A Simple Solution: An SPF Retrofit to Stop Leakage

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ABSTRACT

The presenters will offer a case study of a wellness building in Iowa that, during its first winter, had icicles on the roof eaves, and interior water leakage during its first spring. Investigators found significant deficiencies in the fiberglass batt wall insulation and vapor retarder that allowed warm and humid interior air to migrate through the envelope and condense and freeze as it exited the building. A repair was performed that included replacing the existing insulation and vapor barrier with new SPF as a thermal and air barrier. Whole-building air testing was used before and after repairs to verify the improvement in airtightness.

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BRUCE KASKEL has expertise in exterior wall systems related to glass, glazing, water infiltration, corrosion, structural adequacy, energy performance, anchorage devices, and durability. His projects include aluminum and glass curtainwalls, masonry, exterior windows and doors, and precast concrete and stone panels. Kaskel has provided exterior wall consulting services during design and construction of new buildings, including serving as a building envelope commissioning agent (BECx).

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JENNIFER SCHNEIDER has been involved with numerous projects related to the inspection, investigation, and repair of distressed conditions in existing buildings. Her experience also includes building enclosure commissioning (BECx) and peer design review for new construction, applying her experience in modes of leakage, condensation, and distress to proposed detailing. Schneider applies thermal and hygrothermal modeling to her evaluations of exterior wall systems.
In 2010, a new Health and Wellness Center was constructed in a small town and farm community in western Iowa. The center serves the surrounding community with an indoor pool (complete with water slides), a gymnasium with interior sports courts, a running/walking track, a fully outfitted exercise facility, and office space. The building was located across the street from the local hospital.

The center was an immediate success as the community enjoyed the new amenities, but the success was soon overshadowed when the staff discovered water problems shortly after occupancy.

Water was first identified in the roofing assembly during construction. At the time, the water was attributed to condensation related to a high internal moisture load from initial construction and believed to be temporary. Upon occupancy, it became clear that the building had an ongoing problem. Water was observed as leaks inside the structure, but not associated with rains. Peculiarly, it was mostly occurring when the weather was cold. Not only were there leaks, but on the coldest days, icicles were forming at the exterior of the building, most notably at the eaves. The water leaks were most noticeable immediately after a cold spell when temperatures rose back above freezing. Building staff also reported that the mechanical system was unable to maintain the desired temperature and humidity in the pool space, especially on the coldest days. Failed attempts were made to resolve the issues by balancing the system.

Two Building Types—One With a Problem

The Wellness Center is a 46,000-sq.-ft., single-story structure (not including a mechanical mezzanine). The exterior walls are clad with a stone base, metal siding, and aluminum-framed windows. Although the structure was built as a single building, it was constructed of two adjoining buildings with two very different building types: one a “pre-engineered” steel building, and the other, a conventional steel column-and-beam constructed building. An overall exterior view of the center is shown in Figure 1.

The pre-engineered building encloses 35,000 square feet (approximately 280 by 125 feet in plan) of the overall space and houses all the gym and pool functions described previously. The pre-engineered building has a metal hip roof with a 3-in-12 slope and is approximately 36 feet tall at the ridge line.

Although pre-engineered buildings are often built for storage and industrial functions and, consequently, are not necessarily insulated, in this case, both building types were fully insulated and climate-controlled year round. Only the pre-engineered building seemed to have significant water problems.

The pre-engineered building is further divided into two zones by a full-height concrete masonry demising partition wall. The partition wall is designed to prevent the high humidity and chlorine vapors of the pool-side interior air from infiltrating into the remainder of the space. The gymnasium, track, exercise facility, and locker rooms are located on one side of the partition wall, and the pool is located on the other side. The two zones of the pre-engineered building are separately controlled environments.

Administrative and medical offices occupy the 11,000-sq.-ft. (approximately 65 by 170 ft. in plan) conventional steel-framed building.

Figure 1 – Overall image of the wellness building (courtesy of the owner).
The Pre-Engineered Building: Its Construction and Operation

The structure of the pre-engineered building is typical for this building type and consists of steel columns and roof purlins with 8-inch-deep Z-girts spanning horizontally between the columns to support the exterior wall cladding. Due to window-framing demands, in some locations, 8-inch-square steel tube sections were used instead of Z-girts.

As briefly described above, the exterior walls of the pre-engineered building are clad with an adhered stone veneer at the base of the wall, with corrugated metal wall panel siding above. Where the exterior wall cladding is stone, the space between the Z-girts is infilled with 8-inch steel studs at 16 inches on center to support the cladding.

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The roofing consists of a metal standing-seam system over sloped purlins, also with fiberglass batt insulation and an interior plastic vapor barrier. In this case, the plastic is a white reinforced fabric, which is left exposed as the interior ceiling finish. This is a standard system common for pre-engineered buildings. In addition to being an integral part of the roofing assembly, the plastic fabric is used during construction as fall protection for the workforce installing the roofing. To ensure this safety function, the manufacturer stipulates significant securement of the plastic fabric. Since the plastic fabric is mostly visible, it

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is easy to observe its condition; and in this case, it was deemed to be in generally good condition.

The building is conditioned to approximately 70°F and 45 percent relative humidity (RH) except for the pool space, which is kept warmer and more humid, at 85°F (29.5°C) and 55 percent RH. The building is intended to operate at a slightly positive air pressure relative to the exterior. Within the building, the pool space is intended to operate at a negative pressure relative to the other interior spaces in order to contain the humid, chlorine-filled air. Measurements indicated that the air pressure difference between the inside and outside was negligible.

Investigation of an Air Leakage Problem

Given the previously mentioned problems, the owner hired a consultant to conduct thermal scans of the pre-engineered building in the first winter of 2010 to 2011. These images revealed thermal “shorts” (hot spots on otherwise cold exterior surfaces) which are commonly attributed to: 1) evidence of wet materials, 2) evidence of air leakage through the wall, 3) deficiencies in consistent thickness of thermal insulation, 4) thermal bridges caused by structural metals (such as girts), or 5) a combination of these conditions. These scans suggested that air leakage might be a significant contributing factor to the water problem. Signs of air leakage were especially evident at the roof eaves, where the wall insulation meets the roof insulation (as well as where the vapor retarders should meet). A representative image is shown in Figure 5.

To further understand the water problem, inspection openings were made at the exterior of the pre-engineered building by removing some of the metal panels. Openings were also made at the interior by removing portions of drywall. These openings revealed poor construction of the insulated exterior walls and insulated roof eaves. The plastic vapor barrier was found to have numerous penetrations, open terminations, and unsealed laps in the plastic. The roof’s plastic vapor barrier was found to be in much better condition. Although the vapor barrier had some unsealed penetrations and seams, the fact that the underside of the roof was accessible had allowed building staff to see the problem and make some previous repairs from a manlift.

The information gained from the thermal images and inspection openings together confirmed the diagnosis that the water problem was due to air leakage through the building’s envelope. The appearance of water (as leaks or icicles) was evidence of uncontrolled moist airflow through the exterior walls and roofs of the building. Uncontrolled interior water vapor-laden air was able to pass through the exterior walls and roofs and condense on cold surfaces within the assemblies. When the temperatures were below freezing, the condensation turned to ice when it reached cold surfaces. Likely surfaces for ice accumulation were the underside of the metal deck, the interior side of the metal siding, and the metal framing. Some of this moisture froze upon contact with the exterior air and formed icicles on the outside of the building. When surface temperatures rose above freezing, the frozen water melted. Where ice was present within the roof and wall assemblies, the water then flowed back into occupied spaces as liquid. This airflow occurred throughout the wall but was most concentrated at the eaves, where the wall meets the roof.

The design of the Wellness Center, similar to almost all climate-controlled buildings in the northern United States, relies on a plastic sheet product—referred to as vapor barrier (also often called a vapor retarder)—to manage water vapor diffusion (such products are rated in “perms,” a measurement of vapor diffusion). However, in most locations at this building, the plastic sheet is the only wall element with the ability, if executed properly, to also stop air movement. Industry research has shown that air movements are more problematic in moisture-control situations than vapor diffusion. Within the last 20 years, well-designed walls in northern environments have integrated both vapor retarders and air barriers, often as two discrete products in the wall. In these well-designed walls, the air barrier is typically installed on the continuous exterior surface of a sheathed or CMU backup wall. Installing the air barrier on the exterior side of the sheathing or back-up wall allows easy connections to adjacent systems (roofing, fenestration) to ensure continuity of the air barrier. In buildings located in cold climates with high interior humidity, where there is an air barrier on the exterior side of
the outside wall, a vapor retarder is typically installed on the interior side of the outside wall. In this location, the vapor retarder is inside of the thermal insulation and can control water vapor originating inside the building.

A well-installed plastic sheet vapor retarder requires well-executed seals around the perimeter sheet edges (and lap splices in the sheet itself). However, a vapor retarder need not be near-perfect to be effective in controlling vapor diffusion. An air barrier, on the other hand, requires more critical attention to these seals, since even small openings in the air barrier can allow significant airflow. The inspection openings at the Wellness Center confirmed the imperfect installation of the interior-side plastic sheet. Even if the contractor had attempted to seal the plastic sheet to the best of his ability, it would not have been possible to avoid penetrations through the material caused by items such as electrical outlets and finish fasteners.

**Two Repair Options**

All parties involved in the construction, as well as the building’s owner, agreed that repairs were necessary to make the building perform as intended. However, there was not an agreement on the type of repair to implement. Two repair options were considered, each intended to control the airflow and block the moisture-laden interior air from entering the wall and roof assemblies. The first was to install a new plastic vapor barrier to the existing interior drywall and to fully seal the plastic at all locations. Following this, a new sheet of interior drywall was to be installed to cover and protect the plastic. This solution—treating the new interior vapor barrier as an air barrier—was intended to solve the problem. It would, however, be disruptive to the building’s occupants, since the work would be done from the inside. This solution would also have constructability challenges, working around interior building elements such as light fixtures and suspended ceiling “clouds,” which would have made interior access to the full height of the wall difficult.

These challenges, however, were not the most significant concern with this repair option. Based on the principles discussed above, this repair option misapplies the vapor barrier and air barrier concepts. This repair attempts to use a standard vapor barrier product and its interior-side placement as an air barrier—and hence as a means to control airflow. The inherent contradiction in this application would almost certainly have rendered a less-than-successful repair. Even if successful at first—assuming that the repair contractor could have installed it perfectly with all necessary seals to ensure continuity—the air leakage would certainly return sometime later, when someone inadvertently punched a hole through the drywall, without realizing that the plastic sheet behind the drywall could not be violated without a dramatic impact on the wall’s performance.

The second option was very different. This second option proposed that the repair work proceed on the outside of the building. In this scheme, the metal wall panel siding and metal soffits would be temporarily removed by unscrewing the exterior fasteners connecting them to the Z-girts, in order to gain access to the wall cavity. By accessing the wall in this manner, the fiberglass batt insulation could be removed to the exterior without disturbing the interior drywall. Following the removal of the insulation, new two-pound density, closed-cell spray-polyurethane foam (SPF) would be applied against the exterior surface of the interior drywall. The SPF would serve as both the insulation and the air barrier, and would be installed continuously in the wall and eaves where it would marry with the plastic roof air barrier. Code officials were consulted, and they confirmed that SPF insulation was acceptable for this one-story (and fully sprinkled) building type.

After the SPF installation, the same metal wall panel siding could be rescrewed to the wall framing. One enhancement to the thermal design of the exterior wall

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**Figure 6 – Existing (left) and new (right) exterior eave detail.**
was the addition of new insulating blocks between the metal wall panel siding and the wall framing. These 1-inch-thick blocks provide thermal isolation between the wall framing and the exterior metal wall panel siding, reducing the thermal bridging and conductive energy loss. This second repair option—performed from the outside—would allow relatively undisturbed occupancy of the building during the repair work and would result in a robust repair wall design that would be resistant to future damage if any changes were made to the interior finishes.

As part of this second repair option, the ineffective existing vapor barrier would be removed, since it is not a suitable substrate for the SPF. With a vapor-permeance rating of approximately 0.8 perms, the SPF is sufficient to serve as the vapor retarder, except in the pool space where the vapor pressure is quite high (85°F and 55% RH). Fortunately, the existing interior epoxy paint coating in the pool space had a low perm rating and is the necessary Class 1 vapor retarder.

Both repair options addressed airflow into the roof assembly by continued repairs to seal any noticeable holes in the ceiling’s plastic vapor barrier.

Since closing the brand-new building would have been a major issue to the community, once presented with these two options, the owner decided to pursue the exterior-side second repair option, with the SPF foam as the main repair material.

DETAILS OF THE AIR BARRIER REPAIR

The repair design was to add 4 inches (two lifts) of SPF installed against the existing interior drywall, within the 8-inch-wide exterior wall cavity. The SPF is thickened to the full 8-inch wall depth at the Z girts to encapsulate the steel framing and limit thermal bridging due to heat transfer by conduction. In addition, 1-inch-thick extruded polystyrene (XPS) insulation was added between the Z girts and the metal wall panels to create an insulation block, further reducing the thermal bridge. The steel tube members were treated similarly to the Z girts, with SPF encapsulation and insulation blocks at the exterior. SPF was installed into the ends of the tubes, and splice joints were sealed to prevent airflow within them communicating into the rest of the exterior wall space.

The separation of the metal wall panel siding from the framing required a structural review of the wall system. The wall panels provide lateral stability to the wall framing. This is reduced by the addition of the XPS blocks and the separation of the panels from the framing. The original manufacturer of the building components performed this review and recommended that new metal struts be added within the framing cavity in some locations.

Although the roof was largely left intact, any visible penetrations through the plastic vapor barrier were sealed from the interior to ensure airtightness. The edge of the plastic sheet, which was accessible at the roof eaves once the wall panels were removed, was adhered to the metal framing, and the SPF was lapped onto it (see Figure 6). This connection was essential to create continuity of the air barrier between the wall and roof assemblies.

REPAIR IMPLEMENTATION

A mock-up was performed in 2014 to confirm the constructability of the design (see Figure 7). The full repair project was started and completed in 2015 without any significant disturbances. When the metal wall panels and insulation were removed,
some minor concerns were revealed, including corrosion on metal framing components, failed paint on trim pieces, and areas of missing interior drywall. These conditions were rectified by repair or replacement prior to the installation of the SPF. A photo of the repair work in progress is shown in Figure 8.

The building remained fully operational throughout the duration of the project, with only a brief closure of the pool space when interior lift use was required. The closure was timed to coincide with the annual pool maintenance, which also required a closure. There were no reports of any interior disturbances (such as odors produced by the offgassing of the SPF) during the repair work.

**POST-REPAIR PERFORMANCE**

To confirm the success of the repair project at reducing the interior air leakage, whole-building air testing was performed before and after the repairs to quantify the improvement of air-tightness. The blower door assembly for the post-repair test is shown in Figure 9. The testing revealed that the air leakage was reduced by 70 percent from the pre-repair leakage. The post-repair test quantified the building air leakage rate at 0.13 CFM/sq. ft. at 75 pascals, which is 50 percent lower than the project goal (and current Army Corps of Engineers requirement) of 0.25 CFM/sq. ft.

Commissioning of the mechanical systems was performed after the completion of the repairs, to finally balance the air supply to the pool area. This was the first successful mechanical balancing, since it had been impossible to originally balance the equipment properly due to the high volume of air leakage. Since completion of the project, the owner reported a 20 to 25 percent energy cost reduction during the first post-repair winter. No condensation-related leakage or icicles returned.

In summary, the SPF repair solved the building performance problem by three steps:
- An effective air barrier was installed at the exterior side of the wall, and continuity of the air barrier was assured at roof-to-wall intersections.
- A reasonable vapor retarder was provided by the SPF itself. The epoxy-paint-coated walls were relied on to control the high vapor pressure in the pool room.
- The client’s need to keep the building operational was satisfied.

In summary, this Health and Wellness Center, which admirably serves its Iowan community, was brought back to wellness itself by an effective and efficient enclosure repair solution.