Building Enclosure Testing on Alaska Military Base Projects

Emmett Leffel

ABSTRACT

Airtightness testing of large buildings has been the subject of research since the early 1970s. Since then, whole-building airtightness testing has developed into a robust and vital building envelope commissioning industry. In 2009, the U.S. Army Corps of Engineers (USACE) implemented Engineering and Construction Bulletin (ECB) 2009-29, which specified an airtightness requirement (i.e., maximum allowed air leakage) of below 0.25 cfm/ft^2 at75 Pa (4.7 m^3/h/m^2 at 75 Pa) for the six-sided building envelope surface area for all new construction and building enclosure renovation projects. The implementation of the building airtightness requirements over the past decade on U.S. Department of Defense (DOD) projects has dramatically improved awareness of the importance of air barriers systems. Each construction cycle since 2009 has achieved improvements in design and air barrier products and in installation practices resulting from a progressive learning curve. However, reviews of airtightness results and diagnostics of DOD projects in the Alaskan region over the past decade indicate that airtightness standards may need to be further increased.

This paper presents results of airtightness testing done at military installations in Alaska and identifies areas where air leakage pathways can be significantly reduced through better design and construction methods. Data drawn from test results include averages of new projects and renovation projects in Alaska, comparisons of 1950s and new construction, and comparisons of test results from large and small construction. These test results indicate the need for improved quality assurance during the design and contracting process and for increased airtightness requirements for commercial buildings in cold climates.

INTRODUCTION

Over the past two decades, the impact of building airtightness has been widely studied. Current literature (Anis 2001, Zhivov et al. 2014) confirms the impact that air leakage has on building systems overall and emphasizes the importance of air barrier system performance. Recent studies of the thermal decay of buildings in an Arctic climate identified building airtightness as a contributing factor to resilience during thermal energy disruptions (Oberg et al. 2021).

The U.S. Army Corps of Engineers (USACE) implemented an airtightness requirement for all new construction and building enclosure renovation projects in 2009 (Engineering and Construction Bulletin [ECB] 2009-29) and in 2012 (ECB 2012-16) (USACE 2009, 2012). The maximum air leakage allowed in both was 0.25 cfm/ft^2 at 75 Pa (4.7 m^3/h/m^2 at 75 Pa) for the six-sided building envelope surface area. Over the past decade, the implementation of these airtightness requirements and testing has drastically improved design considerations, construction methods, and the general level of understanding of air barriers systems in U.S. Department of Defense (DOD) projects. Each construction cycle since 2009 has achieved improvements in design and air barrier products and in installation practices resulting from a progressive learning curve.

The USACE air leakage testing protocol is a robust test parameter that broadens the allowable test conditions found in American Society for Testing and Materials (ASTM) Standard E779, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization* (ASTM 2010). USACE requires testing in both directions, at higher induced pressures, and tighter increments of bias pressure readings. ECB 2009-29 includes a full list of deviations from the ASTM standards

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(USACE 2009). These deviations, along with the standardization of the test procedure and building setup, allow testing with higher wind and temperature differentials while maintaining test result accuracies and improving the repeatability of the test results under a wide range of conditions that suit building envelope testing in the Arctic regions.

Infrared diagnostic evaluations of the thermal building envelope and air leakage pathways under negative and positive building pressures are part of USACE air leakage testing requirements. ASTM C1060 (2015) and International Organization for Standardization (ISO) 6781 (1983) provide guidance on conducting qualitative thermal inspections of insulated building envelopes. With the building under neutral pressures, the thermal envelope is imaged under relatively stable conditions. Wind and stack effect must be taken into consideration and measured for reference purposes to isolate thermal anomalies from air leakage conditions. Following ASTM E1186 (2017), infrared (IR) images are taken from the low-pressure side of the building envelope with the building pressurized and depressurized. This combined IR inspection process from multiple standards accommodates imaging anomalies in the building envelope a minimum of three times under changing conditions. By inducing building pressures, a thermographer can effectively map air leakage pathways that can occur at different entry and exit points in the building envelope as well as air movement through an insulated assembly. The comparison of infrared images under changing pressures and conditions allows a trained thermographer to differentiate air leakage pathways from thermal anomalies. IR images taken following these guidelines allow air leakage pathways and thermal anomalies to be mapped in construction plan details, and where necessary, in elevation and plan views (see Figures 2 through 4).

This paper reviews 31 building envelope tests done in Alaska following USACE's *Air Leakage Testing Protocol for Building Envelopes* (USACE 2012). This review, categorization, and graphing of 10 years of test data, including comparisons of thermal performance of new buildings with airtightness of 0.25 cfm/ft^2 at 75 Pa (4.7 m^3/h/m^2 at 75 Pa) and buildings at or below 0.15 cfm/ft^2 at 75 Pa (2.74 m^3/h/m^2 at 75 Pa), reveals several important ways industry practices can be improved. Graph 1-3 in Figure 1 shows airtightness testing results for buildings constructed before the implementation of USACE ECB 2009-29; the graph distinguishes between buildings that have been retrofitted are highlighted and those left unimproved since their initial construction (some as early as 1949). The results and imaging included here may contribute to a new definition of what is considered sufficiently "airtight."

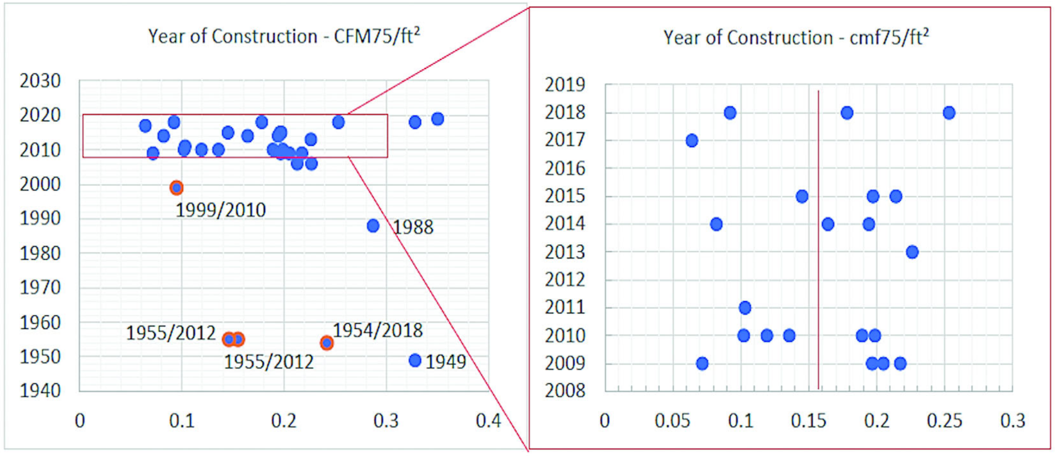
REVIEW OF AIR BARRIER TEST RESULTS

From 2009 to 2019, the author has worked with general contractors, engineers, architects, and crews in the construction of 23 new buildings on Alaskan military bases, ranging from small to large building enclosures. All these newly constructed commercial buildings were air leakage tested and thermally imaged at or near completion of construction following the *USACE Air Leakage Test Protocol for Building Envelopes* (USACE 2012). With the exception of five projects, every project listed in Table 1 (see the appendix) met or surpassed USACE airtightness requirements on the first attempt. These results confirm the great success of USACE projects and are consistent with the much larger data sample reported in Zhivov et. al. (2014).

Graphs 1-1a and 1-2 in Figure 1 show the airtightness test results in cfm/ft^2 at 75 Pa of the new construction projects based on the year of construction. The overall average for all buildings tested by the author, of projects required to be 0.25 cfm/ft^2 (4.7 m^3/h/m^2 at 75 Pa) or less, is 0.158 cfm/ft^2 at 75 Pa. Only two of the new buildings were concrete masonry unit (CMU) building types; 21 projects were primarily constructed with insulated metal panel (IMP) wall systems. Table 1 in the appendix lists the roof and wall systems types for each building. Both CMU buildings tested below 0.1 cfm/ft^2 at 75 Pa (1.83 m^3/h/m^2 at 75 Pa)—some of the tightest construction types seen on Alaskan military projects. These two cases are reviewed in the "The Tightest Air Barriers Examples" section, which is a part of the discussion of things done right along with opportunities missed. IMP wall systems, while proven to be an excellent building envelope system when appropriately constructed, have given wide range of test results, from 0.07 cfm/ft^2 to 0.35 cfm/ft^2 at 75 Pa (1.31 m^3/h/m^2 to 6.4 m^3/h/m^2 at 75 Pa). The fact that four buildings achieved an airtightness less than 0.1 cfm/ft^2 at 75 Pa (and nine buildings tested below 0.15 cfm/ft^2 at 75 Pa [2.74 m^3/h/m^2 at 75 Pa]) while others have difficulty reaching 0.25 cfm/ft^2 at 75 Pa (4.7 m^3/h/m^2 at 75 Pa) reflects a complex problem that is heavily impacted by construction experience, attitudes, plan design, or constructibility issues that can occur in commercial construction. In fact, the constructibility of different air barrier materials can even be affected by variables such as weather and the time of year that construction takes place in an Arctic climate.

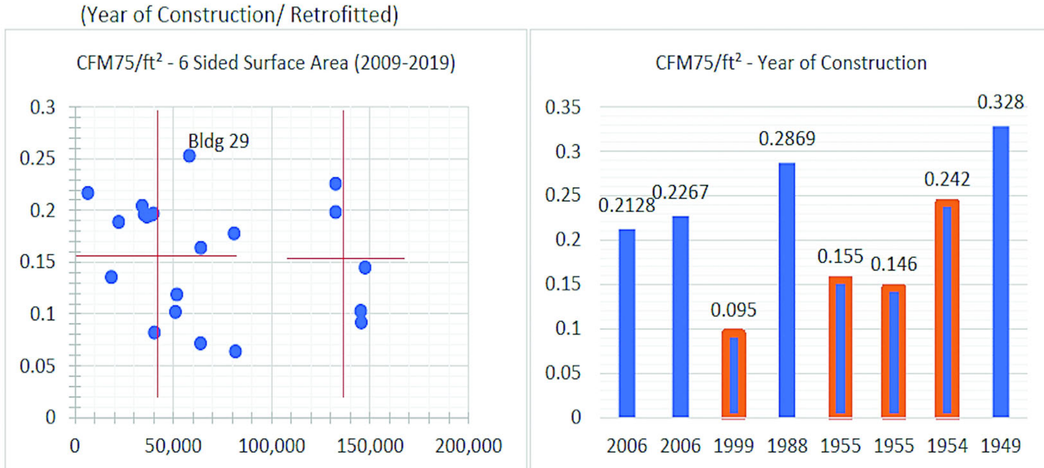
AVERAGED AIR BARRIER TEST RESULTS

Figure 1 shows a set of graphs of the air leakage test results for each subset group. Graph 1-1 shows test results for all cases listed in Table 1 (see the appendix). The area inside the red rectangle in Graph 1-1 is expanded in Graph 1-1a, which represents the airtightness results from 2009 to 2019 construction projects required to meet the 0.25 cfm/ft^2 at 75 Pa (4.7 m^3/h/m^2 at 75 Pa) or less. The average cfm/ft^2 at 75 Pa calculated for new construction test results is 0.158 cfm/ft^2 at 75 Pa, as indicated with a red vertical line in Graph 1-1a. Projects that had an airtightness target of 0.4 cfm/ft^2 at 75 Pa (7.31 m^3/h/m^2 at 75 Pa) are outliers in this group and are not included in the average. Bldgs. 31 (2019) and 2's (1949) test results are comparable with ASHRAE's and International Energy Conservation Code's® (IECC) commercial airtightness requirement and demonstrate how excessive air leakage can result in ice damming conditions in the immediate or mold



Graph 1-1. 1954–2019 Airtightness Results (cfm75/ ft²) (Year of Construction/ Retrofitted)

Graph 1-1a. 2009–2019 Airtightness Results (cfm75/ ft²)



Graph 1-2. Leakage (cfm75/ft²) to Size, w/ Avg. Show

Graph 1-3. 1949–2006 Airtightness Results (cfm75/ft²) (orange outline = Deep Energy Retrofit)

Figure 1 *Graphs 1-3 air leakage test results, 2009–2020.*

conditions and degradation to the building envelope over time. Graph 1-2 charts building surface area against airtightness, which is further discussed in the "Does Building Size Matter?" section. Graph 1-3 shows pre-2009 construction test results, for comparison. Note that buildings constructed before 2009 that had building envelope and ventilation upgrades completed fell within the standard deviation of 0.057 for new construction projects average airtightness. These results suggest that older existing DOD building infrastructure can be retrofitted to achieve the level of performance of new projects. The "The Oldest versus the Renovated" section discusses pre-2009 ECB projects.

DOES BUILDING SIZE MATTER?

The test results and surface areas for projects constructed from 2009 to 2019, charted in Graph 1-2, illustrate the leakage rates of large versus small- or medium-sized building envelopes. Building airtightness results for both large- and medium-size projects averaged 0.153 cfm/ft^2 and 0.160 cfm/ft^2 at 75 Pa (2.8 m^3/h/m^2 and 2.92 m^3/h/m^2 at 75 Pa), respectively. Building size does not appear to significantly impact air barrier system performance. The vertical span of each group is spaced evenly with one outlier in the medium-sized group. (Bldg. 29 could be considered an outlier because of conditions explained below.) If Bldg. 29 is removed as an outlier, the average airtightness for medium and smaller envelope tests is lowered to 0.154 cfm/ft^2 at 75 Pa, almost the same as larger building envelopes. These results from tests in Alaska demonstrate that smaller buildings can be minimally as airtight as larger buildings if they meet mandated airtightness requirements.

These results counter a long-held general assumption that smaller buildings typically have higher air leakage rates because of their higher window-to-wall ratios (Zhivov et. al 2014). The general perception in the industry that the greater surface area of the larger building permits a greater flexibility in designing for airtightness creates a self-fulfilling prophecy: if the airtightness requirement is set at 0.4 cfm/ft^2 at 75 Pa (7.31 m^3/h/m^2 at 75 Pa), then the test results will rise to meet the relaxed requirement. Bldgs. 31 and 32 are clear examples of this phenomenon; their measured airtightness of 0.32 cfm/ft^2 and 0.35 cfm/ft^2 at 75 Pa (6 m^3/h/m^2 and 6.4 m^3/h/m^{2}at 75 Pa), respectively, are more consistent with 1950 construction standards.

FAILURES AND LESSONS LEARNED

Five buildings tested between 2014 and 2020 initially failed to meet the USACE airtightness requirement (see Table 2 in the appendix). A design change in construction types across all Alaskan military bases from IMP roof systems to a constructed steel roof deck system created opportunities for lessons learned in the design and construction phases. Of the buildings that initially failed to meet the USACE airtightness requirement of 0.25 cfm/ft^2 at 75 Pa (4.7 m^3/h/m^2 at 75 Pa), three (Bldgs. 21, 24, and 26) failed due to a similar air leakage pathway identified at the roof-to-wall air barrier juncture. Thermography and smoke leakage testing were effectively used to identify areas of excessive air leakage pathways on each project. This air leakage pathway at the top flutes of the roof steel deck was identified as the primary air leakage pathway on each project. Once this air leakage pathway was sealed and largely corrected, as much as a 26% reduction in air leakage was achieved that allowed the buildings to comply with the USACE airtightness requirements and brought each project to completion. These case studies are discussed in detail below. Bldg. 29 was more complicated; its initial air barrier test failure of the architectural only test of 0.276 cfm/ft^2 at 75 Pa (5.05 m^3/h/m^2 at 75 Pa) included other contributing factors. Although Bldg. 31 passed its building envelope test, it was somewhat of a unique outlier. These case studies illustrate how USACE Air Leakage Test Protocols could better impact building airtightness by examining how the protocols are used to test USACE projects. For example, Bldg. 32, one of the smallest projects, failed to meet the airtightness requirement of 0.4 cfm/ft^2 at 75 Pa (7.31 m^3/h/m^2 at 75 Pa) on an Air Force base because of a design flaw. It was found that the air barrier design review and inspections that would have identified these flaws were not used on this small project.

Bldg. 26 did not initially meet the USACE airtightness requirement. Thermal imaging completed before building envelope testing (BET) revealed significant air leakage at the rake walls (see the IR images in Image 2-2 in Figure 2). The retrofit developed in the field at the time was simple: plug the holes. The primary contributing air leakage pathway was identified and sealed at the top flutes of the steel roof pan decking by drilling ¼-in. (6.3 mm) holes in the flutes and inject high expansion can foam at each pan decking trough. This retrofit was effective and allowed the project to complete on time. Bldgs. 24 and 26 are similarly designed and built by two different general contractors at about the same time. Surface area calculations were slightly different, but the air leakage pathways were almost exactly the same. After air sealing improvements were made to both Bldgs. 24 and 26, final air leakage was measured at 0.196 cfm/ft^2 and 0.197 cfm/ft^2 at 75 Pa, respectively.

The post-construction air-sealing method of injecting can foam into the top flutes of the steel roof decking should only be used in retrofit applications. See Images 2-3 and 2-4 in Figure 2 for details. In more recent projects, this retrofit has been used on similar roofs by filling flutes during the construction of the roof, thus creating a cold joint between foam and dens decking. These methods were used in Bldg. 31 with vastly different results, discussed in detail below. Recent design reviews on 2020 projects included recommendations for filling the troughs with foam at the rake walls during the construction of the roof, where troughs are perpendicular to the wall line, and setting the DensDeck in a bed of caulking at all exterior wall lines to further minimize air leakage above the roof decking at the roof-to-wall juncture.

Bldg. 29 is constructed with an IMP wall system and 6 in. (15.24cm) of polyurethane at the interior. The steel roof is constructed with a vapor barrier on the warm side of the insulation. The hangar section was excluded from the air barrier test requirements (see Image 3-1 in Figure 3). This project failed its initial air leakage testing with an area separation wall included as part of the six-sided building envelope. Significant air leakage pathways were located at the area separation wall between the hangar and office area, which was mapped independently of other walls sections using fog. Air leakage also existed at the parapet and rake walls due to an unsealed gap in the air barrier at the top of wall juncture. These air leakage pathways are outlined in plan and elevation view drawings in Graphs 3-2 and 3-3 in Figure 3. Sealing the area separation wall was completed quickly and cost-effectively, allowing the building to pass the test requirement and construction to finish. The final architectural only air leakage test results were 0.244 cfm/ft^2 at 75 Pa. Because the test zone also included the area separation wall and not the whole-building envelope, more costly and invasive air sealing retrofits at the exterior building envelope did not need to be prioritized to pass the USACE air leakage test requirement. For these reasons, including an area separation wall as part of the six-sided building envelope may not be an effective method in verifying an airtight separation wall or the building envelope enclosure tightness. The air leakage of either wall type impacts the building differently; because of this, area separation walls should be tested differently and even at different airtightness requirements. Fog leakage testing and guarded tests could be used in demonstrating and calculating cfm/ft^2 of an Underwriters Laboratories (UL) listed area separation wall. Testing these walls independently of the exterior building envelope may help to improve knowledge of UL listed walls in the construction industry, specifically of how area separation walls leak air and how they could be better built to achieve air sealing between different building zones. Bldg. 25 is a single-zone warm storage hangar similar in design to Bldg. 29. Bldg. 25 passed the airtightness requirements at 0.145 cfm/ft^2 at 75 Pa. Including a hangar or maintenance inspection bay in the whole-building air

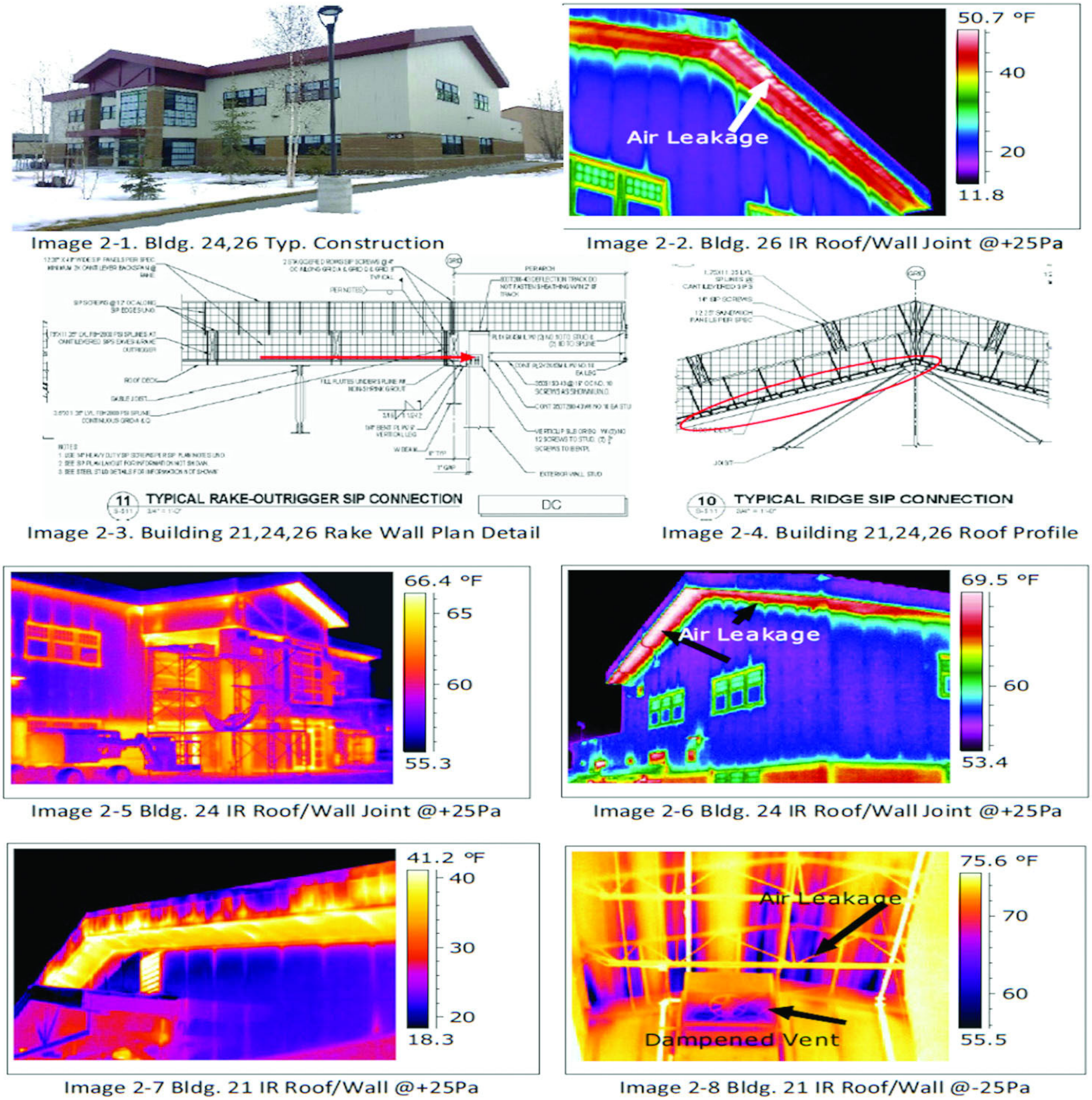


Figure 2 *Failures and lessons learned: Bldgs. 21, 24, and 26 IR and plan details.*

barrier tests in Alaska where these zone types typically are entirely inside the air and thermal barrier boundaries is practical.

Bldg. 31 passed the Air Force airtightness requirements of 0.4 cfm/ft^2 at 75 Pa (7.31 m^3/h/m^2 at 75 Pa), with 0.328 cfm/ft^2 at 75 Pa (6 m^3/h/m^2 at 75 Pa). Extensive air leakage building-wide at critical air barrier joints was found with subsequent ice damming conditions occurring in the first year at the northwest building corner, which created a severe slip trip and fall potential. (See the IR Image 4-1 of Figure 4, where air leakage from the mechanical room is filling the rake wall soffit and adjacent eave soffit with warm air.) A design detail that demonstrates an effective and constructible plan that transitions the roof air/vapor barrier down through the roof steel decking flutes and ties appropriately into the wall air barrier at all eave and rake walls needs to be developed. Additionally, improvements in quality control of the roof air barrier are needed. All portions of the air barrier, including the roof air barrier should be verified at the time of installation by someone with knowledge of the installation of air barriers. The heated and conditioned maintenance

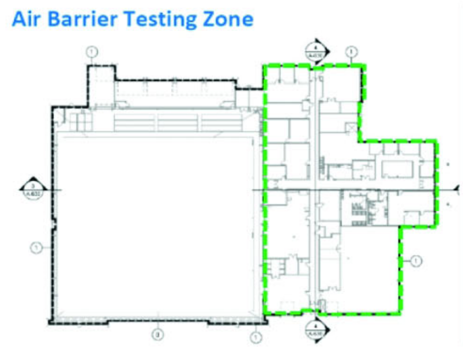


Image 3-1. Building 29 Air Barrier Test Zone

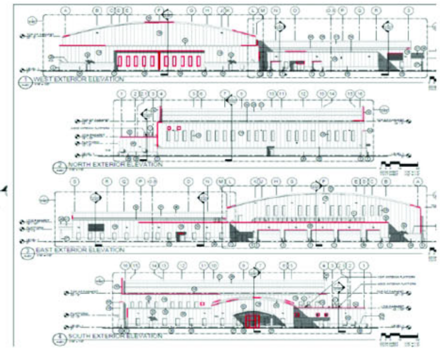


Image 3-2. Building 29 Air Leakage Pathways

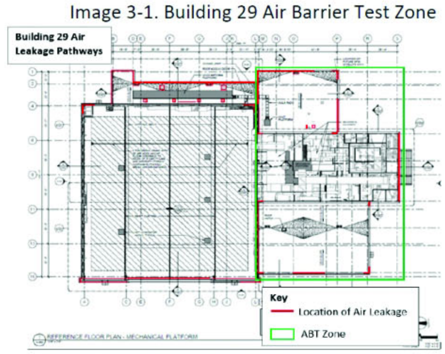


Image 3-3. Building 29 Air Leakage Pathways

Image 3-4. Building 29

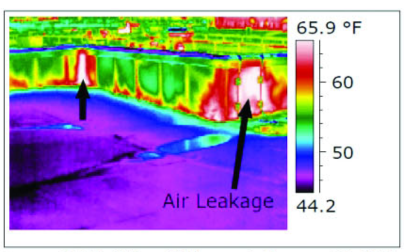


Image 3-5 Building 29 Parapet Corners @+25Pa

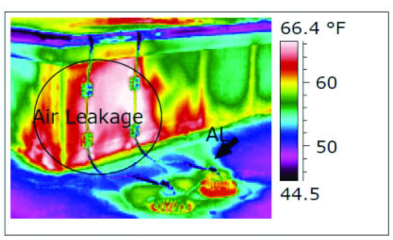


Image 3-6 Building 29 Parapet Corner @+25Pa

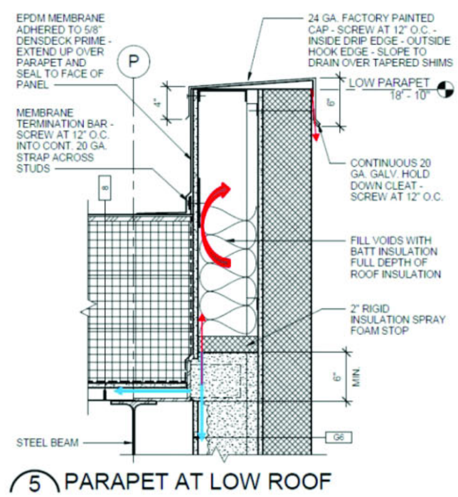


Image 3-7 Building 29 Parapet Detail (Mapped Air Leakage)

Figure 3 *Failures and lessons learned: Bldgs. 29 IR and plan details.*

inspection and garage bays were not included in the air barrier test zone under the Unified Facilities Criteria (UFC) 3-101-01 exceptions for air barrier testing (USACE et al. 2019). Bldg. 31 had air leakage pathways consistently at rake walls, parapet walls, and horizontal IMP joints for long sections at critical air barrier joints. During BET and air leakage diagnostics, changes in indoor temperatures and relative humidity were noticeable in zones having significant air leakage. These conditions and airtightness requirements reflect the potential in ASHRAE and IECC minimum code construction and highlight future opportunities in deep energy retrofits for existing and new construction.

THE TIGHTEST AIR BARRIER EXAMPLES

Bldg. 27, which was constructed in 2017, tested at 0.054 cfm/ft^2 at 75 Pa. The thermal envelope is a CMU wall system with Rockwool at the interior side of the CMU and a self-adhered air barrier at the warm side of the wall system. A vapor barrier is located at the steel roof pan decking. An air barrier design review, air barrier mock-up, and air barrier inspections were completed during the air barrier installation. Note that the steel roof deck and vapor barrier roof assembly of Bldg. 27 are the same as that of Bldgs. 21, 24, and 26, but Bldg. 27 did not have the same failed air barrier joint condition

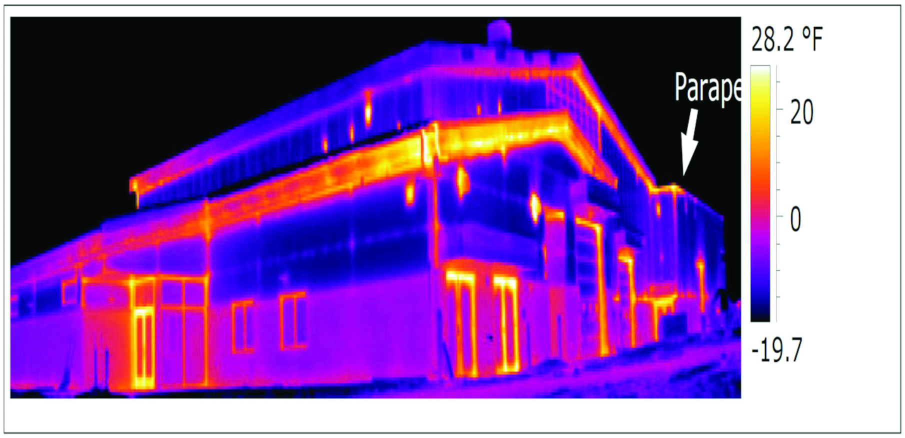
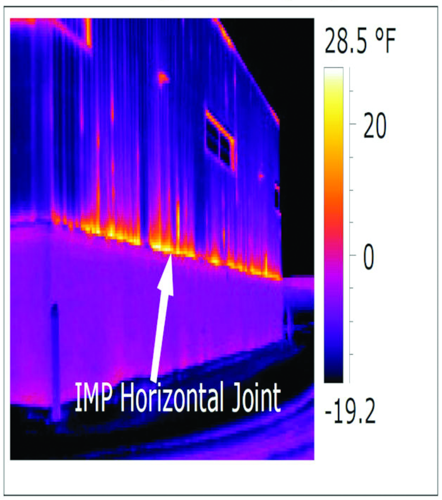


Image 4-1 Building 31 (0.328cfm/ft2 @75Pa) Northwest Building Corner @+25Pa



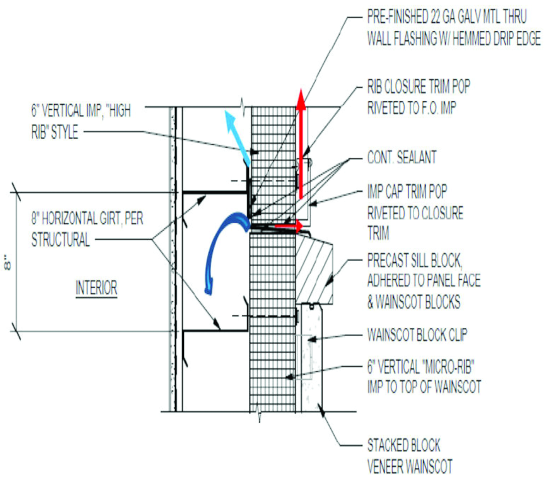


Image 4-2 Bldg. 31 IMP Horizontal Wall Joint @+25Pa

Image 4-3 Bldg. 31 IMP Horizontal Wall Joint Detail

Figure 4 *Minimum code construction: Bldg. 31 (0.4 cfm/ft^2 at 75 Pa [7.31 m^3/h/m^2 at 75 Pa] requirement).*

at the rake walls. The gap in the air/vapor barrier at the top flutes of the steel deck was sealed by injecting foam at the rake wall assemblies in a retrofit application while the exterior soffits were open. The IR images in Figure 5 show the impact and overall airtightness performance of this building. Minimal amounts of air leakage were found. This project included an air barrier design review, inspections, and a mock-up of the air barrier that included Heating, ventilating, and air-conditioning (HVAC) fenestrations, a building corner, and the roof-to-wall juncture.

Bldg. 10, which was constructed in 2009, had an airtightness of 0.0716 cfm/ft^2 at 75 Pa (1.31 m^3/h/m^2 at 75 Pa). The thermal envelope is constructed entirely of IMP wall and roof systems; it was the tightest of IMP projects. Contractor crews were diligent and methodical at air sealing at the roof-to-wall joints, IMP joints, and building corners. Air leakage was found primarily at the base of the IMP wall-to-slab edge, at the translucent panels, and at exterior doors. Very little air leakage was located at the roof-to-wall joints, building corners, or roof sections. The IR images in Figure 6 show areas that could easily have been improved during construction.

Bldg. 23 air leakage tested at 0.082 cfm/ft^2 at 75 Pa. The CMU wall system had very few windows and doors because of its use as a bowling center. This project also has an attic space with metal trusses. Air barrier design review and air barrier inspections played an important role in identifying a gap at the CMU wall-to-ceiling joint and an interior wall partition top plate. Air barrier inspections identified air leakage pathways around HVAC low-leakage dampers and other air leakage pathways during construction as well. These types of quality controls have had a positive impact on projects where air barrier performance is tested. While this project far surpassed the airtightness requirement, opportunities still existed for air sealing and thermal barrier improvements. Figure 7 shows examples of remaining air leakage and overall thermal signatures of the CMU wall system.

Image 5-1. Bldg. 27 CMU Wall & Metal Roof

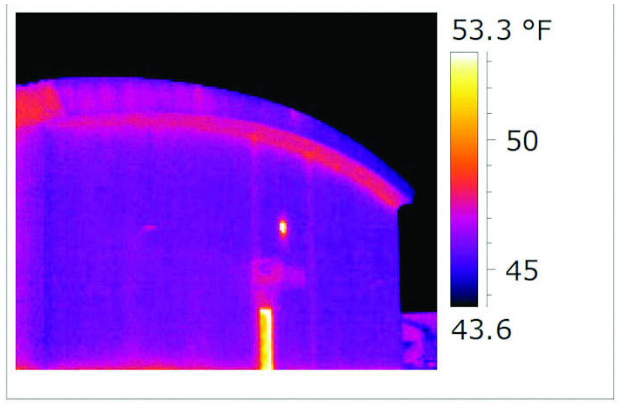


Image 5-2. Bldg. 27 CMU Rake Wall @+25Pa

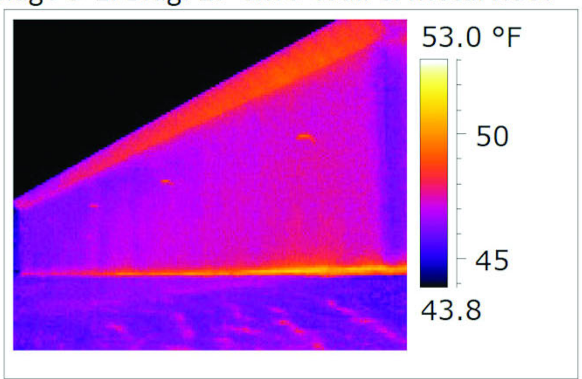


Image 5-3. Bldg. 27 Eave & CMU wall @+25Pa

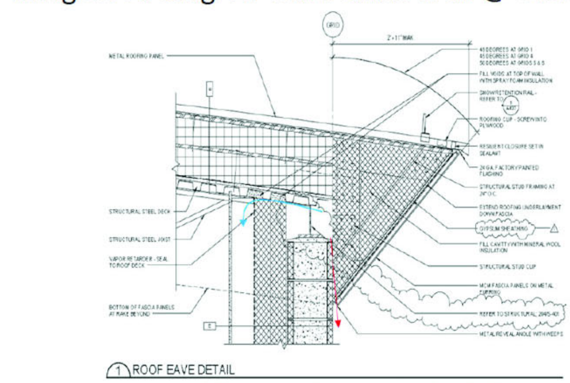


Image 5-4. Bldg. 27 Plan Detail of the Eave

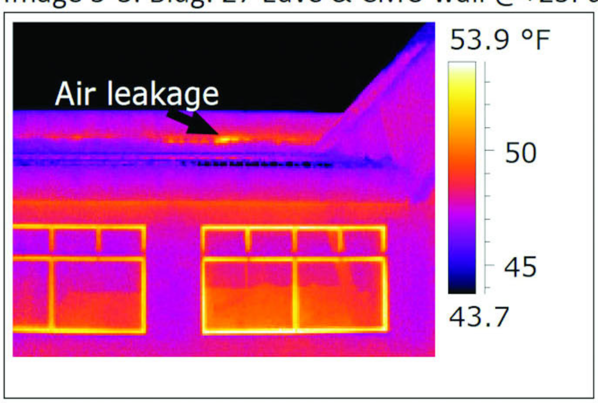


Image 5-5. Bldg. 27 Upper Roof Eave @+25Pa

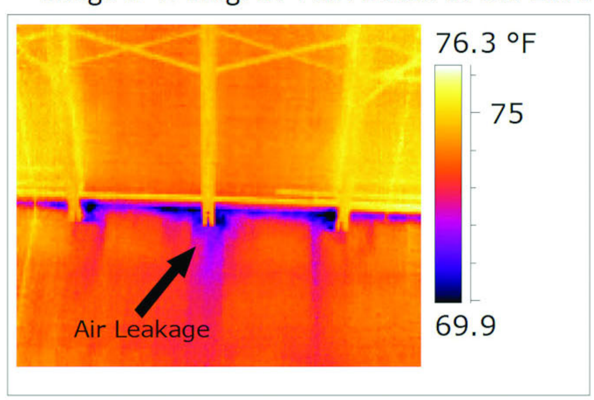


Image 5-6. Bldg. 27 Upper Roof Eave @-25Pa

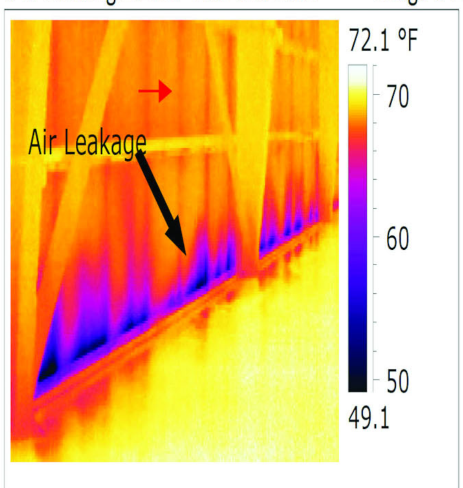
Figure 5 *The tightest building examples: Bldg. 27, IR, and plan details.*

THE OLDEST VERSUS THE RENOVATED

Eight of the buildings tested were constructed before implementation of the 2009 ECB airtightness requirements. Four of the eight buildings were extensively remodeled. Bldg. 2, which was constructed in 1949, is the oldest building of the group and has had no building envelope upgrades. Of these eight buildings, the 1949 construction located at Fort Wainwright has the highest air leakage, as might be expected due to its age and condition. Bldgs. 4 and 5, located in Fort Greely, have similar life spans asBldg. 2 but have less than half of the total air leakage because of their extensive building envelope and HVAC upgrades. Both Bldgs. 4 and 5 are in the lower range of airtightness in this group at around 0.15 cfm/ft^2 at 75 Pa (2.74 m^3/h/m^2 at 75 Pa). Bldg. 3 in Fort Wainwright has had several envelope upgrades, including IMP wall upgrades to the exterior of the original CMU walls and HVAC upgrades with airtight low-leakage dampers; however, it remains the third leakiest building envelope in this group. Buildings that have been renovated along with the two largest buildings constructed before 2006 all meet current USACE airtightness requirements. See Table 1 in the appendix for wall and roof construction types.

Image 6-1. Building 10 IMP Wall and Roof

Image 6-2. Building 10 Panoramic IR Image @+25pa



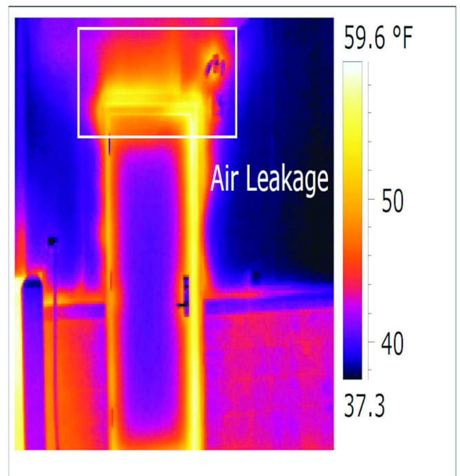


Image 6-3. Building 27 Air Leakage Pathways @-25Pa

Image 6-4. Building 27 Plan Detail of the Eave @+25pa

Figure 6 *The tightest building examples: Bldg. 10 digital and IR imagery.*

Bldg. 2 had an air leakage result of 0.328 cfm/ft^2 at 75 Pa (6 m^3/h/m^2 at 75 Pa). The building has single-pane, double-hung aluminum windows that have significant air leakage. The roof is steel with polyurethane and fire coating, but even this had air leakage at pinholes, expansion joints, and CMU fire break walls in the hot attic. This barracks, which now sit vacant after 70 years of service, need either renovations or demolition. Air leakage was found at the roof-to-CMU rake walls, structural beams, roof eaves-to-wall joints, roof peaks, windows, doors, and HVAC terminations inside cupolas. Moisture signs are typical in this building wherever air leakage is found due to the extreme climate zone, the building's age, and high occupancy. Mold conditions were evident at locations such as expansion joints where significant air leakage pathways were found, and continuous wetting occurred for up to nine months out of a year from condensation.

Bldg. 3, which was constructed in 1954 of CMU, is used as a storage/maintenance facility. The building envelope and HVAC ventilation systems were upgraded in 2018 with an IMP wall at the exterior side of the CMU wall, new HVAC equipment, dampers, overhead doors, and windows. The building envelope meets current USACE airtightness standards at 0.242 cfm/ft^2 at 75 Pa (4.43 m^3/h/m^2 at 75 Pa). However, when the building is pressurized, thermal imaging shows a much different thermal signature than might have been expected from a "tight" envelope. Air leakage pathways were primarily found at the wall-to-roof joints, IMP joints, and all fenestrations. No visible signs of moisture at the building envelope were found during the IR inspection. This building is slightly pressurized during normal building pressures with the HVAC equipment in operation. Because of this, the building's age, and possibly because of the significant air leakage pathway at the roof-to-wall joint, a slight mildew smell could be detected at electrical outlets boxes and inside the insulated wall cavity. Thermal imaging, airtightness testing, and air barrier inspections can identify these concerns in the design and construction phases. Air leakage signatures were consis-

Image 7-1. Building 23 CMU Wall & Attic Ceiling

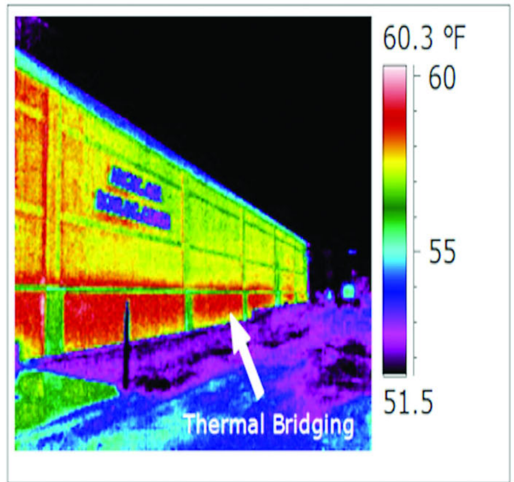


Image 7-2. Building 23 @+25Pa

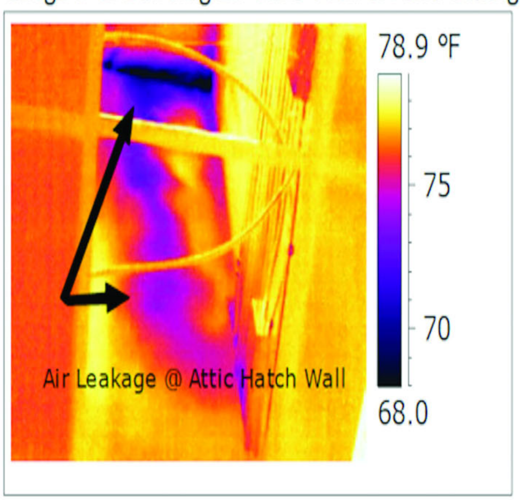


Image 7-3. Building 23 Attic Hatch Wall @-25Pa

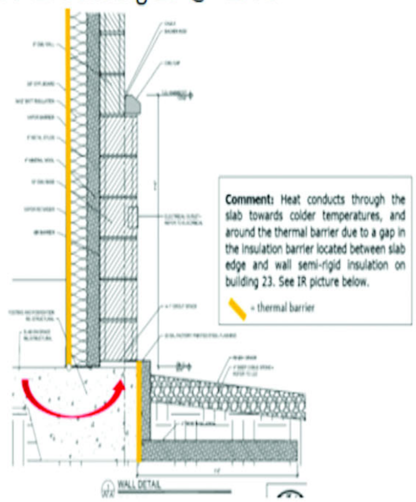


Image 7-4. Building 23 Slab Edge Plans Detail

Figure 7 *The tightest building examples: Bldg. 23 IR and plan details.*

tent building-wide at critical air barrier joints such as the parapet wall system, roofing, and IMPs.

Bldgs. 4 and 5 were both constructed in 1955 and remodeled around 2012 with an exterior insulation finish system (EIFS) wall retrofit, some windows, and limited HVAC upgrades. The air leakage tests for Bldgs. 4 and 5 were 0.155 cfm/ft^2 at 75 Pa and 0.146 cfm/ft^2 at 75 Pa (2.83 m^3/h/m^2 to 2.67 m^3/h/m^2 at 75 Pa), respectively. Air leakage was primarily found at the original HVAC louvered vents, windows, and doors that had not been upgraded. The thermal envelope upgraded walls performed exceptionally well with regards to thermal and air barrier performance when imaged (see Images 10-1 through 10-5 in Figure 10). The air leakage pathways were minor in comparison to projects having 0.25 cfm/ft^2 at 75 Pa (4.7 m^3/h/m^2 at 75 Pa). The EIFS retrofit, along with HVAC upgrades, were successful, and air leakage pathways identified during diagnostics demonstrated that these buildings could have easily achieved even tighter construction.

ARCHITECTURAL ONLY OR ARCHITECTURAL PLUS HVAC TESTING

Five buildings were tested following both building test set up protocols, the architectural only (Arch Only) and the architectural plus HVAC (Arch Plus) as originally defined in the USACE Air Leakage Test Protocol (USACE 2012), Section 4.8.2, “Preparation of the Building.” Figure 11 shows a graph of the test results for Arch Only and Arch Plus. They are a small sample set, but consistently the Arch Only test, which requires masking exterior HVAC louvers, has a lower cfm/ft^2 at 75 Pa, as expected. Where both tests have been required, the Arch Only test goal was set at 0.25 cfm/ft^2 at 75 Pa (4.7 m^3/h/m^2 at 75 Pa) and the Arch Plus test was typically set at 0.3 cfm/ft^2 at 75 Pa (5.48 m^3/h/m^2 at 75 Pa). Before this change, the projects were typically tested with dampers closed


Image 8-1. Building 2 Concrete Wall/Steel Roof

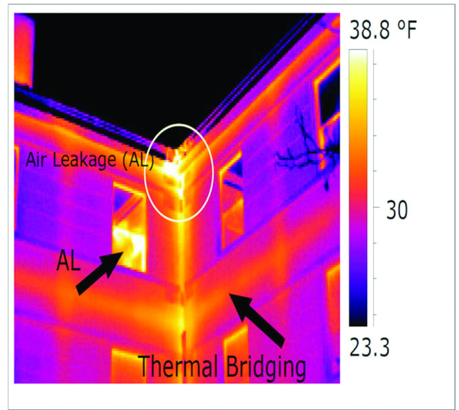


Image 8-2. Building 2 Roof to Wall Joint IR @+25Pa.

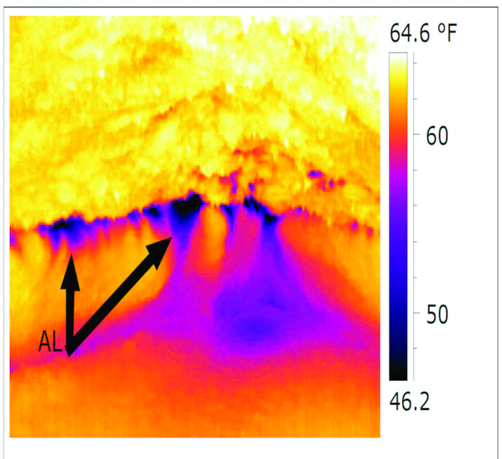


Image 8-3. Building 2 Air Leakage Pathways


Image 8-4. Building 2 Roof to Wall Joint Dig.

Figure 8 *Bldg. 2. air leakage at 0.328 cfm/ft^2 at 75 Pa (5.99 m^3/h/m^2 at 75 Pa) showing several air leakage pathways.*

and unmasked at the test goal of 0.25 cfm/ft^2 at 75 Pa (4.7 m^3/h/m^2 at 75 Pa), resulting in a 20% drop in the airtightness requirement for the USACE requirement.

For buildings that have completed both the Arch Only and Arch Plus tests, the percentage differences between the two-test setup "masked or unmasked" vary significantly from 3.3% to 26% (See Bldg. 27 through 30 and 32 in Table 1). These test results are easily affected by uncontrollable scenarios making them less repeatable. For example, several conditions that can influence the Arch Only tests negatively are

- The difficulty and repeatability issues in applying tape or self-adhesive grille wrap in cold or wet climates. For example, see Images 11-2 and 11-3 in Figure 11.
- Tape or self-adhesive grille wrap sealed to the exterior wall assembly instead of properly sealing just the intentional openings at the air barrier boundary. For example, see Images 11-4 and 11-5 in Figure 11. Images 11-6 and 11-7 in Figure 11 demonstrate the potential air leakage at louvered HVAC vents.
- Variations in the test results between projects due to differences in HVAC systems design, size, and potential impact to building setup from one building to the next.

Due to this sample set size, the results should not be used to draw any conclusions. However, these issues may outline where USACE testing schemes and protocol variations could impact airtightness results negatively. Based on a literal interpretation of Section 3-6, "Air Barrier Requirements," in Unified Facilities Criteria (UFC) 3-101-01, Architecture (NAVFAC 2019), the air barrier system must be a continuous plane. The routinely masked low-leakage dampers are intended to be part of the air barrier system, not an intentional opening. Low-leakage dampers are much like an operable window; they are part of the architectural boundary and air barrier system. From the authors' perspective, the only benefit from masking and unmasking low-leakage dampers for USACE airtightness testing is to highlight the air leakage pathway around dampers that were not installed using airtight methods, or dampers that have not been properly commissioned. According to Section 3-6 of UFC-3-101-01, the air

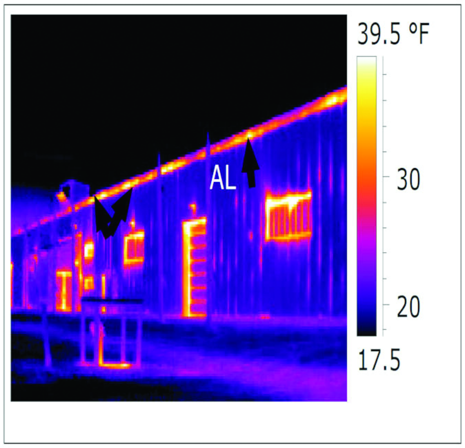


Image 9-1. Building 3 Air Leakage Pathways @+25Pa

Image 9-2. Building 3 Storage Facility and Shop

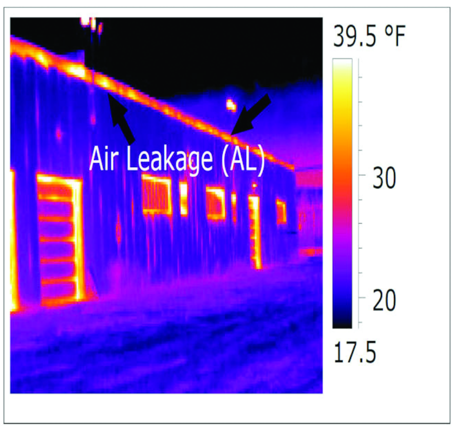


Image 9-3. Building 3 Air Leakage Pathways @+25Pa

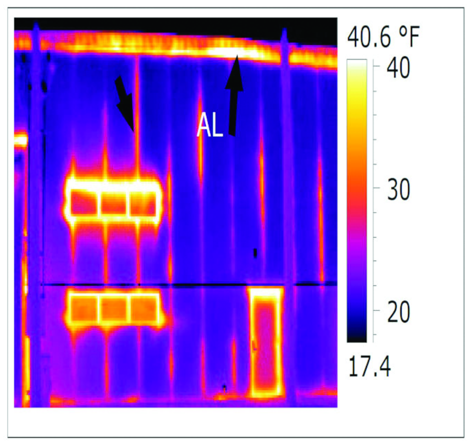


Image 9-4. Building 3 Air Leakage Pathways @+25Pa

Figure 9 *Bldg. 3 (0.242 cfm/ft^2 at 75 Pa [4.43 m^3/h/m^2 at 75 Pa]) showing common air leakage pathways of IMP.*

barrier must properly transition through all fenestration types to be effective (NAVFAC 2019). Eliminating the redundancy in testing, especially in cold climates where no intentional openings typically occur, offers the greatest cost savings potential for testing and an incentive for tighter construction at low leakage dampers; one of the last low-hanging fruits in airtightness.

CONCLUSION

A review of the past ten years of air leakage test results at military installations in Alaska has revealed several key points and issues. When outliers were excluded, DOD Buildings constructed in Alaska achieved an average airtightness of 0.158 cfm/ft^2 at 75 Pa, which is substantially tighter than current USACE's requirement of 0.25 cfm/ft^2 at 75 Pa (4.7 m^3/h/m^2 at 75 Pa) but is consistent with 2014 research (Zhivov et. al. 2014) based on a much larger sample set. A comparison of Bldg. 5 at 0.155 cfm/ft^2 at 75 Pa (2.83 m^3/h/m^2 at 75 Pa) and Bldg. 3 at 0.242 cfm/ft^2 at 75 Pa (4.43 m^3/h/m^2 at 75 Pa) showed significant differences both in measured air leakage rates and in IR images. These thermal signature differences in air barrier performance occurred with new construction projects as well, e.g., Bldg. 10 at 0.0716 cfm/ft^2 at 75 Pa (1.31 m^3/h/m^2 at 75 Pa) in comparison to Bldg. 29 at 0.253 cfm/ft^2 at 75 Pa (4.63 m^3/h/m^2 at 75 Pa).

The extent of the air leakage and location at critical air leakage pathways typically seen in buildings at 0.25 cfm/ft^2 (4.7 m^3/h/m^2) or higher comprise the defining difference between airtight buildings with leakage rates less than 0.15 cfm/ft^2 at 75 Pa (2.74 m^3/h/m^2 at 75 Pa), and those with much greater leakage such as Bldg. 31, with 0.32 cfm/ft^2 at 75 Pa (6 m^3/h/m^2 at 75 Pa), where prominent air leakage pathways occurred at parapet walls and rake walls for long sections. Note that Bldg. 31, which was constructed in 2019 to Air Force airtightness requirements of 0.4 cfm/ft^2 at 75 Pa (7.31 m^3/h/m^2 at 75 Pa), is consistent with ASHRAE and IECC optional airtightness requirements.

More recently constructed projects that have higher air leakage test results have become a trend. Experienced general contractors and project teams that have completed several

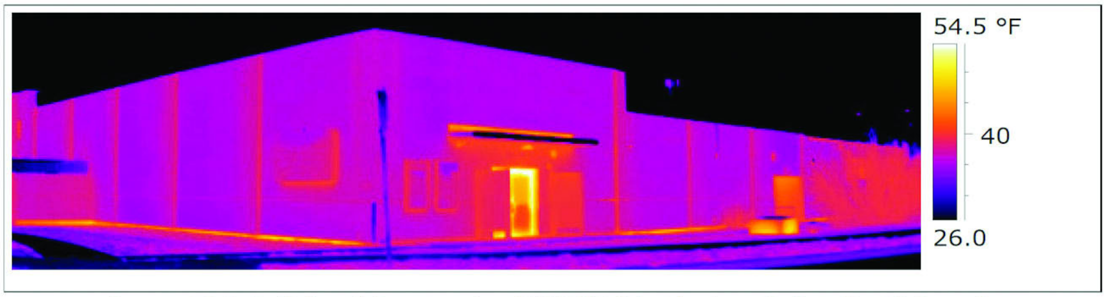


Image 10-1. Building 5 Panoramic of EIFS Wall in the Iron Pallet @ +25 Pascals


Image 10-2. Building 4 Shop Photo

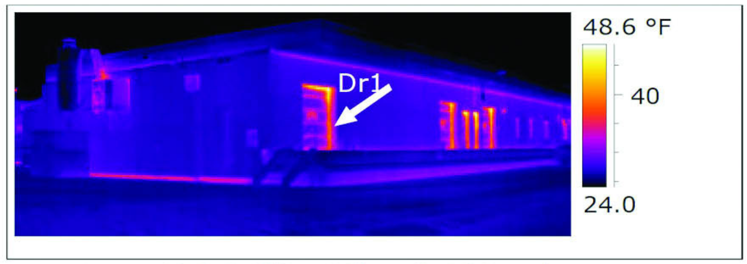


Image 10-3. Building 4 Shop @+25 Pascals

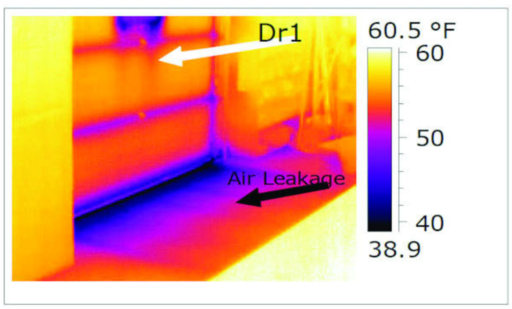


Image 10-4. Building 4 Overhead Door @-25Pa

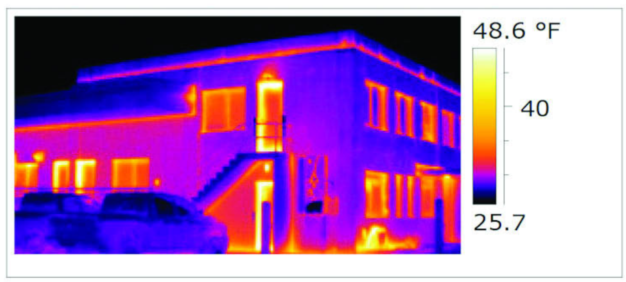


Image 10-5. Building 4 Fenestration & EIFs @+25 Pascals

Figure 10 *Bldgs. 4 and 5, thermal signatures of exterior insulation and finish system (EIFS) wall at air leakage pathways.*

projects are well aware of the amount of time and effort needed to pass the USACE airtightness requirement. The differences in recently constructed projects that have resulted in airtightness between 0.25 cfm/ft^2 at 75 Pa and 0.15 cfm/ft^2 at 75 Pa (4.7 m^3/h/m^2 at 75 Pa and 2.74 m^3/h/m^2 at 75 Pa) coupled with the progressive learning curve required to build airtight buildings, raises concerns that a the competitive construction industry may be more likely to produce buildings closer to 0.25 cfm/ft^2 and 0.4 cfm/ft^2 (4.7 m^3/h/m^2 and 7.31 m^3/h/m^2) than at 0.1 cfm/ft^2 at 75 Pa if requirements or incentives for tighter construction do not progress as well. Tighter construction requirements may be warranted to reverse this trend, and to stem the resulting potential for ice damming conditions and long-term degradation to the building envelope resulting from air leakage.

A review of the USACE testing protocol through revisions or updates could also have benefits. Projects before 2016 were tested and required to be tighter than 0.25 cfm/ft^2 at 75 Pa (4.7 m^3/h/m^2 at 75 Pa) with airtight HVAC dampers mechanically closed typically. Incorporating the Architectural Only (masked) and the Architectural Plus HVAC (unmasked) tests has effectively lowered the bar by as much as 20%, with the Architectural Plus HVAC testing typically increased to 0.3 cfm/ft^2 at 75 Pa. Additionally, air barrier zone testing and the exclusion of hangars and maintenance bays per UFC guidelines may have drawbacks, as exemplified by the performance of Bldg. 29, especially when considering that these excluded zones are typically conditioned in Alaska's zone 8 climate. Area separation walls assemblies between zones are critical wall assemblies that deserve attention because they differ in construction and airtightness requirements. While area separation walls are UL listed, they have not been tested for airtightness. In fact, air leakage diagnostic and testing protocols that isolate area separation wall assemblies have not been developed yet. However guarded tests and the use of fog could be simple and effective testing options. These areas offer the greatest opportunities for improvement in future revisions and updates to the USACE testing protocol.

One of the more interesting finds in the testing results was the similarity in average airtightness between medium-sized and

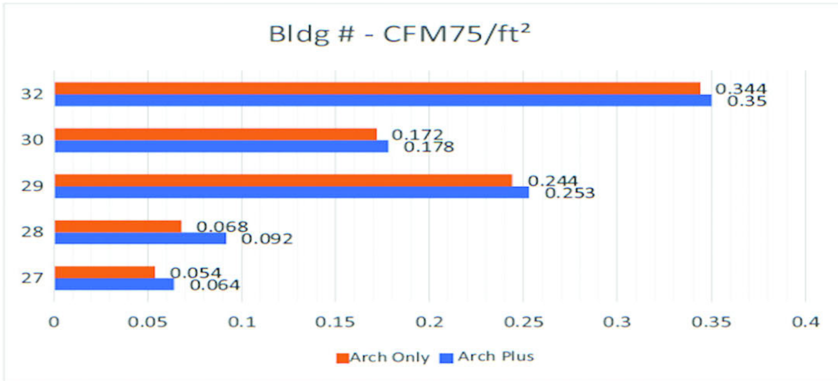


Figure 11-1 Graph Architectural Only Vs. Architectural Plus HVAC Test (CFM75/ ft²)

Image 11-2 EIFS Hood Termination Sealed (Winter)

Image 11-3 EIFS Louver Wall Termination Sealed (Winter)

Image 11-4 IMP Louver Termination Sealed

Image 11-5 CMU Louver Wall Termination Sealed

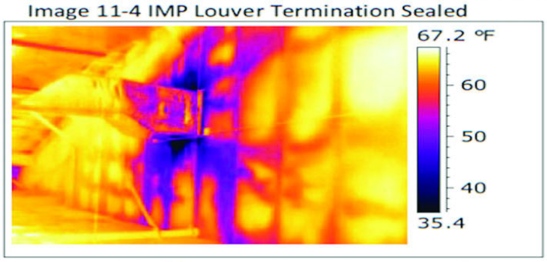


Image 11-6 Bldg. 19. Louver Termination @-25Pa

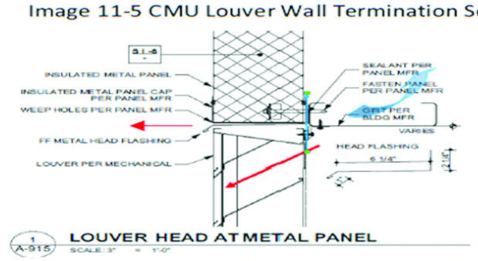


Image 11-7 Louver Wall Termination Detail

Figure 11 *Architectural Only versus Architectural Plus HVAC test and examples.*

large building envelopes, at around 0.15 cfm/ft^2 at 75 Pa (2.74 m^3/h/m^2 at 75 Pa), when outliers were eliminated from the group. This striking similarity in the airtightness performance of large and small building envelopes counters industry perceptions that small building envelopes are inherently less airtight, and suggests rather that airtightness testing requirements themselves may have had a primary impact on the airtightness of small and medium buildings. While many other factors may also come to bear, including the contractor experience level and their understanding of the impact of building envelope size on air barrier testing, these fresh findings certainly require further testing.

Based on our findings the following recommendations can be made:

- Requirements to building airtightness in cold and Arctic climates can be tightened to 0.15 cfm/ft^2 at 75 Pa (2.74 m^3/h/m^2 at 75 Pa) without significant increase in the construction costs. In most cases this will not change the currently used air barrier technologies or construction methods, but may require improved quality assurance (QA) and quality control (QC) during construction.
- The labor, time, and the cost required for air barrier testing in cold and Arctic climates can be significantly reduced by eliminating the redundancy in testing and not masking where HVAC low-leakage dampers are used and no other intentional openings exist.
- Include hangar and maintenance bays in testing requirements in Arctic climates and incorporate zone separation wall testing and diagnostics where practical to improve the resilience and long-term durability of USACE projects.

APPENDIX

Table 1. USACE Airtightness Testing at Alaskan Military Bases

#	Building Type	Arch Plus CFM75/ft^2	Arch Only CFM75/ft^2	Six-Sided Surface Area, ft^2 (m^2)	Year of Construction	Date of Test, Month-Yr	Wall Type	Roof Type
2	FTW barracks	0.328		34,442 (3199.8)	1949	Oct-19	Concrete	PU/Stl
3	FTW organization storage HQ	0.242		66,012 (6132.7)	1954	Oct-19	IMP/CMU	Concrete/EPDM (synthetic rubber)
4	FTG DPW office/shop	0.155		32,006 (2973.5)	1955	Oct-19	Concrete	Concrete EPDM
5	FTG Multi Use	0.146		28,978	1955	Oct-19	CMU/Framed	Concrete/EPDM l
6	FTW Tact. Vehicle Shop	0.2869		45,851	1988	Feb-12	2x Framed	Stl Pavers
7	FTW Plans Vault	0.095		8489	1999	Oct-19	Stud Framed	VB/Attic
8	FTW Alert Holding Area	0.2128		220,692	2006	Nov-11	IMP/Stl Studs	Stl EPDM
9	FTW Pallet Proc. Facility	0.2267		151,490	2006	Oct-11	IMP	Stl EPDM
10	FTW Training Sup. Center	0.0716		63,895	2009	Sept-10	IMP	IMP
11	FTW MP Admin Facility	0.2171		6541	2009	Jun-10	IMP	IMP
12	FTW (COF)	0.2046		34,189	2009	Apr-10	IMP	IMP
13	NOAA Sat. Op. Facility	0.1965		35,132	2009	Jun-10	VB-IMP	IMP
14	FTW Barracks	0.1985		132,460	2010	Dec-11	VB -IMP	Attic
15	FTW WIT SFAC	0.1356		18,484	2010	Sept-11	IMP	IMP
16	FTW WIT Barracks	0.102		51,152	2010	Sept-11	IMP	IMP
17	FTW WIT COH	0.189		22,180	2010	Sept-11	IMP	IMP
18	FTW Aircraft Parts Storage	0.119		51,840	2010	May-11	VB-EIFS	VB/Stl
19	FTR COF	0.1031		145,295	2011	Dec-12	IMP	IMP
20	FTW GSAB Hangar	0.226		132,435	2013	Aug-14	VB-IMP	VB/Stl
21	FTW COF		0.194	36,557	2014	May-16	VB-IMP	VB/Stl
22	FTW Duplex COF	0.164		64,000	2014	Sept-15	6” PU/ IMP	VB/IMP
23	EIE Bowling Center	0.082		40,448	2014	Aug-15	CMU	VB/Attic
24	FTW Battalion Head Quarters (B)	0.197		39,822	2015	Aug-16	VB-IMP	VB-Stl /EPDM
24b	FTW Battalion Head Quarters (B)	0.208		39,822	2015	Oct-19	VB-IMP	VB-Stl /EPDM
25	FTW WS Hangar	0.145		147,492	2015	Sept-16	6” PU/ IMP	VB-Stl /EPDM
26	FTW Battalion Head Quarters (A)	0.196		39,021	2015	Mar-16	VB-IMP	VB-Stl /EPDM
27	EIE Training Facility	0.064	0.054	81,536	2017	Jul-18	CMU	VB/Stl
28	CLR MCF	0.092	0.068	145,549	2018	Jun-19	IMP	VB/ EPDM
29	FTW UAS Hangar	0.253	0.244	58,116	2018	Jul-19	6” PU/ IMP	VB/Stl /EPDM
30	EIE FTD Facility	0.178	0.172	80,955	2018	Feb-19	VB/IMP	VB/Stl
31	EIE AGE Facility (0.4 cfm75/ft^{2}Target)		0.328	11,368	2018	Nov-19	IMP	VB/Stl
32	CLR EC Facility (0.4 cfm75/ft^2 Target)	0.350	0.344	3422	2019	Mar-20	IMP	VB/EPDM

Table 2. 2009–2020 Small, Medium, and Large Construction Airtightness Results

Building No.	cfm/ft^2 at 75 Pa (m^3/h/m^2 at 75 Pa)	Six-Sided Surface Area, ft^2 (m^2)	Year of Construction	Target cfm/ft^2 at 75 Pa (m^3/h/m^2 at 75 Pa)	Failed Initial Test Results
Small-Medium ABT Results					
27	0.064 (0.09)	81,536 (7574.9)	2017	0.25 (4.57)	
30	0.178 (3.25)	80,955 (7520.9)	2018	0.25 (4.57)	
22	0.164 (3)	64,000 (5945.8)	2014	0.25 (4.57)	
10	0.0716 (1.31)	63,895 (5936)	2009	0.25 (4.57)	
29	0.253 (4.63)	58,116 (5399.2)	2018	0.25 (4.57)	0.276 (5.05)
18	0.119 (2.17)	51,840 (4816.1)	2010	0.25 (4.57)	
16	0.102 (1.86)	51,152 (4752.2)	2010	0.25 (4.57)	
23	0.082 (1.5)	40,448 (3757.7)	2014	0.25 (4.57)	
24	0.197 (3.6)	39,822 (3699.6)	2015	0.25 (4.57)	0.269 (4.92)
26	0.196 (3.58)	39,021 (3625.2)	2015	0.2 (3.66)	0.214 (3.91)
21	0.194 (3.55)	36,557 (3396.3)	2014	0.2 (3.66)	0.250 (4.57)
13	0.1965 (3.59)	35,132 (3263.9)	2009	0.25 (4.57)	
12	0.2046 (3.74)	34,189 (3176.3)	2009	0.25 (4.57)	
17	0.189 (3.46)	22,180 (2060.6)	2010	0.25 (4.57)	
15	0.1356 (2.48)	18,484 (1717.2)	2010	0.25 (4.57)	
11	0.2171 (3.97)	6,541 (607.7)	2009	0.25 (4.57)	
Averages	0.160 (2.92)	45,242 (4203.1)	2009–2018		
Standard Deviation	0.057 (1.04)	21,092 (1959.5)			
31 (outlier)	0.328 (6)	11,368 (1056.1)	2018	0.4 (7.31)	
32 (outlier)	0.350 (6.4)	3422 (317.9)	2020	0.4 (7.31)	0.434 (7.94)
Large Envelope ABT Results					
25	0.145 (2.65)	147,492 (13,702.5)	2015		
28	0.092 (1.68)	145,549 (13,521.9)	2018		
19	0.1031 (1.88)	145,295 (13,498.3)	2011		
14	0.1985 (3.63)	132,460 (12,305.9)	2010		
20	0.226 (4.13)	132,435 (12,303.6)	2013		
Average	0.153 (2.8)	140,646 (13,066.4)	2010–2015		
Standard Deviations	0.058 (1.06)	6737 (625.9)			
Pre-ECB-2009 Construction				**Year Remodeled**	
8	0.2128 (3.89)	220,692 (20,503)	2006		
9	0.2267 (4.15)	151,490 (14,073.9)	2006		
7	0.095 (1.74)	8489 (788.6)	1999	2010	
6	0.2869 (5.25)	45,851 (4259.7)	1988		
4	0.155 (2.83)	32,006 (2973.5)	1955	2012	
5	0.146 (2.67)	28,978 (2692.1)	1955	2012	
3	0.242 (4.43)	66,012 (6132.7)	1954	2018	
2	0.328 (6)	34,442 (3199.8)	1949		
Average	0.21155 (3.93)	73,495 (6827.9)	1949–2006		
Standard Deviations	0.0769 (1.41)	73,702 (6847.1)			

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