Fortunately, the pool had been operating correctly under negative pressure (as discussed later in the paper) since it was constructed; otherwise, there would have been significant moisture damage to the soffit space. The recommended fix for this issue (**Fig. 10**) was to ensure the air barrier was continuous at the plane of the enclosure with a fluid-applied membrane (green coating showing past the ccSPF on the roof deck) and spray foam on the wall and in the metal deck flutes, and to entirely wrap the soffit HSS structural members in ccSPF.

Figure 10. *Closed-cell spray polyurethane foam (ccSPF) was installed above the windows at the transition between the metal roof deck and the enclosure over the green fluid-applied air and water barrier. ccSPF was also installed around the entire length of the HSS supporting the soffit and connected to the interior structure to minimize thermal bridging.*

Case Study 6: Single-Family Residence with Pool Near Toronto, ON

Case Study 6 is a residential pool building north of Toronto. The residents were previously unable to use the pool in the wintertime because of the considerable dripping within the space as a result of poor design and construction details in the enclosure. The structure was steel with wood-framed infill and a vented cathedral ceiling. The roof needed significant improvements to the thermal control. To minimize the disturbance to the interior, the exterior surface of the roof was removed, and ccSPF was used to insulate the roof assembly and encapsulate all the structural steel components within the roof assembly before the roof was reassembled. Following the reinstatement of the roof, the condensation and dripping from the interior of the roof was almost completely repaired. One area had been missed by the contractor, which was evidenced by thermal imaging of the interior surface of the roof. That small section of the roof was reopened, and additional spray foam was installed around the thermal bridge to reduce the heat transfer in the problem area to eliminate the dripping on the interior.

HVAC DESIGN

This paper is intended to be largely focused on the building enclosure and not a discussion of HVAC equipment. However, there are some high-level HVAC considerations that are important to consider early in design as well as during forensic investigations of moisture issues because they are related to successful enclosure performance.

Building Depressurization

The ASHRAE HVAC applications guide[1] states that "pool and spa areas should be maintained at a negative pressure of 15–40 Pa relative to the outdoors and adjacent areas of the building." According to the guide, this negative pressure is provided to prevent chloramine odor migration. While controlling odors in adjacent spaces is recommended, the more important reason for depressurization is to control the movement of interior air-based water vapor into the enclosure and reduce the risk of moisture durability issues. Quantifying the depressurization may require the engineers and trades commissioning the HVAC equipment to use different tools because it was found through the case studies that large HVAC balancing is completed to within +/-0.1 in water column, which equates to only 50 Pa of accuracy.

Both Perkins+Will[13] and Jason Der Ananian[14] described the importance of depressurizing the pool space relative to the exterior and to adjacent spaces to reduce the risk of interior moisture entering the enclosure. Achieving depressurization becomes easier with greater levels of airtightness.

When completing both the design and repair work on pool buildings, it is our experience that it is often difficult to convince the mechanical contractor to provide depressurization of the pool space. We often get pushback from the contractor, even when the symptoms and evidence of moisture issues indicate that pressurization is contributing to the reported issues.

Stack Effect

The other key criterion to keep in mind when determining the enclosure pressure is the stack effect within the building.

Stack effect is the term given to the naturally occurring interior pressures in a building related to the height of the interior space and the temperature gradient across the enclosure. **Fig. 11** shows an illustration of typically occurring stack effect pressures during the winter months in a cold climate. Warm air is more buoyant; it rises to the top of the building and finds its way out through holes in the air barrier system. Replacement air is then drawn in at the bottom of the building. Positive air pressures push air out on the top of the building, while negative pressures pull air in at the bottom. The amount of pressure formed increases with building height as well as with greater temperature gradients between the interior and exterior. Stack effect pressures at the top of the building are the greatest in the coldest winter months. Therefore, they need to be considered when the pressure measurements are taken to ensure that the building is negatively pressurized all year round. Pressure measurement should be done during the winter months when it is cold outside to confirm that the building depressurization is still effective even when the stack effect pressures acting within the space are the greatest.

Figure 11. *Illustration of wintertime stack effect with naturally occurring drawing of air in the bottom of the building and exhausting it out the top. Source: finehomebuilding.com.*

POOL PRESSURE FIELD CONTROL CASE STUDIES

We offer the following case studies to further consider pressure field control and its impact on the building enclosure assemblies of natatoriums and pool buildings.

Case Study 7: Community Center Pool in Nova Scotia

Case Study 7 is a newly constructed pool in Nova Scotia, completed in 2022. Lights at the perimeter of the soffit space above the entrance were filling with water and failing. Unfortunately, due to COVID-19, we were unable to travel to the site to do the investigation ourselves. Instead, we assisted remotely with the investigation. The conditioned soffit was part of the interior space and wrapped in self-adhered membrane as well as continuous exterior insulation (**Fig. 12**). The lights were well protected from driving rain events, and there was no correlation between rain events and water in the light fixtures. The accumulated water was most likely a result of warm, moist interior air being pushed along the electrical wiring pathway through the air barrier discontinuity into the light fixtures, resulting in condensation and moisture accumulation. Fig. 12 shows a section of the exterior edge of the soffit with the membranes on the gypsum sheathing, and over the flashing, and thick layers of continuous exterior insulation. **Fig. 13** shows a photograph of water accumulated in the light fixture at the edge of the soffit.

Our recommendation was to negatively pressurize the pool space to prevent moisture-laden interior air from entering the light fixtures. The mechanical contractor assured us that the pool space was depressurized and was not willing to make any adjustments to the mechanical system. A simple assessment, holding the exterior door open an inch, resulted in air moving out of the building, readily confirming that the space was, in fact, positively pressurized at grade.

To ensure that a building is depressurized correctly, the pressure must be measured across the enclosure with a manometer and not determined by measuring the flow rates at the mechanical equipment. We have found that many times, the HVAC contractor will provide evidence of depressurization by using measured flow rates of supply and exhaust, but these do not always correlate to the desired enclosure pressures.

AIR DISTRIBUTION OVER WINDOWS

HVAC design and distribution are also factors contributing to window condensation issues. As a result of the high interior moisture loads, it is common in cold climates that the glazing systems' surface temperatures will fall below the dew point for extended periods. The risk of condensation on glazing systems can be countered with high-performance glazing and framing systems, but reducing condensation more commonly relies on air distribution over the glazing from the HVAC system.

POOL AIR DISTRIBUTION CASE STUDIES

We offer the following case studies to further consider HVAC system air distribution and its impact on the performance of building enclosure assemblies in natatoriums and pool buildings.

Case Study 5 (Revisited): Community Center Pool in Chicago, IL

Case Study 5 in Chicago, previously discussed because of the thermal bridging and air leakage at the soffit, also had issues with condensation on the windows. The lack of air distribution from the mechanical system over the windows and the deep interior mullions disrupted the airflow, promoting condensation. As part of the repair strategy for the building, additional fans, separate from the HVAC supply ducts, were installed specifically to blow air over the windows (**Fig. 14**).

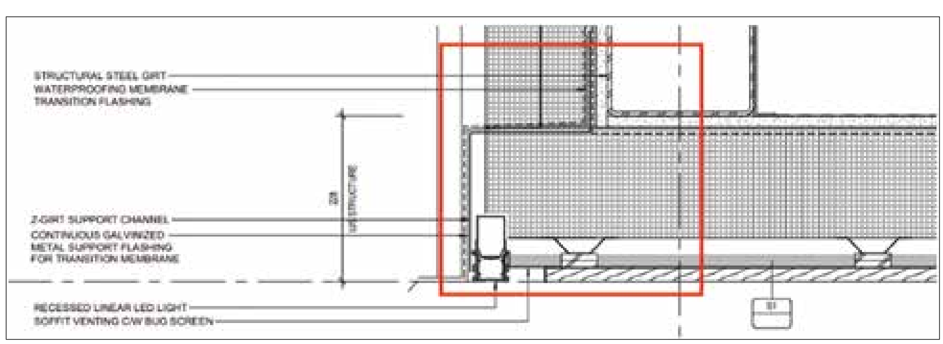

Figure 12. *Many of the light fixtures at the perimeter of the soffit were filling with water and failing because of air leakage from pressurization of the building.*

Figure 13. *Photograph of water within the light fixtures at the edge of the soffit.*

Figure 14. *Fans were added during the building repairs to blow air directly over the windows to reduce condensation on the interior surfaces of the windows.*

Case Study 4 (Revisited): Community Center Pool in Southwestern Ontario

Case Study 4, previously discussed because of the moisture accumulation in the parapet and roofing, also had issues with mechanical distribution. Air supply grilles and ductwork were provided around the perimeter of the pool with linear diffusers to supply air to the glazing at floor level (**Fig. 15**). A few years following the construction of the building, there were some issues with the masonry on the exterior of the building with crumbling mortar as well as staining of the masonry, mostly around windows (**Fig. 16**). The parapet cap was removed during inspection to look down into the drainage/ventilation cavity behind the masonry. The air coming out of the gap was humid and smelled of chlorine. The high humidity air in the masonry veneer cavity resulted in icicles and moisture accumulation at the top of the wall under the parapet flashing during the wintertime (**Fig. 17**). The masonry wall issue was the result of a combination of factors, including, most importantly, the lack of air barrier continuity. However, it also involved installation deficiencies in the HVAC ductwork, since in some locations, the air from the ductwork was blown directly into the brick veneer cavity, resulting in premature failure of the masonry on the building. The building repairs included air barrier replacement and improvements to control airflow and eliminate air exfiltration.

Case Study 8: Multi-Family Building with Pool in Vancouver, BC

In Case Study 8, the importance of air movement over the interior of glazing was highlighted. The design of the visually stunning Butterfly Westbank pool project in Vancouver did not follow the best-practice recommendations of keeping window areas small and of providing large ducts with lots of air to the window areas. RDH Building Science worked with a company that provided extensive computational fluid dynamic analysis modeling on the airflow, analyzing interior surface temperatures to determine the best strategy to provide airflow over the glazing with the concealed ductwork. Many iterations and variables were run in the analysis, with

Figure 15. *Linear grilles adjacent to the windows are designed to apply airflow to the window area, reducing condensation.*

Figure 16. *Around the windows, there was greater mortar damage and efflorescence as a result of the lack of deficient air barrier details.*

Figure 17. *At the top of the wall, icicles, wetting, efflorescence, and mortar damage were all present as a result of air leakage.*

two of the simulations shown here. **Fig. 18** shows the model output for the plan view of the roof. The entire roof/skylight area is red, indicating condensation is expected to cover the entire skylight/ceiling assembly. **Fig. 19** shows the predicted surface temperature and condensation results with a higher temperature set point as well as additional fans blowing air over the glazing surfaces. This approach significantly reduced the predicted condensation risk over most of the skylight/ceiling of the pool space, as indicated by the mostly blue and white coloration of the surfaces.

RECOMMENDATIONS FOR POOL ENCLOSURE DESIGN

The authors have been involved in many natatorium enclosure designs and failures over the past two decades. Our experiences are distilled into the following seven recommendations that will minimize the risk of enclosure and durability issues in a pool building.

1. **Early Design:** Communicate the importance of the key design criteria such as continuous exterior insulation, continuous air barrier system, and accurate construction details early in the process when these strategies can still be incorporated into the project budget and construction scope.
2. **Continuous Exterior Insulation:** Wrapping the structure in control layers and installing continuous exterior insulation with as few penetrations as possible is typically the lowest-risk design for all enclosures, especially buildings with high-humidity interior environments, like pools, in cold climates.
3. **Thermal Bridges:** Limit all thermal bridging through the insulation layer as much as possible in design. In instances where the structure must pass through the insulation layer, design structural thermal breaks or other strategies to control the interior surface temperatures of the structural elements.
4. **Continuous Air Barrier System:** We have concluded based on the case studies as well as other previous research that a continuous air barrier system across all surfaces of the enclosure (that is, roof, walls, floor, and partition walls) that is also continuous at all penetrations, such as windows and doors, is required to be nearly perfect to minimize the risk of enclosure durability issues.
5. **Negative Pressurization of the Building:** In a cold climate, to minimize the risk of interior air entering the enclosure, the pool space should be kept at a negative pressure, which will reduce the risk of condensation of interior air within the enclosure. This is a requirement for pool buildings.
6. **Airflow over Glazing:** Windows in pool buildings in cold climates often require air to be directed at the surface of the windows to minimize condensation on the interior surfaces.
7. **Construction Quality Control:** It is crucial to always be aware during construction of the modifications/penetrations to the air barrier system. Any penetrations that are required should be reported and tracked, and repairs should be done by the responsible trades. Airtightness testing with the use of thermal imaging or tracer smoke can also help identify potential air leakage pathways and is recommended as a quality control tool prior to covering the air barrier system, although this is often difficult in reality due to construction sequencing on the project.

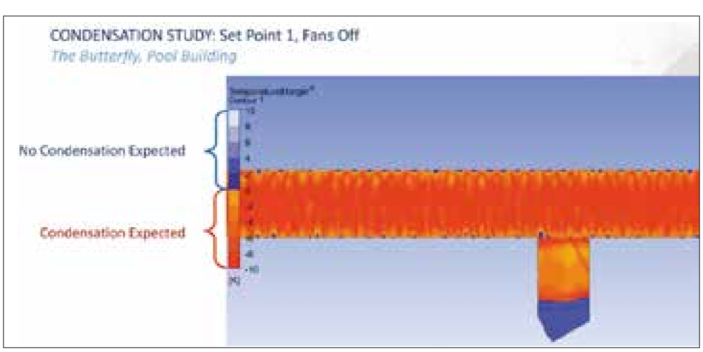

Figure 18. *The predicted temperature margin and condensation risk on the skylights of the pool without any fans indicates that the other ceiling will be covered in condensation.*

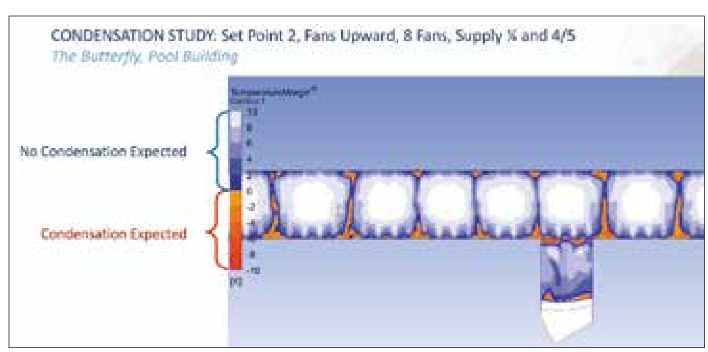

Figure 19. *The predicted temperature margin and condensation risk on the skylights of the pool with a higher temperature setpoint and additional fans shows a significantly decreased risk of condensation.*

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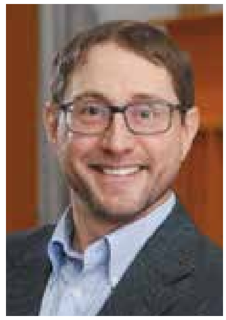

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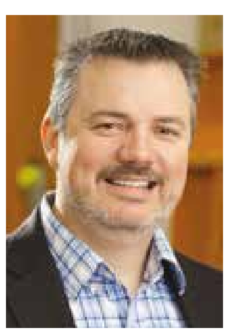

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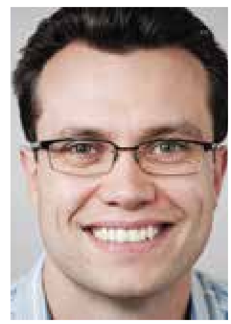

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