Too Hot to Keep Your Cool

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ABSTRACT

A reputable design-build team assembled the necessary professionals and trades to develop a modern $50-million long-term health care facility. Shortly after occupancy, the facility’s staff grappled with their inability to maintain temperature and humidity for the variable air volume (VAV) mechanical systems. A forensic evaluation discovered a number of low-flow air leaks at the building envelope lines that, when combined, resulted in large building envelope air leaks, throwing the mechanical systems out of control.

The presenter will describe the original design, detailing, and design coordination that led to the building failure and will also review various investigative techniques and cost-effective repair solutions that resolved the building issues.

SPEAKER

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TIMOTHY MILLS, president of TAM Consultants, brings over 30 years of experience as an engineer, building envelope specialist, and roofing systems consultant for the built environment. Mills is also a licensed field auditor, instructor, and speaker for the Air Barrier Association of America (ABAA). Project types include commercial, federal, municipal, educational, institutional, single- and multifamily residential, historical, industrial and manufacturing facilities, laboratory, parking, green buildings, and retirement facilities. Mills is a frequent speaker on building envelope, forensic issues, and roofing systems. He has spoken at numerous RCI symposia and has appeared as a guest lecturer at Penn State University.
INTRODUCTION

It is not uncommon for well-intentioned, professional design, construction, and development teams to work diligently together in an effort to meet project objectives. Unfortunately, these teams often miss these objectives, resulting in frustrated team members and dissatisfied customers. In this case study, a private developer approached a public state agency for the purpose of creating a public-private partnership with the goal of replacing dilapidated facilities with modern, cost-efficient facilities. The project proposer and developer assembled a team including a reputable, experienced general contractor, an experienced design team, and various other key partners to develop a $50-million replacement campus-style long-term medical care facility that by all accounts was long overdue and would provide a necessary improvement for patient care.

The new campus-style facilities consisted of a large two-story central core space for administrative, support, and other group activities, as well as multiple single-story pods, housing patient rooms, and nursing stations. The pods are connected to the central core building with connecting corridors.

Shortly after occupancy of the new facilities, patients and staff began lodging complaints to the development team indicating that the building’s interior environment and the patient pods were uncomfortable. Specifically, on hot summer days, the heating, ventilation, and air-conditioning (HVAC) systems appeared unable to maintain comfortable temperature and relative humidity levels. This continued throughout the summer; and as summer turned to winter, the building occupants found themselves again uncomfortable due to the inability of the mechanical systems to maintain comfortable temperatures during the coldest winter days.

As might be expected, the project team’s first responses were to check and double check the operation of the HVAC systems and the design approach and execution. The project team made a small number of modifications to the HVAC systems, changing controls and increasing the size of motor-operated louvers and other small changes. This resulted in little success in resolving the problems. These efforts continued for over a year, with the blame ultimately directed towards the engineers for failure of the system to function as intended. The owner’s level of frustration with the development team had reached the point of considering legal intervention. It was at this stage in the process that the author was retained to provide an evaluation of the reported conditions and make an effort to determine what was causing the problems and what the best course of action might be.

BACKGROUND

The single-story patient pods are simple structures constructed with concrete slab-on-grade floor slabs with light-gauge, load-bearing metal stud walls supporting light-gauge metal roof trusses. Exterior wall construction is brick cladding and cement siding, a cavity, building wrap, gypsum sheathing, light-gauge metal stud framing insulated with glass fiber insulation, and painted gypsum drywall interior finish.

The roof trusses form a large nonventilated attic space and support ceiling finishes and a sloped steel roof deck, which supports a compact, ventilated insulated roofing assembly. This roof assembly is comprised of asphalt shingles over a synthetic underlayment, OSB roof sheathing, a continuous vent space beneath the sheathing, and rigid polyisocyanurate roofing insulation directly fastened to the metal deck. The compact roof assembly is ventilated by an open continuous soffit vent where soffits occur on the building and a continuous ridge vent at the top of the roof slope. The sloped shingle roofing on the one-story connector corridors butts into the vertical two-story wall at the central core building. The buildings are designed to give the look and feel of residential structures.

INVESTIGATION

A review of the plans, specifications, and construction photographs provided clues and an initial direction for the path of the investigation.

The design calls for a traditional building wrap on the exterior wall sheathing, which serves as the wall weather barrier. The building wrap is not specified as an air barrier but serves solely as the weather barrier (the difference being primarily in detailing), whereas an air barrier would require more attention to airtight connections at all of the penetrations openings and transitions between dissimilar building materials, as well as airtight connections between the

Figure 1 – Construction photo depicting gable end and detailing.

Figure 2 – Construction photo depicting one-story resident pods. Gable ends are open to the attic plenum.
The design does not refer to, detail, or specify that an air barrier be installed in the roof assembly. The compact roof assembly does include a roofing underlayment membrane under the shingles; however, the underlayment is on top of the sheathing and, therefore, on top of the ventilated airspace beneath the roof. The installation of an air barrier could have readily been accomplished by placing a self-adhered membrane directly on the roof metal deck prior to installation of the roof insulation. With the absence of an air barrier and the roof assembly, there is no means of tying the wall and roof intersections in the wall and foundation.

Figure 3 – Partial roof plan view depicting two of the patient pods and administrative support building.

Figure 4 – Inside of ceiling plenum in administration building, showing measurement of high temperature (90°F) and relative humidity (51%) air leakage at a parapet wall into the return air plenum.

Figure 5 – Photograph at a masonry wall where the cavity wall has been depressurized due to the return air plenum pulling air into the cavity from the exterior.

Figure 6 – View of a partially deconstructed roof gable end where trim has been removed to allow inspection of the roof deck and support framing.

Figure 7 – Close-up view of the gable end condition where building wrap seam tape is used to seal the building wrap to the roof deck.
Roof sheathing
vent space.

Figure 8 – Close-up view of the roof gable where the fluted metal deck, which serves as the top portion of the return air plenum, is open to the exterior other than being covered with wood blocking and trim.

Figure 9 – Photograph of connector roof-to-two-story wall intersection. The other side of the wall is a return air plenum. Each roof deck flute is open to the plenum that is located behind the wall.

Figure 10 – Close-up (below) of connector roof-to-two-story wall intersection. The other side of the wall is a return air plenum, and the roof deck is open to it. Arrows indicate air leak path at every deck flute.

weather barrier to the roof system in a manner that could have controlled air leaks.

During the construction of the buildings, there was some discussion regarding the intent for terminating the weather barrier on the exterior walls at the roof soffit and roof gable ends. At the time, it was determined that the best course of action was to simply tape the weather barrier to the flutes of the extended sloped metal roof deck with the weather barrier seam tape. This approach also left the upper portion of the deck at the gable ends open to the plenum (Figures 1 and 2).

The mechanical systems for the facility are more sophisticated than the relatively simple design and construction techniques of the building’s structure and envelope systems. The HVAC system includes large rooftop HVAC air handlers located on the two-story administrative building with supply air-ducted to above-ceiling variable air volume (VAV) boxes located in the patient pod structures (Figure 3). Each air handler serves multiple building pods. In addition, the attic spaces above the single-story patient pods were designed to be large return-air plenums for the rooftop units on the adjacent administrative building. The attic space above the connecting corridors serves as return air plenum ducts, returning air back into a large return-air plenum in the administration building.

In addition, the mechanical system was set up with controls to seek an indoor positive pressure set point, which is accomplished by drawing in outside air through fresh air louvers to pressurize the building.

A review of the detailing—such as the lack of an air barrier in the ventilated roof assembly, the lack of an adequate connection between the wall weather barrier and the roof assembly, and the presence of a large open return-air plenum in the attic space, as well as consistent reports of the inability to maintain temperatures on design-day conditions—steered the investigation in the direction of probable air leaks in the building envelope. If the mechanical system was, indeed, designed and installed correctly, but the building envelope had large openings or a series of many small openings in it allowing air leaks to occur, the mechanical system would be thrown out of control as it sought to maintain building pressurization by bringing in more and more outside air. With potentially large air leaks in the return air plenum, not only was the system possibly unable to pressurize the building, but it was also possibly drawing in unconditioned air through leaks in the building envelope.

Areas of concern were identified prior to the field investigation. Focus during the field investigation efforts included roof-wall intersections, roof-soffit and ridge vent
detailing and performance, leaks at window systems and their installation, and the wall slab intersection. Some of these areas were hidden from view and inaccessible, such as detailing around windows and the floor slab. (See Figures 4-10.)

The investigation team utilized a handheld smoke generator, a handheld hygrometer, a micromanometer, and thermal imaging equipment to quickly investigate the most easily accessible and identifiable areas where leaks in the building envelope might be occurring. The investigation team worked closely with facility staff members, who were able to change the control settings on the HVAC system to pressurize and depressurize the building during the investigation and assist in identifying areas of air leaks.

As part of the investigation, several cement soffit panels had to be removed to allow physical access to the wall/roof deck tie-in. Roof trim at the gable ends, as well as gable-end blocking, were removed to allow a visual inspection of the ends of the steel roof deck. The work also included a lot of crawling around in the attic spaces with a handheld smoke generator looking for air leaks in the plenum.

Areas of air leakage in the building envelope were quickly identified using these techniques. Large air leaks were identified at the roof-wall intersection, both along the entire soffit of the buildings and the roof rake edges (Figure 11). Air leaks were particularly severe at the open flutes in the metal deck along the roof rakes and where the single-story roof areas tied into the two-story walls, allowing large quantities of air to be drawn out of the ventilated roof assembly directly into the return air plenum. (See Figures 12-15.)

The investigation team found that there was so much outside air being introduced to the return side of the mechanical system that it was impossible for the mechanical system to maintain control of pressure, temperature, and relative humidity. The mechanical system was overwhelmed by unconditioned outside air. Smaller air leaks were also found at window openings, roof penetrations, and gaps in the roof deck and roof insulation boards.

The air leaks in the envelope were prioritized based on the severity of the air leaks and the ease of repair. The project team focused on cost-effective solutions to seal off the air leaks without having to remove the entire roof system on the buildings and while maintaining occupancy.
REPAIRS

Following a study of several options, it was decided to seal off the roof-wall intersection at as many areas as practical using two-part, medium-density spray polyurethane foam (SPF). The repair approach required removing the cement board soffit along all of the roof eaves and removing trim and rake boards at all of the roof gable ends to seal off both the bottom and the top portions of the metal deck flutes. The repair necessitated drilling a ½-in.-diameter access hole at every steel deck flute along the gable end rake edges and injecting foam to seal off the space between the bottom of the roof insulation and flute (Figure 16).

One of the largest air leaks and most effective repairs occurred at the intersection between the sloped roof system at the connecting corridor and the two-story administrative building (Figures 14-15). This condition occurs where every pod roof connects to the two-story building. This repair (Figures 17-19) did require removing a certain amount of roofing material for a width of approximately 2 feet to gain access to the intersection between the metal roof deck and the adjacent wall structure, where there was a return air plenum located on the other side of the wall. Air was being drawn directly into the plenum from the top of the metal deck. In essence, all of the flutes in the metal roof deck were acting as small ducts, collecting air from all over the roof perimeter and directing it into the return air plenum. This repair required the use of a self-adhered air barrier membrane tying the two-story wall weather barrier to the roof deck and sealing all of the metal flutes with medium-density, closed-cell SPF. The roof insulation, decking underlayment, and shingles were replaced to match what was already there. All the high-priority repairs were completed with minimum disruption to the operation of the facility and without vacating patients from the premises. In addition, the repairs did not affect the ventilated aspects of the compact roof assembly, necessary to ensure long-term performance of the asphalt shingle roofing system.

Following the repairs of the high-priority air leaks, the mechanical system was easily able to maintain the design set points and satisfy the building occupants.
discount the fact that having an airtight envelope is advisable any-
way and is now a code require-
ment. However, with this particular system, the building failed quickly
because of the mechanical system’s design; using attic area as a return
air plenum demanded a reasonably
airtight assembly.

3. The cause of a problem is not
always what it appears to be. In
this case, the mechanical system
was blamed for being ineffective,
when in reality, the system would
have worked just fine if the build-
ing envelope were airtight. When
approaching building failures, keep
an open mind as to what the cause
might be.

4. Work as a team. Big problems can
be solved, often economically, when
the team works together in evaluat-
ing the problems and coming up
with solutions by inviting input from
all of the participants.

5. Education is necessary. There con-
tinues to be a critical need for con-
tinuing education for design pro-
essionals pertaining to the critical
interaction among the various build-
ing systems and air barriers and
how, when these systems are not
executed correctly, building failures
occur.

LESSONS LEARNED
1. Airtightness matters. Regardless
of the type of mechanical systems
employed in buildings, it is impor-
tant that the envelope be constructed
airtight. Leave it to the mechanical
engineers to determine ventilation
rates by mechanical means. Many,
many buildings are constructed with
leaky envelopes, but because their
HVAC systems are either oversized
or not seeking pressure set points,
building owners are unaware that they
are wasting energy and money
heating and cooling the neighbor-
hood.

2. Coordinate design efforts. In this
case, the architect was unaware
of how impor-
tant having an airtight
envelope was
to the proper
operation of
the mechani-
cal system.
That is not to

Figure 17 – Repair details depicting the use of SPF and an air barrier to seal air
leaks at roof to second-story wall intersection.

Figure 18 – Ongoing repair at roof. Second-story wall
intersection using an air barrier membrane and SPF.

Figure 19 – Ongoing repair at second-story
soffit utilizing SPF to seal air leaks in the
soffit roof-wall intersection.