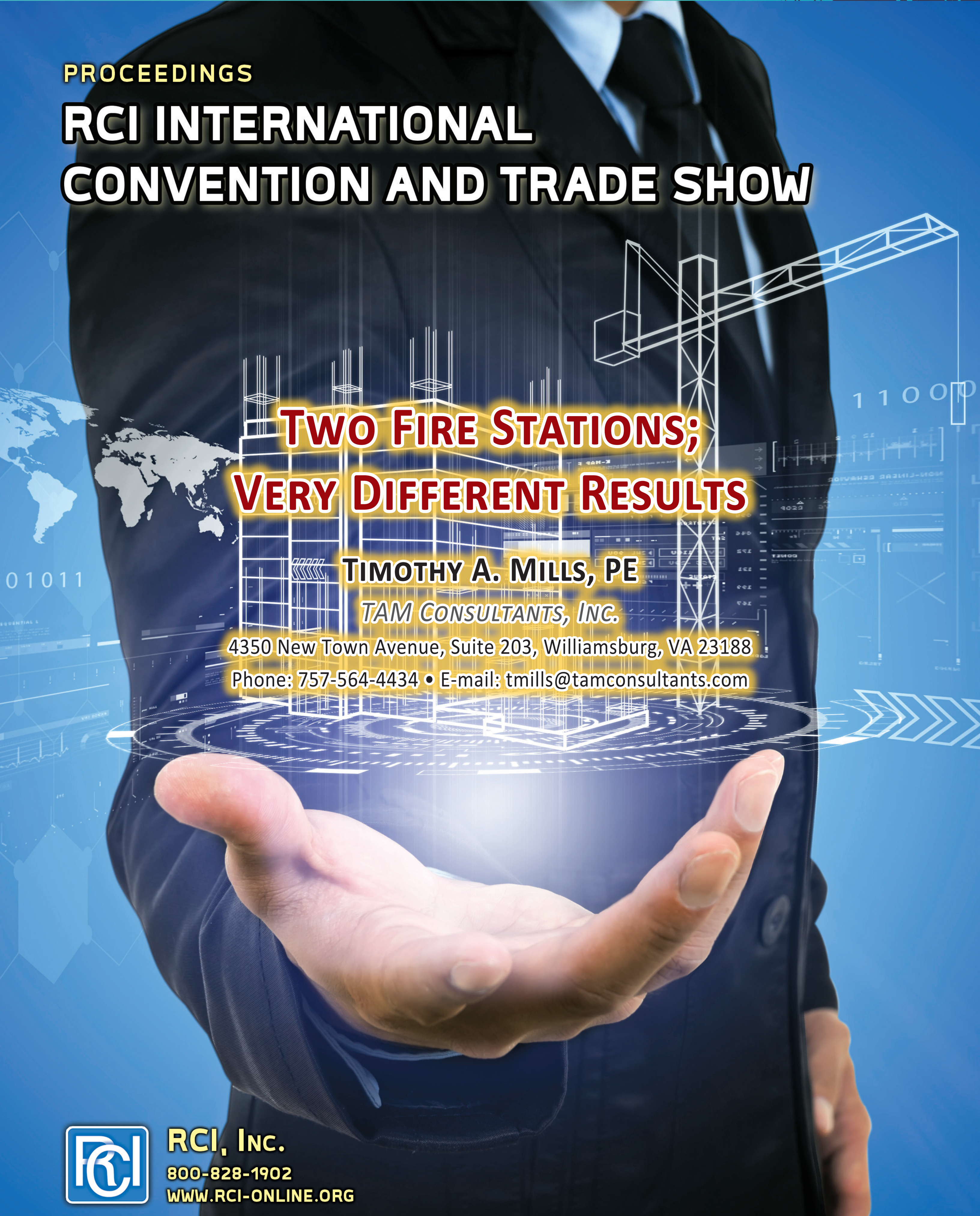
PROCEEDINGS

RCI INTERNATIONAL CONVENTION AND TRADE SHOW



Two Fire Stations; Very Different Results

Timothy A. Mills, PE

TAM Consultants, Inc.

4350 New Town Avenue, Suite 203, Williamsburg, VA 23188

Phone: 757-564-4434 • E-mail: tmills@tamconsultants.com

RCI, Inc.
800-828-1902
www.rci-online.org

ABSTRACT

This is a unique case study of two replacement fire stations designed and constructed for the same owner in the same county at the same time by the same general contractor with the same envelope consultant, but designed by two different architects. The study offers insight into two different design approaches for the building envelope and how detailing, construction, and testing of the materials and systems played out.

The result was that one fire station, when tested for airtightness, yielded a very tight building envelope; the other initially failed, and then later passed following some repairs.

In this case study, we will evaluate different approaches in detailing an installation at the critical building envelope transitions: the foundation walls, windows, door openings, roof-to-wall intersections, and interior wall separations between conditioned and occupied spaces and unconditioned apparatus bays.

During the course of construction, both projects were reviewed for compliance with the plans and specifications, and areas of potential air or water leaks were addressed as the work progressed. A number of construction issues arose between the various trades, requiring close coordination between the masonry, roofing, air barrier, and exterior sheathing subcontractors.

Prior to occupancy, both buildings were tested in accordance with ASTM guidelines for whole-building air testing, resulting in substantially different findings, which are attributable to the complexity of the designs and the attention to detail during construction. In both projects, the owner has benefited in the form of substantially lower energy costs to operate these facilities.

SPEAKER

Timothy Mills, PE, LEED AP – TAM Consultants, Inc. – Williamsburg, VA

TIMOTHY MILLS graduated with a BS degree in engineering from Brooklyn Polytechnic Institute of New York in 1983. Prior to forming TAM Consultants in 2002, Mills had experience with a number of multidiscipline design and inspection firms. He has published numerous articles and completed nearly 1500 residential home and commercial building inspections and 300 energy audits. He is an instructor for ABAA training courses that educate and certify contractors in the proper installation of air barriers, as well as a certified ABAA Auditor in their quality assurance program.

Two Fire Stations; Very Different Results

INTRODUCTION

In this case study we have an opportunity to look at two fire stations. Although constructed at the same time for the same owner by the same low-bid contractor, the architectural firm for each project took a different approach in the design and implementation of the building envelope systems. One approach was perhaps more complex than the other, resulting in a somewhat lower building envelope performance in the end. One of the unique aspects of this case study is the opportunity to examine just the building envelope performance, because almost all of the other aspects of the projects were similar for each fire station: they were subject to the same codes, built in the same year, by the same contractor, with the same R-values for building components.

The county had embarked on the process of designing and constructing two replacement fire stations with separate requests for proposal (RFPs) within a year of each other. Each plan called for the demolition of the two original stations after each new station was completed adjacent to the existing structures. The owner used the tried-and-true traditional design–bid–build process for each project, selecting two different architectural firms. It turned out that the general contractor selected for the first-awarded fire station also was the most responsive bidder for the second, allowing the general contractor to construct both projects.

The owner retained the same building envelope consulting and testing firm for both projects. The end result was the owner building two fire stations during approximately the same time period with the same general contractor and two different architects with different design approaches.

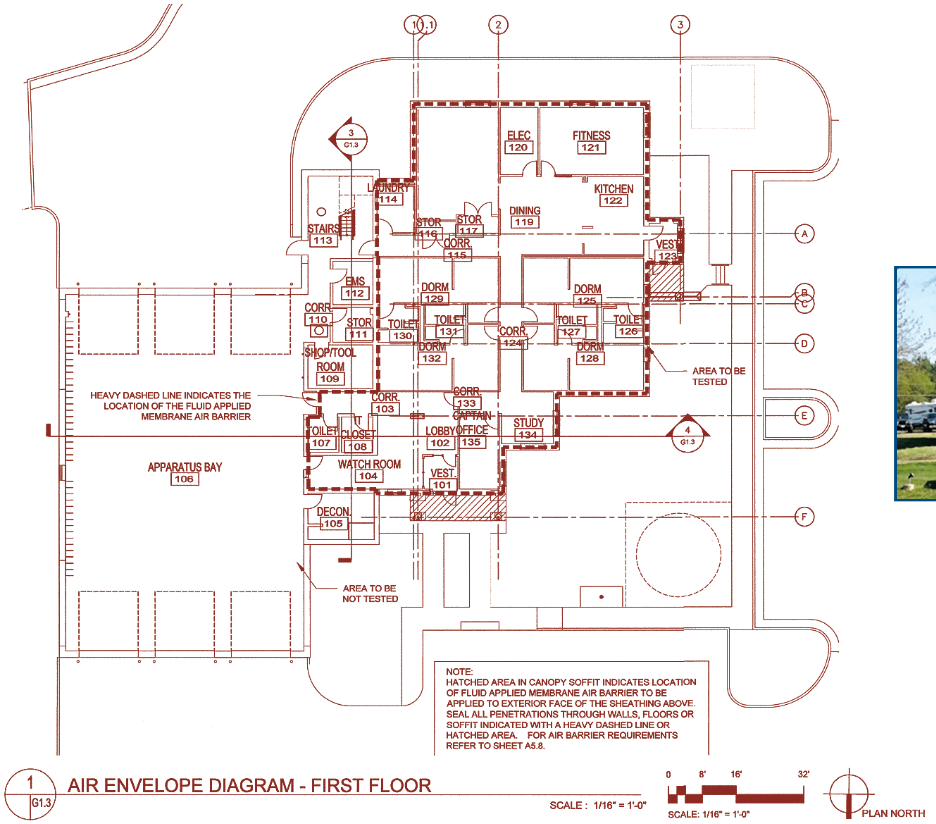
BACKGROUND

The owner, in this case, has a track record of striving to achieve greater and greater energy efficiency in the development of its projects. The county had implemented certain standards to improve building envelope performance, including the implementation of the Air Barrier Association of America's (ABAA's) Quality Assurance Program, as well as adopting the U.S. Army Corps of Engineers' (USACE's) Standard for Whole-Building Air Testing at the completion of each project. The county had adopted the USACE Whole-Building Air Testing Leakage Rate of a maximum of 0.25 cubic feet per minute (CFM) per sq. ft. of building envelope area.

For the purpose of this discussion, we have referred to the two fire stations as "Fire Station A" and "Fire Station B" and have provided detailed information regarding the construction of both facilities.

Fire stations, although generally small-footprint, low-rise buildings of just one or two stories, can be quite complicated little projects. This is because these projects often include office spaces, training spaces, public and community gathering spaces, sleeping quarters, fitness facilities, a commercial kitchen and dining facilities, equipment and turnout gear storage and maintenance spaces, as well as multiple large apparatus bays and fueling facilities. Small fire stations for smaller fire departments often are very basic pre-engineered metal buildings. As counties grow and become more populated, often older facilities are replaced with more robust, larger, durable facilities. Such is the case for this owner.

Figure 1 – The original fire station before demolition and construction of the new fire station.



NOTE:
HATCHED AREA IN CANOPY SOFFIT INDICATES LOCATION OF FLUID APPLIED MEMBRANE AIR BARRIER TO BE APPLIED TO EXTERIOR FACE OF THE SHEATHING ABOVE. SEAL ALL PENETRATIONS THROUGH WALLS, FLOORS OR SOFFIT INDICATED WITH A HEAVY DASHED LINE OR HATCHED AREA. FOR AIR BARRIER REQUIREMENTS REFER TO SHEET A5.8.

Figure 2 – Fire Station A. Site plan showing "Air Envelope Diagram" depicting the limits of the air barrier systems separating them from the apparatus bay, stair towers, and other support spaces.

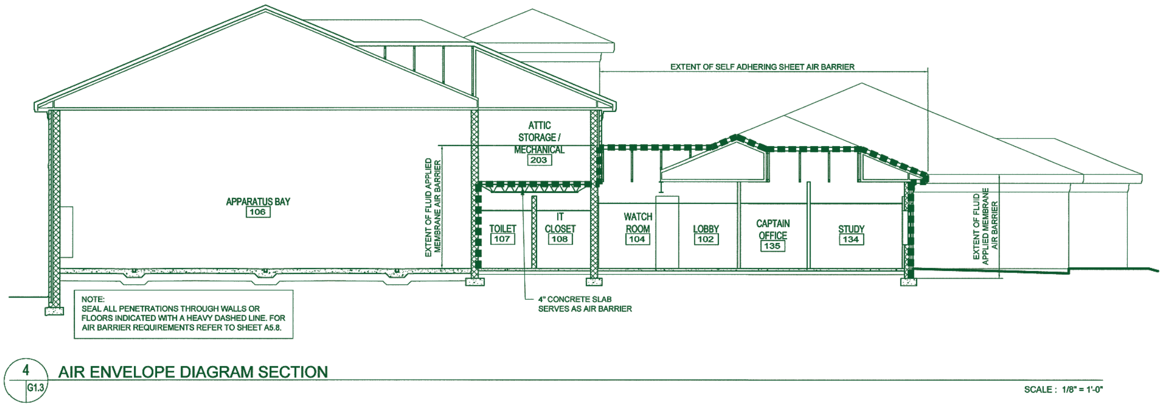


Figure 3 – Fire Station A, "Air Envelope Diagram Section." Architect's cross section depicting the limits of the air barrier boundary within the fire station's occupied spaces.

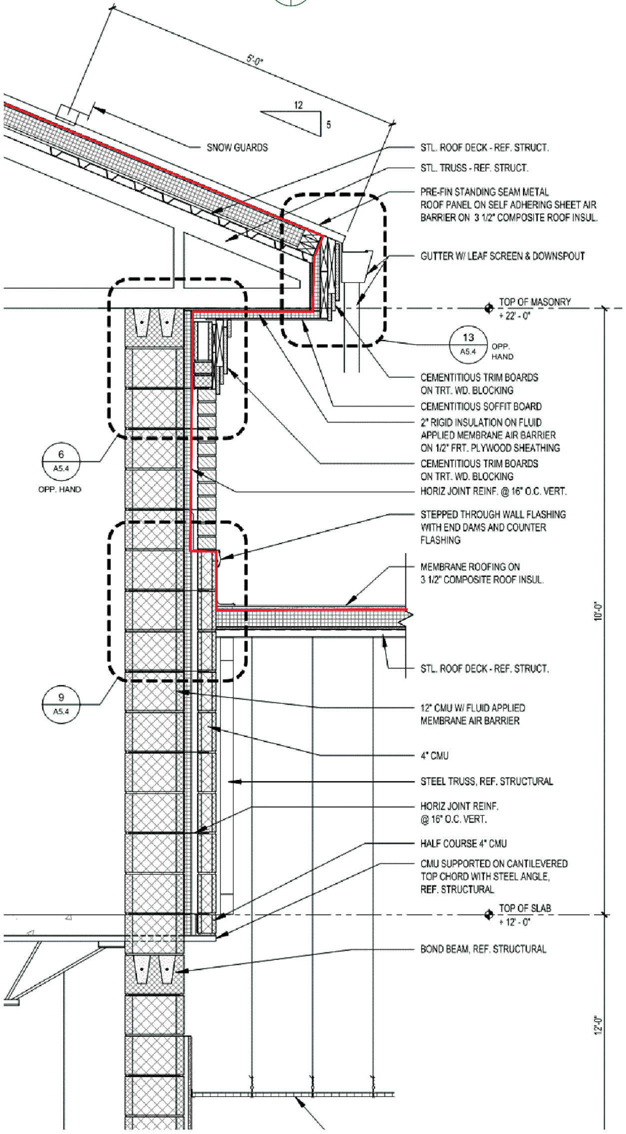


Figure 4 – Fire Station A. View of the demising wall between the conditioned and unconditioned spaces and location of the air barrier as designed.

DESIGN APPROACHES

Fire Station A

Fire Station A (*Figure 1*) is a new, larger, one-story replacement facility with three large apparatus bays that is a replacement fire station for the previous pre-engineered metal building that served the county well for many years. The architect for Fire Station A took a more traditional and perhaps simpler approach to the selection of the various building envelope components, resulting in a simple, efficient, effective design solution. The building is of robust construction, including load-bearing concrete masonry unit (CMU) walls with brick cladding on the exterior. The building features concrete slab-on-grade construction and a sloped standing-seam metal roofing system. The architect included air barrier diagrams both in plan and section views in the contract documents in order to delineate the location of the air barriers throughout the project (*Figures 2* and *3*). The equipment apparatus bay was not part of the conditioned spaces and, therefore, was separated from the other portions of the building with an air barrier demising wall and floor. Mechanical rooms and other equipment spaces were also cut out of the air barrier envelope.

The architect selected a wall assembly that primarily consisted of load-bearing CMU with a vapor-permeable, liquid-applied air barrier, which is covered with continuous rigid board polyisocyanurate insulation with brick cladding. In some cases, such as gable ends, soffits, and eaves, light-gauge metal framing with gypsum sheathing and liquid-applied, vapor-permeable air barrier was installed. The simple approach also applied to the roofing system where the air barrier, thermal barrier, and roofing system all followed the sloped metal roof deck, which was installed on light-gauge metal frame trusses. The air/weather barrier for the roofing system consisted of a 0.04-in.-thick, high-temperature-rated, self-adhered membrane, which was adhered directly to the mechanically fastened unventilated composite

Figure 5 – Fire Station A. View of backup wall following installation of liquid-applied air barrier where it ties into the foundation wall, wraps around the building cornice, and ties into the sheet-applied air barrier on the roof deck.

polyisocyanurate/OSB rigid board roof insulation. The standing-seam metal roofing system's concealed fasteners were screw-fastened directly through the air barrier to the composite insulation.

The design allowed for continuity in the air barrier system by tying the air barrier at the base of the wall to the foundation system, and by lapping the liquid-applied air barrier at the top of the walls onto the soffits, eaves, and fascia sheathing. The self-adhered air/weather barrier on the roof was then installed and weather lapped over the air barrier along the eave line. This simple approach and detailing resulted in a very simple airtight assembly (*Figure 4*).

Perhaps a more difficult or challenging aspect of the project was ensuring continuity of the air barrier at the inside demising walls and floors between the conditioned spaces and the adjacent apparatus bay, as well as the upstairs mechanical spaces. Attention to detailing and thinking in three dimensions are critical to ensuring continuity of the air barrier system between the inside building components and the exterior walls. One critical location is where exterior masonry cavity walls turn into the building and tie into interior demising walls, which can easily allow unintended air flow into and past the air barrier components (*Figure 5*).

Fire Station B

Fire Station B (*Figure 6*) is substantially larger than Fire Station A. It has significantly more training spaces to support county-wide training for search and rescue techniques. This is a two-story station with sleeping quarters and a fitness center on the second floor. The architect also included air barrier line drawings in both plan and section views to delineate the location of the air barrier system as it wound its way around the building, separating the conditioned spaces from the apparatus bay and certain training and mechanical and other support areas (*Figures 7*, *8*, and *9*).

Figure 6 – Fire Station B. Architect's rendering of the project.

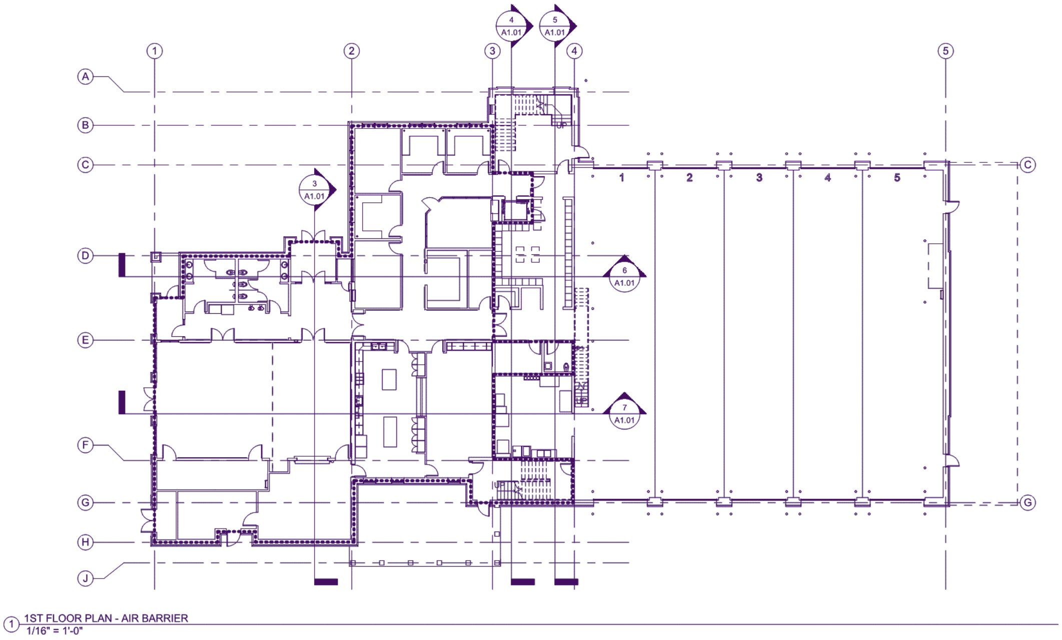


Figure 7 – Fire Station B, first floor. Architect's "Air Barrier" floor plan depicting the location of the air barrier line separating the conditioned spaces from the unconditioned spaces.

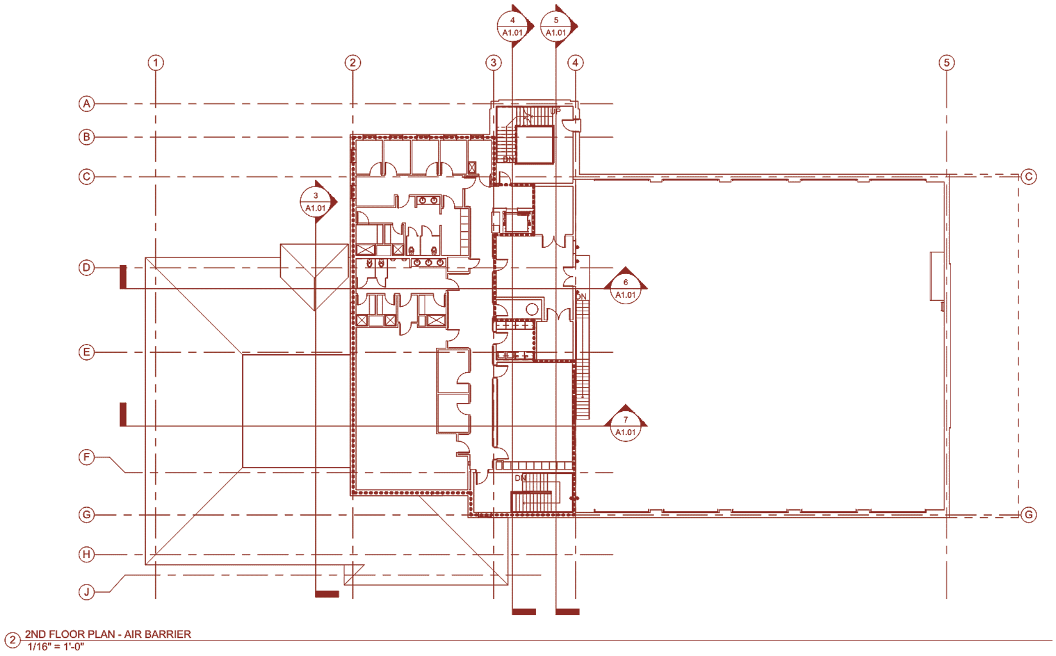


Figure 8 – Fire Station B, second floor. Architect's "Air Barrier" floor plan depicting the location of the air barrier line separating the conditioned spaces from the unconditioned spaces.

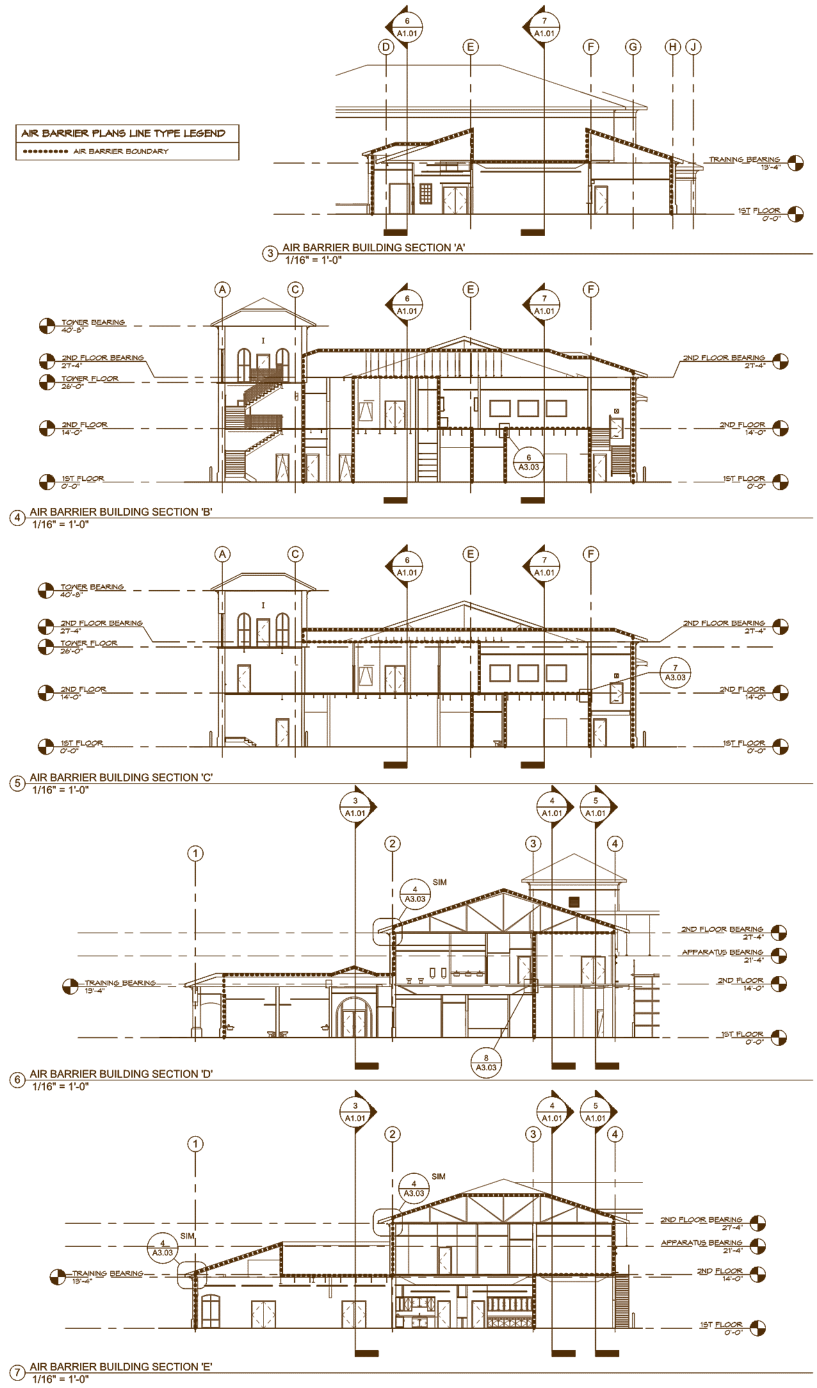


Figure 9 – Fire Station B. Architect's "Air Barrier Building Sections" depicting the complex interaction between the air barrier systems between the occupied and unoccupied spaces.

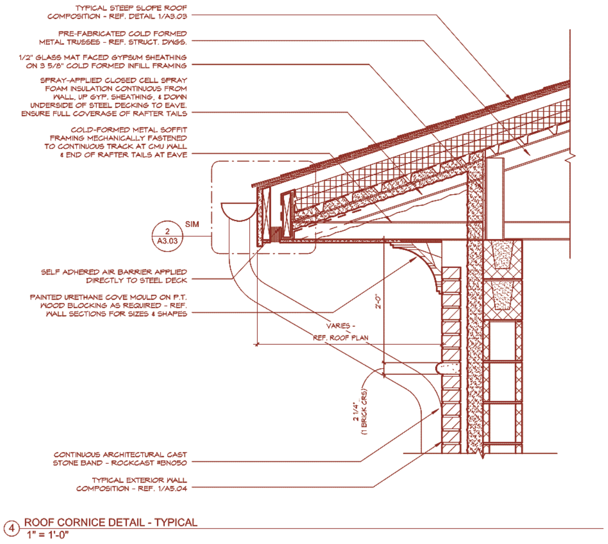


Figure 10 – Fire Station B. Roof cornice detail where SPF is used as an air barrier and where the wall SPF system ties to the roof sheet-applied air barrier at the overhanging metal deck. Note significant areas of potential air leaks at the roof truss penetrations where they occur at two feet on center around the entire building.

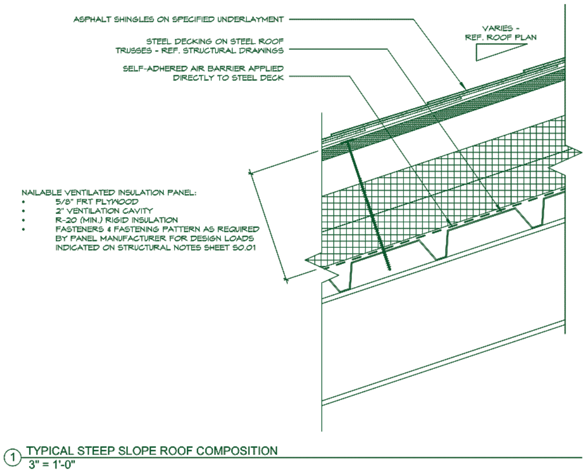


Figure 11 – Fire Station B. View of compact, ventilated shingle roof assembly where the air barrier is located at the metal deck and roofing underlayment, and the weather barrier is located above the sheathing. Penetrations through the deck need to be sealed to ensure that the ventilation space underneath the roof sheathing is not open to the attic space.

The project also features robust construction that consists primarily of load-bearing CMU masonry walls and brick veneer cladding. Wall and floor construction includes concrete slab-on-grade construction and exterior load-bearing masonry cavity walls using medium-density 2.0 PCF spray polyurethane foam (SPF) as both the thermal barrier and air barrier. The roof construction includes a compact sloped roofing system with asphalt shingles. The roof design incorporates a compact assembly where there is a ventilated roof assembly with an air space and both soffit and ridge vents to allow for ventilation underneath the shingle roofing to minimize overheating of the roof shingles and to control moisture accumulation in the assembly. The roof construction includes light-gauge metal frame roof trusses supporting a sloped steel roof deck with a self-adhered air barrier; ventilated composite insulation, including an air space; a wood roof deck; underlayment; and roofing shingles (*Figure 10*).

The spray foam air barrier on the exterior walls makes generous use of a self-adhered transition membrane to tie the spray foam to the other building envelope components, such as windows, doors, foundation walls, and the roofing system.

The design of the compact ventilated roof assembly necessitated placing the air barrier at the structural steel roof deck, under the roof composite board thermal insulation with the air gap located between the insulation and the wood sheathing. The synthetic roofing underlayment was installed on the wood sheathing of the composite insulation product, and the shingles were nailed to the sheathing (*Figure 11*).

Challenges for the project team included creating an airtight seal at the wall-to-roof intersection for the interior demising wall between the unconditioned apparatus bay and the adjacent attic space over the second-floor sleeping quarters, which is included as part of the air barrier envelope (*Figure 12*).

Additionally, all penetrations through the roof deck for exhaust fans, plumbing pipes, conduits, etc., needed to be sealed properly in order to maintain an airtight seal between the air space of the ventilated compact roof assembly and the attic area (*Figure 13*).

Finally, the design of the eave included many penetrations through the air barrier assembly where the pre-engineered light-gauge roof truss tails extended through the exterior envelope line to support the roof eave.

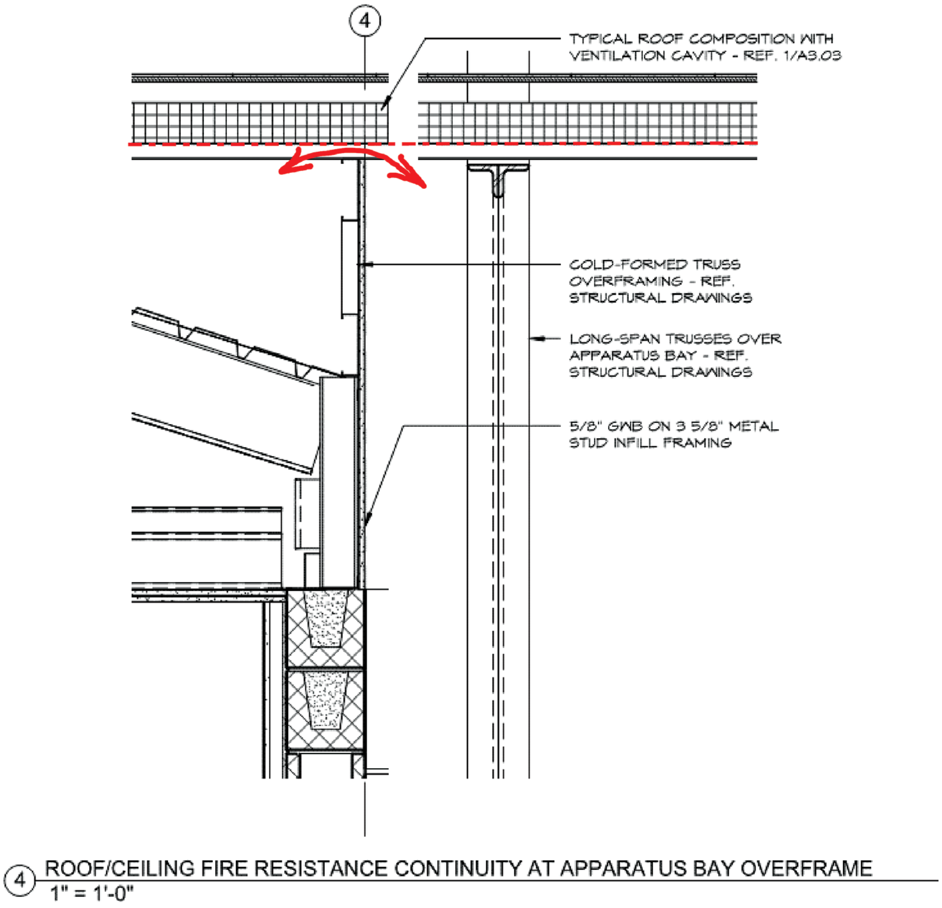


Figure 12 – Fire Station B. Architect's detail of demising partition separating the conditioned and unconditioned spaces between the apparatus bay and the occupied portions of the building. Attention to detail is required to ensure an airtight seal at the flutes of the metal deck where it passes by the demising wall.

CONSTRUCTION

Fire Station A

The overall design concept and material selection resulted in a straightforward implementation of a tight air barrier assembly. The architect's simple and effective approach to detailing the air barrier transition from the wall to the roof assembly also helped during the construction process. At the base of the wall, the liquid-applied air barrier ties into the foundation and onto the CMU backup. Attention to detailing during construction ensured that all of the penetrations and even masonry brick ties were airtight. See *Figures 14* and *15*.

At the wall-to roof intersection, the liquid-applied air barrier system transitioned around the soffit and fascia onto the roof system. This was done by wrapping the entire soffit with the liquid-applied air barrier system and using transition membrane when transitioning from one material to another (e.g., CMU to gypsum sheathing). The liquid-applied air barrier extended up onto the roof deck, where it was weather-lapped with the self-adhered, high-temperature-rated underlayment/air barrier as part of the roof assembly. See *Figures 16* and *17*.

The architect specified rigid composite board insulation with wood sheathing, allowing for a smooth, stable, solid substrate for the roofing underlayment/air barrier metal roofing. Likewise, at windows, the liquid-applied air barrier system turned into the rough openings with gun-grade-applied transition membrane materials aligned for

Figure 13 – Fire Station B. View of typical roof deck penetration for a duct where the roof deck penetration must be sealed on the top side of the deck to prevent air infiltration/exfiltration via the compact ventilated roof assembly.

Figure 14 – Fire Station A. View of ongoing preparation work of the liquid-applied air barrier above and below the through-wall flashing tying it into the foundation wall, rough openings, and through-wall flashing.

Figure 15 – Fire Station A. View of liquid-applied air barrier preparation work sealing all masonry ties prior to application of the finished product.

an air sealant joint on the back side of the window frames, transitioning from the window frames to the rough openings. One other feature of the building required an air barrier at the demising wall between the living quarters and the apparatus bays. This wall extends up through and past the roof line, separating the roof assembly with an air barrier from the roof over the apparatus bays where an air barrier was not required. See *Figure 18*.

During construction, one potentially very large air leak was discovered when it was realized that the second-story

Figure 16 – Fire Station A. Closeup view of the liquid-applied air barrier creating airtight assembly at the roof soffit.

Figure 17 – Fire Station A. View of self-adhered high-temperature weather/air barrier membrane on top of the roof deck under the standing-seam metal roofing system.

Figure 18 – Fire Station A. Typical view of air sealing efforts internal to the building, separating conditioned spaces from unconditioned spaces at roof-floor intersection.

Figure 19 – Fire Station A. View of steel-supported second-story masonry veneer cladding and large potential air leaks, which were discovered and sealed during construction at the base of the open cavity above the first-floor ceiling space.

Figure 20 – Fire Station A. View of nearly completed occupied portion of the building where the exterior walls and roof line comprise the air barrier line.

brick veneer cladding on the demising wall between the apparatus bays and the rest of the building contained a wide-open masonry cavity. This cavity was open to the above-ceiling space on the first floor (*Figure 19*). Outside air could easily find its way from the masonry cavities on the front and rear elevations or at through-wall step flashing locations and work its way to the building's interior; or alternately, interior conditioned air could leak out through the masonry cavity via exfiltration. Regular air barrier audits during construction picked up on this condition, which was easily corrected by sealing the bottom of the open masonry cavity where it was exposed in the ceiling space. See *Figure 20*.

Fire Station B

Although the use of spray foam as an air barrier system traditionally results in extraordinarily airtight assemblies, a number of the design and detailing approaches resulted in challenges during construction. At the base of the wall, the spray foam air barrier systems on the exterior walls tied into the foundation walls with a transition membrane. The same occurred at all window and door openings in the CMU backup wall. See *Figure 21*.

Figure 21 – Fire Station B. View of SPF air barrier over CMU backup wall. Note areas of detailing around windows and other penetrations.

Figure 22 – Fire Station B. Close-up view of soffit where detailing and preparation work for the air barrier system (SPF) is ongoing using transition membrane and sealants.

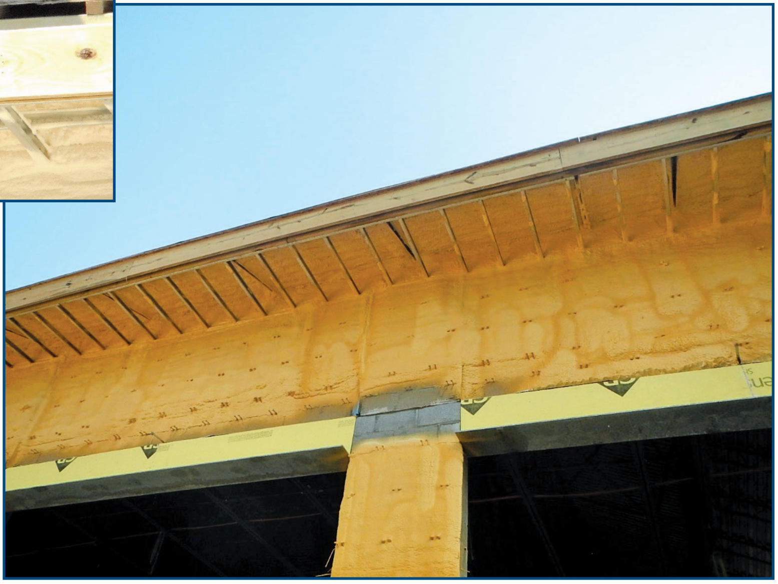


Figure 23 – Fire Station B. View of nearly complete SPF/air barrier installation at the roof cornice.

At the roof-wall intersection, the design called for the spray foam air barrier system to extend all the way up past the soffit and tie into the structural metal deck. The light-gauge metal frame engineered roof trusses extended through the air barrier at each truss location at both the top and bottom cords. The roof deck included a self-adhered air barrier, which was adhered to the structural steel deck, creating a transition through the metal deck between the spray foam and the self-adhered air barrier. See *Figures 22* and *23*.

The roof assembly was a compact ventilated asphalt shingle roof requiring a ventilation space between the roof deck and the insulation, as well as roof vents both along the soffit and the ridgelines. Roof shingles were installed over synthetic underlayment installed on the wood sheathing. This was accomplished using composite board insulation with an integrated ventilation space between the rigid board insulation and the roof wood sheathing. Air barrier detailing and air sealing at each of the metal truss penetrations was a tedious job. It would have been better to wrap the air barrier system around the soffit using a self-adhered membrane applied to sheathing on the bottom side of the soffit and tie it into the fascia board. This was discussed during design but ultimately was not selected as a design solution. See *Figure 24*.

Given the condition where the air barrier at the roof level was installed directly on the metal deck, and the presence of a ventilated roof assembly underneath the shingles, it was important that the air barrier be maintained at all penetrations. During audits of the air barrier installation process, opportunities for large air leaks were discovered, including penetrations through the roof deck where ducts, conduits, and plumbing pipes extended up through the roof assembly. These penetrations allowed for direct air leaks from the ventilated roof assembly into or out of the attic space. All roof penetrations needed to be sealed airtightly to the metal roof deck to ensure that these potential air leaks were eliminated.

Another challenge was the demising wall between the apparatus bay and the remaining portions of the building where the apparatus bay was outside of the building air barrier envelope. The demising wall extended up to the bottom of the roof deck and stopped. This detail allowed for the potential for large air leaks to extend from the apparatus bay. The air barrier above the roof deck needed to be tied into the air barrier of the demising wall through the roof deck at each of the roof deck flutes. This required the use of a transition membrane and SPF—both above and below the roof deck—in order to ensure an airtight assembly.

TESTING RESULTS

A number of quality control measures were implemented by the owner during the design and construction phases of both projects. These measures included:

- Two plan reviews during the design phase of the project, checking for good detailing in an effort to ensure weather- and water-tightness in the building envelope systems
- A preconstruction meeting for the building envelope trades prior to each trade beginning their work
- The implementation of the ABAA Quality Assurance Program, requiring the use of ABAA-licensed contractors, installers, and a third-party-licensed ABAA auditor. ABAA audits require daily testing of the installed air barrier and components, including spray foam density testing and liquid- and sheet-applied membrane adhesion testing.
- The owner also commissioned the building envelope consultant to conduct whole-building air testing (ASTM E1827). The whole-building air test required both pressurizing and depressurizing the building while checking for air leaks using

thermography and tracer smoke.

- Finally, the owner required thermographic inspections of the completed low-slope roofing portions of the project, checking for trapped moisture in the newly installed low-slope roofing systems.

The results of the whole-building air testing were somewhat surprising, but resulted in some lessons learned. Fire Station A, which incorporated the simple design approach and the concept of wrapping the entire building envelope with air barrier components and providing clear separation between the conditioned and non-conditioned portions of the building, as well as the use of non-operable windows and a limited number of penetrations through the envelope, resulted in the lowest building envelope leak rate that we have ever tested. The owner's requirements matched those of the USACE for a maximum leak rate of 0.25 CFM per sq. ft. of building envelope area. Testing in Fire Station A resulted in a measured leak rate of 0.07 CFM per sq. ft. In fact, the building was so tight and energy efficient that the mechanical system had difficulty dehumidifying the interior space, and the system was determined to be slightly oversized for the constructed conditions.

Fire Station B, which employed a more complicated design and detailing, creating a number of challenges during construction, actually failed the initial whole-building air test, exceeding the maximum allowable leak rate of 0.25 CFM per sq. ft. Infrared and tracer smoke testing during the whole-building air test quickly identified numerous air leaks where the light-gauge metal roof trusses penetrated through the exterior walls at the roof truss end bearing points. It was determined that the detailing and spray foam work around the complex geometry of the light-gauge metal framing components did not provide an airtight seal at hundreds of locations. Additionally, air leaks were observed through numerous roof deck penetrations. The air barrier installing contractor was quickly able to address each air leak from the attic area, and the building passed the second whole-building air test with a 0.19 CFM per sq. ft. leak rate.

Fire Station B also had to have a large portion of its low-slope TPO single-ply roofing system replaced when thermography inspections found trapped moisture in the roofing system. It was ultimately determined that worker activity on the roof following roof installation caused a significant amount of damage to the installed roof, requiring work to be redone.

Figure 24 – Fire Station B. View of installed vapor/air barrier on the roof deck prior to installation of the compact ventilated roof system insulation and roof sheathing.

ENERGY USE FINDINGS

Given that these two fire stations were replacement fire stations and that the owner has taken a progressive approach to energy savings throughout the county, the owner was able to compare energy usage for the new and replacement fire stations over the year or more following occupancy. Discounting for energy costs and equalizing for the difference in square footage between the new and replacement fire stations, the owner was able to calculate the energy used per sq. ft. for each building and compare it to the original buildings. The results are encouraging. New Fire Station A improved energy usage by 35% over the original fire station, and Fire Station B improved energy usage by 27%. These are real-world numbers representing significant savings for an owner who is dedicated to constructing airtight energy-efficient buildings. These results not only show the benefits of airtight construction, but they also reflect energy efficiencies from higher R-values and more efficient mechanical systems.

LESSONS LEARNED

1. Even with peer reviews and competent architects, significant breaches in the air barrier can go undetected until construction begins or much later.
2. Indicating the extent of the air barrier in the documents (on plan and section views) is not enough. The need to properly detail how airtight seals are created between building components should be shown.
3. It is important to recognize the value of quality assurance efforts, including field inspections during construction with specific attention directed towards the building envelope components.