There's a Lot of Hot Air in Consulting—What's It All About?

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THE CONCEPT OF a strong foundation is not new. In fact, the concept was well known even in biblical times—see Matthew 7:24–27.

Success in building enclosure consulting depends on having a strong foundation in building enclosure knowledge, including a clear understanding of moisture movement. It is widely understood that the primary function of the building enclosure is to prevent water from passing from the exterior environment to the interior environment. However, that is only a portion of the foundational knowledge needed for building enclosure consulting. Another foundational element of water management that consultants must understand is that moisture and free water are not produced solely from outside sources such as rain and groundwater aquifers. There's a lot of "hot air" to consider!

Whether you are consulting on a design project that is yet to be constructed or conducting a forensic investigation and determining the root cause of a problematic condition, you must understand moisture movement and vapor drive and carefully consider them during the course of the project. The impact of heat, air, and moisture on structures extends from below grade through the roof and includes all exterior surfaces in between.

FOUNDATIONAL CONCEPTS IN THERMODYNAMICS

To understand vapor drive, the natural tendency for moisture vapor to seek equilibrium and migrate from a wetter to dryer area, one needs a strong foundation in the second law of thermodynamics, which explains how heat, air, and moisture move and affect building enclosure design.

In terms of building and roofing science, thermodynamics means:

- Hot moves to cold.
- Moist moves to dry.
- High pressure moves to low pressure.

Heat, moisture, and pressure always seek to equalize whenever possible—that is, if paths are available to do so (**Fig. 1**). That is why there is a drive for warm, moist air to leave a building during winter when it is cold and dry outside. When unintentional paths are available in the building enclosure, problems can arise. If warm, moist air is able to find a cool, dry surface along the path, condensation is possible. Therefore, designing to prevent unintentional airflow and the accumulation of moisture is critical.

BUILDING ENCLOSURE CONTROL LAYERS

ASTM E2947, *Standard Guide for Building Enclosure Commissioning*,[1] defines "building enclosure" as referring "collectively to materials, components, systems, and assemblies intended to provide shelter and environmental separation between interior and exterior, or between two or more environmentally distinct interior spaces in a building or structure." Building enclosure design involves four key control layers: water, air, thermal, and vapor. These four key control layers should generally be continuous across all six sides of the building enclosure. The following sections explore the design goals and principles for each layer.

Water

Goal: The goal of a water-control layer is to keep bulk water out of the building. This is a critical function of roofs, walls, and foundations.

Principles: Construction-related moisture, installation deficiencies, and damage in the use phase can introduce moisture into the roof, wall, and foundation systems. Construction acceptance testing, scheduled inspections, and regular maintenance play an important role in ensuring that systems are able to meet their intended performance over time.

Air

Goal: Most buildings require a continuous air barrier for energy efficiency and to mitigate condensation risk. The air barrier must be continuously detailed across all six sides of the building enclosure to be effective.

Principles: To achieve continuity, the air-control layer design will involve much more than selecting a material or specifying

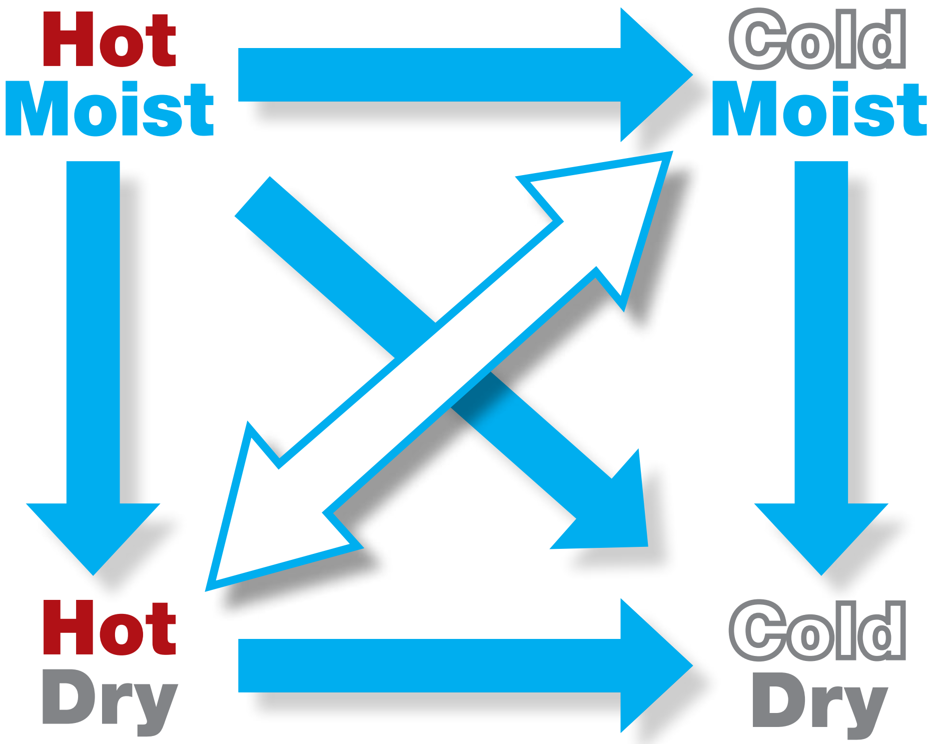

Figure 1. The principles of thermodynamics.

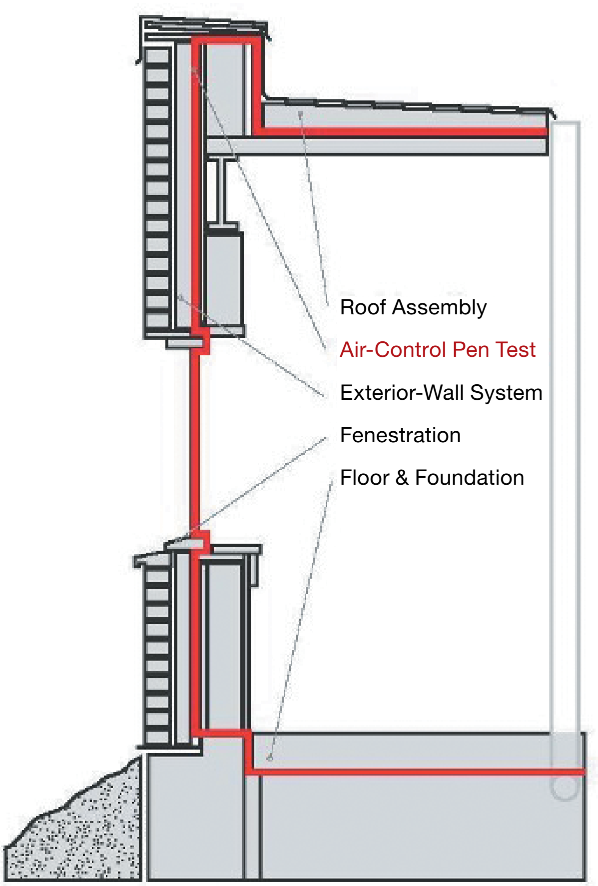

Figure 2. A simplified Air Control "Air-Control Pen Test" to examine continuity across the building enclosure.

a laboratory-rated assembly. Air-control discontinuities can lead to water ingress, affect occupant comfort, waste energy from loss of conditioned air, lead to damage from condensation moisture, and transmit airborne contaminants through the building enclosure.

Thermal

Goal: Maintaining continuity of the insulation layer, especially the continuous exterior insulation, is important to achieve the energy performance intended for the building, and to prevent moisture condensation on cold surfaces.

Principles: In the current editions of the *International Energy Conservation Code*[2] (IECC) and ASHRAE 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*,[3] the basic prescriptive requirements for both walls and roof systems include the use of continuous insulation in many climate zones and construction types. Continuous insulation is far more effective than cavity insulation, which is installed into the voids between framing members.

Vapor

Goal: The primary function of a dedicated vapor-control layer is to prevent condensation that results from vapor diffusion. Vapor diffusion occurs when water molecules in the air (vapor) pass through a solid material due to a pressure differential (high to low) on either side of the material.

Principles: Vapor diffusion through a solid material, even a vapor-permeable one, is a slow process. There are specific scenarios where enough vapor is able to diffuse through a solid material (not carried along by air leakage) to result in significant moisture accumulation over time. (Think of all the moisture that can potentially accumulate in a roof system as a concrete roof slab cures.) When it comes to vapor control, adding a vapor-impermeable material to an assembly may actually cause moisture problems. For example, intentional or unintentional use of a vapor-impermeable material could potentially prevent incidental moisture in the assembly from drying.

CONTROLLING HOT AIR AND MOISTURE

When vapor control is discussed, the conversation may quickly slip into "air control" strategies to manage condensation-related issues. Air control is emphasized because air movement can transport a far greater volume of moisture than vapor diffusion alone.

In a warm climate, air transports 10 times more water than vapor diffusion does, and in a cold climate, air transports 100 times more water than diffusion. This is why air-transported moisture is much more critical to prevent than water vapor that enters a building by diffusion. Note that vapor retarders often act as air barriers as well and can be incorporated into the continuous air-barrier design.

The National Institute of Standards and Technology estimates that air infiltration and exfiltration make up 25% to 40% of the total heat loss in a building in a cold climate, and 10% to 15% of total heat gain in a hot climate. This relationship between airflow and heat gains and losses is likely why IECC[2] includes air-barrier requirements but does not have any significant vapor-retarder requirements for building enclosures.

THERMAL CONTINUITY

IECC[2] and ASHRAE Standard 90.1[3] include thermal requirements that are focused on avoiding heat loss and designed to control energy consumption and costs. The code requirements and industry standards are primarily focused on the overall thermal performance of materials, individually or as an assembly. Thermal performance requirements vary depending on the climate zone in which a structure is located. IECC defines climate zones in Section C301 and provides a map outlining the locations for each climate zone.

IECC primarily uses *R*-values and U-factors to measure thermal performance.

- *R*-value indicates how well insulation resists the flow of heat through a given thickness of materials, with higher numbers indicating better insulating properties.
- U-factor measures heat transmission through a building part or a given thickness of materials, with lower numbers indicating better insulating properties. The U-factor is the inverse of the *R*-value.

Both IECC[2] and ASHRAE Standard 90.1[3] allow thermal evaluation to follow the prescriptive method or a component performance alternative. A prescriptive code requires that each component is built to a certain standard, such as "The roof *R*-value shall be at least 30." A performance code requires that the building, as a whole, performs to a certain standard, such as "The building shall use less energy than the same building built to prescriptive code."

Heat transfers through conduction. Thermal conductivity, the rate at which the heat is transferred, is different for different materials. Limiting opportunities for heat transfer through wall and roof elements is achieved by reducing or eliminating conductive connections (thermal shorts or thermal bridges) between the exterior and interior. To limit thermal bridging, continuous insulation is often specified.

ASHRAE 90.1[3] defines the concept of continuous insulation as insulation that is continuous across all structural members without thermal bridges other than fasteners and service openings. Continuous insulation can be installed on the interior or exterior, or it can be integral to any opaque surface of the building enclosure.

The insulating layers of a roof or wall, from the inside out, include the following:

- Substrate (roof deck or wall sheathing)
- Underlayments (roof) or weather-resistive barrier (walls)
- Flashing at penetrations and transitions
- Insulation
- Ventilation (air)
- Exterior finish (roof covering, or wall cladding)

Each insulating layer includes a thermal performance value, either an *R*-value or a U-factor; the IECC includes a table of these values for calculating thermal performance (Chapter 4 Table C402.1.3). The combined value of the insulating layers in an assembly is the calculated thermal performance of that assembly. One challenge is creating continuity in areas where the assembly changes, such as the transition from the roof to the exterior wall, or from the concrete slab on grade to the exterior wall.

IECC and ASHRAE 90.1 do not identify where in the assembly moisture may accumulate due to vapor drive, or how the continuity of both the air barrier and thermal layer is required to prevent moisture accumulation within building enclosure assemblies.

A bridge in the thermal layer may result in a transfer of cold from the outside through the insulated wall assembly to interior elements. When warm interior air (hot air!) comes in contact with the cold surface of the interior wall due to the thermal transfer, that can cause the vapor being held in the warm air to condense into liquid water, wetting materials in the building enclosure assembly. Therefore, to avoid moisture accumulation, it is necessary to establish continuous control layers to prevent thermal bridging and the movement of warm moist air.

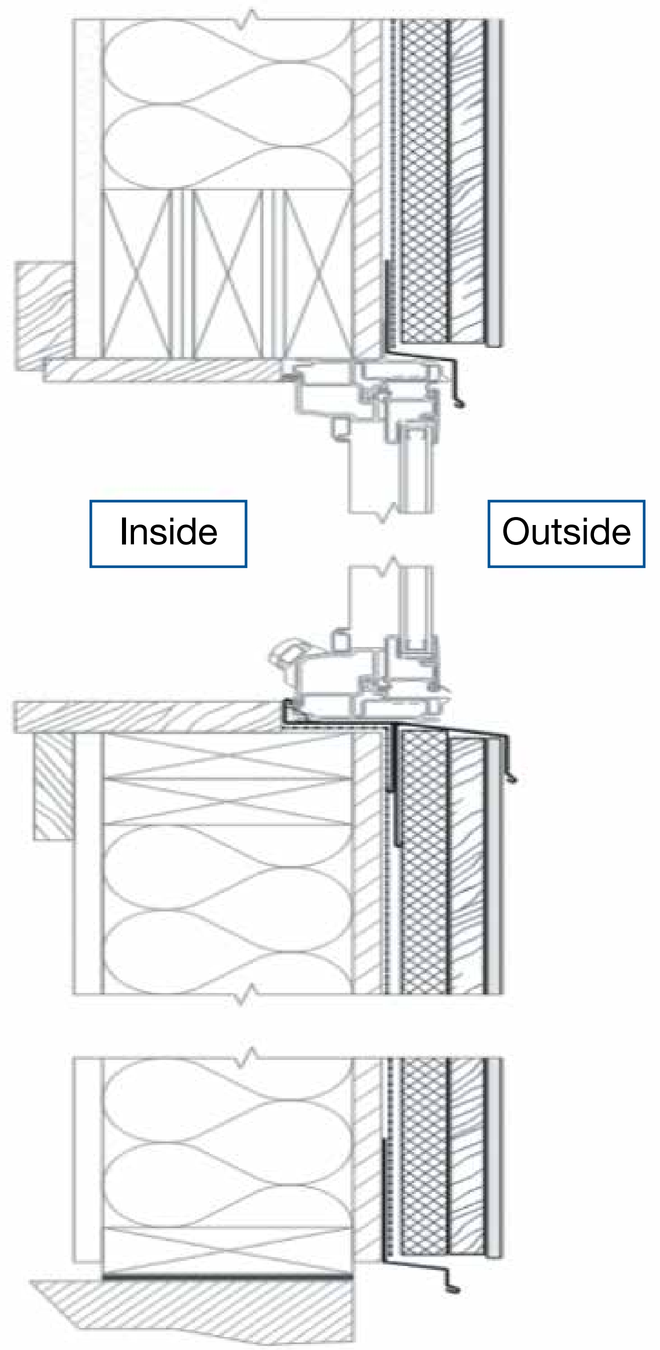

Figure 3. Residential window and wall details.

FOUNDATIONAL TOOLS

There are simple design tools to connect the control layers as they transition between enclosure systems. The "pen test"—tracing each of the control layers across all details in the building enclosure—is a helpful tool to design and communicate the intent of the critical components and their function or functions in the building enclosure assembly **(Fig. 2)**.

However, this effort is a tedious practice, requiring the design professionals to zoom into hundreds of details across the entire building enclosure to vet the continuity of each control layer. Given the volume of moisture that can be carried by air, the focus tends to be on the air-control layer.

Remember the *Highlights* magazine from your childhood, whether it came to your house or sat on the table at the doctor's office to "entertain" you while you waited? There were puzzles and games to solve, and the answers were provided in the last few pages in the

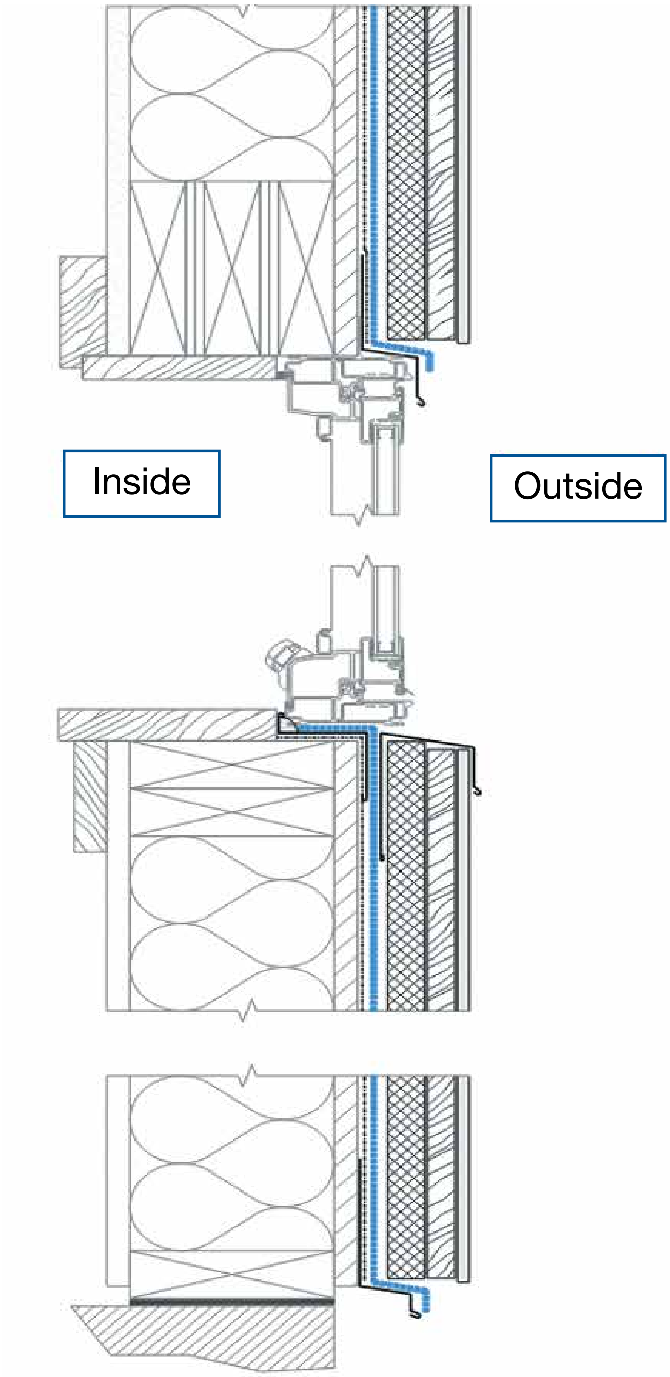

Figure 4. A blue pen is used to track the water path to be addressed by the water-control layer.

magazine. Let's take a trip down memory lane. It's your turn to be the consultant and trace the air-control layers on building enclosure details.

CASE STUDY

This case study involves a residential house in a suburb in Climate Zone 3. We will begin by reviewing window details (**Fig. 3**) for control-layer continuity.

The first step is to get your control-layer pen set out. An acceptable pen set is as follows:

- Water: blue pen
- Air: red pen
- Thermal: yellow pen
- Vapor: green pen

Next, use your blue pen to highlight the materials that are intended to act as the water-control layer in **Fig. 3**. In many cases, there will be the bulk-water layer (think of the exterior-wall cladding) and the primary water-control layer, which, if designed correctly, provides a clear drainage path for water that makes it through the cladding system.

If, at any point, you need to pick up your pen and move it to another point, that signals a discontinuity in the control layer. Identify this discontinuity with a circle, as it will require a conversation with the project team regarding the risk associated with the discontinuity and how to resolve it. (See **Fig. 4** for the answers to this exercise.)

In the scenario, the siding sheds the bulk water while the water barrier (which is usually the air barrier as well) installed over the sheathing and behind the insulation acts as the primary water-control layer. The water barrier extends over the flashing at the head of the window, avoiding any reverse laps that could trap water, and terminates at the drip edge, which directs any water that reaches the primary water-control layer out of the wall assembly.

In the most simplistic of terms, the window glass acts as the bulk water-control layer while the drainage track and weep holes act as the primary water-control layer for any water that bypasses the window gaskets. The sill pan below the window collects any water that bypasses the window assembly, connecting directly to the water barrier on the sheathing, and this water is (hopefully) directed out at the base of the framed wall.

The water-control layer for these window details is continuous, so barring any installation challenges or manufacturing defects, the risk for water intrusion has been managed.

Next, we will review these window details for "hot air." Starting with Fig. 3 and using your red pen, trace the elements that make up the air-control layer. Identify any discontinuities in the system and circle them in red. Please see the answer on page 17.

Designers can repeat this exercise for all control layers and all project details. This time-consuming effort can help mitigate the risks associated with discontinuities in the control layers.

CONSULTING AND COLLABORATION AMONG BUILDING ENCLOSURE CONSULTANTS, ARCHITECTS, AND ENGINEERS

One of the most successful design collaborations we have witnessed occurred during a design meeting at an architect's office regarding the development of an extremely large data center. The design meeting included two days of breakout sessions within the architect's office to take the design package from schematic design to bid documents. The breakout groups were:

- Mechanical, electrical, plumbing (MEP)
- Civil-structural-architectural
- Communications
- Interiors-design integration

In four different rooms, the teams were responsible for using the base data from the schematic design and early design development stages, along with the owner's project requirements, to develop the designs.

The building enclosure design was initially included in the civil-structural-architectural group, which primarily focused on the roofing elements to maintain a dry lid over the very expensive electrical and computing equipment housed within the data center. As the first-day collaborations between structural and architectural professionals commenced, input from the building enclosure consultant was primarily focused on the intersection between the roof and the parapet wall because a fair amount of movement was anticipated in six different directions at this joint. This joint alone required a unique approach to maintain thermal continuity and properly design the air-barrier and vapor-barrier control layers to function as intended despite the potential differential movement between the roof diaphragm and the walls.

When the civil-structural-architectural group and the MEP group came together at the end of the first day to discuss equipment requirements for environmental conditions within the data hall space, another control-layer issue arose. The climate requirements of equipment to be housed within some interior rooms dictated that those rooms must have specific temperature, humidity, and interior air-pressure conditions. Therefore, control layers were needed for those interior walls that would be separating environments within the larger space, in a manner similar to exterior wall separation. For example, interior climate in one location could reach 80°F (27°C) with relative humidity as high as 50%. The adjacent room was specified to have a climate of 68°F (20°C) with an average relative humidity of 35% (common human occupancy conditions). The change in temperature between the two spaces of 12°F (7°C) could result in surface conditions on the interior of the warmer space reaching dew point (the point at which moisture in the air becomes free water and condenses), resulting in accumulated moisture either on the surface of the wall or within the wall.

Based on the discussion with the MEP and civil-structural-architectural groups, the building enclosure consultant suggested mapping the interior climates and creating a vapor-retarder plan to ensure that interior walls, under exterior climate conditions, would include a sealed air and vapor retarder on the warm side of the wall to avoid moisture movement. Also, the designs developed for this project included a thermal break between framing and wall sheathing at interior walls to prevent thermal bridges.

The building enclosure consultant essentially "carried water" back and forth between the civil-structural-architectural and MEP teams to prevent all that hot air from becoming a hot mess! Ultimately, the collaborative efforts resulted in newfound respect and understanding among all teammates.

CONCLUSION

Thermodynamics and the movement of heat, air, and moisture are foundational concepts in one's understanding of the performance of the building enclosure. Tools such as the pen test help us think through the continuity of the control layers and bring visibility to discontinuities that need to be resolved to manage the risk of poor performance. To learn more, be on the lookout for future educational offerings through IIBEC.

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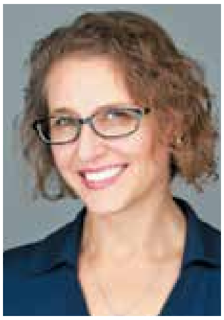

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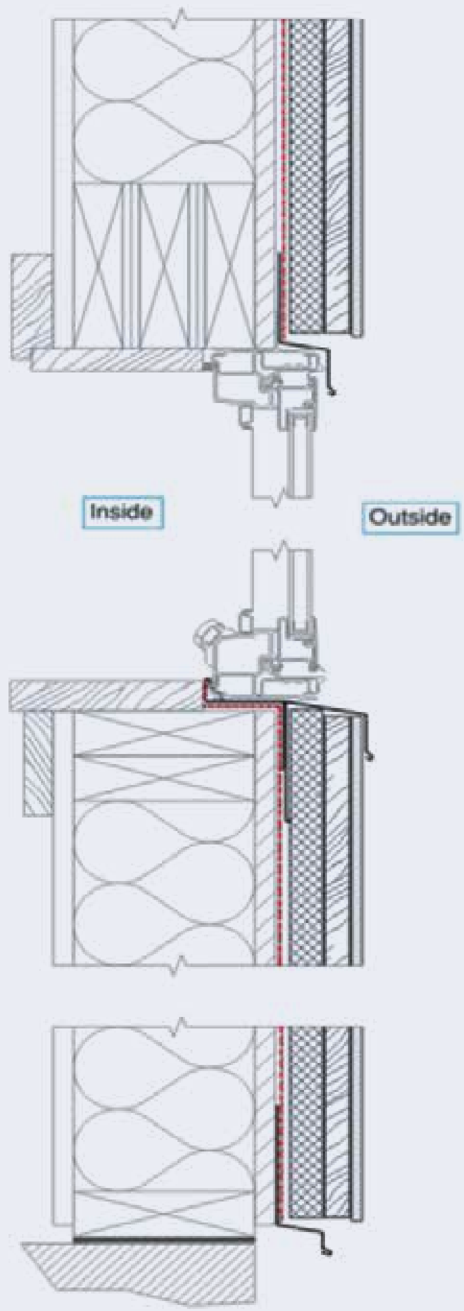

Figure 5. A red pen is used to identify any discontinuities in the elements that make up the air-control layer.

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