BEST 2 WB 3-4 SIX WAYS FOR CONDENSATION IN BUILDINGS

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Abstract:

Six of the ways condensation can occur on cold surfaces in buildings are discussed here. They are:

1. Air Leakage,
2. Diffusion
3. Convection,
4. Thermal bridges
5. Fenestration
6. Ground contact

Each of these ways will be discussed in this paper and solutions suggested to mitigate and avoid the problems from occurring,

Preventing condensation, or more accurately, avoiding an increase in the moisture content of building materials to levels that can support the growth of microorganisms, especially molds within the enclosure and on interior surfaces, is fundamental to avoiding health and air quality problems in buildings; it is also essential in avoiding premature deterioration of enclosure components.

The growth or amplification of microorganisms in buildings not only results in biodeterioration of susceptible construction materials but also leads to the production of allergens and microbial VOCs (the cause of musty odors) that can affect occupant health and air quality. A complex microbial ecology (e.g., mites feed on mold and skin particles; other organisms feed on mites) can develop in or on construction materials that are chronically wet or damp. Allergens associated with molds and arthropods (their feces and body parts) growing in chronically wet construction niches can enter the indoor environment and pose a risk to sensitive occupants.

The moisture content of building materials increases due to water vapor transport across enclosure assemblies, either by infiltrating, exfiltrating, or convecting air coming in contact with surfaces that have a temperature lower than the dew-point of the moving air, and/or by diffusion due to a difference in water vapor pressure across the assembly, or by capillary transport through the microscopic voids in building materials.

Properly designed enclosure assemblies have greater drying potential than wetting potential. They achieve a moisture balance over time. When that balance is not achieved problems occur. Many building designs do not get sufficiently scrutinized to ensure that the designs are appropriate for the climate they are expected to weather.

Thermal bridges are conductive materials that partially or completely penetrate the insulated enclosure. The heat loss that results can drop temperatures of interior surfaces to levels below the dew-point of the indoor air and promote condensation

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Building enclosures are often designed without a proper understanding of the performance of the assembly when subjected to the exterior weather and interior boundary conditions. Code requirements may even impose solutions that are problematic such as requiring vapor retarders prescriptively in circumstances that ignore local conditions. Water resistive barriers that may be too vapor permeable under certain weather conditions. Prescriptive criteria in codes are slowly being improved, but the substitution of a single material in an assembly can radically change how the assembly performs over time.

Building enclosures should be designed by a knowledgeable design professional using design tools referenced in the Handbook of Fundamentals (ASHRAE, 2009 chapter 25)[1], in order to avoid the likelihood of moisture-related problems.

Control Air Leakage

Air leakage is identified as the biggest cause of condensation in buildings (CBD 23 A.J. Wilson, 1961). Condensation of moisture in interstitial cavities from exfiltrating air in northern climates, or from infiltrating hot humid air in southern climates, can cause condensation and mold growth that can promote health problems and premature building deterioration. Unlike the moisture transport mechanism of diffusion due to a vapor pressure difference, air pressure differentials can transport hundreds of times more water vapor through air leaks in the envelope over the same period of time *(Quirouette, 1985).* This water vapor can condense within the building enclosure in a concentrated manner, depending on the pathway, and the internal temperature distributions.

There are three major air pressures on buildings that cause infiltration and exfiltration:

- Wind Pressure
- Stack Pressure (sometimes called chimney effect, or buoyancy)
- HVAC Fan Pressure, including appliances such as clothes driers.

Figure 1 - Condensation of water vapor carried by air exfiltrating between the SIPS panels caused condensation and rot of OSB within one year of construction of this natatorium.

Figure 2 - Infiltrating warm humid air into this air conditioned plenum caused condensation on cold surfaces of chilled water pipe insulation.

Control of convection

Air in contact with cool surfaces will be cooled down. Cool air is heavier than warm air and will sink down, being replaced by warmer air carrying moisture, promoting accumulation of condensation on the cool surfaces due to a “convective loop”. Eliminating and avoiding voids (see Fig. 4) adjacent to cool surfaces is key to reducing condensation due to convection. Controlling convection currents within envelope assemblies caused by connecting air on the cold side to air on the warm side of insulation or the interior air by sealing the interior (Figure 3). This is the typical mechanism of mold formation in insulated basements, where air that is adjacent to a cool concrete basement wall cools down, gets heavier and sinks, pulling in warm humid air at the top of the insulated wall. Typical glass-fiber insulation is low density and promotes convection; denser insulations such as cellulose, rigid board insulations and spray foam insulations can eliminate this convection when carefully installed.

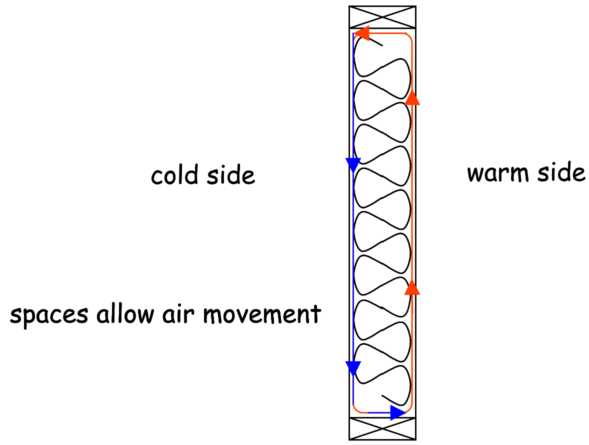


Figure 3 - A convective loop deposits condensation on the cold side of the wall

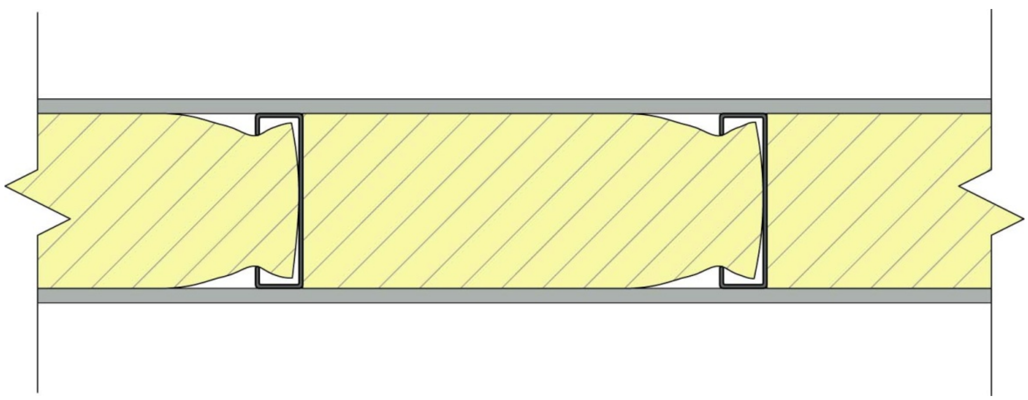


Figure 4 - Air spaces due to shape of studs create pathways for convection of air.

Design

Airtightness of the enclosure

Include a continuous air barrier system[2] in the building enclosure:

- Select a material in each opaque wall, floor and roof assembly that meets a maximum air permeance of 0.02 L/s.m^2 @ 75 Pa (0.004 cfm/ft^2 @ 0.3" w.g) and join it together with tapes, sealants etc., into an assembly; or select an assembly (ASTM E 2357 or E 1677) with a maximum air permeance of 0.2 L/s.m2 @ 75 Pa (0.04 cfm/ft2 @ 0.3" w.g.)

- Join the air barrier layer of each assembly with the air barrier layer of adjacent ones, and to all fenestration and doors, until all enclosure assemblies (roof, walls, and below grade components) are interconnected and sealed.

- Seal all penetrations of the air barrier layer.

- The airtight layer of each assembly will support the entire air pressure of wind, stack effect and HVAC fans. Ensure that the airtight layer is structurally supported and can support the maximum positive and negative air pressures it will experience, without rupture, displacement or mechanical damage. Stresses must be safely transferred to the structure.

Convection

Air gaps adjacent to cool or cold surfaces can promote convection within a wall assembly. Cold air is heavier and sinks, pulling in warm humid air to replace it and deposit moisture on the cold surface. This is especially true in vertical or sloping assemblies. The colder side can be the sheathing or precast concrete in colder climates or the interior drywall in warmer climates. Eliminating the air space on one or other side of the insulation can be effective in preventing these convective loops. Fibrous insulation, however, which is mostly air, will also allow these convective loops to happen. Denser insulations including cellulose, rigid board insulation when installed in a manner to prevent air gaps, or spray foam insulation can be especially useful in avoiding this problem.

Diffusion

A vapor retarder with appropriate permeance for the application[3] should be placed on the predominantly high vapor pressure side of the assembly. To design assemblies for appropriate diffusion control, hygrothermal analysis using either the steady state dewpoint or Glaser methods described in the Handbook of Fundamentals, (ASHRAE, 2009 Chapter 25) or by using a mathematical model that simulates transient hygrothermal conditions (the ASTM manual, Moisture Analysis and Condensation Control in Building Envelopes (Trechsel, 2001) reviews these models). Users of such methods must understand their limitations, and interpretation of the analysis results should be done by a trained person to reasonably extrapolate field performance approaching the design results. The International Energy Agency Annex 14 (IEA, Hens 1991) has established that a surface relative humidity of 80% averaged over a period of 30 days represents a reasonable threshold for designers to achieve a successful building enclosure assembly for temperatures between 40°F and 120°F (5°C and 50°C). This is a threshold above which mold can grow and building assemblies deteriorate.

Window and Skylight Selection

Fenestration should be selected carefully by designers to avoid condensation. Fenestration is selected taking into account the interior boundary conditions and exterior weather conditions; from a chart developed by the American Architectural Manufacturers Association (AAMA)[4], (see Fig. 5) the appropriate Condensation Resistance Factor (CRF) for the window or skylight is determined by comparing the indoor relative humidity against the 99.6% winter design temperature.

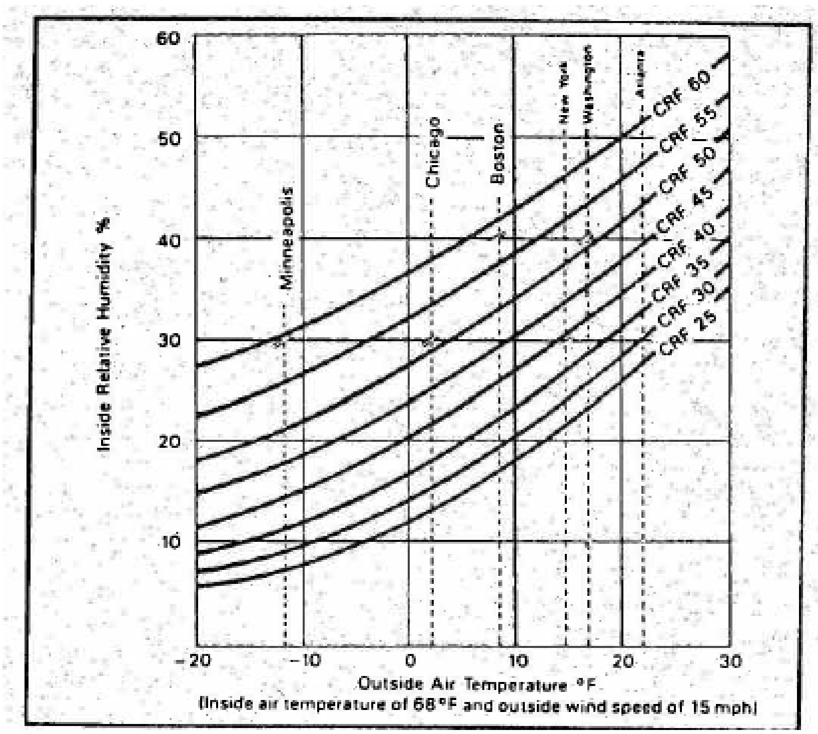


Figure 5 Condensation Resistance Factor curves (AAMA)

Fenestration with a good thermal break (> 1/4" thick of low-conduction material) that minimize the amount of exterior metal exposed to cold usually perform best, and from a condensation resistance perspective, may out-perform non-metal units (non-metal units may have improved U-factors though). The edge spacer of the insulating glass unit is usually the most conductive (and coldest) location in a window assembly. A new generation of "warm-edge" spacers that include thermally broken aluminum spacers, stainless steel spacers and non-metallic glass-fiber reinforced plastic spacers are increasingly being used to improve the thermal performance of fenestration. Inert gas fills such as Argon and Krypton, and multiple low-E films reduce heat transmission further by reducing convection and radiation. Window and skylight manufacturers generally can provide National Fenestration Rating Council (NFRC)[5] simulations using the software THERM that shows how a specific selection of window, spacer and glass, with various gaseous fill will perform. It is also important to note that some non-metal windows that have an improved U-factor may have a worse CRF than a metallic thermally broken window with a higher U-factor. Custom designs are often required to be verified using the THERM and WINDOW software, and validated by physical laboratory testing as well.

Common problems, in addition to poor selection of a window, and their design, construction and installation include:

1. Poor location of thermal break, or no thermal break at all.
2. The warm side of a thermally broken window frame exposed to cold temperatures.
3. Weepholes that communicate between the indoor and outdoor environments result in air leakage of cold air into the window frame.

4. Air Leakage at the interface of the window frame to the opaque wall's air barrier causing cooling of the warm side of a thermally broken window.

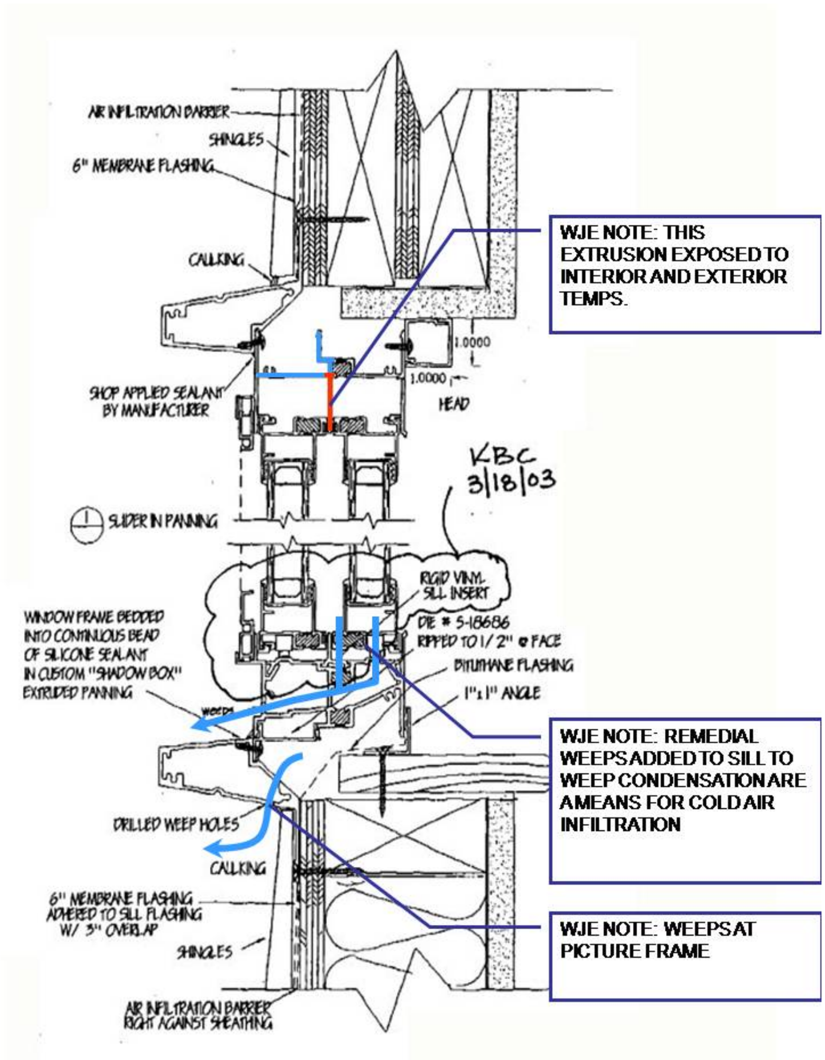


Figure 6 - Weep holes connecting interior and exterior environments. Thermal breaks in poorly selected location.

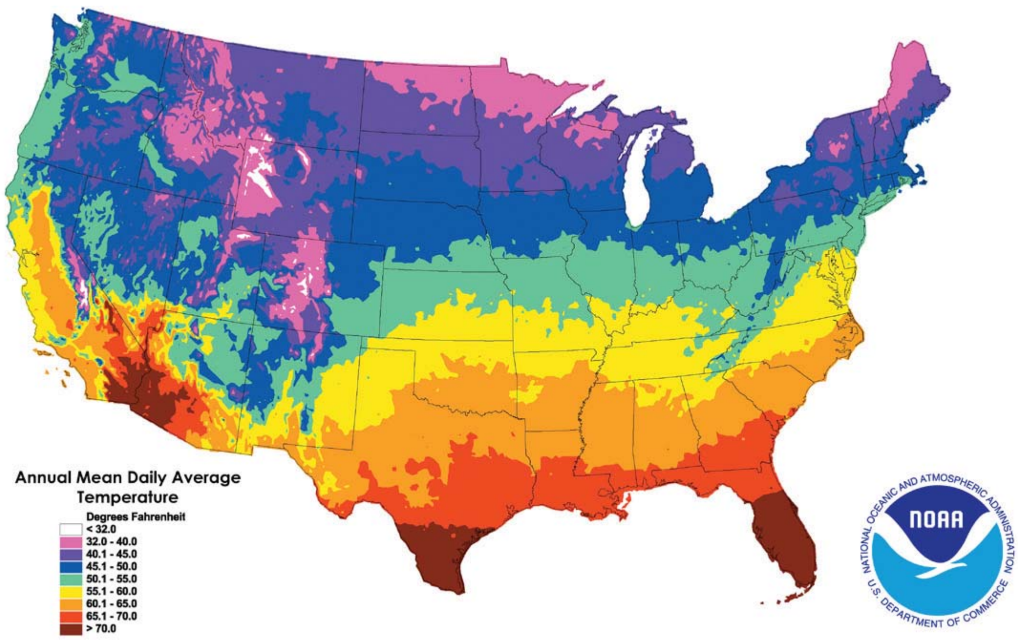
Figure7 - Frost on a curtain wall frame due to lack of primary air barrier seal.

Below Grade Walls and Slabs on and Below Grade

Deep ground temperature in a locale is not unlike the average annual temperature, with local variations due to shading from vegetation, elevation or proximity to the coast. Comparing the annual average temperature with the August dew-point temperature of the air (see Fig. 8) is a good indication of whether condensation is likely to occur on slabs and walls of below grade structures. Concrete is highly conductive and will attain a temperature similar to that of the ground and, potentially, become a likely condensation surface. Insulating the outside of the concrete walls and floors is the best choice for keeping the concrete above the dew-point of the indoor air. In termite-infested areas, select rigid insulation that has termiticides included; that renders poisoning the soil unnecessary. Full insulation under slabs with a vapor retarder on top of the insulation in intimate contact with the slab is the best strategy for a dry slab.

Selection of insulation density should take into consideration maximum point loads with an appropriate factor of safety to avoid crushing.

Insulating on the inside of below-grade walls is possible, but it is best to insulate using adhered rigid insulation so as to avoid convection through fibrous insulation (see Fig 9).



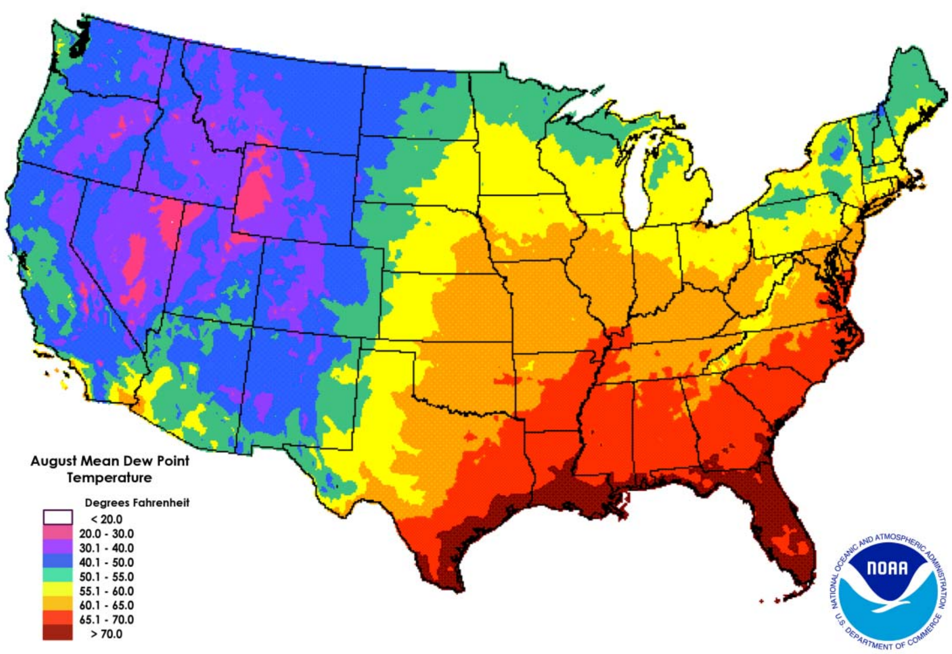


Figure 8 - Comparing a location's average annual temperature with the August dew-point of the air is a good indication of whether below-grade structures may cause condensation and mold.

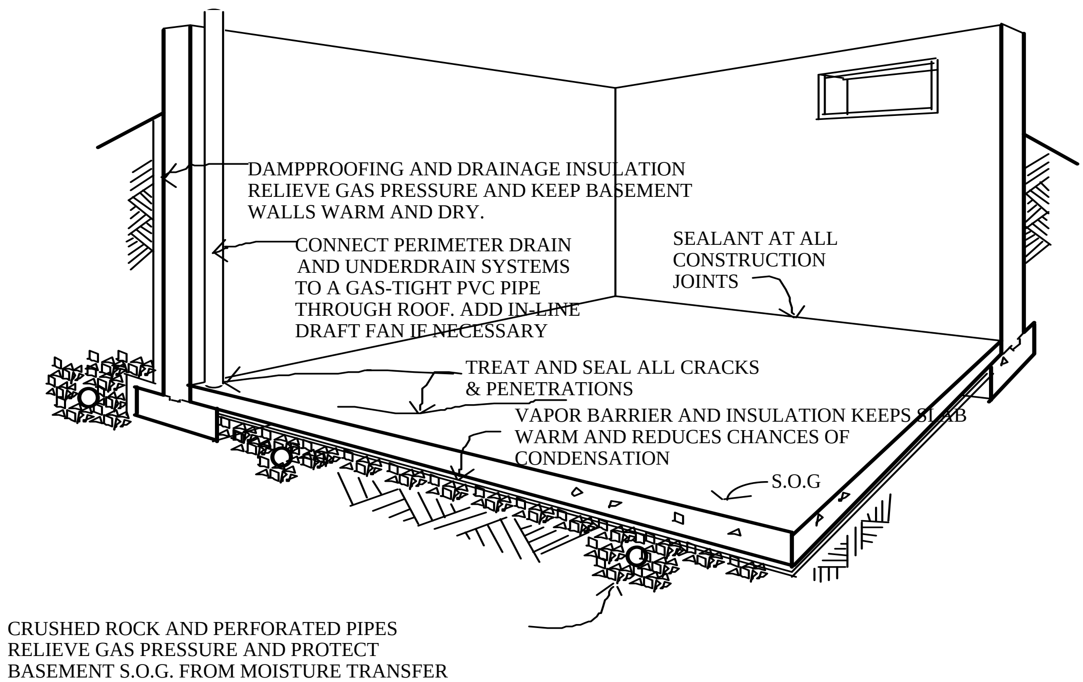


Figure 9 - Insulate outside below-grade structures

Thermal Bridging

Thermal bridges, due to conductive materials that penetrate or interrupt the thermal insulation layer, cause a drop in temperature of the interior surface in cold climates; buildings with "exoskeletons", or buildings with exterior structural components are a typical example. This can cause condensation due to colder temperatures and result in mold growth. It can also cause deposition of particulates onto the cold interior surfaces called "ghosting". In the building shown below in a cold climate, interior humidity, candle smoke and thermal bridging combined to cause ghosting of the steel studs; (see Fig. 10 and 11).

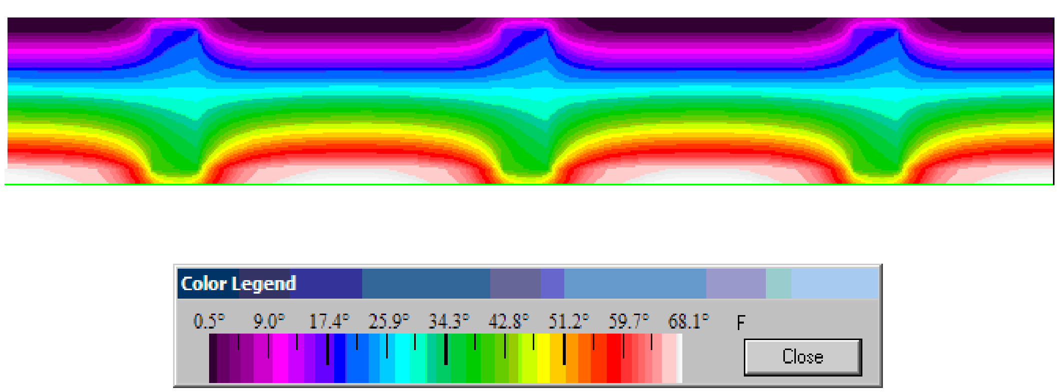


Figure 10 THERM analysis showing temperature variation caused by thermal bridging by steel studs (Anis, 2007)

Figure 11 - Steel studs lowering temperature of interior surfaces causing ghosting

Figure 12 - These exterior steel columns are heat sinks, drawing heat from the beams that penetrate from the conditioned space. Beams inside the building were dripping wet.

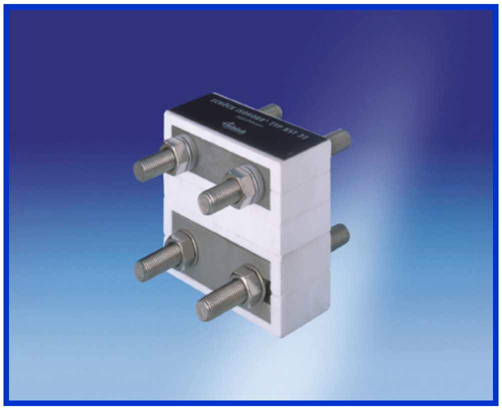


Figure 13 - A steel beam to steel beam structural thermal break, one of many designs available.

Structural members that are outside the thermal insulated enclosure (see Fig 12) can be heat sinks dissipating heat into the environment and dropping interior temperatures below the dew point. Smaller thermal bridges including metal fasteners and furring members can also be a problem; it is important to remember that stainless steel has about one third the conductivity of carbon steel and one tenth that of aluminum**.**

Conclusions:

Keeping enclosure component temperatures above the dew-point of the air coming in contact with it, controlling air movement, vapor pressures and thermal bridges in building enclosure assemblies is critical to avoiding condensation in/on building enclosures. Knowledgeable professionals should follow sound building science principles in the choice and design of enclosure assemblies for the applications and climates involved.

References:

[1] Handbook of Fundamentals; ASHRAE 2009, Chapter 25
[2] Air Barrier Systems in Buildings, Whole Building Design Guide www.wbdg.org; Anis, W. FAIA
[3] International Building Code 2009, International Codes Council
[4] www.aamanet.org
[5] www.nfrc.org