Feature

Failure Is Not an Option: Water Vapor and Healthcare Building Enclosures

By Allison McSherry, RA, BECxP, CxA+BE, LEED AP BD+C, CEM, NCARB, and Brian Mathus, RA, BECxP, CxA+BE

This paper was presented at the 2025 IIBEC Building Enclosure Symposium.

CONDENSATION FUNDAMENTALS

Condensation is the conversion of vapor to liquid. Think of a glass of cold iced tea on a hot summer day or your bathroom mirror after a shower. For the purposes of this paper, we will explore water vapor contained in air, which has a limited moisture-holding capacity that is based on temperature. As the air temperature increases, its capacity for water vapor also increases. When air is saturated with water vapor at its maximum capacity, the relative humidity (RH) is 100%. "Relative" humidity is relative, as its value is dependent upon temperature. If 100% RH air is heated, the relative humidity decreases, therefore increasing its capacity for additional grains of moisture. If it is cooled, the excess moisture in the air condenses.

When considering the moisture content of air (that is, the number of individual grains of moisture contained by a pound of dry air) as a constant and temperature as a variable, the dew point can be calculated. The dew point is the temperature at which air of a constant moisture content reaches 100% RH and begins to condense excess moisture. Dew point can be calculated using online tools, formulas, or a psychrometric chart.

Considering an example interior winter setpoint of 70°F (21.1°C) and 20% RH, that same air would reach 100% RH at 27°F (−2.8°C). This means that any substrate that maintains a temperature at or below 27°F (−2.8°C) and is in contact with interior air will form condensation. Preventing moisture from reaching these substrates is essential.

If continuous, impermeable air and vapor barriers are not present, moisture will migrate through the enclosure assemblies via mass air transit or absorption through permeable components. Note that there are varying degrees of material permeability, but for this discussion, we are referring to any material that allows the transfer of water vapor through its full thickness.

DRIVERS OF CONDENSATION FORMATION IN BUILDING ENCLOSURES

The risk of damage due to elevated humidity and condensation is present, to some degree, in all buildings. Some buildings are at greater risk than others, and a building's risk is largely dependent on the surrounding climate and the use of the building (that is, expected relative interior humidity).

In hot climates, condensation risk is related to hot, humid air from the exterior bypassing the air barrier (or moisture migration through permeable substrates) and condensing on cooler interior surfaces. In an extreme example, such as a controlled environment (refrigerated warehouse) building in Florida, the air and vapor barrier is typically placed at the far exterior side of the enclosure to allow all structure and insulation to be placed inboard, therefore preventing exterior air, which would almost always be warmer and more humid, from entering the enclosure. In Klein & Hoffman's experience, even a ¼ in. (6 mm) hole in the air barrier of a controlled environment building can result in a block of ice on the interior the size of a small car.

In cold climates, we encounter the same behavior, with the only difference being that the heat and humidity is elevated on the interior. The design response to this is to place the air and vapor barrier inboard of the thermal control layer. Another extreme example would be a natatorium in Alaska. In this example, the design challenge would be to provide an enclosure that accommodates a continuous air and vapor barrier that can consistently stay above the dew point.

For all climates and building types between the examples noted above, we rely on climate information from sources such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), building usage information provided by the building owner or mechanical engineer, and computer modeling to assess the risk of condensation in building enclosures.

Any level of condensation in building enclosures that results in damage to a substrate constitutes a failure. If the presence of moisture due to condensation remains on organic surfaces for too long, this failure may be compounded by organic growth. These failures stem from either faulty design or installation and are always due to improper placement of one of the four control layers (air, water, vapor, or thermal), or a discontinuity in one or more of these control layers. Note that a discontinuity of a control layer could represent either a physical gap or an insufficient property, such as permeability or *R*-value.

When designing, careful thought must be given to maintaining continuous control layers as necessary to resist moisture transport to substrates that cannot maintain temperatures above the dew point. Ample detailing must be included to clearly define each control layer, especially at enclosure system transitions.

When specifying systems, components, and materials, the same consideration must be carried through when determining attributes such as vapor permeability, adhesion, and durability.

When installing, it is of paramount importance that the installer understand the function of each part and piece contributing to the control layers and how they relate and transition to adjacent systems.

Figure 1. *Frost buildup on the interior face of precast concrete.*

CONSEQUENCES OF POOR CONDENSATION CONTROL IN HEALTHCARE FACILITIES

Healthcare facilities are required to operate with elevated humidification, typically offering a minimum humidification of around 30% RH in patient rooms for the health and comfort of the occupants. In other spaces, such as intensive care units, neonatal intensive care units, or surgery rooms, the interior humidification may exceed 50% RH. This elevated minimum humidification assists in the recovery of patients with respiratory illnesses and helps to reduce transmission of diseases.

However, this elevated minimum humidification results in design challenges for facilities located in cold climates. The elevated minimum humidification results in condensation that forms at a higher temperature, which means that enclosure components are more susceptible to damage at an increased number of days per year if the control layers are not designed and installed properly. The long-term exposure to elevated humidity and/or the formation of condensation within the enclosure system (inboard of the water control layer) can result in corrosion of structural components. Water damage to substrates such as wood and gypsum board is also likely as the condensate begins to drip. Additionally, if the substrate is below freezing, the condensation may turn to frost (**Fig. 1**), which can build up over time. Once the substrate temperature rises, the frost that built up inside the enclosure is susceptible to quickly melting, often resulting in symptoms that resemble heavy leakage from the exterior. Think of defrosting an old freezer.

The risk of organic growth, associated with elevated moisture within the enclosure is especially concerning in healthcare facilities (**Fig. 2**). Considering the havoc this organic growth can wreak on healthy human bodies when aerosolized, this effect is amplified on patients who already suffer from other ailments. Complications due to mold encountered during a hospital stay could mean the difference between life and death for many patients. According to the Centers for Disease Control and Prevention (CDC), "mold outbreaks can occur in healthcare facilities causing severe illness and death among patients. Two common types of healthcare-associated invasive mold infections include mucormycosis and aspergillosis. Depending on the organism and patient characteristics, death rates can be more than 50%."[1]

Figure 2. *Organic growth at the interior face of the exterior sheathing within a neonatal intensive care unit space.*

According to data from the US Fire Administration (a division of the Federal Emergency Management Agency), an average of approximately five people are killed in institutional building use fires each year, out of a total of approximately 3,000 people killed in building fires per year.[2] Note that institutional buildings also include prisons, assisted-living facilities, and group homes. The CDC has estimated that at least 7,000 US citizens die each year due to fungal/mold infections, with more than 75,000 hospitalizations.[3] Based upon this documented risk factor, the same amount of consideration should be given to moisture control in the enclosure as is given to fire prevention in buildings.

Figure 3. *Temperature and humidity datalogger on a windowsill.*

Figure 4. *Thermocouple datalogger leads at the surfaces of an insulated glass unit and mullions.*

Figure 5. *Testing of added heat sinks at a four-way glazing system intersection.*

DESIGN CONSIDERATIONS TO MITIGATE CONDENSATION FORMATION WITHIN THE ENCLOSURE

Effective condensation control begins with a clear understanding of the project's climate, interior use, and the required temperature and humidity setpoints. Good enclosure design avoids common pitfalls like thermal bridging and discontinuities in control layers, especially at system transitions.

A helpful design tool is the "pencil test"—tracing each control layer through a detail without lifting the pencil—to verify continuity. However, designers must also consider out-of-plane transitions (for example, splices or terminations) and address material compatibility and long-term durability to ensure performance across all conditions.

INVESTIGATION STRATEGIES FOR EXISTING BUILDINGS AND EXAMPLES OF POOR CONDENSATION CONTROL

Performing an initial visual review while utilizing a few rules of thumb is generally a good place to start an investigation. This will set the basis for the investigation and inform what additional investigation techniques may be prudent for each scenario.

Review the construction documents and the physical area for other visible factors, such as moisture or frost buildup, potential organic growth, a visible lack of air/vapor barriers, or even thick window coverings that are tight to the window opening, which may prevent interior air from warming the underlying window surfaces.

Thermography may be utilized to review the area for potential thermal bridging. Results from this effort are typically more conclusive on days that are nearest to the exterior design temperature. However, as thermal transfer is generally a linear relationship, thermal imaging results can often be interpolated (for illustration purposes) to determine the approximate interior surface temperature at the exterior design temperature. If the anatomy of the exterior enclosure is known, thermal modeling software such as THERM can also be utilized as an illustration tool to indicate areas of potential thermal bridging.[4]

Temperature and humidity dataloggers are useful tools for measuring ambient air within different locations, such as inside the wall, on the windowsill (**Fig. 3**), within an affected room, within a nonaffected room, within the interstitial space, at the exterior, etc. These devices, paired with surface temperature thermocouples, placed at areas of suspected or known condensation development, will provide a detailed account of the hygrothermal profile of each area within an investigation (**Fig. 4**).

Confirm heating, ventilating, and air-conditioning (HVAC) system operation is within the intended parameters established when the building was constructed, as it relates to the enclosure design. We often observe that condensation within the enclosure is a result of the HVAC system operating outside the original parameters set for the building or the building automation system's humidity sensors having drifted out of calibration.

SUCCESSFUL MITIGATION STRATEGIES FOR EXISTING BUILDINGS

Mitigation strategies range widely but generally consist of either eliminating thermal bridges, adding (or subtracting) insulation, ensuring control layer continuity at transitions, adding heating devices, or adjusting the interior temperature and humidification setpoints.

The elimination of thermal bridges often requires the replacement of enclosure components, such as glazing system components or anchorage. If adding or subtracting insulation, care should be taken to confirm associated thermal and hygrothermal modeling. Note that the ideal location of air and vapor control layers may shift based on the location of the thermal control layer, and this displacement should be considered and accommodated.

When weighing options to add heat to the enclosure, note that there are both active and passive strategies. A passive approach could include adding a heat sink to the interior surfaces (**Fig. 5**). Note that this passive approach does reduce the thermal efficiency of the enclosure and should be closely reviewed for compliance with the energy code. The active approach to adding heat to the enclosure includes installing heat trace elements where needed. This method is often effective but requires design assistance from an electrical engineer, needs replacement over time, and uses energy.

ENERGY CODE CHANGES THAT AFFECT YOUR PROJECT

As the energy codes head towards net zero, condensation prevention becomes more difficult. The three main items in the latest energy codes that directly impact the condensation potential of your project are continuous air barrier, thermal bridging, and envelope backstop. Note that the code iteration in effect for your project is dependent on your state or municipality, and the current energy codes, as they become adopted, may have a very significant impact on the enclosure design.

Continuous air barriers have been a requirement of the energy codes for multiple cycles, but the latest energy codes (the 2024 International Energy Conservation Code [IECC] and ASHRAE 90.1–2022) have been updated to provide even more specific requirements. The updates aim to assure that a continuous air barrier is not only designed and detailed properly but also installed as designed. In addition to more robust documentation requirements, the 2024 IECC clarified language that requires most new projects to perform whole-building air barrier testing. ASHRAE 90.1–2022 still allows the choice between whole-building air barrier testing and a design and installation verification program.[5,6] There is a significant difference between the two, which should be taken into account when the project team is deciding on the appropriate energy code compliance path at the beginning of a project. For example, whole-building air barrier testing may be appropriate for a small, stand-alone retail building. In this case, testing could occur before the cladding is installed, allowing the air barrier to be accessed if any deficiencies are discovered. In contrast, a large hospital would likely benefit more from a design and installation verification program, as testing would be logistically difficult and large-scale repairs would be infeasible.

Both the 2024 IECC and ASHRAE 90.1–2022, for the first time, include prescriptive thermal bridging requirements or a calculation method with limits addressing balconies, floor intersections, cladding support, parapets, vertical fenestration, and structural elements.[5,6]

The aim of the energy codes is to reduce the number of thermal bridges within a building and ensure that significant thermal bridges are adequately accounted for when using energy modeling for performance-based compliance.

The days of your typical multifamily high-rise with window-wall glazing and exposed concrete slab edges or balconies are over.

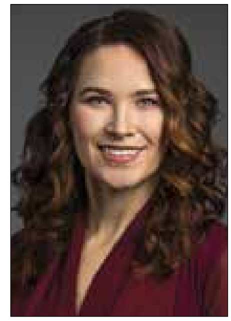
It must be noted that the energy code's treatment of thermal bridging is driven by the energy transfer, heat loss or gain, through the thermal bridges and does not directly address condensation risk. For example, the prescriptive vertical fenestration section limits the alignment of the wall insulation with the plane of the exterior face of glass. This follows the general design rule that the fenestration thermal break should be in line with the wall insulation. However, it does not dictate the actual detailing, which may require THERM simulation to evaluate condensation potential.

ASHRAE 90.1–2022 introduces an envelope backstop that limits how much envelope performance can be traded off against HVAC and lighting in performance-based energy modeling.[5,6] Previously, envelope components could underperform as long as the building's overall energy model exceeded baseline performance, often relying on high-efficiency systems to compensate. However, because the envelope lasts the life of the building—unlike replaceable HVAC and lighting—this approach creates long-term inefficiencies. To address this, the 2022 update limits envelope trade-offs to 15% over the base envelope performance factor for multifamily, hotel/motel, and dormitory buildings and 7% for all other types. This change limits the use of low-performance systems like curtainwalls, pushing designers toward designs utilizing a mix of different cladding systems. More transitions between material systems increase the risk of condensation and bulk water intrusion if not properly detailed. As this is specific to ASHRAE 90.1–2022, it is important to consider during early energy code path decisions.

REFERENCES

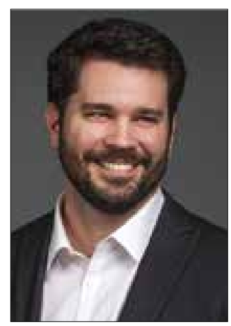
1. U.S. Centers for Disease Control and Prevention, "Guidance for Healthcare-Associated Mold Outbreaks," *CDC,* Oct. 28, 2024. [Online]. Available: https://www.cdc.gov/fungal/php/guidanceinvestigating-outbreaks/moldhealthcare.html.
2. U.S. Fire Administration, "Data Sets," *Federal Emergency Management Agency,* Feb. 14, 2025. [Online]. Available: https://www.usfa.fema.gov/statistics/data-sets.
3. Indoor Science, "At Least 7,000 People in the United States Died from Mold and Fungal Infections in 2021," *Indoor Science,* Jan. 24, 2023. [Online]. Available: https://indoorscience.com/blog/at-least-7000-people-in-the-united-states-died-frommold-and-fungal-infections-in-2021.
4. D. Arasteh, C. Huizenga, R. Mitchell, C. Kohler, D. Curcija, and J. Carmody, *THERM Version 7.8,* Berkeley, CA, and Oak Ridge, TN: Lawrence Berkeley National Laboratory; distributed by the Office of Scientific and Technical Information, U.S. Dept. of Energy, 2003.
5. American Society of Heating, Refrigerating and Air-Conditioning Engineers and Illuminating Engineering Society, *ANSI/ASHRAE/IES Standard 90.1–2022, Energy Standard for Buildings Except Low-Rise Residential Buildings (I-P Edition).* Atlanta, GA: ASHRAE, 2022. [Online]. Available: https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_90.1_2022_IP. Accessed: May 5, 2025.
6. International Code Council, *2024 International Energy Conservation Code.* Washington, DC: International Code Council, 2024. [Online]. Available: https://codes.iccsafe.org/content/IECC2024V1.0. Accessed: May 5, 2025.

ABOUT THE AUTHORS



ALLISON MCSHERRY

Allison McSherry *specializes in building enclosure commissioning, consulting, and investigation along with energy modeling of building enclosures. She has shared her energy modeling and energy code expertise with architects, engineers, code officials, and contractors through a variety of certified continuing education courses and webinars, including developing and delivering three courses with the Illinois Building Industry Training and Education program, serving more than 600 industry professionals. In addition, she has performed LEED energy modeling, LEED facilitation, retrocommissioning investigations, THERM, and EPAct 179D energy modeling and analysis.*



BRIAN MATHUS

Brian Mathus *is a licensed architect at Klein & Hoffman in Chicago, Illinois, and an alumnus of the University of Illinois—Urbana Champaign Master of Architecture program. He provides building enclosure commissioning, consulting, and investigative services for healthcare, industrial, and residential buildings throughout Chicago and the Midwest. Mathus began his career in the field of enclosure restoration, and he applies this experience to the construction of new buildings.*

Please address reader comments to chamaker@iibec.org, including "Letter to Editor" in the subject line, or IIBEC, *IIBEC Interface* Journal, 434 Fayetteville St., Suite 2400, Raleigh, NC 27601