CONDENSATION WITHIN THE BUILDING ENVELOPE

Water vapor [in indoor air] condenses in a film on surfaces that are at temperatures below the dew-point temperature of the inside air. If the surface temperature is below freezing, frost forms. Sometimes, condensation occurs first, and ice from the condensed water forms when temperatures drop below freezing. Condensation can cause extensive structural, aesthetic, and health problems. Specific examples include rotting of wood, saturation of insulation, and mold growth.

Condensation within a building envelope is a complex mechanism. The purpose of this "white paper" is to provide a technical, but layman's description of the phenomenon.

I. DEFINITIONS:

A. Dry Bulb Temperature:

The "dry bulb temperature" of air is a measure of the dry heat content of the air (also called "sensible" heat). This is what one normally thinks of as "air temperature" and is easily sensed by a human being.

B. Enthalpy:

Air at the same dry bulb temperature but different moisture content has a different total energy content. The "total energy content" is called enthalpy. The more water vapor the air has, the higher its enthalpy, even though its dry bulb temperature is the same.

Air that is fully saturated with water vapor (100% relative humidity) contains the maximum amount of energy possible for air at that dry bulb temperature.

C. Relative Humidity:

Relative humidity is a measure of the relative moisture content of air. Air with the same amount of moisture content has different relative humidities at different dry bulb temperatures. Given the same moisture content, air's relative humidity increases as its dry bulb temperature decreases.

D. Specific Humidity:

The total moisture content of air (regardless of its temperature) is measured by "specific humidity" (also called "**absolute humidity**"). Specific humidity may be measured in pounds of water vapor per pound of dry air.

E. Dewpoint Temperature:

Depending on its temperature, air at a constant specific humidity may have different relative humidities. But that air's "dewpoint temperature" is constant. The dew point temperature is therefore sometimes used to measure specific humidity. The dew point temperature is that dry bulb temperature at which air with a given specific humidity will become fully saturated.

In other words, air at its dewpoint temperature is also at 100% relative humidity. Any surface in the pool enclosure building (or Natatorium), which is at a temperature less than or equal to the air's dewpoint temperature will become wet due to condensation of the water vapor in the air.

The dewpoint temperature defines absolute humidity as well as vapor pressure of the air.

F. Vapor Pressure:

Vapor pressure is the partial pressure of water vapor in the air. The higher the moisture content, the higher the vapor pressure. Like any pressure differential, vapor pressure differentials cause water vapor to flow from a location with high moisture (high vapor pressure) to low moisture (low vapor pressure).

It is the vapor pressure differentials between the warm, moist Natatorium and the relatively cool, dry outside air that drives damaging moisture into the thermal envelope.

G. Saturation Vapor Pressure:

A vapor pressure at (or above) the saturation vapor pressure will cause excess moisture to condense. A vapor pressure below the saturation vapor pressure will allow a material to "store" or "absorb" moisture without condensing. If the actual vapor pressure is always below the saturation vapor pressure at every point within an assembly, no condensation will occur. Water vapor will flow through the assembly without damaging it.

H. Equilibrium Surface Relative Humidity (ESRH):

The relative humidity of a surface in equilibrium with the surrounding air. Moisture is neither being lost nor gained by the surface.

II. FACTORS AFFECTING THE FORMATION OF CONDENSATION WITHIN THE THERMAL ENVELOPE

Condensation within or "on" a wall or roof assembly is a consequence of surface temperature and the amount of moisture present within the assembly at the point of interest.

Simply stated:

- If directly exposed to indoor or outdoor air, condensation will occur when the surface temperature is at or below the air's dewpoint temperature. In the winter, outside air is very dry, but can chill surfaces. Indoor air is usually much more humid and can carry significant amounts of moisture into the thermal envelope.

  Therefore, the movement of air into and out of the thermal envelope is to be avoided. Since such movement is almost impossible to completely control, exterior walls and roofs should be designed and constructed to allow drying of the expected seasonal movement of moisture into the assembly.

- If exposed to vapor diffusion (only), condensation will occur if the material's local vapor pressure is at or above its saturation vapor pressure. Saturation vapor pressure is a direct function of temperature. Local vapor pressure is a direct function of vapor pressure differential across the assembly and the resistance to vapor diffusion (e.g., vapor permeability) of the materials used in the assembly.

Moisture can be transported into an assembly by three main mechanisms: weather leaks, air leaks and vapor diffusion.

Weather leaks are easy to understand. Obviously, a good exterior assembly will resist water intrusion from weather.

However both the “air transport” and “vapor diffusion” may cause condensation within an exterior assembly. They are somewhat more difficult to understand.

A. **Air Transport**

Water vapor can be transported directly into an assembly by air movement. Air can hold a large amount of water vapor. When moist air encounters a surface at or below its dewpoint temperature, the water in the air condenses on the surface. Therefore, any air permeable assembly is subject to condensation problems.

Similarly, outdoor air can infiltrate into an assembly. Although outdoor air may not transport water vapor into the assembly, cold air can chill the assembly. In this case, the surface’s temperature is lowered (potentially below the air’s dewpoint temperature) and condensation may occur on the chilled components. This mechanism can occur in assemblies without air-tight weather barriers.

Air movement from either direction is undesirable. The solution is to construct exterior walls and roofs with good indoor and outdoor air retarders or “air barriers”.

Often, the primary air retarding and vapor retarding mechanisms are provided by the same layer(s).

However, the air transport mechanism can move hundreds or thousands of times more moisture into an assembly than can vapor diffusion. Therefore, good “air barriers” are much more important than “vapor barriers” or “vapor retarders” in all exterior assemblies.

Air pressure differentials create the potential for air movement through an assembly.

1. **Space pressurization:**

Many buildings require that the building be generally positively pressurized by the HVAC system (with respect to the outside). Design indoor air pressures of 0.05 inches water column (“w.c.) are often used by HVAC system designers. However, this is very difficult to achieve in most buildings.

2. **Wind Pressure:**

Wind pressures tend to increase space pressurization on the leeward side and reduce it on the windward side. Wind velocities of less than 20 mph may create pressure differentials greater than 0.05”w.c. on the windward side of a building.

3. **Stack Effect:**

"Hot air rises". Most multi-floor buildings are susceptible to "stack effect" pressurization. "Stack effect" is caused by the density difference between warm indoor air and cold outdoor air (in the winter. Stack effect tends to pressurize roofs. Stack effect also causes cold outside air to infiltrate through the bottom of wall assemblies. Stack effect can add to any wind or mechanical pressurization of the roof. In Denver, a six-story building (floor to roof height of 70 feet, will have as much as 0.12"w.c. higher pressure at the roof, then at the first floor (assuming a neutral pressurization at the first floor, Denver elevation and 0º outside air temperature/ 72º indoor air temperature).

Only a slight positive pressure differential across a roof or wall assembly is required to create air movement (and potential condensation) - if the assembly is air permeable.

B. **Vapor Diffusion**

This moisture transfer mechanism is driven by the vapor pressure differential between the inside and the outside air.

"Vapor barriers" or "vapor retarders" can control vapor diffusion. However, every material used in construction has some resistance to vapor diffusion. For instance, wood is less permeable than gypsum wallboard, but a plastic "vapor barrier" is even less permeable. Sheet steel is essentially impermeable.

Walls and roofs experience the highest rates of vapor diffusion at extreme temperature and/or humidity variances between the inside and outside. In Colorado, the largest vapor pressure differential occurs when it is very cold outside; and warm and humid on the inside. Condensation is more likely when the indoor space is humidified. Humidification can be "natural" (i.e., caused by normal human activity) or "mechanical" (i.e. caused by a humidifier, swimming pool or other obvious moisture source).

1. **"Wetting" by Vapor Diffusion**

Vapor diffusion may be considered "bad" when it loads the assembly with moisture. "Bad" vapor diffusion may occur in some assemblies in the winter. However, vapor loading will not be a concern if the assembly:

a. Limits diffusion,
b. Allows water vapor to pass through to the outside, and/or
c. Allows water vapor to be stored in hydrophilic layers.

In many assemblies, layers can be arranged such that their respective thermal resistance ("insulation value") and resistance to vapor diffusion ("perm rating") allows water vapor to pass THROUGH the assembly. Such an assembly usually includes a "vapor retarder" on the inside of the assembly, a layer of vapor permeable insulation and vapor permeable exterior finish (such as brick). The minimal amount of water vapor that passes through the vapor retarder continues to pass through the assembly to the outside (without condensing).

Other assemblies include at least one highly absorptive layer that simply absorbs the water vapor during the winter (without condensation). Wood and gypsum board typically have high-vapor absorption capacity. They are "hydrophilic".

2. **Drying by Vapor Diffusion**

Vapor diffusion is not always "bad". As hydrophilic materials absorb water and warm, their local vapor pressure increases. This may cause vapor to "dry" out of an assembly – as long as some part of the assembly is vapor permeable or is ventilated. In fact, most roof assemblies absorb considerable interior moisture (in the form of water vapor) during the winter, but completely loose it during the summer.

If a roof is not ventilated or if it does not have a sufficiently vapor permeable layer (to allow drying), it may see a net annual increase in moisture content. At some point in time (sometimes months, sometimes years), it will become "wet".

C. **Semi Vapor Permeable "Vapor Retarders"**

If possible, roofs and walls should be built with semi-vapor-permeable air barriers/vapor retarders on the inside layer. These types of vapor retarders (VRs) limit "bad" vapor diffusion in the winter. If installed air-tight, they limit moisture accumulation from air leakage. They also allow "good" vapor diffusion to dry-out the assembly when conditions allow.

Asphalt impregnated paper is a very good semi-vapor-permeable VR. "MemBrain" by CertainTeed is also claimed to be a good semi-vapor-permeable VR (for wall assemblies). However, these vapor retarders must be covered by an acceptable thermal barrier for fire safety reasons.

III. "DEWPOINT PLANE" DISCUSSION

Many people are confused about the concept of a "dewpoint plane" within a roof or wall assembly. By definition, the "dewpoint plane" is that location within the assembly where its temperature matches the interior air's dewpoint temperature. The temperature drops even lower toward the exterior of the assembly.

A common misconception is that condensation will occur within the assembly at the dewpoint plane (regardless of moisture transport mechanism, and regardless of assembly).

However, as long as the outside air temperature is low enough, the exterior portion of every roof or wall assembly will be colder than the interior air's dewpoint. If this misunderstanding of "dewpoint plane" was valid, every roof or wall would experience condensation. However, condensation does not occur in every wall, in fact it is relatively rare, especially in Colorado.

On the other hand, if indoor air is allowed to exfiltrate through a roof or wall, condensation WILL occur at the dewpoint plane. Therefore, any air permeable assembly may be subject to condensation problems.

A. AIR LEAKAGE

“Air barriers or “air retarders” control air leakage.

As discussed above, water vapor can be transported directly into an assembly by indoor air movement into the assembly.

Similarly, outdoor air can infiltrate into an assembly. If very cold, it is very dry. Although it will not carry significant amounts of moisture into the assembly, it can chill the assembly. In this case, normal levels of water vapor may condense on the chilled components (such as steel studs in an exterior wall). This mechanism can occur in assemblies without air-tight weather barriers. It is relatively rare in a roof assembly, but common in some wall assemblies.

Air movement from either direction is undesirable. The solution is to construct exterior walls and roofs with good indoor and outdoor air retarders.

If an assembly is sealed substantially air-tight, and substantially weather-tight on the outside: The only moisture intrusion mechanism of concern is that of vapor diffusion.

Often, the primary air retardering and vapor retardering mechanisms are provided by the same layer(s).

However, the air transport mechanism can move hundreds or thousands of times more moisture into an assembly than can vapor diffusion. Therefore, good air barriers are much more important than “vapor retarders” in most exterior assemblies.

B. VAPOR DIFFUSION

As discussed above, this moisture transfer mechanism depends on the vapor pressure differential between the inside and the outside air to drive moisture in the form of water vapor through an assembly.

Condensation is more likely when the indoor space is humidified.

In the summer, the direction of the vapor differential reverses as the assembly is heated (by the sun). The direction of vapor diffusion reverses and the assembly dries to the inside.

However, summer vapor pressure differentials can also wet assemblies. For example, there is a tremendous injection of water vapor INTO a sun-baked wall assembly immediately after a summer shower.

C. DIURNAL AND SEASONAL “DRY OUT”

Summertime or “reverse” vapor drive can cause condensation at impermeable vapor retarders on the inside of an assembly. This is especially true at roof assemblies with "leaky" vapor retarders and where the exterior of the roof is generally also vapor impervious. When vapor diffusion is "halted" at an impermeable ceiling vapor, accumulated water vapor can condense on the top of retarder and run (by gravity) to any joints or tears in the vapor retarder, then onto the ceiling at drywall joints, beams or light fixtures.. Often this moisture is mistaken for a roof “leak”.

Condensation can also occur in walls at the vapor barrier at impermeable vapor retarders in assemblies with unvented masonry finishes (and poor drainage planes) – especially after a driving rain.

Semi-vapor-permeable VRs are essential in some unventilated roof assemblies.

On the other hand, vapor impermeable VRs (such as polyethylene sheeting) are acceptable on walls with vapor permeable exterior finishes, good drainage planes (with good flashing details) and good air barriers. They are also acceptable in roof assemblies that are ventilated (such as attics).

IV. HOW TO MANAGE CONDENSATION WITHIN THE THERMAL ENVELOPE

1. All thermal envelope assemblies must be weather-tight.

2. All thermal envelope assemblies must control the migration of water vapor (by both transport mechanisms).

3. To prevent condensation:
   a. Keep air out of the assembly, as much as possible.
   b. Expect some intrusion of water vapor into any assembly. Make sure there is a good way for the moisture to exit the assembly.
   c. Understand the how weather extremes and interior air conditions will affect the magnitude and direction of air and vapor flow through an assembly.

END OF WHITE PAPER