Materials & Media 1

*The Use of Urethane Foam Technology in Historic Renovation and Remediation Work*

Presented at the Restoration & Renovation Exhibition and Conference 2002
Hynes Convention Center
Boston, MA

March 21, 2002

Presented by **Henri C. Fennell**, President of Building Envelope Solutions, Inc. d/b/a FOAM-TECH
North Thetford, Vermont

*The Use of Urethane Foam Technology in Historic Renovation and Remediation Work*
Urethane foams offer historic buildings scientifically correct solutions that prevent thermal envelope failures while maintaining the integrity of the original architectural detailing. Urethane foam technology has advanced to the point where numerous chemical formulations and delivery systems offer the versatility required to answer most thermal envelope problems. This is especially important for historic structures that were not designed to meet modern standards for energy efficiency.

The following discussion elaborates on the variety of applications which are possible when using urethane foam technology for restoring and renovating historic buildings. It includes a general discussion of the urethane material itself, processing methods, and case studies which demonstrate the methods of incorporating urethane foams into a number of historic structures. Building science experts, architects, and engineers specializing in historic landmarks and buildings collaborated on many of the projects that are mentioned. The case studies include museums, art galleries, and other historic structures, many of which are on the National Register. They explore the thermal envelope problems that were solved in each representative project, and provide an explanation of how the urethane foam installation related to the project design. The procedures for implementing the scientifically correct solutions are explained with a series of images which convey the evidence of the problems, the methods for gaining access to the work areas, and the completed work. Before, during, and after essays include photos, infrared images, and text reports which describe the process. Diagnostic and quality-assurance testing procedures which support the urethane foam installations are also discussed.

I. Why are urethane foam systems appropriate for historic buildings?

Most buildings constructed before the energy crisis in the 1970s were not originally designed and constructed for today’s insulation values, or to handle the narrowly-controlled environments necessary for museums and artifact storage and display. Many older buildings are uninsulated and have no provisions for vapor control or ventilation.

In some cases, where the use of an historic building is being changed, keeping the building uninsulated is chosen as the best solution for maintaining the historic character of the structure because methods of improving energy performance, without major changes or damage to the building, are unknown. This choice limits the use of the building, wastes energy, or may lead to various types of building failures if the use of the building creates new environmental conditions for the structure. Most renovations and energy-conservation upgrades of historic and landmark buildings are compromised by the commitment to maintain the original character and architectural detailing of the structure. Achieving modern thermal performance requirements poses a real challenge for these older buildings which new construction does not have; modern framing provides space for more insulation and roof ventilation, and current building practice includes provisions for vapor and air-leakage control. Properly installed urethane foam systems can be utilized to overcome many of these limitations, allowing historic structures to maintain their aesthetic charm while meeting modern energy conservation and climate-control needs. Urethane’s unique combination of high R-value, vapor control, and air sealing properties allow designers to meet modern building envelope standards in the smaller cavity sizes common in most retrofit projects. This especially applies to roof applications.
where not only are the cavity sizes too small, but ventilation is difficult or impossible due to the constraints of the existing soffit and ridge details.

II. Why is urethane foam effective for protecting historic buildings?

Urethane foams offer more than just R-value. While it is important to prevent conductive losses through the thermal envelopes of historic buildings, many building failures are due to air flow through building cavities. In heating climates, buildings without air barriers allow air leaking outward (exfiltration) from warm, moist conditioned (interior) spaces. Moisture-laden air reaches cold surfaces of the building cavities (usually near the outside) causing condensation. Severe moisture accumulation can produce mold, mildew, and rot. Builders who have taken apart an older building with batt or loose-fill insulation have probably seen black areas (mold and mildew) in the insulation along air-leakage paths, but not in more air-tight sections.

Air leaking inward (infiltration) can cause frozen pipes, foundation failures, discomfort, and excessive fuel bills. Vapor migration through building cavities can also contribute to building failures, although diffusion is often a less significant source of moisture than convection. All properly installed urethane foam systems provide air sealing and viable vapor retarders (closed-cell urethanes) for most building climates. Reducing the likelihood of air leakage and moisture flow reduces the susceptibility of the building envelope to vermin and indoor air quality problems. Roofs insulated with urethanes do not require ventilation. Many successful unvented applications exist without problematic ice dams or premature deterioration of the roof materials or structure. Foamed-in-place urethanes have been used for over fifty years in retrofit applications and have a good track record of providing successful solutions for improving building envelopes and isolating interior conditioned spaces to support environmental control systems.

III. What is urethane foam?

Urethane foams are a family of plastics that are “blown” with various gases to create light-weight “foamed” insulation and sealant materials. Rigid urethane foams are commonly used in high-performance refrigerators, freezers, and hot water heaters. Flexible urethanes are used for pillows, furniture cushions, carpet pads, and packaging.

Urethanes are not to be confused with expanded or extruded polystyrenes or urea formaldehyde foams. Urea formaldehyde foam was prone to outgassing and dimensional stability problems when processed incorrectly, and unfortunately continues to be associated with all foam insulation products. Polystyrenes (EPS) are commonly available as expanded bead board (white molded packaging) or as blue or pink extruded board stock, commonly used as exterior below-grade and under-slab insulation. These materials cannot be practically field-processed from their raw materials.
IV. What are the advantages of urethane foam?

Many chemical formulations for urethanes are available which can be:
- field-processed using an number of installation techniques
- produced to exhibit a wide range of physical properties
- produced on-site with a number of industry-standard delivery systems

The most significant advantage of urethane foams is that they can be field-processed and field-applied using reasonably practical methods with the expectation of consistently producing a quality product. Urethane technology has advanced to the point where numerous delivery systems and chemical formulations offer the versatility needed to answer most thermal envelope problems.

Installation techniques include spray, injection, and small scale “caulking” methods. Spray techniques produce monolithic, air-tight applications that can continuously coat and seal even the most complicated surfaces. Urethane foam bonds to almost any dry substrate and provides some reinforcement or stabilization of the material to which it is applied. Injection techniques provide cavity-fill capability, while avoiding the removal of historic and otherwise stable interior and exterior finishes.

Densities and cell configurations can be controlled to vary the strength, permeability, and dimensional stability of the foam. Urethanes are now available in both open and closed-cell formulations. Closed-cell foams have higher R-values and lower perm ratings than open-cell foams, but open-cell foams are less expensive and therefore appropriate in situations where large cavities must be filled and permeability is not an issue. Urethane foams have the highest R-value available in a field-processed insulation product. Low-conductivity blowing agents used in the production of closed-cell foams yield higher R-values (6.5 to 7.3 per inch) than other common insulation materials. This allows adequate R-values in undersized wall and roof cavities. Product data sheets indicating physical properties and processing requirements are available on line at: http://www.foam-tech.com/supergreen_spec_data_sheet.htm Additional information on R-values, blowing agents, thermal barriers, sound control, and permeability for urethane foams is also available on this web site.
The installed products also provide superior thermal envelope performance by reducing air infiltration, resisting performance degradation caused by convection and wind, and vapor control in a one-step process. To put this in perspective, installing 3” of urethane foam in/on a 3” wall cavity is equivalent to a vapor retarder, 6” of batt insulation, and an air-barrier material with all of the joints sealed. A 5” application of urethane foam installed between 5” rafters directly at the underside of the roof sheathing is equivalent to a vapor retarder with all of the joints sealed, 12” of batt insulation, vent chutes, room for an air space, soffit vents, and ridge vents.

Urethanes are also available as rigid foam board insulation or in the form of pre-manufactured structural insulated panels (SIPs). These materials have the same advantages as field-applied urethane foams, with the exception of the inherent air-sealing advantages at the panel joints. For this reason, many applications include a combination of rigid foam board or SIPs with urethane sealant at the panel joints.

Another advantage of using urethane foam in restoration work is the ability to perform non-destructive quality assurance procedures at any phase of the construction. When urethane foam is spray-applied in open cavities, testing can be performed before the installation of the interior finishes. Batt and loose-fill insulation materials rely on vapor barriers and interior finishes to create a complete thermal envelope system. As urethane foams provide all three of the components of the thermal envelope - insulation, air sealing, and vapor control - testing can verify envelope performance while the foam barrier is still accessible. This allows the installer to correct any deficiencies in the installation while the work is in progress, avoiding the removal of finishes to access problem areas in a later phase of the construction. When foam is installed in blind, cavity-fill installations, testing can be performed with the existing finishes in place, as the work progresses. The exothermic heat of urethane’s chemical reaction is hot enough, even in warm weather, to allow thermographic inspection and recording. Examples of
non-destructive quality assurance testing with infrared thermography, pressurized fog air-leakage testing, and
temperature and humidity monitoring are included in some of the case studies below.

Infrared image of R=38
batt insulation with
convection

Infrared image of R=38
injected urethane foam

This selection of installation techniques, chemical formulations that provide a wide range of physical
properties, and quality assurance techniques provide the flexibility needed to address even the most complicated
set of building conditions and building science objectives. A paper on the use of infrared testing for the quality
assurance of urethane foams (published in the proceedings of the SPIE Thermosense XI Conference) is available on

V. What are the disadvantages of urethane foam?

The primary disadvantage of urethane foams is cost. Urethanes are significantly more expensive than
recycled or mineral-based products that do not require high-tech installation equipment. However, this cost factor
is weighed on a case-by-case basis against lower-cost insulation systems that may still require expensive
air/vapor-leakage control and ventilation measures to complete the thermal envelope. In some cases, there are no
viable alternatives for providing these critical air/vapor control components with other methods. Where cavity
sizes are too small, higher R-values provided by urethanes may provide energy savings sufficient to offset the
initial cost difference. This is often true in roof configurations where there isn’t enough space for higher R-values
and ventilation is difficult or impossible. Foamed plastics also have fire protection issues that must be addressed.
In closed cavities, the interior finishes usually meet the code requirements for a thermal barrier, but exposed
applications in attics, unfinished basements, and crawl spaces may require additional thermal barrier installations,
adding to the costs. Ventilation and process temperature requirements may be more strict for urethanes than for
other types of insulation, depending on the application type. Finally, urethane foams bonded directly to a
structure may raise concerns about the reversibility of renovation efforts. Some historic projects consider this
factor in product selection. Methods are available which keep the installation reversible, but still provide effective
building performance. Examples of these are included in some of the case studies.

MSDS sheets indicating the safety of installed urethane foams are available on line at: http://www.foam-
tech.com/msds/Supergreen_MSDS/supergreen_msdsh.htm.
VI. How are urethane foams processed on-site?

Following is a description of the three on-site processing techniques for walls, roofs, and floors utilized in the case studies below:

A. Techniques

1. Injected, poured, blown-in, or foamed-in-place (FIP):

   This application technique is known by several names; basically, it involves injecting a relatively slow, pre-expanded foam system into a closed cavity. The foam reacts, expands again, and solidifies in the cavity within a few minutes. The process generates pressure, heat, and vapors. The result is a rigid, bonded product which fills the entire void. Properly executed, this ensures a thorough fill and complete bonding to the substrates. This requires a certain installation technique (small lifts and/or bracing), and fastening of the cavity surfaces in applications where pressure from the expanding foam may distort the finishes. The heat of the chemical reaction (240 degrees) is useful for quality assurance testing using an infrared camera to verify a complete fill free of voids. This installation approach requires that the area be warm (usually a minimum of 40 degrees F) before, during, and after the processing and curing periods (24 to 48 hours). The vapors require proper ventilation or personal respiration equipment to be utilized.

   ![Injecting through slots](image)

   ![Injecting through holes](image)

   **Comments:** Injecting a closed cavity creates little waste, requires less masking than spray applications, and has minimal personal health issues (airborne particles) for the applicator. A clean, dry surface will maximize adhesion or bonding.

2. Spray-applied or sprayed-on:

   This application involves spraying a hot, fast, atomized foam system onto an open surface (like spray painting). The foam reacts, expands, and solidifies on the surface in seconds. This process generates heat, airborne particles, and vapors. The result is a rigid, bonded product which covers the exposed surface in a continuous coating. The rapid expansion requires a proper installation technique to make the coating as even as possible; however, the finish will never be perfectly "flat". For this reason it is typical to spray-apply an "average thickness" which allows for a certain “plus or minus” tolerance. Alternately, a "minimum thickness" may be specified. The speed and heat of the chemical reaction also requires that the substrate and ambient temperatures be warm before, during, and after the process to prevent thermal shocking of the
finished product during the processing and curing periods. Various chemical formulations have
different temperature requirements, and the foam system must be appropriately chosen for the
specific project conditions. Chemical systems are
available for applications as severe as the frozen
earth project at Boston’s “Big Dig”. The
particles and vapors require proper ventilation or
personal respiration equipment to be utilized.
Masking or protecting finishes from over-spray is
required as well.

Comments: The spray operation allows
the installation to be a specified R-value in a
cavity that is too large for injection due to
practical considerations. If over-spray is not an
issue, this technique has the highest productivity
and usually the lower per-unit cost.

3. Sealant:

This application involves dispensing a medium-fast, pre-expanded foam system onto an
open surface or into narrow cracks. This process is not atomized as much as a spray system;
therefore, the pattern created is "courser", but can be varied from a caulk-type bead to a broader
fan configuration. The foam reacts, expands (low or high-expansion systems are available), and
solidifies on or between the substrate surfaces in seconds. The process generates heat, fewer and
larger airborne particles than spray applications, and vapors. The result is a rigid, bonded,
product which covers small areas of exposed surface or expands to fill narrow cracks. The
expansion requires a proper installation technique to fill a crack level with the plane of the
surfaces being sealed; however, the finish will never be perfectly "flat". Caution and/or bracing
may be required in applications involving window jambs where pressure from the expanding
foam may distort the trim if precautionary measures are not taken. This technique requires that
the area be warm during the processing and curing periods to assure the quality of the finished
product. Sealant is normally processed in small volumes, and while the vapors may still require
ventilation, personal respiration equipment typically is not required. Masking areas which have
permanent finishes, and trimming of excess material which expands out of the narrow cavity, may
be required.

Comments: Foam sealant is usually used for detail work in small areas; therefore, the
equipment output and the related productivity is much lower than with the injection or spray
methods. Truck-mounted and small-scale portable equipment are available for this technique.

B. Applications
1. **Walls:**

   a. Injected walls are filled through holes from the side determined by access or job-site conditions. Typically, 1” holes are drilled 4' O.C. vertically in each bay. Walls with narrow cavities may require a more frequent pattern of holes. Holes are drilled in the top corners of each bay unless the bay can be "topped off" from above. This includes staggered studs unless the stagger space is 2” or more. Bays open at the top to attic spaces can be filled without holes, except for bays under window openings. Walls enclosing large cavities should have a release material on one side of the wall behind the sheathing if the wall needs to be absolutely flat. This layer prevents the possibility of thermal shock pulling the sheathing material out of plane. If this material also acts as a vapor retarder, it can serve to protect the framing from moisture. Fasteners should have a maximum spacing at all sheet edges of 8 to 12 inches, depending on the sheathing thickness and fastener holding capacity. Temporary bracing would be required for areas with inadequate fastening.

   b. Sprayed walls are sprayed from the open side, as determined by access or job-site conditions. This includes building the foam out to the required minimum coverage. No release material is needed unless drainage planes are required in below-grade applications. The unfilled space in the framing cavity is available for mechanical system retrofits.

   c. Sealed rigid foam board wall applications are possible when sequencing, project conditions, or code issues make the use of sheet goods more cost-effective than open spray applications. This involves filling an intentional gap left around the perimeter of rigid foam panels or board stock which has been cut and fit in each wall bay. Sealed rigid foam board applications are done from the open side, as determined by access or job site conditions. The rigid foam board stock should be glued, braced, or fastened in place to prevent the foam sealant from lifting the board away from the sheathing on the closed side of the wall.

2. **Flat ceilings and roof slopes:**

   a. Injected ceilings and roof slopes are filled through holes from the side determined by access or job-site conditions. Injecting from the open top of the bays is generally faster when conditions permit. Typically, 1” holes are drilled 2' O.C. in each bay. Holes are drilled in the end corners of each bay. One side of deep ceiling cavities should have a release material to maintain finish flatness. The rest of the process is as described in the injected walls section, above.
b. Sprayed ceilings are sprayed from the open side (above or below), as determined by access or job-site conditions. Again, working from the top is generally faster. This involves layering the foam out to the required minimum coverage. No release material is needed. When done from above, the top can be vented if required.

c. Sealed rigid foam board ceiling applications are done from the open side, ideally from above, in a manner similar to the sealed walls approach.

3. Floors:

a. Injected floors are filled through holes from the side determined by access or job-site conditions. Working from the top is generally faster. Typically, 1" holes are drilled 2' O.C. horizontally in each bay. Holes are drilled in the end corners of each bay. One side of deep floor cavities should have a release material to maintain finish flatness. The rest of the application is similar to the injected walls.

b. Spraying floors is done from the open side, as determined by access or job-site conditions. Again, working from the top is generally faster. This work involves layering the foam out to the required minimum coverage.

c. Spray-applied foam can be used under slab-on-grade floors when uneven sub-grades prevent the use of rigid foam board stock insulation. A higher density foam system is typically used to reduce permeability, and a vapor retarder can be positioned on the sub-grade before the installation to increase the resistance to long-term water absorption in wet applications. The sub-grade should be dry, compacted fill or a concrete sub-slab. The finish will not be perfectly flat, but the finish slab thickness can easily accommodate the variation.

d. Sealed rigid foam board floor applications are done from the open side in a manner similar to the sealed-walls approach.

C. Sequencing
Project sequencing is generally project dependent, but typically follows normal construction practices. Project sequencing and preparation for the various installation techniques are too numerous and extensive for this discussion. Information is available on line at:
http://www.foam-tech.com/About_FT/Pricing_and_Scheduling/Project_Sequencing/project_sequencing.htm
http://www.foam-tech.com/Urethane_Foam_Installation_FAQ/urethane_foam_installation_faq.htm

D. Architectural Specifications

Sample architectural specifications (Section 7) are available on line at:
http://www.foam-tech.com/Application_Specification_List/application_specification_list.htm

VII. Case studies

A. The Allen Memorial Art Museum

Oberlin College
173 West Loraine Street
Oberlin, OH 44074

Founded in 1917, the Allen Memorial Art Museum (AMAM) is now ranked among the finest college or university collections in the nation, and is one of the greatest cultural assets of Oberlin College. The comprehensive collection, which contains over 11,000 works that span the entire history of art, is particularly strong in the areas of 17th-century Dutch and Flemish painting, European art of the late 19th and early 20th centuries, contemporary American art, and Old Master and Japanese prints. The buildings that house the Allen Memorial Art Museum’s collection, and the college art department, are no less engaging than the works of art within. The complex of buildings designed by Cass Gilbert in 1917 represents an eclectic dialogue between Tuscan Renaissance and Midwestern vernacular architectural styles. The addition to the Allen Memorial Art Museum by Robert Venturi, Denise Scott Brown, and Associates is one of the earliest and finest examples of postmodern architecture in the United States. In its complex dialogue with the Gilbert building and its innovative use of ornamentation, this building was pivotal in the new appreciation of architectural context and symbol that developed during the 1970s and 80s. (Allen Memorial Art Museum Web Site)
Urethane foams were used in the Venturi Gallery Addition portion of the project to stop problematic moisture migration through the exterior walls. This moisture was causing staining and spalling of the checkerboard cut-stone façade.

Improved climate control was also a goal of this project. A medium density (2.5 pound per cubic foot), zero ozone depletion potential, closed-cell foam was introduced into the 8” cavity (R=60, perm. <.25) using an injection method. Narrow strips of the inside sheathing and the window shelf were opened to provide access for filling the cavity between the interior sheathing and the existing high-density batt insulation. This technique avoided the need to remove the entire interior sheathing surface.

The cavities were injected in lifts up to each successive slot and then closed with the original cut-outs. This work included filling the small 1 ½” space (R=10, perm.<1) between the pilasters and the interior sheathing.
Infrared thermography was utilized to assure complete cavity fill.

Incidental open areas in the gallery, such as the two-foot deep shelf cavity above the recessed entry of the building, were sprayed with 3” of closed-cell foam (R=21, perm. <1). This typically occurred where the cavities were too large to fill or when opening the cavity provided access for other work.
The original heating and cooling distribution system used outlets along the bottom of the wall and in the window sills. The wall framing was supported by a beam just above the wall-base registers. This system was open to the wall cavity, creating a convection flow of conditioned air inside the wall against the masonry. A light gauge aluminum form was installed to create a diverter for the air flow and to serve as a stop for the foam. The injected foam filled around this form, providing permanent support for the diverter, with enough space behind it to allow adequate R-value and moisture control.

At the window sills, a plywood form was temporarily braced in position to extend the floor supply ducts up to the sill register. This was held to the inside to assure adequate room for foam to isolate the masonry from the air flow. Foam was injected around this form to provide permanent support for the air passage.

The security roll-up door offered another challenge for this retrofit work. The wall cavity at the intersection of the two buildings was not sealed or insulated where a door had been cut out between the old and new buildings. Injecting this cavity as it existed would have filled the operator and leaked out of the sliding door track. A form was installed on the side of the doorway from the dropped-ceiling above to protect the hardware before the cavity was filled. This door was kept closed during the renovations and the room was depressurized during the work to keep dust and vapors from entering the rest of the museum which was still in operation.

The tops of the walls above the dropped ceiling areas were insulated from the inside with 3” of spray foam (R=21, perm.<.70) applied directly onto the open wall surface. Visual inspection and frequent gauging of the foam thickness during the work were the primary methods utilized for quality assurance in this area.
Air sealant was utilized at the intersection of the two buildings.

Outside view showing the two ends where the buildings join together

View before and after the underside of the roof intersection was sealed with foam sealant

The roof framing cantilevers out to carry the soffit along the perimeter at the top of the wall. This area was essentially open to the outside soffit, and the existing insulation batts displayed the effects of moisture migration. The perimeter was air sealed from the outside through open sections of the soffit.
Urethane foams were also used in the Ripin Gallery in the Allen Memorial section of the building to stop energy loss and condensation in the exterior vaulted plaster ceiling cavity.

Damage from this source was occurring on the ceilings. Blooms in the plaster from water infiltration caused by condensation were evident in a number of places in the ceiling.

Improved climate control was also a goal of this project. The same medium density foam (2.5 pound per cubic foot) closed-cell foam was introduced into the vaulted ceiling cavity (R=42 to R=160, perm<.5) using the injection method. 4” holes were drilled through the wire lath plaster and at the apex of the vault and along the skylight openings to provide access for filling the ceiling cavities. The deep sides of the vaults were filled first, then the more uniform center area was filled progressively from arch to arch. Infrared thermography was utilized to guide the technicians and to confirm the cavity was full.
B. Vermont History Center - Spaulding Graded School

Main Street (Route 302)
Barre, Vermont
Construction Manager: H. P. Cummings, Inc.

The Vermont Historical Society is in the process of converting the Spaulding Graded School in Barre into the new Vermont History Center which will house its research library, collections storage, exhibits, education facilities, and offices. The Vermont History Center is scheduled to open June 1, 2002. On September 14, 2000, the Society purchased the 1891/92 Richardsonian Romanesque school building (with its 1914 annex) and began the renovation of the school for use by the Society as a "history center." The school will add more than 60,000 square feet to the Society's current 14,000 square feet of operating space. The center will:

- provide secure, climate-controlled collections storage areas;
- enhance the Society's ability to actively collect for the foreseeable future;
- reinstall and expand the library's research facilities;
- create a study collection gallery, changing exhibit areas, and hands-on history gallery;
- augment educational space by adding classrooms and an auditorium; and
- provide earned income/rental opportunities.

When the new library opens it will occupy 7,500 square feet on the second floor of the Vermont History Center, an increase of almost three times the size of the current library. The stacks will remain open as in the old building, but staff work areas will be separated from public spaces. Special air conditioning and humidification systems will work to preserve the collections. There will be separate rooms for microfilm readers, computerized databases, and maps and photographs. The Vermont History Center will also include classrooms, an auditorium, display galleries, and storage for library and museum collections (Vermont Historical Society Web Site).
The thermal envelope of this large building consists of many types of wall and roof configurations. A number of urethane foam formulations and installation techniques were used in this project to provide:

- the exterior thermal envelope
- isolation between interior climate-controlled spaces

In the original 1891 section of the building, the exterior walls were comprised of brick with wood-framed stud walls inside on the upper floors. The 8” cavities are separated from the masonry by an air space and exterior diagonal wood sheathing. Most of the cavities have intermediate back-plastering near the outside of the wall.

These closed cavities and the window-weight pockets were injected with less expensive open-cell urethane foam (R=30) due to the large cavity size. The insulation was injected through small holes drilled in the lath and plaster until an elevation at the top floor was reached where the wall could be topped off from the attic. Depressurized infrared quality assurance testing was used to locate blocking or other voids during the installation.
Infrared images taken during the injection work and

Some wall cavities had to be opened up in the 1891 section. This occurred where the blackboards were removed to restore the original plaster finish, the wainscoting was removed to make mechanical installations, or where rubble or existing insulation had to be removed.

These bays were insulated with approximately 6” of open-cell spray formulation (R=20) or a 3” layer of closed-cell urethane foam (R=21), depending on project sequencing.

To complete the thermal envelope at the intermediate levels in this section, the perimeter between the floor joists was sprayed with 3” of closed-cell urethane foam (R=21) when open floors or ceilings provided access. Bays closed to spray application by the location of the first floor joist were filled with open-cell urethane foam from above or below; again, depending on the available access.
In the 1914 addition or annex wing, the exterior masonry walls on the upper floors were solid brick with the plaster and finish trim applied directly onto the brick. Much of this section of the building is planned as expansion space for the History Center, and no insulation was installed on the exterior masonry walls at this time, except around the outside of the new elevator shaft. This new concrete block shaft was built entirely inside the brick structure, spaced about a foot away from the outer wall. Prior to closing in the block shaft, the outside wall was sprayed with approximately 2 ¾” of closed-cell urethane foam (R= 19). Because the monolithic coating was bonded to the outside masonry, this protected application saved the cost of installing a stud wall around the outside of the elevator shaft. Long-range plans for the rest of the 1914 addition include the addition of stud walls, spray-applied foam on the masonry, and new interior finishes.

The original 1891 building has a huge attic with some existing ventilation. The attic floor had an average of 4” of cellulose and Rockwool insulation (R= 15) in 2X8 joists. The majority of the floor area was sheathed with diagonal wood sheathing boards. There was no vapor retarder on the warm side of this thermal envelope and the lath and plaster or beaded board ceilings were the only existing air-barrier materials.
To address the thermal envelope correctly would require the removal of the floor boards and the existing insulation. After the ceiling had been cleaned out, and spray-applied foam air/vapor barrier had been installed on the warm side of the ceiling, new insulation and floor sheathing would be required. A more efficient plan was developed. The existing floor sheathing and insulation were kept in place, except over the demising walls around the climate-controlled spaces below. Narrow slots were created in the attic floor over the demising walls to allow a “connection” from the air/vapor barrier on top of the floor boards down to the top-plates of the boundary partitions below. The top of the floor was then covered with a 3” layer of rated, foil-faced, rigid urethane foam board (R=27) protected with walkways in areas where normal limited access would be required. It was determined that this R-value for the rigid foam was adequate to keep the dew point out of the existing insulation on the warm side of the foam panels. The layers of the sheet insulation were staggered and the top sealed with foil tape.

Foam sealant was used at the perimeter, at small areas with complex framing or mechanical systems, and at changes of plane. This treatment extended up and over the knee walls where the 1917 annex was higher than the attic.

In the small dormers over the arched windows, the curved plaster ceilings were cleaned off and sprayed with 4” (R=30) of closed-cell urethane foam.
Infrared quality assurance testing was used to locate any remaining warm air leakage into the attic spaces after the foam sealant application. Penetrations around new mechanical installations and several other warm-air leakage paths were located during this process.

These included the original ventilation shaft (approx. 6’ by 12’) which had been torn down to just below the roof level and left with an open-top in the attic. This was discovered during the infrared testing and then determined to be a significant source of attic warming. The same type of rigid urethane foam board (R=11) was installed on the sides of the masonry shaft to prevent radiant heat loss through the sides of the shaft into the cold attic. Rigid foam panels were also installed and sealed over the top of the open shaft to stop warm-air flow due to the four-storey stack effect. Another complex problem was identified during the testing. A warm-air bypass around the attic floor envelope was identified in the brick cavity where the two wings of the building come together.
In this area, the brick cavity in the common wall between the original 1891 section and the 1914 annex are warmed by the heated space where this is an interior wall on the floors below. This warm air bypasses the thermal envelope at the attic floor and flows up into the attic at the two ends (locations 2 & 3 on the plan) of the overlap between the two buildings. The source of the heat is likely to be conduction through the interior brick walls and warm air leakage at any interior rough openings or mechanical penetrations on the floors below. Air sealing at the top of the brick cavity in the attic is underway using a combination of foil-faced rigid foam board and foam sealant.

In the 1917 annex and the 3rd floor connector, the flat and sloped roof areas were generally unventable given the existing building elements. This thermal envelope problem was addressed by spraying 4” of closed-cell urethane (R=30, perm. <1) onto the underside of the roof sheathing from below. This approach eliminated the need to retrofit ventilation systems on top of the existing roof or to provide more insulation within the roof framing. It also avoided changes to the exterior trim detailing.

The masonry exterior walls in the basements of both the 1891 and 1914 wings of the building were sprayed with ¾” of closed-cell urethane foam (R=5, perm. <1 due to high in-place density). The rim areas between the floor joists were essentially an extension of the basement walls and were also sprayed with closed-cell urethane foam.
Interior stud walls for the mechanical systems and interior finishes were built after the foam application. The basement work included spraying over blocked-up windows and the underside of the exposed granite slabs in the two recessed entry stairways.

Isolating the interior climate-controlled spaces in both sections of the building utilized spray-applied urethane foam as both an air-sealant and a vapor-control measure on the floors and floor perimeters. Closed-cell urethane foam was applied to the demising floor and joist perimeter surfaces in a ¾” thickness, the amount specified to maintain the required temperatures and prevent moisture migration and airborne moisture transport between the conditioned and unconditioned spaces. Some floors were sprayed from below. Others with historic steel panel ceilings were isolated from above.

Vapor-retarder film was installed on new or renovated interior partitions. Vapor-retarder paint was used for the existing interior walls. In some of the climate-controlled rooms, the exterior windows were to be eliminated as sources of natural light and climate-control losses. On the upper levels, these windows were coated with a release agent, painted black, or replaced with spandrel glass; they will be sprayed with R=21 closed-cell urethane foam to maintain the original layout on the outside façade. This tactic was developed to allow the window to be replaced.

C. The Currier Gallery of Art

The Currier Gallery of Art
201 Myrtle Way
Manchester, NH 03104
In the late 1800s, former Governor Moody Currier laid plans for a generous gift to the people of New Hampshire. His plan was realized when the doors of the Currier Gallery of Art were opened to the public in October 9, 1929. When the museum opened, the permanent collection consisted of only a few oil and watercolor paintings, and scenic wallpaper panels donated by early patrons. Because the permanent collection was so small, the first exhibitions were loaned to the Currier from sister museums. Over the course of seven decades the collection has grown significantly and the Currier is now considered one of the finest small museums in the country. In 1979, the Currier expanded its facilities by adding two pavilions to its 1929 building. The pavilions, designed by the architectural firm of Hardy Holzman Pfeiffer, increased the museum’s exhibition space by 60%. A second major renovation and addition project was undertaken in May of 1995 and lasted through the Spring of 1996. (Currier Gallery of Art Web Site; Grand Opening Brochure, 1996)

There were several building envelope problems to solve at this complex of art galleries. The original 1929 building had condensation problems along the inside of the roof perimeter in the attic above the second floor galleries. The 1979 West Pavilion and Fuller Gallery pavilion wings were being renovated to house year-round collections which require accurately controlled indoor climates. The new and existing underground art storage facilities were also receiving new climate-control systems capable of maintaining the same conditioned environments as the galleries.

The roof in the original 1929 building is steel-framed with concrete infill below skylights which provide diffused natural light through ceiling lay-lights to the exhibit areas below. Urethane foam work for this project included insulating the underside of the low edge of the roof slab and the back of the box gutter built into the cornice. The goal was to reduce heat loss and prevent condensation which was dripping into the galleries below.
The majority of the gallery renovations involved the installation of new climate-control equipment in the galleries and the art storage spaces. The related building envelope work was designed to reduce equipment size and minimize energy consumption while avoiding the creation of moisture-related problems. The engineer specified 4” of spray-applied urethane foam (R=28, perm<.8) and foam sealants to repair and upgrade the exterior wall thermal envelopes in all of the climate-controlled spaces. Urethane foam was also used to isolate the pavilion galleries and the art storage areas from the rest of the building. The spray foam was applied directly onto block back-up walls to a thickness designed to prevent condensation on the inside and moisture migration into the masonry. Access to the wall surfaces in the West Pavilion and Fuller Gallery pavilion wings was gained by removing the interior display sheathing. Spray application was chosen over injection as the space behind the walls housed duct work and the size of the wall cavities made filling them impractical.
Foam sealant was used to seal and insulate the structural steel roof framing to prevent air leakage, condensation, and thermal bridging where possible. This work was coordinated with the replacement of the gallery skylights.

Skylight replacement at the Fuller Pavilion

Detail of the skylight showing urethane foam insulation and sealant
Foam insulation/sealant trimmed to the steel profile

Open roof during the skylight change-out with urethane foam insulation/sealant along the top steel support angle

The new underground art storage facilities beneath the new plaza (shown here under construction) and in the basements of the two 1965 pavilion addition wings were insulated with 3” of closed-cell urethane foam (R=21, perm <1). The undersides of the recessed first floor entry slabs were insulated with four inches of spray-applied foam (R=28, perm<.8).
D. New Hampshire Historical Society - Museum of New Hampshire History

The Hamel Center
6 Eagle Square
Concord, NH 03301-4923

When the historic 1879 Stone Warehouse at Eagle Square in Concord was renovated to become the Museum of New Hampshire History (20,000 sq.ft.), the challenge was to create exciting spaces for a museum shop, classrooms, curatorial offices, and climate-controlled exhibition galleries and collection storage facilities. A conscious decision was made to avoid re-creating historic elements in favor of using complimentary modern attributes in a rigorously restored shell. The original granite walls were restored and exposed to view wherever possible. An earthquake resistant frame was inserted, walls insulated with urethane foam were built around all of the gallery and storage spaces, and a sophisticated climate-control system was installed. Construction was completed in the fall of 1994 and the museum opened in April of 1995. (Banwell Architects Website)

The goals of this project were to upgrade the thermal envelope of the building and to create climate-controlled spaces for exhibition galleries and collection storage. Addressing the thermal envelope first, the wood-framed top floor of the History Museum received spray-applied urethane on the open walls. The flat roof was injected with closed-cell foam. The observation tower walls and roof were sprayed with closed-cell urethane.

Open walls on the top floor with spray-applied urethane foam
Stone parapet is still visible at the base of the gable-end wall
Roof framing prepared for foam injection
The urethane foam application utilized in this building that has not been covered in the previous case studies is the treatment of the masonry walls. Forming an integral part of the thermal envelope, these walls were insulated and sealed using 3 ½” foam-core stressed-skin panels, spaced away from the granite walls, to permit reversibility and maintain a drainage plane behind (outside) the panels. A gutter drainage system was installed at the base of the wall panel on the below-grade levels. Mechanical race-ways were incorporated into the panel design. Foam sealant was used to connect the panelized envelope system at the floor and wall terminations.

To successfully separate the climate-controlled spaces, interior 2X4 wood-framed partitions around the climate-controlled display and collections-storage spaces were filled by the injection method and sealed with urethane foam to isolate them from the unconditioned spaces.
The Roswell P. Flower Memorial Library, commonly known as the Flower Library, is the principle research center for Jefferson County. Staffed by a group of dedicated and competent volunteers, it has collected the best assortment of genealogical and historical materials in the county. The library underwent extensive renovation work in 1998 to remediate problems related to plaster and paint damage on the inside of the dome (Roswell P. Flower Memorial Library Web Site).

The goal of this project was to eliminate heat loss and moisture migration into the attic above the domed wire lath and plaster ceiling in the center of the building. The domed ceiling had been tarred to prevent leakage, but the moisture problem had persisted. The center skylight well was a tapered cylinder ("the drum") extending from the center of the inner dome up to the skylight at the top of the outer dome. The dome was sprayed with 2.5" (R=14) of medium density closed-cell urethane foam (R=14, perm. <1). The dome was covered with a layer of 15-lb. felt to allow the retrofit to be reversible. The foam application was extended out across the light cove to provide a complete air seal from the conditioned space below.
VIII. Conclusion

These case studies are just a few of the many examples of how urethane foams can be used in historic buildings. Numerous projects completed in collaboration with Architects, Engineers, and Building Science experts demonstrate that urethane foams are both appropriate and effective. The versatility and performance advantages of this material allow experienced urethane foam contractors, knowledgeable in both building science and the use of urethane technology, to provide the specific application and equipment capabilities necessary to solve almost any building envelope problem.

IX. Demonstrations

Infrared Camera
Samples of urethane foams

\begin{flushright}
Henri C. Fennell is President of H. C. Fennell, Inc. DBA FOAM-TECH, North Thetford, Vermont, USA
\end{flushright}

Author of:
\begin{itemize}
\end{itemize}

Co-author of:
\begin{itemize}
\end{itemize}

Registered AIA Presenter:
American Institute of Architects - AIA/CES Registered Provider Program.