

BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

CAN A POOR AIR SEAL CAUSE ROOF FAILURE?

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ABSTRACT

A hospital owner in the Mid-Atlantic region experienced complete roof failure within five years of installation. Components within the roofing assembly had debonded, warped, twisted, cupped, and distorted, causing the roof to no longer drain properly. This left the owner fearful that large portions of the roof would fail and blow off in a storm event.

During the course of the evaluation, thermography, roof cores, moisture meters, document review, and visual inspection techniques were used to demonstrate a number of defects in not only the design of the building but in the installation of various roofing components.

The installing contractor claimed that the building's mechanical system was solely responsible for pressurizing and damaging the roofing materials to the point of failure. The owner claimed that there must have been a number of defects in the installation of the roofing system that caused the system failure.

During the course of the forensic evaluation, it was demonstrated that the mechanical system was not responsible for the failure of the roofing system; however, it was determined that defects in the design and construction of other building components, such as the structural steel heliport, the roofing air/vapor barrier, and roofing components, contributed to total system failure. These defects, coupled with significant workmanship issues, led to the premature failure of the roofing system.

SPEAKER

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TIM MILLS earned a BS degree in engineering from Brooklyn Polytechnic Institute of New York. He is a licensed professional engineer in Virginia, North Carolina, and South Carolina. In 2002, he founded TAM Consultants, a professional services firm. His 30+ years of experience cover a wide range of public and private projects. He has published numerous articles. Mills has completed nearly 1,500 residential home and commercial building inspections and 300 energy audits. He is an instructor for ABAA training courses, which educate and certify contractors in the proper installation of air barriers, as well as a certified ABAA Auditor in the Quality Assurance Program.

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INTRODUCTION

In this case study, we are taking a look at a medical facility in Climate Zone 4 in the Mid-Atlantic region of the United States. The project is located in a mountainous region that experiences warm summers and cold winters.

Within a few years following installation of the roof on this facility, the roof condition was such that it already required replacement as it was determined to be irreparable (Figures 1 and 2). This study came about as a result of an insurance and potential legal claim filed by the owners with their property insurance company.

Insurance claims are unique as the insurer is not only interested in the scope and extent of the damage that has occurred or been reported, but also is very interested in the cause(s) of the reported damage or failure(s). The insurer will often retain a forensic engineering company to produce what the industry refers to as a Cause and Origin Report. The purpose of the report is not only to define the scope and extent of the physical loss that has occurred but also to determine cause and ultimately to assist in determining which parties are liable for

the repair costs. The results of a forensic engineering effort are often used by the insurance company to subrogate against a third party to allow the insurer to recover some or all of its costs associated with the claim.

BACKGROUND

Not too long after completion of construction of this medical facility's multistory large addition, the owner began to have issues with the installed low-slope roofing system. There were signs of excessive ponding, deformation, warping, and cup-



Figure 1 – View of failed roof system. The photo does not convey the large amount of insulation deformation. Note dirty spots where ponding frequently occurs.



Figure 2 – View of roof area following a storm event, where ponding areas and insulation deformation are more evident.



Figure 3 – View of a parapet wall where EPDM membrane has debonded from the wall surface.

Figure 4 – Thermal image of parapet wall where membrane separation is clearly visible.



ping of the insulation boards under the roofing membrane. After five years and filing numerous warranty claims and obtaining advice from various roofing companies and suppliers, the lawyers and insurance companies got involved.

During the course of the investigation as to what went wrong, a number of activities took place, including:

- A site visit was conducted to visually observe the roof during the daytime and evening.
- Five large core cuts were made to review the construction and condition of the various roofing system components.
- Roof seams were probed and inspected.
- Moisture meters were used to verify the presence of wet insulation.
- Thermal imaging was utilized to check for the presence of saturated insulation in the top layer of insulation.
- Differential building pressure measurements were also taken across the roof membrane at various locations.

Various parties involved in the construction and management of the building were interviewed as well, and a number of construction-related documents and warranty claim reports were reviewed. The assessment of the roof system was conducted in late summer.

INVESTIGATION

The failed roofing system construction included a 22,000-sq.-ft. 0.060 black EPDM single-ply roofing membrane fully adhered to tapered rigid board insulation consisting of multiple layers of polyisocyanurate insulation with paper facers bonded together with hot mopped asphalt. The rigid board insulation is adhered in most places to a vapor retarder

set in asphalt on the composite concrete deck. The EPDM roofing system turns up and over a short pre-cast concrete parapet wall on all sides and is topped with a prefinished metal coping system.

Prior to cutting cores in the roof, visual observations immediately indicated that



Figure 5 – View of parapet wall where membrane is ballooning out and has debonded from the pre-cast concrete wall.

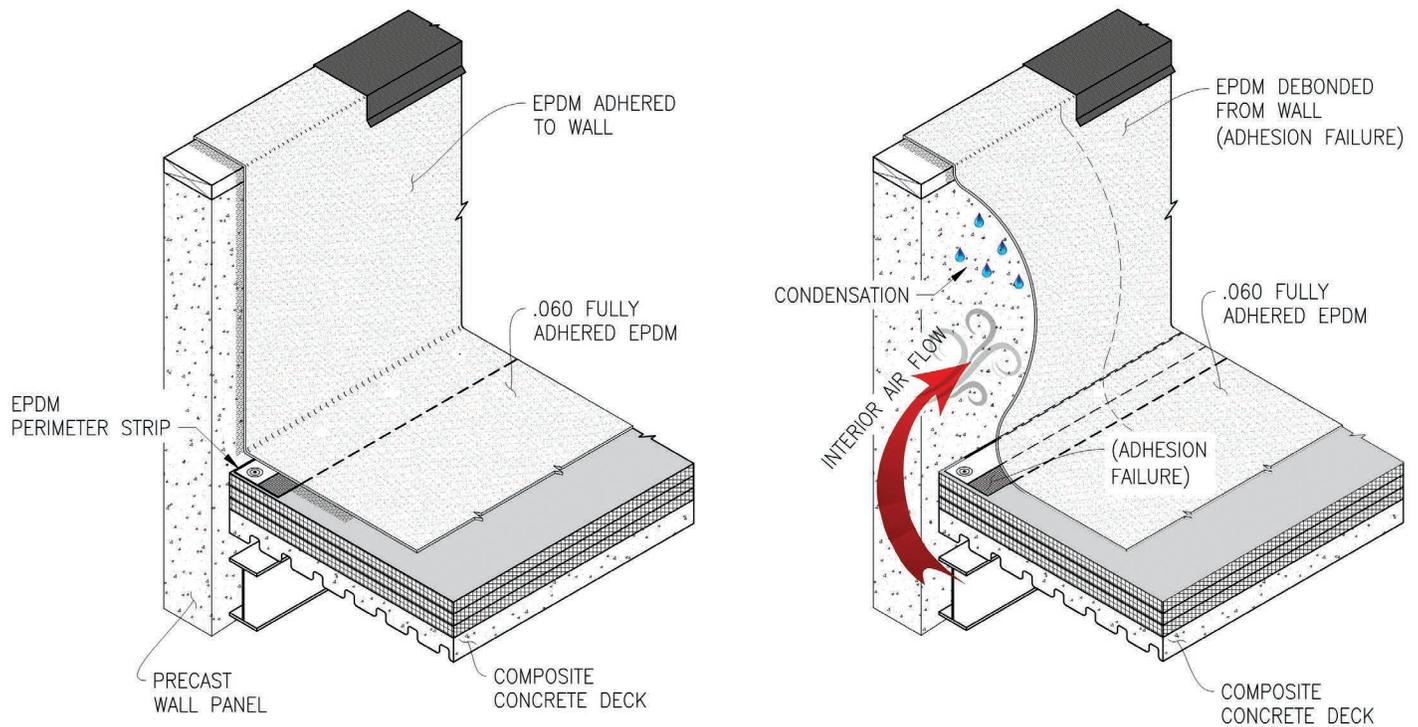


Figure 6 – Sketch of parapet wall condition before and after system failure where pressurized interior building conditioned air has easy access into the roof assembly, causing condensation and ultimately adhesive or product failure.

there had been widespread bowing, cupping, delamination, or debonding in large areas of the roof insulation. This was readily visible on approximately 30 percent of the roof area. This damage to the roof insulation occurred lengthwise along the long direction of the insulation boards, as is typical. The displacement of the insulation was severe enough that it created many ponding areas across the roof and impeded water flow, preventing the roof from easily draining.

In very few areas it was evident that the roof membrane itself had become debonded from the top layer of insulation, but in the vast majority of locations, it appeared as though the insulation layers were either coming apart from each other or separating (debonding) from the roof deck. The areas where the roof membrane had debonded from the top layer of insulation primarily occurred at the roof access doorways.

The owner had reported that for the most part the roof system had remained leak free with a few leaks noted over the years that were quickly repaired under the warranty.

During the course of some of the warranty repairs that had previously been executed, a significant portion of the roof membrane and insulation had been removed and reinstalled with a urethane adhesive rather than hot asphalt, as the repairs would have

been easier at the time for small areas in an occupied building. The portions of repaired roofing had also showed similar failures in the insulation as those that had occurred with the original roof installation.

It was observed that the fully adhered roof membrane had separated from the precast parapet walls in many areas around the entire perimeter of the building. During the inspection of the roof membrane lap seams, it was determined that, in general, the EPDM roof membrane seams appeared to be in serviceable condition with very few deficiencies noted, and were in need of perhaps a small amount of maintenance. It was also observed that interior building air pressurization from the mechanical system was affecting the roofing system to the extent that where the roof membrane had become debonded on the parapet walls, the membrane was ballooning out due to internal building pressure. In addition to the observed debonding of the membrane from the parapet walls (Figure 3), the membrane had also become debonded from the reinforced EPDM strip at the base of the wall where the roof membrane turns up the wall and is adhered to the EPDM strip (Figure 4).

A key issue that needed addressing as part of the insurance claim was that the installing roofing contractor, the general contractor, and the roofing system

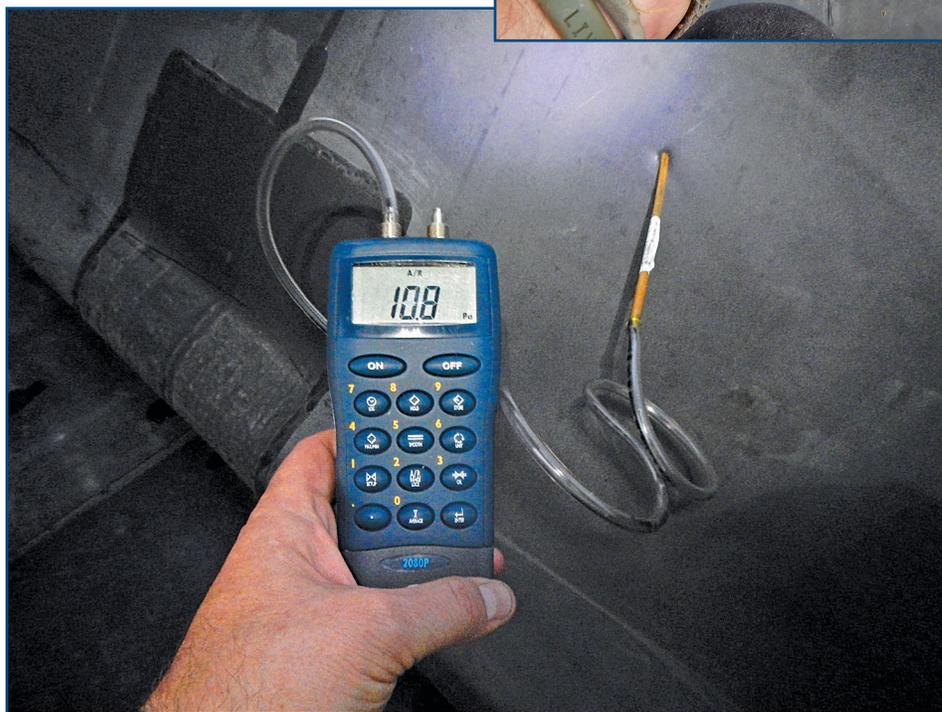
manufacturer had emphatically made the claim that the building's HVAC system was positively pressurizing the roofing system with enough pressure to cause "structural damage" to the roof system, including the membrane and the insulation debondment, delamination, and overall failure (Figure 5). Therefore, as part of the evaluation and using a micromanometer, pressure measurements were taken at various areas around the building, particularly at the parapet walls to measure the differential pressure between the interior and the exterior of the building across the roof membrane (Figure 6). This differential pressure was taken on a windless day and represents the pressure induced by the HVAC system and any pressure associated with the stack effect due to the height of the building. Wind effect, if measured, would have greatly increased the pressure readings.

With few exceptions and in nearly all building types, it is desirable to have a pressurized interior environment relative to the exterior of the building. This desirable effect is achieved by the mechanical engineer's design where the total amount of conditioned outside air that is being introduced into the building through intake louvers is greater than the total amount of air that is being exfiltrated from the building envelope through mechanical exhaust and air

Figure 7 – Using a moisture meter for a quick check for moisture content at both the surface and deep layers of insulation.



Figure 8 – View of the use of a micromanometer and pressure probe to measure the air pressure difference across the parapet wall roof membrane.



leakage through the building envelope.

In an ideal world, the amount of air that is exfiltrated can be completely controlled by mechanical means, and unintended air leakage through the building envelope is reduced to near zero. The importance of an airtight envelope cannot be overemphasized. Medical facilities are somewhat unique in that very often they rely on 100 percent outside air for the HVAC systems and don't return much if any air back to the air handlers via return ducts. This does have a tendency, depending on how the systems are operated, to create relatively

moderate interior building pressures as noted in this case.

Using a micromanometer, pressure differentials between the interior and the exterior building were measured between 10 and 15 pascals positive where the interior of the building was positively pressurized relative to the exterior at the roof level. Although elevated, these pressures are not uncommon. (See Figures 7 and 8.)

The evaluation also included the use of an infrared (IR) thermal imager to evaluate the roofing system for readily observable areas of saturated roofing materials.

The result of the IR study found only four small areas of wet surface insulation, and those areas were adjacent to penetrations and not located in areas where the failed and delaminated roof and insulation had occurred. The thermal imaging survey also clearly revealed areas of debonded roofing membrane at the parapet walls around the entire roof area.

Based on the thermal imaging results and the differential air pressure measurements, it became clear that conditioned air from the interior of the building was easily finding its way to the roof level at the perimeter condition where the roof deck and parapet wall meet.

During the study, five roof core cuts were made. Four of the core cuts were made in the field of the roof, and one additional cut was made in the membrane at a parapet wall location. During the course of reviewing results of the core cuts, it was observed that the interlayer adhesion for the various rigid board insulation layers was poor. Hot asphalt was used as the means of adhesion between the insulation layers and for adhesion of the insulation to the roof deck. Poor adhesion occurred as a result of either too little asphalt, the use of asphalt that was too cold, or insulation boards that were not stepped into place as they were placed into the hot asphalt. Some or all of these issues likely came into play during the installation of the roofing insulation, creating insufficient roofing insulation adhesion at all of



Figure 9 – View of deformed polyisocyanurate insulation.

Figure 10 – View of poor interlayer adhesion between insulation boards.



the test locations in the field of the roof.

In the roof core cuts where the insulation was found to be damaged, warped, and delaminated, there was significant evidence of previous or intermittent wetting, although at the time, very little moisture was measured in the insulation.

In the areas directly outside of roof access doorways—either from stairwells or mechanical room access doors—it was noted that the roof membrane had become debonded from the top layer of insulation. This ultimately was attributed to physical damage due to crushing of the very top surface of the polyisocyanurate insulation from frequent activity across the surface of the roof membrane—either by moving equipment or maintenance staff walking on the roof (Figure 9). This condition was primarily localized and would likely not have occurred if a gypsum cover board had been installed as part of the project.

The roof core cuts indicated that by and large, the EPDM roof membrane was well adhered to the top layer of insulation at all locations. What the investigation also found, though, was that there was poor adhesion between the layers of insulation (Figure 10), ranging from 25 to 75 percent coverage at all locations surveyed. At the parapet wall core cut, it appeared that the roof membrane had been fully bonded to the parapet wall but had become debonded following installation. In all of the roof cut areas, even though insulation had been badly deformed (Figure 11), only one roof cut yielded saturated insulation, and only at the bottom of the assembly. In all locations there was a strong odor



Figure 11 – View of large deformation in the insulation. Note evidence of water staining even though insulation was dry.

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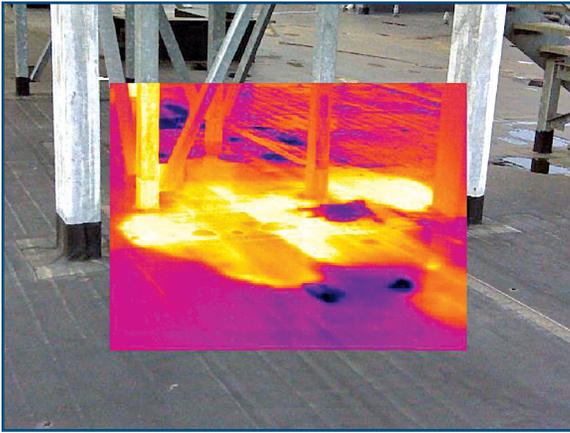


Figure 12 – Thermal image of saturated roof insulation adjacent to galvanized steel columns where drain holes are allowing water entry into the roof system.



Figure 13 – View of mechanical screen galvanized steel columns with exposed drain holes at the top of each column.

mold and some light mold growth, and when the roof was cut open and in the roof core where high moisture content was measured, significant mold growth was observed.

Another feature of the project included a heliport and walkway located on a steel platform supported by tube steel columns well above the roof surface. The entire heliport, access stair, and walkways were supported by galvanized structural steel tube sections, which created square penetrations throughout the center portion of the roof area. Additional structural steel tube sections were installed along certain portions of the roof as well as for supporting screening from street views.

As determined from the IR study, there were four areas of saturated surface roof insulation adjacent to structural steel tube column penetrations. Further evaluation of the steel structures revealed small 3/4-in.-diameter drain holes in the tube steel members. More often than not, when galvanized structural tube steel is used for creating roof features, as part of the galvanizing process, drain holes are installed at both ends of the tube steel assembly in order to allow the steel assemblies to drain once they are lifted from the galvanizing dip tanks.

These drain holes are not part of the design documents and sometimes don't show up on shop drawings but are required for the production and galvanizing process. Some galvanizing shops will seal those holes with a plug, but often they are never sealed. This frequently results in misdiagnosed roof leaks for years because the holes are facing up or otherwise hidden from view or are high above head level and not noticed (Figure 12).

During the course of this study, it was determined that the installed galvanized tube steel columns supporting the heliport, walkways, outside stair, and mechanical screening all had open drain holes—either at the top or sides (near the top) of the structural steel members (Figures 13 through 16). Many of the members were protected from direct rain entry but were still left with open holes. This observation yielded two



Figure 14 – Close-up view of exposed drain holes in the galvanized steel columns, allowing direct water infiltration and air exfiltration. Note some holes are drilled and some are cut with a torch.



Figure 15 – View of upward-facing drain hole in a galvanized steel column.

Figure 16 – View of upward-facing drain hole in a galvanized steel column.

conclusions: 1) any water that got into the structural steel tube sections was directed to the bottom of the roof assembly directly to the concrete deck where the column base plates were attached to the deck, and 2) each structural column was acting like a tiny chimney, providing a direct air path from the roof assembly to the exterior—a highly undesirable condition.

FINDINGS

Fundamentally, insurance claims and the included Cause and Origin Report are used to resolve an argument between two or more parties so that responsibility can be assigned. Sometimes the answers are not so evident, and the investigation yields unexpected causes of the observed failures that might be assigned to other parties such as different subcontractors and/or even the building designer.

In this matter the owner claimed defective work as the cause for all of the failures, and the contractor and roof system manufacturer claimed building pressurization through the HVAC system as the cause. Both of the arguments failed to explain all of the observations that were made during the investigation.

First, to be clear, the owner's claim that the roofing system was defective due to faulty workmanship was a valid claim. The investigation yielded evidence of very poor adhesion of the insulation layers. The condition of the roof created somewhat of



an emergency situation for the owner as the roof was a potential candidate for a complete blow-off should there be a high-wind event. However, although the owner's claim was valid, it did not explain why the repaired areas were also failing, nor did it account for water moisture at the bottom of the roof insulation and intermittent wetting of the insulation. Therefore, something else was also at play.

Second, the contractor, roofer, and manufacturer's claim that the HVAC system was the cause of the failures does not

stand up. Calculating the pressure of 15 pascals as measured at the parapet walls and converting it to pounds per square foot (PSF) yields a differential pressure of a mere 0.3 PSF. Given, for example, even a relatively low rating for an FM Global FMG 1-60 roof, designed for field pressures of 30 PSF and tested to pressures of 60 lbs. PSF, we are looking at orders of magnitude of 100 or more in the difference between what the mechanical system is capable of producing for internal building pressure versus what a properly installed roof system

is capable of resisting. It can be seen that the contractor's argument has no merit, since the HVAC system was not creating enough pressure to cause the roof to fail. In fact, the internal building pressure is just barely capable of lifting the self-weight of the EPDM membrane, not including any other materials. Wind-induced pressures on roofs are far, far greater than those created by the mechanical systems.

The investigation continued to search for answers that explained what the observed conditions demonstrated. Following a review of the construction documents and an under-deck inspection, it became evident that the designer of record had failed to provide detailing to ensure that there was an adequate air seal between the roof deck and the adjacent pre-cast parapet walls; in fact, there was a large gap at the intersection.

The results of the infrared survey, core cuts, and moisture meter readings suggest that portions of the lower layers of insulation were or had been saturated. The absence of significant leaks in the surface of the membrane suggests that water was getting into the system either at leak points (holes) that were noted at the structural steel columns where it was finding its way directly to the concrete deck, or by other means. These holes, in combination with the presence

of measured internal air leaks around the perimeter of the roof, could have also served as a means of interior air flow directly into the roof system at the perimeter.

This condition of uncontrolled air flow via exfiltration through the roof assembly very likely caused condensation during the cold winter months. This helps explain why so much of the adhered parapet wall membrane has failed as well. The lack of air sealing at the parapet wall is a highly undesirable condition where interior building conditioned air, particularly in the winter months, has clear access to the roof system via gaps between the concrete deck and the adjacent pre-cast parapet wall system. This condition can cause condensation on the roof membrane, and, over the long term, cause membrane adhesive to fail, leading to debonding of the roof membrane at the parapet wall. This condition was greatly affected by the presence of numerous small holes in the structural steel tube columns allowing constant air flow to occur across the roof system from the parapet walls towards the interior where the structural steel columns are located.

As an example, if a winter interior set point of 68 degrees Fahrenheit and 50 percent relative humidity is assumed, and taking into account approximately 50 vent

holes in the structural steel columns and the measured differential pressure, it can be calculated that approximately 10 gallons of water in vapor form is being transferred through the roof assembly via air flow alone every single day. This is not an insignificant amount for a 22,000-sq.-ft. roof. Also, this amount of water vapor transfer would be much higher when the wind is blowing. It can be assumed that a considerable amount of condensation might occur within the roof assembly during the cold winter months, with a certain amount of drying occurring during the warmer seasons or warmer days. This amount of air flow and subsequent water vapor transfer, combined with direct water leakage in a few of the steel columns that were exposed to the weather, had a significant impact on the poorly installed insulation, greatly exacerbating the failure condition that occurred.

The final recommendations included replacing the entire roofing system and ensuring an airtight seal between the roof deck and the parapet walls and at all other penetration locations so that the transfer of interior building air into the roof assembly is mitigated. The final recommendations also included sealing of all of the drain holes in the structural steel tube columns. 