Simplifying Whole-Building Airtightness

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AIR BARRIERS, AIR infiltration, airtightness—these words may seem to have been around the industry forever, but in the timeline of buildings, they are relatively new concepts. The Air Barrier Association of America (ABAA) was founded in 2001 and air barriers were first called out as a requirement in the *International Energy Conservation Code* (IECC)[1] in 2012. As an industry, we are still learning best practices for how to install and test for air leakage in our buildings. And it is for good reason. Air leakage was first identified as a major source of heat and energy loss in buildings. Hence, the code requirements for air barriers are found in the energy code and not with the water-resistance requirements in the *International Building Code* (IBC).[2] Air leakage is also a major source of moisture in our buildings, which comes by way of moisture-laden air. If that moisture is allowed to condense in the wrong place, it can lead to a whole host of problems, such as mold and material degradation. Furthermore, the additional moisture load on the structure increases the operating energy costs for a building. It takes a lot of energy for an HVAC system to remove moisture from the air, and it may not be able to remove enough moisture to get to the levels needed to prevent issues without the addition of a dehumidification system. As such, ensuring a continuous air control layer around the entire building enclosure is critical to long-term success of a building's performance.

Moisture is not the only contaminant that joins unintentional airflow into and out of a building enclosure. Indoor air quality is also improved through an airtight building system. If air enters through the exterior wall and roof assemblies, it brings with it contaminants such as wildfire particles, secondhand smoke, dust, and odors. When air movement into a building comes only through the mechanical system, it is able to be filtered before it enters the occupied space instead of by way of circulating in the air through the entire system before filtering. This will also save on the energy load of the mechanical system.

Air control is important for the entire building enclosure (including the roof and foundation), not just the walls. Even more importantly, success relies on the continuity of the air control layer at the interface between different building systems. Because the different systems and transitions are installed by different trades and get hidden during construction, the best way to determine if a truly airtight building has been constructed is to conduct a whole-building airtightness test (WBAT).

AIR BARRIER REQUIREMENTS IN IECC AND ASHRAE 90.1

Buildings are constructed of thousands of products produced by hundreds of manufacturers installed by numerous trades, all with the expectation that they perform together to keep the inside in and the outside out. Manufacturers can test materials and systems of materials in a controlled lab setting, but that cannot guarantee perfection during actual construction. As the importance of minimizing air leakage has become more well known, so has the building code recognized the importance of ensuring that the constructed building is airtight.

The IECC first started requiring air barriers in certain climate zones in 2012 after ASHRAE Standard 90.1[3] first required them in 2009. Over the last 11 years, the requirements for the use of an air barrier, air barrier assembly, and WBAT have continued to become more strict. The current 2021 IECC requires air barriers everywhere but in Climate Zone 2B, which primarily covers southwestern Arizona. The air barrier requirement includes that it is the design professional's responsibility to make sure that the "air barrier and air sealing details, including the location of the air barrier" are included in the construction documents.[1] Air barrier materials and system requirements have expanded to include WBAT for many buildings. It has continued to expand to specific jurisdictions, such as Washington State, and specific building owners, such as the United States Army Corps of Engineers (USACE), requiring WBAT.

The air barrier requirements adopted by the IECC originate in ASHRAE 90.1, which has an ultimate goal of designing buildings to be able to achieve zero energy by 2031. Each version of the model code uses the most recently published version of ASHRAE 90.1 with the associated gradual energy use reduction. This means that the current 2021 IECC references the 2019 ASHRAE 90.1 and has set limits on the air leakage through the building thermal envelope. The 2021 IECC states that a continuous air barrier must be constructed and verified *or* a WBAT must be performed. The intricacies of these requirements are not simple, as diagrammed by Meyer and Weston[4] (**Fig. 1**).

The complicated nature of determining what exactly has to be done to meet the code can be simplified by performing WBAT on the building. Both the 2018 and 2021 IECC require a maximum whole-building airtightness less than or equal to 0.40 cfm/sq. ft at 75 Pa. When the 2021 IECC mandated more whole-building testing, an "oops" clause with a limit of 0.60 cfm/sq. ft at 75 Pa was introduced. There are air leakage limits for dwelling units as well.

The 2024 IECC has updated the air leakage limit to 0.35 cfm/sq. ft. All of these changes are based around the ASHRAE 90.1 updates going from 2019 to 2022 with the same changes to air leakage limits. Meyer and Weston have published a more detailed overview of all things ASHRAE 90.1 and IECC over the last five years.[4]

The airtightness testing to meet the code requirement must be completed according to ASTM E779,[5] ASTM E3158,[6] ANSI/RESNET/ICC 380,[7] or ASTM E1827.[8] While these tests are all listed together, it does not mean that they are equivalent. The test methods were developed over multiple years as the industry continued to learn how to test for this performance attribute. ASTM E1827, *Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door*, is rarely used, as its accuracy is limited compared with the other methods. This test method is unable to detect changes in the test specimen while testing. For this reason, ASTM E779 became the default test method until the development of ASTM E3158.

WHOLE-BUILDING AIRTIGHTNESS TESTING

History

Originally approved in 1981, ASTM E779, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*, was developed to provide a standardized method for measuring building enclosure airtightness.[5] The standard provided the construction industry with the ability to verify building performance at the completion of a construction project. Initially, ASTM E779 was predominantly a test method for residential construction. Its procedures align with characteristics of smaller buildings, like single-family homes or unit testing in larger residential buildings. However, ASTM E779 did not preclude the use of the test method for commercial construction.

As its use in the commercial space became more widespread, the shortcomings of the test method became apparent. The required test pressure range, lack of restriction of data extrapolation, and limited statistical analysis parameters made the test vulnerable to accuracy and repeatability issues with more complicated, larger, and taller commercial buildings. To a large extent, this was due to the increased impact that environmental conditions have on commercial buildings, mainly wind pressures and temperature difference (stack pressure).

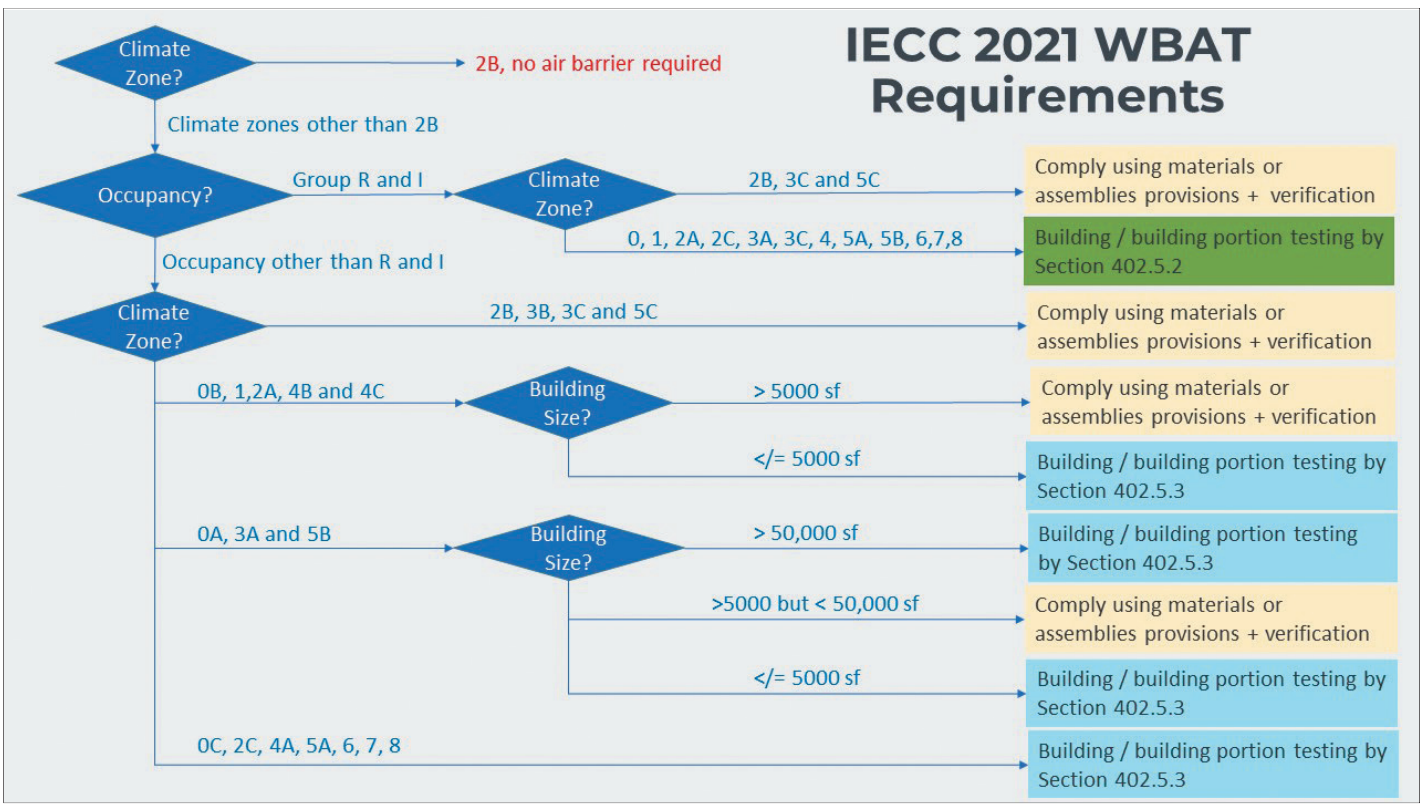

Figure 1. *Building testing requirements decision tree for compliance IECC-2021 (Figure courtesy of Siplast).*

The United States Army Corps of Engineers' (USACE's) *Air Leakage Test Protocol for Building Envelopes*, version 3, in 2012 adopted additional requirements for the ASTM E779 test method to ensure accurate and repeatable testing procedures more suitable for commercial construction.[9] USACE partnered with the ABAA on this project. Significant modifications to ASTM E779 included baseline pressure limits, a higher multipoint test pressure range with minimum and maximum test pressure limits, an acceptable range for the pressure exponent (n), and correlation coefficient squared (r^2) pass/fail criteria.

Based on the work with USACE and input from industry professionals, ABAA recognized that the building code adoption of WBAT for commercial construction needed a new test method to address concerns with ASTM E779. This new standard would reflect many of the changes adopted in the USACE test protocol[3] described above. The ABAA WBAT Task Group worked for several years to develop the ABAA Standard Method for Building Enclosure Airtightness Testing, which was published August 25, 2016. This document became the basis for the development of ASTM E3158-18, *Standard Test Method for Measuring the Air Leakage Rate of a Large or Multizone Building*.[6]

In addition to the multipoint test procedure carried over from ASTM E779/ USACE, ASTM E3158 also includes updated versions of the single-point and two-point test procedures included in ASTM E1827. These test procedures are not commonly specified or performed, but the industry recognizes that these procedures still provide value in limited use cases. The intent is for ASTM E3158 to become the main standard for blower-door testing to eventually supersede ASTM E779 and ASTM E1827 in commercial construction for WBAT.

Overview of Testing Preparations and Procedure

Typical Building Preparations

A significant amount of time is required for building preparation and this often represents the majority of work involved to execute a commercial WBAT. Typically, this scope of work is performed by the contractor to limit cost and to mitigate liability of the testing agency resulting from damaged equipment or materials that may occur when preparing the building for testing.

- Power down HVAC equipment.
- Mask, seal, and close HVAC dampers/louvers.
- Close and lock all test boundary exterior windows and doors.
- Fill all plumbing traps with water.
- For suspended drop ceiling tiles and underfloor air distribution computer floors, remove one tile for every 500 sq. ft of area (minimum of one tile per room).
- Prop open all interior doors within the official test boundary. Doors connecting the main corridors to any portion of the enclosure, including walls, roofs, and slab-on-grade conditions, must be open to achieve uniform pressurization.
- With taller buildings, elevator doors on each floor may need to remain in the open position with the elevator car parked at the optimum location to promote airflow throughout floors.

Procedure

Blower door fans are set up in exterior doors and can be distributed on each side of the building and/or at immediate and main roof levels. The size and complexity of the building will dictate the number of fans and fan locations. With multiple-fan testing, communication cables are typically run from micromanometers located near each fan and sometimes at specific locations for pressure monitoring, back to a centrally located laptop computer to monitor and control all test equipment and collect pressure and flow data.

Pressure monitoring consists of exterior and interior pressure tubes that are run across the building enclosure and throughout the building to monitor exterior pressure differentials and interior pressure uniformity, respectively, with micromanometers. Fan pressures are also measured with micromanometers to determine airflow (cfm). Interior differential pressure measurement taps are located at representative locations to compare building extremities and verify pressure uniformity throughout the building.

WBAT can include in testing both directions (pressurization and depressurization) or single-sided testing (pressurization or depressurization). Baseline pressure readings are recorded before and after the test flow measurements, with the fans sealed. Test flow measurements are recorded at predetermined test pressure(s), averaged over a period of time (typically a minimum of 10 seconds) for each data point. Singlepoint testing includes only one data point, typically at the required test pressure. Two-point testing includes two data points, at the lower and upper limits required for the test. Multipoint testing consists of a minimum of 10 equally spaced data points (required by USACE and ASTM E3158), ranging between minimum and maximum test pressures.

Importance of Hiring a Certified Technician

WBAT testing requires a significant amount of organization and test preparation. Project management is key to performing a successful test. It is also critical that the technician have a thorough understanding of the test methods and operation of test equipment. These tests typically require a significant amount of effort to mobilize and limited time onsite to execute, leaving little room for error. Because the test specimen is the entire building, there are many ways to have complications, and it is up to the technician to diagnose and determine how to solve issues on the fly that commonly occur when testing. False positive or false negative results can also occur if the test technician is not competent or lacks the required experience needed to perform the test.

ABAA recognized there is a lack of experienced testing agencies in the construction industry that can perform WBAT and determined it was absolutely essential to develop a training program to elevate testing agencies to meet the testing needs of today and the future, when the testing becomes mandatory for all commercial construction. The ABAA now offers the training programs and a blower door technician certification.

COMMON PROBLEMATIC DETAILS THAT IMPACT BUILDING AIRTIGHTNESS

Six common building assembly details are frequent sources of air leakage found during WBAT. Each one needs special attention during the design and construction process, focusing on the materials used for the transition, order of installation, and sequencing of trades during the construction process. Often, simply highlighting the interface's importance for the building performance will cause the installers to give the extra attention these details deserve.

Roof-to-Wall and Rising Wall Conditions

Roof-to-wall and rising wall conditions are frequently a challenge due to the number of materials from different suppliers and trades that must be sequenced in order to perform as required. **Fig. 2** shows how a leaky interface can be seen by way of a forward- looking infrared (FLIR) camera. The lighter colors show where cold air is coming through the transition, causing the substrates around the leak to be cooler than the bulk of the opaque wall. Wagner Watts and others have written multiple articles focused on how best to design and install these tricky transitions.[10]

Figure 2. *(a) FLIR image and (b) photograph of the same rising wall parapet condition showing air leakage at the interface.*

Canopies

The continuity of the air barrier through a canopy condition must be determined during the design phase of a project. The determination of if the air barrier is going to wrap around the entire canopy or be continuous behind it, cutting off the canopy from the rest of the building enclosure will determine how it is detailed (**Fig. 3**). Clear communication in the drawings of where the continuous air barrier is at these details will prevent issues during the construction process. It is also important to note that even though the air barrier may cut the canopy off from the building enclosure, that does not negate the need for a water-resistant barrier and/or roof membrane on these structures to prevent water damage.

Figure 3. *Canopy transition condition that is frequently a source of air leaks during a whole building airtightness test.*

Podiums/Parking Levels

Podiums and parking structures are often overlooked as part of the building enclosure. This is true when the structure is underneath the building (where it would be the bottom of the whole-building air barrier) or directly adjacent and acts as one of the walls of the continuous air barrier assembly. The entire side of the parking or podium structure that is part of the thermal envelope must have an air barrier that is tied into the air barrier of the rest of the enclosure. Additionally, these structures often have multiple penetrations that must be sealed for airtightness (**Fig. 4**). These details should be reviewed similarly to how they are reviewed for continuity in other parts of the building.

Mechanical Areas/Interfaces

To put it simply, ductwork must be sealed at the interface with the building roof. It is no different than a wall condition where similar penetrations exist. The HVAC contractor is typically responsible for this transition, but does not traditionally have a focus on airtightness with the rest of the enclosure. Because the HVAC team is not responsible for the air barrier assembly, or is not always knowledgeable about the importance of the transition to the performance of the enclosure, sealing of these interfaces is often overlooked, as shown in **Fig. 5**. Making sure these transitions are clearly called out in project drawings, submittals, and specifications will help ensure they are sealed prior to WBAT.

Traditional mechanical systems are not the only culprits. **Fig. 6** shows two images from inside open-air plenums. These are the gray areas between the enclosure and the mechanical systems, as they are both ductwork and exterior wall at the same time. It is often the assumption that the louver is the air barrier plane, but the plenum enclosure is not sealed, so there is a giant hole in the whole-building air barrier assembly. A review of systems during the design process will provide clarity at these extensions of the enclosure.

Loading Docks/Work Bays

Loading docks and work bays are notoriously leaky and are often the culprit in poor WBAT

Figure 4. *Penetrations through the wall of a parking structure that must be sealed airtight to complete the building's continuous air barrier.*

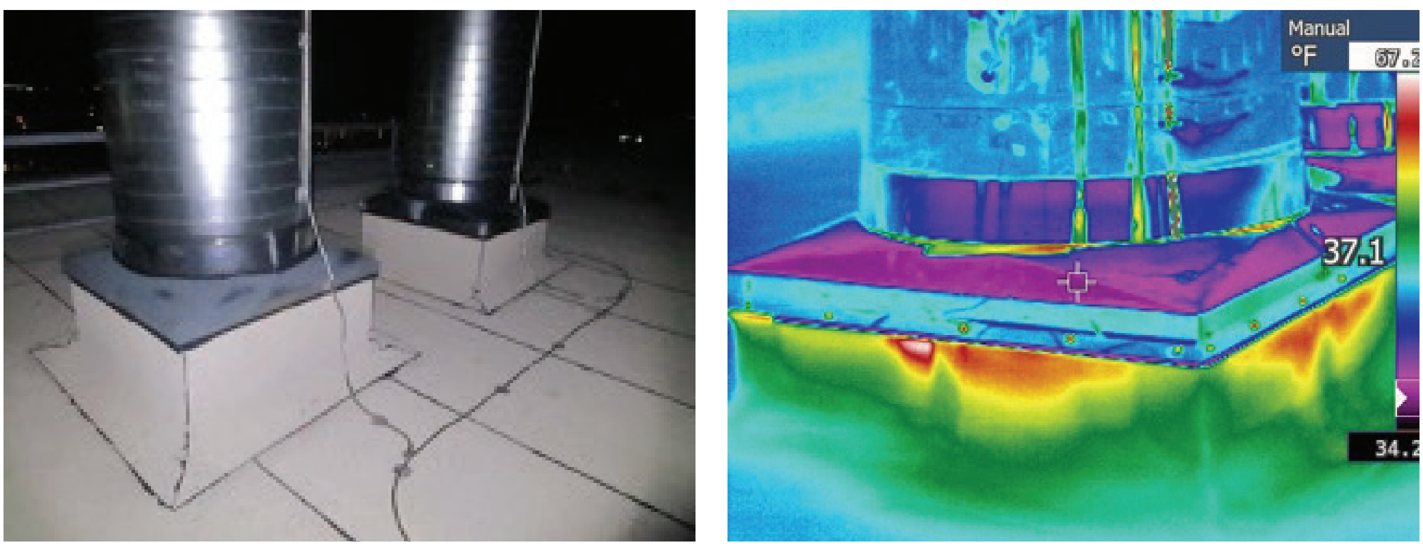

Figure 5. *Mechanical system ductwork (a) and an FLIR image (b) of the same condition showing the high level of air leakage where the ductwork meets the roof assembly.*

Figure 6. *Two different plenum shafts where the interior wall must be sealed as part of the air control layer.*

(**Fig. 7**). There are ways to enhance the seal of these doors if they are not used frequently. Even adding brush seals to the perimeter will improve performance. Another option is to compartmentalize the loading dock completely and separate it from the rest of the building enclosure. This option can be more reliable but the decision must be made earlier during the design process. It is not a repair option if a leaky door is realized after a test occurs.

CONSTRUCTION DOCUMENT REQUIREMENTS

Air Barrier Boundary Sheets

Air barrier boundary sheets are plans that identify the continuous air barrier boundary and the specific material for each enclosure assembly responsible for the air control. These sheets should be both plan and section drawings. Clearly identify or note the continuous air barrier plane in all plans and the enlarged section details. Continuity is not always apparent in architectural details. If possible, isolate or exclude spaces such as loading decks, vented spaces, etc., inside the building that are frequently/continuously exposed to exterior ambient air conditions. One way to do this is shown in **Fig. 8**, where circles call out critical details for the performance of the building enclosure. The isolated loading area is circled, as it is clearly excluded with its own air barrier system.

Written Specifications

In addition to clear drawing sets, the written specification should include requirements for WBAT, which should reside in Division 01. This includes requirements for the testing itself and the team performing the testing. The most critical components of the specification are as follows:

- Pretest meeting and inspection
- Submittal requirements, including the qualifications for the technicians and agency performing the test
- Equipment requirements
- Testing details including preparation

Pretesting Meeting and Inspection

As with preconstruction meetings, a pretesting meeting allows for alignment of all parties before the start of testing. The meeting will ensure that all parties (including the owner, air barrier assembly contractor, and testing team) understand the boundaries of the test envelope, which equipment will be used, and the building preparation that will be required for the test to be performed properly. One key component of this meeting is determining who is responsible for disabling the HVAC systems as required and how the test area will be secured so preparation work is not compromised. Finally, there needs to be an understanding of what will happen if the test results do not pass the project requirements, including responsibilities and procedures for repairing deficiencies and retesting.

Submittal Requirements

The submittal requirements for WBAT should include the boundary sheets mentioned in the previous section along with a detailed test plan from the testing agency. The test plan should be submitted prior to the pretest meeting so that all parties are able to review it beforehand. Finally,

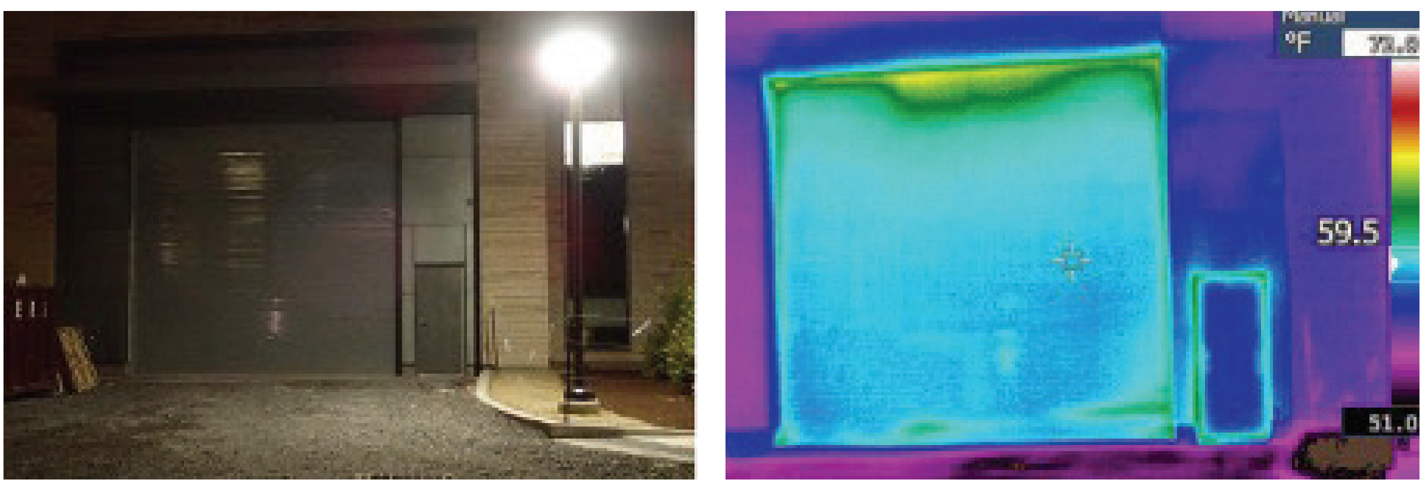

Figure 7. *Photograph (a) and FLIR image (b) of a loading dock bay and man door displaying large amounts of air leakage.*

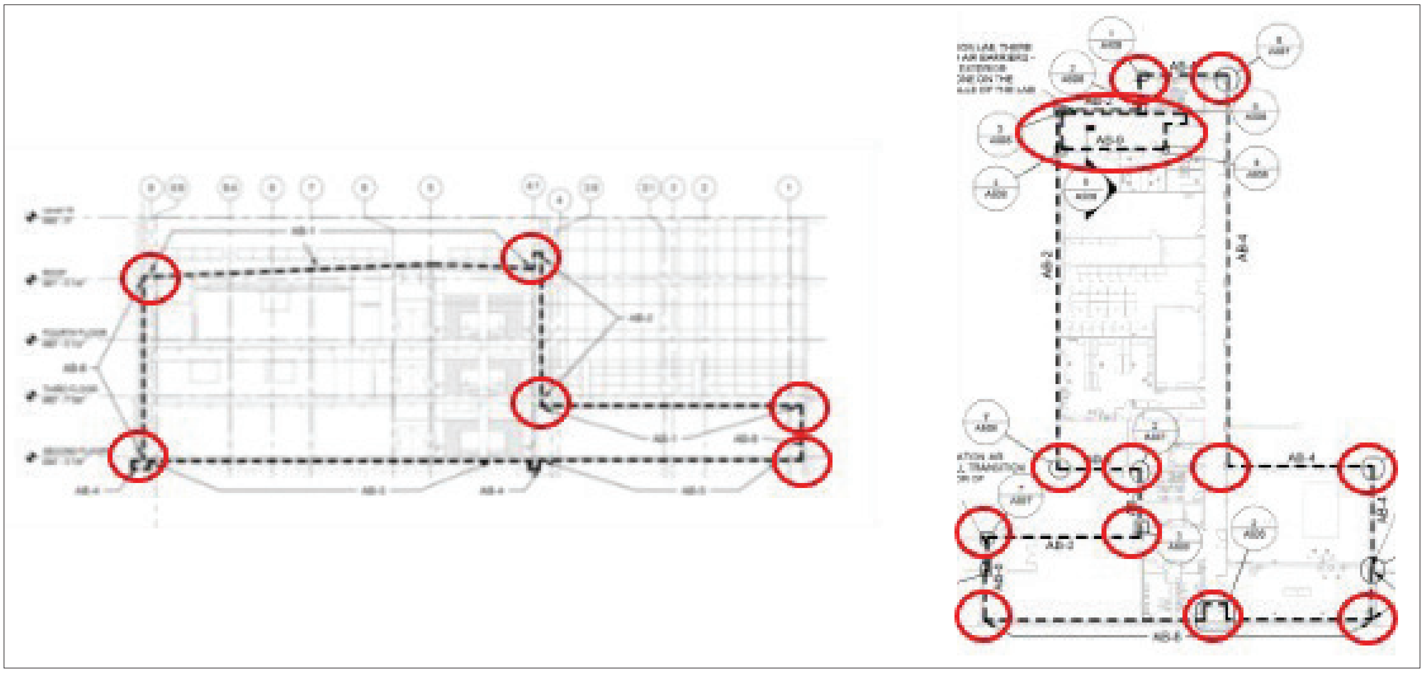

Figure 8. *Plan and elevation using circles to call out details critical to the air tightness of the building enclosure.*

the submittals should require proof of the test agency accreditation and that the individuals performing the test are certified in accordance with ISO 17024 to perform the required test methods.[11]

Equipment Requirements

It is the testing agency and certified technician's responsibility to clearly define which equipment will be used for the testing. This information will be included in the test plan submittals and discussed at the pretest meeting. However, the specification should include requirements for calibration of the equipment, such as how recently it was calibrated. Finally, it is recommended that specifiers call out the requirement for digital gauges instead of analog ones to ensure greater accuracy in the test measurements.

Testing Requirements

Different types of WBAT test methods are available, and the specification should be clear which type is required for the project. This will define the boundaries of the test and the test method that will be performed, such as ASTM E3158. The specification should include the requirement to perform testing both during pressurization and depressurization of the building enclosure and recording results separately. Additionally, the pass/fail criteria must also be included in the specification. These criteria may stem from the building code for the local jurisdiction or the owner project requirements.

It is helpful to define some of the preparation requirements for the testing within the specification. The test conditions for when the test can be performed will provide clarity for all parties as the test date approaches. Details such as closing and locking all exterior windows and doors, propping open internal doors, and having an explicit requirement for maintaining even pressure within the test envelope will prevent conflict.

If one is unfamiliar with all this terminology and the testing process, creating a specification from scratch can be a daunting task. There are sample specifications available to use as a starting template, including from industry associations such as ABAA.

CONCLUSION

The importance of whole-building airtightness cannot be overstated as a means to ensure energy-efficient and moisture tight buildings. The IECC and ASHRAE Standard 90.1 are both moving to more stringent requirements for buildings to achieve. However, meeting the new air barrier code requirements is achievable. The simplest way to meet the code requirements is to perform a WBAT on a project. WBAT may be a new test for many, but it does not have to be scary.

Multiple case studies from various parts of the country have shown that it is very reasonable to expect to pass testing at the airtightness levels required by the current IECC. Years of development and improvements have gone into the test methods as they moved from primarily using ASTM E779 to ASTM E3158. Trained and certified technicians have the proven techniques needed to perform tests, including the critical preparation procedures, such that buildings have a higher likelihood of passing.

However, testing cannot do it alone. All members of the construction team must pay attention to critical transition details throughout the design and construction process. This includes highlighting the critical areas in drawing sets as well as including all of the test requirements in the written specification. In the end, all these components work together to ensure a successful WBAT as one crucial part of ensuring a durable, energy-efficient building enclosure.

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