Gothic Revival: Lessons Learned From a Failed Historic Roof Restoration

Robert Fulmer

Fulmer Associates, Building Exterior Consultants LLC

29 Forrest St., East Hampstead, NH, 03826
Phone: 603-828-2458 • E-mail: rfulmer@becsolutions.net
ABSTRACT

Recently, a private preparatory school commissioned the envelope restoration of its chapel, originally designed in the Gothic Revival style by noted Boston architect Henry Vaughn in 1899. The restoration project incorporated historic and contemporary materials and processes in the design of a copper roof system and limestone restoration. The restoration failed within two years of completion due to design and workmanship errors, incurring remediation costs of $1.5 million.

This presentation is a case study of the design and workmanship that led to that failure and provides guidelines for successful integration of contemporary materials and processes to achieve enhanced building performance in historic structures.

SPEAKER

ROBERT FULMER — FULMER ASSOCIATES, BUILDING EXTERIOR CONSULTANTS LLC

ROBERT FULMER specializes in analysis, diagnosis, and integration of historic and contemporary building envelope issues, providing specification and oversight of appropriate remedial solutions. Recognized as an expert in copper and slate roofing, he has consulted on significant projects throughout North and Central America. Fulmer is a published author of trade-specific articles and has lectured throughout the U.S. on historic preservation and building envelope topics. He is qualified as an expert witness in roofing litigation. Fulmer is past president and currently on the board of the New England Chapter of RCI and is the current senior vice president of the National Slate Association.
INTRODUCTION

Recently, a private school in Boston, Massachusetts, commissioned the building envelope restoration of its campus chapel. Noted Boston architect Henry Vaughn originally designed the chapel, circa 1899, in the Gothic Revival style.

The 2000 restoration project incorporated a mix of historic and contemporary materials and processes in the design and installation of a new copper roof, flashing, and roof drainage systems, as well as the cleaning and restoration of the chapel’s limestone exterior. Although traditional building materials with an 80-year service life were specified, the restoration failed within two years of completion due to design and workmanship errors. The result was over $150,000 in subsequent water damage to the building and the requirement to redesign and replace the 2000 restoration in 2012 (11 years later) at a cost of $1.5 million.

This case study illustrates how a combination of failed design elements and non-standard workmanship resulted in the systemic exterior restoration failure of a noted historic building. The failed restoration, however, would provide an opportunity, 11 years later, to design and construct exterior building systems using a combination of both historic and contemporary materials and technologies. The end result would be extended service lives of exterior systems that would provide improved thermal efficiencies while enhancing building performance.

Some of the challenges encountered included ventilating Gothic architectural roof system spaces, modern insulation considerations for historic structures, and proper thermal-dynamic design of copper roof systems, as well as field research, testing, and use of contemporary building technology and materials in historic structures to improve thermal efficiencies and address thermal dynamic issues. Lessons learned also highlighted the requirement to fully qualify all contractors and underscored the need for thorough and extensive project management to ensure a positive project outcome.

Gothic Architecture Characteristics and Challenges

The first recorded example of Gothic architecture occurred in 1140 with the construction of the Abbey of St. Denis in Paris. The original, true Gothic order officially ended during the early to mid 16th century with buildings such as Henry VII’s Chapel at Westminster.

Far from dying out in the 16th century, original Gothic architecture was recognized as one of the primary structural systems of institutional construction. Its incorporation of masonry structural members “in compression” enabled the construction of tall, buttressed structures with interior load-bearing masonry columns and structural vaulted ceilings. This style of construction is ideal for cathedral and institutional structures with large open spaces and tall stained-glass windows. The ornate Gothic order survived and flourished over the centuries under a number of transformations and movements such as Early English, Norman, French Neo-Gothic, Venetian, and, more recently, Vernacular and Carpenter revival movements.

The Gothic Revival movement (also referred to as Neo-Gothic or Victorian Gothic) began in England in the mid 1700s as a response to renewed interest in the “High” or “Anglo Catholic church.” The movement’s popularity was exported to the United States in the early 1800s and reached a peak of interest in the early twentieth century.

The subject property of this case study was designed by noted Boston architect Henry Vaughn in 1898-1899. Vaughn was born in Cheshire, England. He moved to Boston in 1881 to bring the English Gothic style to the Anglican (Episcopal) community in the United States. He became one of the most influential proponents of the Gothic Revival movement there. Vaughn’s notable projects in the United States include the Cathedral of St. John the Divine in New York City, Seearles Castle in Windham, NH, the Washington National Cathedral in Washington, DC, as well as numerous college and private school cathedrals and chapels, including the subject property in this case study.

In 1898, when Vaughn began his design of this chapel (see Photo 1), he viewed his work in the same perspective as Gothic architects had centuries before him. He incorporated high-quality materials with extensive service lives. He specified a solid masonry structure with substantial brick and veneer walls stabilized by flying buttresses. The brick core (4-ft.-thick at grade) was faced with 8-in.-thick local limestone blocks, which constituted both exterior and interior ornately finished façade surfaces. Solid structural masonry columns “in compression” anchored ribbed vaulted ceilings that supported the large, open roof areas. This construction type provided the large, open interior spaces desired for worship and a venue for rows of ornate stained-glass window panels, exceeding 25 ft. in height. Vaughn protected the structure with a copper roof and drainage system, utilizing both standing-seam and flat-seam copper panels. The low-slope roof areas are found on the bell tower and semitranscept roofs, as well as all flat gusset areas between the crenelated parapet and the foot of the steep-slope roof sections. These areas received fully soldered flat-seam, 16-oz. natural (red) copper panels. The steep-slope roofs on the nave, nave-aisle, and sacristy roofs received double-lock, standing-seam panels of the same material. The roof drainage system is a combination of historically accurate, copper-lined “gargoyles” scuppers (Photo 2) and...
copper downspouts.

Vaughn had specified the roof system components with a 70- to 80-year service life. As with other architectural genres, Gothic architecture, by its defining characteristics, presents its own unique design challenges.

For example, a principal Gothic architectural characteristic is the use of crenelated parapets that incorporate the decorative merlon stones, punctuated by crenel openings defining the upper termination of exterior walls or battlement. This detail is problematic in cold climate zones, creating waterproofing issues during periods of ice and snow accumulation. Like his peers throughout the centuries, Vaughn neither specified nor designed for any insulation or ventilation considerations. It was believed that these large, open interior spaces were “self-ventilating,” and any heat loss above the lower third of the structure was not recoverable or useful. When these substantial structures are restored, however, the modern design must address these and other building performance issues.

The application of contemporary building principles and technologies must be carefully considered and designed as requisites for successful historic restoration projects.

2000 Chapel Restoration

As the building envelope systems of the chapel began to deteriorate over time, water infiltration began to occur throughout the roof, drainage, and exterior wall flashing systems. Over the years, numerous repair attempts were made, from the construction of steep-slope roofs over chronically leaking low-slope roofs and gussets, to the prodigious use of asphalt cement. Most of the repairs were incompatible with the original architectural style or materials, and none had compatible service lives.

In the 1970s, a slate roof was installed over the ailing standing-seam copper nave roof. This attempt eventually failed as a result of the use of a BUR roof system to replace the original flat-seam copper gusset. After an extended period of interior water damage, in 1999, the board of trustees voted to perform a restoration of the building envelope that would include the use of the original copper roof and flashing materials specified by Vaughn. The process of design team selection began. After much research and due diligence by the trustees, the design team finally included a respected Boston architectural firm, noted for its work in historic preservation. Also included were an historic architectural consulting firm, two engineering firms, and a landscape architect. With the respected and qualified team in place, the design work began. In the late winter of 2000, a contractor was selected and the contract awarded. The chosen firm was selected based on references of other notable historic restoration and copper roofing projects. They were not the low bidder.

By May of 2000, the design team and contractors were waiting for the June project start date when the students left campus for the summer. Based on the request of the board of trustees and the recommendations of the historic consultants, the design team had included much of Vaughn’s original intent into the envelope restoration. The existing slate roof was to be removed and replaced with a new standing-seam and flat-seam copper roof system. The interior limestone walls had been inscribed over the years with the names and class year of notable alum, in addition to ornamental moldings and school insignia (see Photo 3). Years of water infiltration had left the limestone heavily stained with contaminants and efflorescence. The exterior limestone walls had also been affected by environmental surface contaminants and efflo-
rescence. Consequently, the repointing and cleaning of both the interior and exterior limestone façade were included in the scope of work. The design team also incorporated design changes to take advantage of contemporary building technology and materials. For example, ice and snow accumulation within the low-slope gusset areas behind the crenelated parapets had been a long-standing source of water infiltration. Consequently, an extensive heat-trace system was specified behind all parapets and roof drain scupper locations through the parapets.

Most of the cast gargoyle scuppers were replaced with Gothic drain tail pieces fabricated in natural copper, diverting roof runoff into copper conductor heads and downspout assemblies (Photo 2). The parapet heights from the gusset to the crenels varied from 36 to 40 in. In an effort to reduce snow buildup at this detail, the decision was made to elevate the gusset by fabricating a new wood-frame gusset, approximately 18 in. above the original. (The original gusset was located on the roof rafter tails at the parapet sill plate.) The new gusset framing was installed at all parapets on all elevations, along the 135-ft. building length. All roof drainage occurred via steel bowl drains located within the flat-seam copper gusset areas behind the parapets. Rainwater then passed through 4-in.-diameter cast pipe beneath the gussets and exited through the parapets at the copper drain tailpiece, and finally coursed through the new copper conductor head/downspout assemblies. This 2000 detail created a continuous unventilated and uninsulated cavity along all parapets that would later become a source of significant deterioration within the gusset assembly (see Photo 4).

Another design addition was made to the roofing underlayment system. After demolition of the existing roofing material down to the tongue-and-groove roof sheathing on all low-slope and steep-slope surfaces, a continuous, fully adhered layer of .060 ethylene propylene diene monomer (EPDM) was applied to all sheathing surfaces as an underlayment. The design theory was to provide a durable, waterproof underlayment to protect the structure while work was in progress, at a reduced cost compared to a conventional self-adhered, high-temperature, ice-and-watershed product.

The chapel had originally been constructed with a decorative interior and vaulted oak ceiling ornamented with hand-carved oak icons. A cavity space of two to three feet exists between the ceiling and roof sheathing. This space below the roof was never insulated or ventilated. The 2000 design did not address or alter these systems.

Based on these and other design alterations, construction began in June of 2000. The chapel was recommissioned five months later for a total restoration cost of $1.6 million.

Postconstruction Issues
In the spring of 2001, the first water infiltration issues began to occur. The inscribed limestone block in the north-elevation nave aisle area became saturated below the parapet/gusset area. This area had just been cleaned, so staining was obvious. The contractors were contacted and responded to find several failed solder seams in the flat-seam copper gusset above. These seams were subsequently resoldered. Approximately six months later, the previously repaired area began leaking again. In addition, several other areas of water infiltration were observed on the north and south elevations of the upper-nave roof and at the north-elevation semitranscept roof. The leaking areas of the nave roof were all located within the flat-seam copper gussets in the vicinity of the roof drains and crenelated parapet.

The water infiltration within the semitranscept roof was located at that roof’s intersection with the north-elevation nave exterior wall. The leakage at this location was of particular concern, as the chapel’s large and ornate pipe organ was housed directly below. A cycle of repairs and callbacks with the contractor began and extended over a period of several years. Most of the repairs involved the resoldering
of failed solder seams, which at the time were attributed to poor workmanship. While new leakage occurred within the roof system, older leaking areas went unresolved and persisted. The volume of water infiltration within the semitransep roof over the pipe organ continued to grow. This low-slope roof section is not visible from the ground, and in an effort to curb restoration costs, the design team had specified a fully adhered EPDM roof system both there, as well as on the bell tower and sacristy roofs. The potential for damage to the pipe organ was so great that the contractor built an “interior copper duct” system to divert the leakage away from the organ loft and into the chapel’s interior drainage system.

Meanwhile, the area of leakage continued to grow and encompassed an area approximately 25 ft. long along the interior limestone wall of the north-elevation nave aisle. This wall had been recently cleaned and restored during the 2000 project at a cost of $65,000.

Several years after project completion, water infiltration issues continued to multiply. Most problems were occurring within all parapet/gusset areas and were noticeably worsened by accumulation of ice and snow. The residential-grade heat trace system began to fail periodically, compounding the leakage and forcing members of the facilities staff to shovel ice and snow off of the flat-seam copper gusset areas. A cabled fall-arrest system was installed at all parapets to enhance the safety of the snow removal process.

While repairing failed solder seams in the spring of 2004, workers began to notice small “tears” or “splits” in the flat-seam copper panels. These were occurring at the soldered corners of the panels and at brake-formed “pitch changes.”

Frustrated, the owner summoned the original 2000 design team to inspect and specify a remediation process. A building envelope consulting firm was retained by the original architects to perform inspections and make recommendations. In spite of the fact that flat-seam copper gusset areas were approximately 8 ft. wide at the parapet/steep-slope juncture and continued the length of the building, no expansion joints had been designed or installed throughout the extensive copper roof system during the 2000 project. The building envelope consultants identified the lack of expansion joints as an issue and designed the retrofit of their installation. The original roofing contractor performed the installation during the summer of 2006. During the following winter, water infiltration continued unabated.

In the spring of 2007, additional failed solder seams and damaged copper panels were observed throughout the flat-seam copper installation. When the original roofing contractor was contacted to return yet again, it was discovered that the firm had been purchased by a national roofing franchise. The new entity refused to honor or assume liability for the former company’s work.

Over the next several years, two roofing firms attempted to perform remediation to stop the persistent water infiltration. They resoldered failed solder seams, some as many as four times. They caulked other seams and applied EPDM patches to damaged copper details. Limestone details were beginning to spall from freeze/thaw cycles (see Photo 5). Still, the remediation efforts failed and water infiltration continued.

Unable to remediate the persistent roof problems, the building envelope consulting firm recommended covering the entire ten-year-old copper roof system with an acrylic coating product, stabilized with a polyester mat. The product was guaranteed to “restore” metal roofs for twenty years. The manufacturer of this product had been in business for four years. Completely frustrated, the owner was considering the option. They now demanded to know how this could happen. They had done their due diligence and hired a reputable architectural firm, who in turn recommended two reputable consulting firms. They added two prominent engineering firms to complete the Design Team. They had hired a contractor who was not the low bidder, had good references and had demonstrable experience with similar projects. They installed the specified roof system that they were told had an 80-year service life and had paid $1.6 million for it.

The reality was that water infiltration had occurred throughout the building within months of project completion. Years of repairs have not solved the leakage problems. They had hired a new building envelope consulting firm and two new roofing contractors who could not diagnose or remediate the systemic issues. Ten years after construction, the owner was left with a leaking historic building that had accumulated over $150,000 in water-related damages.

**Premature Systemic Failure**

In the spring of 2011, my firm was retained by the owner to perform an existing conditions survey (ECS) to determine the extent and nature of the systemic failures on the chapel. The survey began with a series of forensic inspections to determine material and assembly conditions, as well
as the confirmation of as-built details and water infiltration sources (see Photo 6). The ECS revealed numerous design and workmanship errors.

It was observed that a number of flat-seam copper panels on the gusset (abutting the standing-seam copper installation) were oversized. Industry standards specify a maximum panel size for flat-seam copper installations to be approximately 24 x 18 in., prior to forming the panel locks. The panel sizes observed on existing panels within the low-slope gusset area varied between 24 x 18 in. and up to 96 x 24 in. The larger panel sizes create "oil canning" and stress on the copper panels, as well as excessive thermal movement within the flat-seam system.

Industry standards require that flat-seam copper panels be attached to the roof deck with copper clips, having two copper nails per clip for adequate attachment. The copper clip is subsequently folded over the nail heads. The copper clips observed within the existing low-slope copper roof system test areas had one 1¾-in. copper nail per clip, without the "finish" fold on the panel attachment clips. In addition, a single steel nail was observed in some copper clips. In this dissimilar metal condition, copper occupies a higher position than steel on the galvanic scale, resulting in the corrosion of the steel nail in the presence of an electrolyte (moisture). This condition could compromise the panel attachment if it occurs frequently enough.

The existing copper panel edges were not pretinned with solder prior to forming the panel locks. Proper soldering technique dictates that all flat-seam locks be formed with panel edges that have been fully pretinned with solder prior to forming. Pretinning allows the solder to be completely distributed throughout the multiple folds of the soldered lock when sufficient heat is applied, thereby ensuring the integrity of the solder joint.

The solder joints exhibited an abnormally high failure rate throughout the flat-seam system. The principal reasons for the premature failure of the soldered seams were due to the lack of pretinning of the panel edges by the installers prior to forming the panel locks. In addition, the solder application was inconsistent, with an inadequate volume of solder applied on many seams. This was a result of the installers perform-
the large, uninsulated and unvented cavity space beneath the redesigned gusset sections. EPDM is not designed as an underlayment material and does not provide a waterproof seal around the shanks of fasteners that penetrate the material.

Using EPDM as an underlayment throughout the roof system constitutes a nonstandard material application (see Photo 7).

The roof drains located within the gusset area were improperly installed. No drain sump was created, allowing the drain bowl flanges to protrude ¾ in. to 1 in. above roof panel surface, thereby creating standing water surrounding the drains.

Standing water was observed beneath the redesigned copper gusset roof deck, within the unventilated cavity space. Ponding water existed within the original gutter, directly adjacent to the drains. The EPDM membrane in the original gutter location was damaged (punctured) in several locations, apparently during installation. The presence of standing water at the punctured membrane on the nave aisle roof at the parapet scupper/drain was the probable leak source that damaged the inscribed interior limestone wall directly below.

At locations where the copper drain tailpiece exited through the exterior wall, a small weep slit, approximately 1/8-in. wide x 3-in. long, provided an intended exit point for condensate and other moisture, accumulating within the open cavity area under the gusset. This weep drain configuration was insufficient to allow proper drainage during freezing weather and was susceptible to blockage by debris. The adjacent heat trace system did not contact the gusset location and consequently did not prevent the weep from freezing. Standing water was observed adjacent to several nonfunctioning weep details.

No ventilation or insulation provisions were designed for the large (approximately 7-ft.-wide x 18-in.-deep) area beneath the redesigned flat gusset deck. This open cavity created a continuous air space along the length of the building, both the north and south elevations. This space is subject to heat loss from the uninsulated attic space below and cold material temperatures from the roof and adjacent parapet during the winter months. Within proper relative humidity and temperature parameters, dew point is reached with condensation forming within the unventilated space. The gusset sheathing and framing consists of ⅝-in. CDX plywood over untreated 2 x 4-in. framing. These details were saturated and observed in various states of decay. Mold growth was observed on the underside of the plywood sheathing and 100-year-old steel, 8d framing nails were observed to be rusted through.

At the crenelated parapet, a continuous copper through-pan flashing extended horizontally across the crenel and beneath the merlon stones. When removing merlon stones to confirm as-built attachment methods, it was observed that the workers had installed the specified stainless steel pins to anchor the merlon stones but had only installed them one inch above the through-pan flashing. The 5/8-in. stainless steel pins were epoxied into the parapet, wrapped in copper, and soldered to the through-pan flashing. The 1-in. pin height was insufficient to anchor the stones in place. Under a side load of snow and ice in the gusset area, the merlon stones could easily become dislodged (see Photo 8).

**SUMMARY OF INVESTIGATION FINDINGS AND CONCLUSIONS**

Based on data collected and observations made during the ECS copper roof system inspection of the chapel, the following conclusions were formulated.

As a result of a combination of both design and installation issues observed during our inspection, the flat-seam copper roof systems on the gusset areas of the chapel had prematurely failed. Properly designed and installed, a comparable copper roof system would have an expected service life of 75 to 80 years with no significant scheduled maintenance requirements.

As a result of the prematurely failed performance of the roof system, as well as the systemic issues observed, it was recommended that the entire copper roof and drainage systems on the chapel be redesigned and replaced. Immediate short-term remediation was recommended as a priority maintenance requirement with the expectation and intent to prevent further water infiltration into the building within the next (one) year. The short-term repair objective was achieved by applying a strip cover to all solder joints and material gaps within the low-slope copper gusset system, using a methyl methacrylate-based (MMA) system, using a copper primer, mat, and coating process. The short-term repairs were not considered a permanent solution, as only a full roof system replacement would provide the service life and performance of the originally intended system.

The presence of significant moisture at various locations within the copper roof and gusset systems promoted mold growth and deterioration of wood components within the substrate system. For this reason, it was recommended that permanent remediation (and the resultant drying of the roof
substrate) should occur within one year.

A complete roof and drainage system replacement with both 20-oz. copper standing- and flat-seam systems was advised, based on the performance, service life, and low maintenance requirements of copper systems.

In addition to performance advantages, the copper systems are compatible and representative of the historic fabric and architectural style of the chapel.

It was further recommended that the replacement system be properly designed and specified in accordance with all considerations and standards of copper roof and drainage systems. The installation of the system would be performed only by pre-qualified, competent tradesmen, familiar with industry standards pertaining to copper and with demonstrable experience in working on projects of similar size and scope. In the new roof design, the 2000 flat gusset (and cavity) area would be eliminated, reverting back to the original gutter and roof drainage configurations.

Based on the results of the ECS, the owner commissioned a “Basis of Design” document from our firm that would outline new design elements and a scope of work that would address the systemic failures. Having been through a ten-year remediation process, the owner was skeptical of a redesign that would incorporate the same historic copper systems and improve overall building performance. In January of 2012, the decision was made by the owner to replace all copper roof, flashing, and drainage systems on the chapel. Our firm was awarded the contract to redesign, specify, and manage the construction process. The owner’s expectation was that water infiltration issues would be eliminated and appropriate system service life would be attained, with improvements in overall building performance.

Although the copper systems were only 11 years old at this time, the 2000 installation was unable to be salvaged or warranted. With a new budget and approximately $150,000 in damages to the building, a new envelope redesign began for the chapel.

2012 CHAPEL REDESIGN

The 2012 redesign of the chapel building envelope system restoration began by acknowledging the owner’s intent to use the original materials and configurations specified by Henry Vaughn, the original architect. Where possible, the owner wanted to enhance building envelope performance by incorporating contemporary materials and technology. In new construction, the building is designed with consideration of modern materials and technologies. In historic restoration, the designer must work within the parameters of an existing building or architectural style. Gothic architecture presents some unique challenges to the modern designer. For example, decisions must be made to ventilate or insulate a building that historically may have had neither system. Providing enhancements to thermal performance in buildings with large open spaces; columnar supports with ceiling heights in excess of 50 ft.; solid masonry walls; large areas of single-pane, uninsulated stained-glass panels, etc., all require careful consideration by the designer. Even one of the most prominent features of Gothic architecture—the crenelated parapet (or battlement)—provides a challenge to utilizing the “passive roof ventilation” system so common in modern design. Contemporary materials and technologies can enhance the performance of historic structures, but the designer must perform due diligence to avoid costly design mistakes. The following are some of the design challenge issues addressed in the 2012 redesign of the chapel subject property.

Copper Roof System Insulation and Ventilation

Many traditional Gothic structures had neither roof ventilation nor insulation systems as a part of their original design. These buildings had various heating systems for the occupants’ comfort, but air-handling ductwork to support those systems was the extent of passive air handling within the structure. The decision to insulate the roof system should be based on careful thermal and dew point calculation, as well as return on investment (ROI), but should also be supported by common-sense justification. After all, insulating a roof above a 50-ft. ceiling supported by solid masonry walls that contain hundreds of square feet of single-pane, uninsulated stained glass, will not likely make a large reduction in the owner’s heating costs.

However, the decision to insulate (and ventilate) the roof systems of the chapel was based on other performance considerations. While adding R-value to the roof system was calculated to produce slight reductions in heating costs, the cost of design and installation of those systems produced an extended ROI. The owners were skeptical. However, a more significant consideration than the reduction of heating costs was the moderation of the roof and “attic” temperatures. This was accomplished by designing a both ventilated and insulated roof assembly (see Photo 9). Such an assembly reduces the extreme temperature operating parameters to which the original system was exposed.

Thermal dynamics are one of the most important design considerations in copper roof systems. The cyclical thermal elongation and contraction of copper assemblies occurs on a daily basis. When material and substrate temperatures reach extremes, so do the thermal stressors on the copper components. Although adequate expansion provisions (i.e., expansion joints) are an essential component of the copper design process, moderating the temperature variations the system is exposed to reduces dynamic stress on the copper components. The combination of mechanical expansion provisions and assembly temperature moderation results in extended system service life and reduces the potential for premature material failure.

The same principles were also applied to the decorative wood ceiling below the nave roof. The ceiling material is 1½ x 6-in. red oak and is located approximately 18 in. below the roof sheathing. This cavity space is empty, with no insulation. Measured thermal parameters indicated summer tem-
Dew point calculations for the assembly were performed, and airflow calculations for this system indicate positive dynamic pressures within acceptable CFM displacement parameters. The system is constructed of composite framing materials and covered with copper. The roof-waterproofing layer comprises of two layers of a self-adhesive, ice-and-water shield applied to the sheathing surface. This ventilated insulation assembly was installed at all roof surfaces and parapet walls (see Photo 10). In order to assure system performance during periods of snow and ice accumulation, a commercial-grade heat trace system was installed at the intake of the ventilated wall assembly, as well as at the adjacent copper gusset.

Materials Testing and Due Diligence

Most architectural designers are constantly searching for ways to improve the efficiencies of their designs and assemblies. Technological development in the construction materials industry within the last 25 years has moved forward at an unprecedented rate. The results have been mostly positive, but not all new products are appropriate for every application. As designers, it is incumbent upon us to perform our own due diligence. Sipsheets under metal roofing have been used since the mid-eighteenth century. Surprisingly, they have evolved very little from their organic, cellulose composition. Four-pound rosin paper has been a standard specification under metal roofing for a long while.

When a colleague told me about a new synthetic, highly permeable (but waterproof) underlayment for metal roofing, I was anxious to try it on this project. I read the cut sheet and MSDS but had questions. I called the manufacturer and asked (among other things) about the melting point for the product. I informed the tech rep that I wanted to use it under flat-seam copper roofing that would be soldered. The rep stated he didn’t know but would look into it. He contacted me and stated that he didn’t know the “melting point,” but the product was formulated to be used under copper to be soldered. I then contacted a local distributor who informed me that “this product has a higher melting point than high-temperature ice and water shield.” We decided to perform our own testing. We ordered a roll of the product, built a mock-up, and applied flat-seam copper pans to be soldered on top of the new underlayment. When the soldering iron touched the copper, the new product instantly melted. We added a layer of 30# felt, and it still melted. We added a second layer of 30# felt and a layer of rosin paper over the new product, and while not as severely, it melted again. I then called the president of the company, who after doing some research, informed me that the product melting point was 330°F. When I stated that the melting point for 50/50 solder is 365 to 419°F, he suggested I only use it under standing-seam copper. Had we not performed our own testing, the product failure while work was in progress could have resulted in a significant change order—or worse—gone undetected. As designers, it is essential that we research and test products with which we are unfamiliar (see Photo 11).

Thermal Dynamic Considerations for Copper Systems

One of the most important components of a functional copper roofing design is the allowance for cyclical thermal movement within the entire system. If this movement is not provided for in the design documents, the resultant material stresses can cause...
premature failure of the copper and its components. In the 2000 design of the flat-seam copper roof system of the chapel, there were no expansion joints called for. The two largest systems are approximately 135 ft. long and 8 ft. wide. Utilizing a generic thermal movement calculator, each system will migrate approximately 1¾ in. longitudinally and ¼ in. vertically every 24-hour weather period. Thermal elongation forces are omni-directional, and they occur in cyclical progression. These forces are created mostly by solar gain and are affected by temperature extremes, speed of temperature transition, and asymmetrical temperature exposures (i.e., snow load on a copper roof on a sunny winter day). The flat-seam copper gusset roofs on the chapel require a large box-type expansion joint every 33.5 ft. These box expansion joints are framed into the roof deck and extend from the gusset to the through-pan flashing (approximately 36 in. high) and up-rafter to the standing-seam roof transition (established water table) for a length of approximately 7 ft.

The expansion requirements for the steep-slope roof area can be accommodated with expansion locks at the ventilated ridge caps and at the standing-seam eave termination. Expansion joint configuration and spacing requirements are defined by conditions such as square-foot areas and lineal-foot measurements of copper systems, roof pitch, locations and frequency of through-copper penetrations (including walls and parapets), etc. While there are standard criteria and configurations for copper gutter expansion joints, the requirements for copper roofing systems or large copper details are more diverse and complex. In large-scale copper design, the various copper organizations are an excellent design resource.

Copper thermal provisions can be simple or complex; and requirements vary by size, configuration, and project. A simple axiom is: “If you specify copper, you need to specify provision for its movement” (see Photo 12).

Quality Assurance

As specifiers and designers, there are measures at our disposal to ensure a successful and high-quality project for our clients. Quality assurance should extend beyond a boilerplate section in the project manual. Some assurance requirements are obvious, such as contractor qualification and project management. However, other project issues require specific consideration. Listed below are several quality assurance measures specified in the chapel project documents.

Pipe Organ

The chapel pipe organ was manufactured by Aeolian Skinner in 1935. The company was a noted American builder of high-quality pipe organs for important cathedrals across the U.S. The company closed for business in 1972. The instrument is impressive, standing approximately 35 ft. tall and composed of over 5,500 pipes. The organ loft is housed directly under the north-elevation, semi-transept roof. The complete covering of all pipes by a professional organ restoration company was required. The owner inquired about the need for and cost of the covering. They were told that construction dust could damage the organ to the point of requiring rebuilding.

The owner was uncertain of the value of the organ, so we commissioned an appraisal. The value was established at $4.1 million for the organ and $750,000 for the console. The estimate to restore the organ if damaged by dust was $175,000 to $250,000. The organ was subsequently protected per our project documents, prior to the project start date (see Photo 13).

Mock-Up Process

The mock-up process is particularly useful as quality assurance for a copper roof installation. One of the principal causes of premature failures within copper systems is a failed solder joint. Full-size mock-ups should be created to demonstrate both horizontal and vertical seams, as well as any difficult solder applications, in order to assess the contractor’s ability to solder correctly. The seams should be dismantled after soldering to verify adequate coverage of the solder throughout the soldered joints. Mock-ups of all copper details specified should be created as a quality standard for all as-built details.
Water Testing

Prior to the installation of copper, water testing should be performed on all waterproof underlayment systems, where possible. The gusset areas behind the parapets on the chapel were identified as priorities for water testing. They are also the locations for the roof drains and scuppers. These susceptible areas were specified to receive two layers of ice- and watershield. After performing the requisite live-load calculations, water tests were performed after the installation of the first membrane layer by blocking the drains and scuppers. The gussets were then flooded with 12 in. of water. After successful testing, the second layer of ice and watershield was applied just prior to the copper gusset system installation.

Contractor Qualification and Project Management

Thorough vetting of contractors asked to perform specialty roofing services is essential. Our qualification statement contains five pages of information relevant to the scope of the work. The information requested includes extensive project-specific references, financial information, and criminal offender record information (CORI) forms for employee background and security checks. Managing the successful contractor during the project keeps everyone on track. Meticulous project records and documentation are essential. Specialty trades require above-average skill sets. The essential quality of the work varies among companies and employees within the same company. Watchful oversight can benefit the owner and contractor as well.

Peer Review

Peer review of design work is an often overlooked but critical component of the design and specification process. It can be beneficial (and humbling) to have one’s peers review one’s work. A fresh perspective can lend credibility and integrity to a project. There were four peer reviews of the design work done on the chapel.

SUMMATION

The premature failure of the high-quality building envelope system on the historic chapel in 2000 was both unfortunate and avoidable. Poor design and poor workmanship were equally to blame. While knowledge of some historic materials and processes is both nuanced and specific, there are resources available to both designers and contractors alike. Our peers and material manufacturers are good places to begin. When we are challenged by combining modern building technologies with historic applications, we are required to do our due diligence to ensure a successful project outcome. We owe that to our clients and our historic buildings.