MOISTURE CONTROL REQUIREMENTS IN CODES

By Wagdy Anis, AIA, LEED

INTRODUCTION

National model codes attempt to prescribe moisture control in various ways and fail miserably, sometimes unwittingly prescribing failure! One solution does not fit all! Potential national solutions that are less prescriptive and more performance-based are reviewed in this article.

Moisture control in a building depends on three variables: 1) local weather and subsoil conditions, 2) interior environment of the building, and 3) the proposed building enclosure assembly components. Moisture has different phases – solid, liquid, and gas. Snow and ice need to be managed, and liquid moisture must be controlled and deflected back out of building assemblies without damage to the materials.

The mechanisms of capillary moisture and water vapor transfer, however, are quite complex. Moisture moves in building materials by capillary pressure, by convection of air caused by surface temperature differences, by air transfer under pressure differentials, and by diffusion through materials under gas pressure. The primary method of moisture control in enclosure materials is by determining that the increase in moisture content of those materials (inboard of the drainage plane) will not rise to levels where mold, decay, or corrosion will result.

Moisture in Buildings

The source of moisture in buildings can be summarized as follows, from the importance of the quantity of moisture to the magnitude of problems it can cause to the building and its enclosure:

1. Liquid water from precipitation and from ground sources, causing leaks, moist conditions, and "rising damp."
2. Water vapor carried by air pressure differences across or through the envelope, causing condensation.
3. Water vapor diffusion through building materials.

The solid phase of water, snow, and ice: So long as it stays solid, it does not damage the envelope. Freezing water due to freeze-thaw cycles of wet, porous enclosure materials, however, can damage those materials.

I. LIQUID WATER

By far the greatest problem is liquid water intrusion and its management. Because of the loss of use of facility space and the liability such leaks create to designers and builders, most codes require the use of flashings, drainage planes, waterproofing, etc., and most designers understand how to manage liquid water. Wall assemblies must be designed with flashings and drainage planes and should not depend on a single sealant layer as the primary means of water resistance; they should have a secondary drainage plane inboard of the rain screen and flashings to direct water out of the assembly via weep holes. Because they eventually leak, all windows should have a pan flashing. The building enclosure below grade must be designed to manage liquid water intrusion using waterproofing, dampproofing, and dewatering techniques. A capillary break will reduce the likelihood of rising damp. Roof assemblies are either a membrane in low-slope applications or shingled in pitched applications. Therefore, roofs must be pitched to drains, and wall panel systems should have two-stage sealants in the joints.

Control of soil moisture without a hydrostatic head

To control soil moisture, provide a capillary break to rising moisture using a 6"-

(150 mm) thick, highly permeable layer of material beneath the slab and adjacent to basement walls, such as crushed stone. Use a perforated pipe network that connects the sub-slab and footing drain pipes. Collect and dispose of below-grade water by connecting the pipe network to the storm sewer, a retention pond, or other means of water detention. Inhabited spaces below outdoor, open-paved, or planted areas must have a waterproof membrane (a protected membrane roof) – usually pitched to drain – and a water collection system. Walls below grade must be dampproofed at the least.

Control of moisture in basements with a hydrostatic head

Basement walls and floor slab, and possibly the roof, need to resist the structural load and pressure of the head of water. As the structure is designed like a concrete boat, with walls connected to the slabs by moment connections, designs of the waterproofing system should be appropriate to hydrostatic head conditions.

That being said, the focus of this article will be on the second and third sources of water in buildings, probably the most misunderstood subjects by national code writers. These sources are moisture accumulation due to convection and water vapor due to diffusion.

2. CONDENSATION OF MOISTURE TRANSPORTED BY AIR MOVEMENT

Weather in North America is extremely varied and includes enormously different combinations of rain-loading (rain and wind) temperature, water vapor, solar radiation, and cloud cover.

Below-grade conditions of soil temperature and moisture also change dramatically from location to location. An understanding of exterior air and below-grade conditions is vital to determining whether the requirements in the codes of ventilating attics and crawlspaces are actually effective. A clear understanding of the exterior boundary conditions in a particular site above and below grade, and the specific configuration/design of the building enclosure are essential to implementing effective moisture management solutions. The prescriptive approach that codes take to these matters can be extremely problematic if the specifics are not studied.

Take, for example, a building in Florida. A code requirement to vent the attic (to dry out moisture) would introduce hot, humid air that can encounter air-conditioned surfaces (such as ducts and vent pipes) that are below the dewpoint of the outside air. The result? Condensation, damage, rot, and mold. Air conditioning has changed the picture.

Air that moves water vapor from the outside to the interior (including interstitial spaces) in hot, humid climates, and from the inside to the outside in predominantly colder climates, can cause major damage due to condensation of large amounts of moisture (over 200 times the amount that can go through the assembly by diffusion in the same amount of time.) (Quirouette, 1986.) There is confusion throughout the United States about the importance of this mechanism of water vapor transfer (i.e., by air pressure differentials). The confusion is with the function of vapor retarders (vapor barriers) in controlling diffusion, versus air-transferred moisture due to air migration.

In addition to condensation, uncontrolled air infiltration can affect energy consumption, disrupt HVAC design pressure relationships, move pollutants, microbials, and odors within and into buildings from the exterior, and cause discomfort to the occupants. How do codes and standards deal with this issue? This subject is dealt with usually in the energy code, not the building code, presumably because the former code recognizes the potential energy impact. Typically, this is called "air sealing" or air infiltration control. Usually, the code provides a prescriptive list of which parts of a building to tape and seal. The problem arises when the desired result is not described conceptually or philosophically, – namely, to achieve a building envelope that is airtight from roof to foundation.

Why don't the codes state the goal outright? An example would be: "The intent is to achieve an airtight building envelope that controls infiltration and exfiltration." One of the philosophical deficiencies of air infiltration management in codes is that codes have long focused on the maximum allowable air leakage of glazed products such as windows, skylights, and curtainwalls. Doors, including garage and revolving doors, have maximum air leakage rates that are quantified in the codes. In the average commercial building, windows and doors account for perhaps 25-35% of exterior walls. Strangely, few code writers thought to quantify the maximum allowable air infiltration of the opaque envelope, believing that it was tight. Most building professionals and code writers alike believe that infiltration occurs through windows and doors.

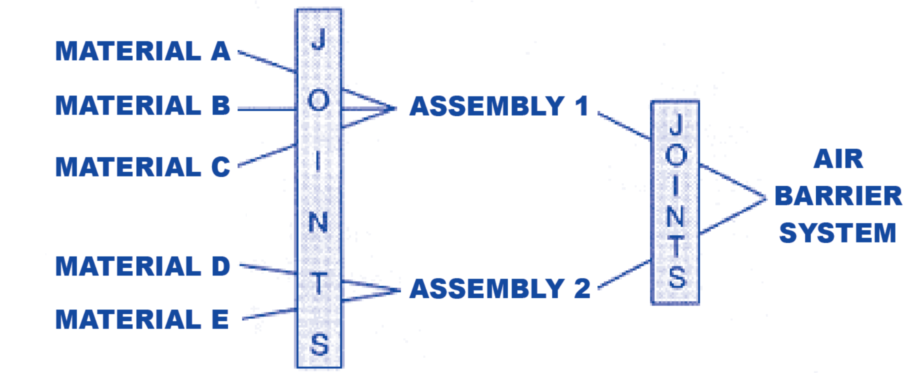

Figure 1: Lux and Brown, 1986.

Studies conducted at the National Institute of Science and Technology (NIST) indicate that we are designing and constructing buildings with very large holes (Persily, 1998; Emmerich and Persily, 1998, 2003). Those holes are primarily in the interconnection of envelope materials and the lack of continuity in the plane of air-tightness, from one material to the next and from one system to the next. (See *Figure 1*.)

The lack of quantification of acceptable maximum air permeance rates for building materials that form the plane of air-tightness in an assembly has caused major blunders in the design of buildings. A prime example is dramatized in the study conducted by Florida Solar Energy Center, where a suspended acoustical tile was the only separation (besides the glass-fiber insulation) between the conditioned space and the ventilated attic. (Withers and Cummings, 1998). The ceiling was performing atrociously as an air barrier; in the offices, conditioned air was being driven through the ceiling into the attic, and in the hallway, hot humid air was being sucked into the conditioned space from the attic at the air handler's return grille.

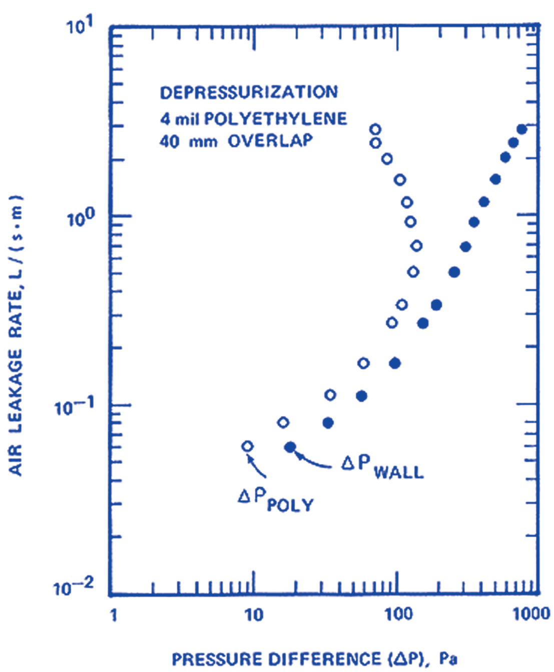

Figure 2

Once a material in the envelope has been targeted for air-tightening, it must be understood that this layer will usually carry the full design wind load, both positive and negative. Stack effect pressure and HVAC fan pressure may add to the wind pressure. This is where the codes and many practicing professionals fail in understanding that vapor retarder films that are not rigidly sandwiched between board materials and only supported on one side by fiberglass batts will fail under wind loading. The plastic film will rupture. (See *Figure 2*.) (Lux and Brown, 1986.) Structural support is essential.

Materials that are suitable to be part of an air barrier system can be either vapor permeable or vapor retardant. In order to control air pressures, air-tightening can be done either on the high-vapor pressure side of the enclosure or on the low-vapor pressure side of the wall. The preference is to keep the air barrier on the stable temperature side of the wall to avoid too much movement and possible failure of the joints.

Following is the code language as it stands today, proposed to ASHRAE SSPC 90.1 as a continuous maintenance proposal under negotiation for the requirements of an air barrier system in the building enclosure:

5.4.3.1 **Building Envelope Sealing.** The building envelope shall be designed and constructed with a continuous air barrier to control air leakage into, or out of, the conditioned space. All air barrier components of each envelope assembly shall be clearly identified on construction documents and the joints, interconnections, and penetrations of the air barrier components shall be detailed.

5.4.3.1.1 **Compliance Options.** Compliance of the continuous air barrier for the opaque envelope can be demonstrated by meeting the air permeance requirements of individual materials, or by meeting air leakage rates for assemblies of components, or by whole building testing of the completed building.

(a) Individual materials are compliant if they have an air permeance not to exceed 0.004 cfm/ft^2 under a pressure differential of 0.3 in. water (1.57psf or 0.02 l/s.m^2 @ 75 Pa) when tested in accordance with ASTM E-2178.

(b) Assemblies of materials and components are compliant if they have an average air leakage not to exceed 0.04 cfm/ft^2 under a pressure differential of 0.3" w.g. (1.57psf or 0.2 l/s.m^2 @ 75 Pa) when tested in accordance with ASTM E-1677.

(c) A completed building is compliant if the air leakage rate of the building envelope does not exceed 0.40 cfm/sf at a pressure differential of 0.3" w.g. (1.57 psf or 2.0 l/s.m^2 @ 75 Pa) in accordance with ASTM E-779 or an equivalent approved method. The exterior envelope area is comprised of the lowest floor area, the roof or highest ceiling area, and the area of all exterior envelope walls, including below-grade walls.

Exception to 5.4.3.1.1: Buildings in Zones 1, 2, and 3 constructed with mass walls are exempt.

5.4.3.1.2 **Characteristics.** The continuous air barrier shall have the following characteristics:

(a) It shall be continuous throughout the envelope (at the lowest floor, exterior walls, and ceiling or roof), with sealed connections between all transitions in planes and changes in materials, at all joints and seams, and at all penetrations.

(b) It shall be joined and sealed in a flexible manner to the air barrier component of adjacent assemblies, allowing for the relative movement of these assemblies and components.

(c) It shall be capable of withstanding positive and negative combined design wind, fan, and stack pressures on the air barrier without damage or displacement, and shall transfer the load to the structure. It shall not displace adjacent materials under full load.

(d) The air barrier materials shall be maintainable in accordance with the manufacturer's instructions, or, shall meet durability requirements established by the design professional.

(e) Where lighting fixtures with ventilation holes are to be installed in such a way as to penetrate the continuous air barrier, provisions shall be made to maintain the integrity of the continuous air barrier.

Control of Moisture Accumulation due to Convection

One of the most common problems throughout most of the United States is the "musty basement syndrome." Caused by surfaces with temperatures lower than the dewpoint of the air, it is generally caused by the fact that surfaces below -rade are at temperatures closer to the average annual temperature for a locale. This temperature is usually lower than the summer dewpoint of the air. Another contributor is concrete, which is a good conductor of heat and therefore tends to have a surface temperature close to the soil temperature. Add to that interior fiberglass insulation, and one has a recipe for mold – air adjacent to the concrete cools down to a high relative humidity, and the moisture is absorbed into the concrete, increasing the moisture content and providing an environment supporting mold growth. The cooled air is heavier and drops, entraining more air with moisture at the top of the wall.

The solution is simple: decouple the concrete from the earth temperature by a layer of rigid insulation on the exterior of walls and slabs. This brings the concrete temperature closer to the temperature of the air and less likely to present itself as a

DEFINITIONS:

CONTINUOUS AIR BARRIER:
The combination of interconnected materials, flexible sealed joints, and components of the building envelope that provide the air-tightness of the building envelope.

AIR LEAKAGE OF THE BUILDING ENVELOPE:
Q/S, the average volume of air in cubic feet per minute (liters per second) that passes through a unit area of the building envelope in square feet (square meters), expressed in cfm/sf (l/s.m^2), where Q is the volume of air in cubic feet per minute (liters per second) flowing through the whole building envelope when subjected to an indoor/outdoor pressure in accordance with ASTM E-779, and S, measured in square feet (square meters), is the total area of the envelope air pressure boundary including the lowest floor, any below-grade walls, above-grade walls, and roof or ceiling (including windows and skylights) separating the interior conditioned space from the unconditioned environment.

Annual Mean Daily Temperature

condensing surface. Another compromise strategy is to insulate on the inside using a layer of rigid insulation with sealed edges to avoid convective currents entrained behind it. An additional layer of batts is optional but unnecessary. Code language can be drafted to eliminate this common problem.

3. CONTROL OF WATER VAPOR CONDENSATION DUE TO DIFFUSION

Third on the list and the least serious of all sources of moisture is the diffusion of water vapor through building materials. It does, however, deserve a clearer understanding of the mechanisms of control. Water vapor moves due to a difference in water vapor pressure from the high-vapor pressure to the low-vapor pressure side of an assembly. It is the writer's belief that it is impossible to safely prescribe a specific vapor retarder that will work for all buildings and assemblies because the high-vapor pressure side changes from inside to outside in the same building during the same day, and changes also from building type to building type. It is the writer's belief that diffusion control must be left to the designer to determine in a responsible manner. The code takes too much responsibility away from the design profession when it prescribes vapor retarders and ineffective assemblies that do not work for some buildings and assemblies under certain climatic conditions. Code enforcement officials who blindly enforce the requirements in situations where the designer knows better create enormous problems and are counterproductive, to say the least.

Following is the proposed performance language:

The design of building enclosures (envelopes) shall not create conditions of wetting due to condensation caused by diffusion of water vapor:

1. To the exterior in winter conditions,
2. Due to contact of humid air with a surface temperature below the dewpoint, or
3. Due to vapor drive to the interior due to solar heating of rain-saturated cladding materials.

Envelope materials shall be selected for maximum drying potential outward as well as inward, and, therefore, design shall avoid the use of vapor retarders (vapor barriers) whenever possible, using Methods 2 or 3 below. Vapor retarders to control diffusion shall be selected with the highest permeance value that will satisfy the design requirements.

1. Underslab and below-grade vapor retarders shall be selected to withstand punctures and damage during construction, and chemical and biological attack during their service life. All joints, penetrations, and perimeter terminations shall be sealed.
2. Design for control of moisture due to diffusion in walls, roofs, and floors shall be in accordance with either:
   - **Method 1:** Follow procedures outlined in ASTM C-755, "Standard Practice for Selection of Vapor Retarders for Thermal Insulation." Assume steady-state heat transfer. Assume indoor air design conditions determined by a licensed professional and exterior air temperature indicated as "Average Temperature for the Coldest Month" in *Table 1*.
   - **Method 2:** Design assemblies without vapor retarders by maintaining the temperature of potential condensing surfaces (typically the temperature of the exterior sheathing/cavity insulation interface) above the dewpoint of the indoor air. Under this design approach, assume an indoor air temperature of 70°F and 35% relative humidity (unless determined otherwise by a licensed professional). Assume indoor air design conditions de-

termined by a licensed professional and exterior air temperature indicated as "Average Temperature for the Coldest Month" in *Table 1*. Assume steady-state heat transfer and follow the "Dewpoint Method" described in Chapter 23 of the 2001 edition of the *ASHRAE Fundamentals Handbook*, "Steady State Design Tools."

- **Method 3:** Design envelope systems that maintain the moisture content of all building materials in the assembly below the equilibrium moisture content that the materials would achieve when exposed to a relative humidity of 80%. For calculation purposes, use Chapter 23 in the 2001 edition of the *ASHRAE Fundamentals Handbook*, "Mathematical Models." Assume indoor air design conditions determined by a licensed professional.

If Method 1 above is used, materials selected for the envelope outboard (toward the exterior) of a vapor retarder shall be at least five times more permeable than the vapor retarder.

Exceptions:

1. Low-slope roof membranes.
2. Sealed double skin metal panels.
3. Materials outboard of a ventilated rainscreen assembly.[1]

CONCLUSION

The New Buildings Institute has adopted much of the language and concepts described above in its new E-Benchmark, the *Advanced Building Guidelines*. Codes in the United States today fall far short of having appropriate requirements for controlling infiltration and moisture due to condensation in the building enclosure. Codes require ventilation of cavities in climates that are hot humid, and it becomes counerproductive to ventilate those cavities. Codes are charged with protecting the health, safety, and welfare of the public; yet in this critical area of control that can cause mold, aggravate asthma, cause deterioration by corrosion and decay, and pollution migration within the building, they fail to represent a sufficient level of understanding of the mechanisms or the solutions. Change is needed, and a concerted effort is required to educate code writers, design professionals, the construction community, and enforcement officials nationwide.

Table 1. Average Temperature for the Coldest Month (Develop for all climate zones using Mean DBT for January.)

Climate Zone	Mean Dry Bulb Temperature
12a	29˚F
13a	28˚F
14a	21˚F

DOE Ashrae 90.1 -1999

[1] Mean Dry Bulb Temperature for January. Available from the National Climatic Data Center.

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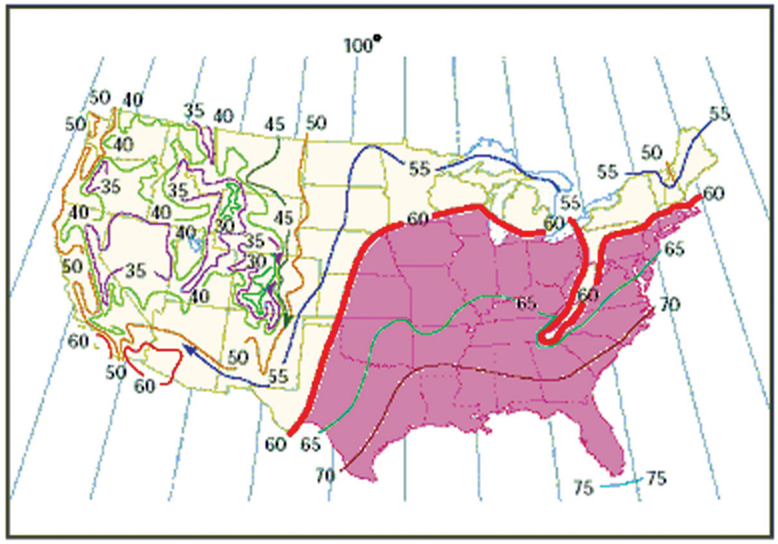

Figure 4: Mean dewpoint temperature isolines for August (1946 to 1965). Source: Climatic Atlas of the United States.

REFERENCES

Emmerich, S.J., and A.K. Persily, "Energy Impacts of Infiltration and Ventilation in US Office Buildings Using Multi-zone Airflow Simulation," paper delivered at the ASHRAE IAQ and Energy Conference, 1998.

Emmerich, S.J, NIST, 2005

Lux, M.E., and W.C. Brown, "Air Leakage Control," NRC, 1986.

Persily, A., "Blowing Holes in the Myth of Air Tightness of Institutional and Commercial Buildings," *Whole Buildings VII*.

Quirouette, R., "The Difference Between an Air Barrier and a Vapor Barrier," NRC, 1986.

Withers, C.R. Jr., and J.B. Cummings, "Ventilation, Humidity and Energy Impacts of Uncontrolled Airflow in a Light Commercial Building," ASHRAE Transactions, 1998.

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Wagdy Anis, AIA, LEED, has an architectural career spanning almost four decades. He has designed and led hundreds of projects, both nationally and internationally. His professional focus is the integrity and performance of the building envelope from a research, design, and troubleshooting perspective, as well as sustainable design and indoor air quality. As a principal of Shepley, Bulfinch, Richardson, and Abbott (SBRA) in Boston, he is head of technical resources. Mr. Anis serves as a director of the Boston Society of Architects and chairman of BETEC. He serves as chairman of the Energy Advisory Committee for the Massachusetts State Board of Building Regulations and Standards. He is a board member of the Boston Society of Architects' Building Enclosure Council and co-chair of the Indoor Air Quality Committee. He is a board member of the Air Barrier Association of America and a member of its technical committee. He is a member of ASHRAE SSPC 90.1 and TC 4.4 committees. Anis is the author of *Indoor Air Quality: A Design Guide*, published by the Boston Society of Architects. Most recently, he was primarily responsible for the historic agreement between the AIA and NIBS to establish Building Enclosure Councils in cities of the U.S.