THE BRICK INDUSTRY ASSOCIATION

TECHNICAL NOTES on Brick Construction

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June
2006

Condensation - Prevention and Control

Abstract: This *Technical Note* describes a variety of conditions that can cause condensation to occur in brick walls and analytical tools used to determine the likelihood of occurrence. Use of air barriers and vapor retarders to control condensation is discussed.

Key Words: air barrier, condensation, dew point, humidity, permeance, relative humidity, saturated vapor pressure, saturation temperature, vapor pressure, vapor resistance, vapor retarder.

SUMMARY OF RECOMMENDATIONS:

- Consider the possibility and location of condensation in building design
- Reduce the possibility of condensation by:
  - Providing adequate ventilation/dehumidification to reduce humidity in the building
  - Adding insulation and minimizing thermal bridges to increase heat resistance of the wall
  - Add an air space to increase the drying potential of the wall
  - Add an air barrier or vapor retarder at the appropriate location when analysis indicate the probability for condensation

INTRODUCTION

Moisture within masonry walls may enter during construction, in service as wind-driven rain, through poor detailing or maintenance, or result from condensation of water vapor. Air movement within walls and differences in humidity between inside and outside air can move water vapor to areas where condensation can occur, resulting in wetting of wall elements.

When moisture and air movement are considered during the design phase, walls can be designed and constructed to prevent detrimental condensation. Condensation tends to form on nonporous surfaces. Materials such as brick may absorb water and not show evidence of water droplets formed by condensation. The presence of this moisture within the brick masonry wythe can damage the brick when freezing and thawing occurs. In most cases, the brick wythe dries out with no damage caused. However, other wall elements can be damaged by this moisture, posing structural, health and aesthetic concerns.

CONDENSATION BASICS

Dew Point

Air is a mixture of gases and water vapor. At a given temperature and pressure, there is a limited amount of water vapor that air can hold. When this limit is reached, air is considered saturated. At a constant pressure, the amount of water vapor that air can hold increases with temperature. If saturated air at a temperature of 50 ºF (10 ºC) is warmed to a temperature of 70 ºF (21 ºC), the mixture is no longer saturated and can absorb additional water vapor. However, at a constant pressure, unsaturated air can be cooled to a temperature at which the air is saturated. This temperature is called the dew point and, if the mixture is cooled below the dew point, water vapor will condense, returning to liquid water. When water vapor moves through a wall system, condensation can result if water vapor reaches the dew point. This liquid water can cause deterioration or greatly reduce the performance of some materials. Dew is one of the most common examples of condensation.

Relative humidity is the common term used to describe the ratio of the amount of water vapor air contains to the amount it can hold at saturation at a given temperature. For air with a fixed amount of water vapor, the relative humidity increases as the temperature is lowered and decreases as the temperature rises. Air which is saturated has a relative humidity of 100 percent.

In Figure 1, the difference in temperature between the air and the dew point is shown for relative humidities from 50 percent to 100 percent. The figure illustrates that for relative humidities above 80 percent, a drop in temperature of 6.8 ºF (3.7 ºC) or more will cause condensation. These high humidity conditions usually occur during the summer. If the temperature difference between the inside and outside surfaces of a wall exceed the temperature drop in Figure 1, there is a possibility of condensation occurring on or within the wall.

Vapor Pressure

The concentration of water vapor may also be stated by giving its pressure. Part of the atmospheric pressure of air is maintained by water vapor and the remainder of the pressure by the other constituents of the atmosphere. Water vapor pressure is independent of the other gases in the air. The vapor pressure when air is saturated, as described above under **Dew Point**, is defined as the saturated vapor pressure for that temperature. Data on saturated vapor pressures are listed in tables of the ASHRAE *Handbook of Fundamentals* [Ref. 1] and Table 1 gives saturated vapor pressures for various temperatures as included in the 2005 edition.

The ratio of the actual pressure of the water vapor to the saturation pressure of the water vapor for the particular temperature is also termed relative humidity. When quantified, the value is essentially the same as that given previously.

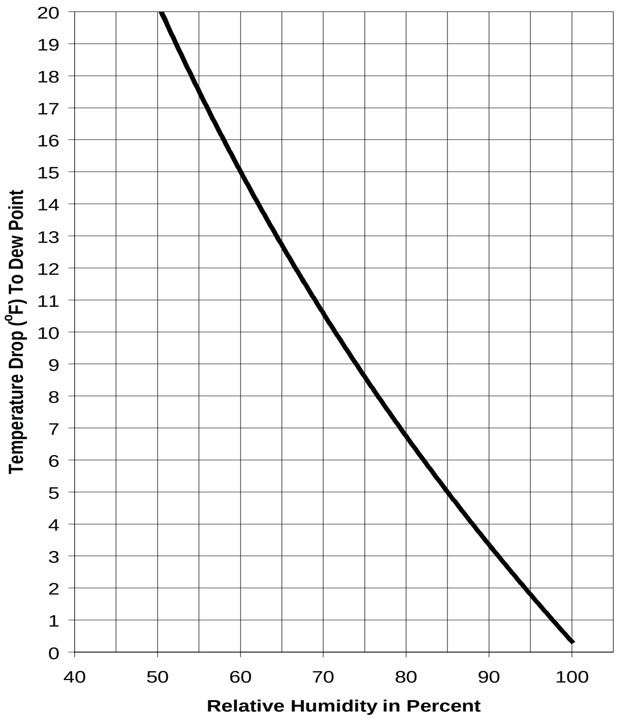

Figure 1
Temperature Drop Curve for Relative Humidity

Per Dalton's Law of Partial Pressures, water vapor from a higher pressure zone will move to a lower pressure zone. In other words, when a vapor-pressure differential exists, water vapor will move toward the lower pressure independently of air. Differences in vapor pressure through different parts of the wall from inside to outside distribute themselves in proportion to the vapor resistance of the respective parts. When vapor passes through pores of homogeneous walls that are warm on one side and cold on the other, it may reach its dew point and condense into water within the wall; but, if the flow of vapor is impeded by a vapor-resistant material on the warm side of the wall, the vapor cannot reach that point in the wall at which the temperature is low enough to cause condensation.

Permeance

The water vapor transmission coefficient for a material is expressed as permeance. Permeance is measured in perms. (1 perm = 1 grain of water passing through 1 ft² of wall in 1 hour under a vapor pressure differential of 1 inch of mercury). A perm-inch is the permeance of 1-inch thickness of a homogeneous material. The reciprocal of permeance is called vapor resistance. It is analogous to thermal resistance in that differences in vapor pressure through each part of the wall are proportional to the vapor resistance of these parts.

Temperature Gradient

Thermal resistance, or R-value, describes the steady-state resistance to heat flow. Walls with a higher R-value tend to have better insulating ability. The temperature gradient or temperature differential across a wall is directly proportional to the thermal resistance of individual elements. For example, if the total wall R-value is 8.0 hr•ft²•ºF/Btu (1.4 m²•K/W) and the resistance of one element is 2.0 hr•ft²•ºF/Btu (0.35 m²•K/W), the temperature drop across this element under steady-state conditions will be 2/8 of the air temperature difference across the wall.

INFLUENCERS ON CONDENSATION

Air Leakage and Air Barriers

Air leakage has the potential to carry significantly greater amounts of water vapor than does vapor diffusion, and consequently tends to have a greater impact on the condensation potential. Air leakage through building envelopes can occur through doors and windows, at the sill plate, through electrical and plumbing penetrations, and through the walls themselves. The building envelope should be as airtight as possible. Not all cracks and openings can be sealed, so the designer should assume that some water vapor flows into, or through, the wall assembly and provide a means for it to exit.

Table 1
Saturated Vapor Pressures

Fahrenheit Temperature	Vapor Pressure, in. Hg
-10	0.0220
0	0.0376
10	0.0629
15	0.0806
20	0.1027
24	0.1243
30	0.1645
40	0.2477
50	0.3624
60	0.5216
70	0.7392
75	0.8750
80	1.0323
90	1.4219
100	1.9333

In some cases, operating the building's mechanical system to provide a slight positive or negative pressure can help control air flow through the envelope. For example, during the cooling season, a slight positive indoor pressure (relative to the outdoor air pressure) helps prevent humid outdoor air from being drawn into the building.

Air barriers are membranes made of polyethylene, polypropylene or polyolefin and are intended to prevent air leakage through the building envelope, hence reducing the associated energy losses and moisture movement. Most air barriers allow water vapor transmission, while some also act as vapor retarders. Manufacturers may provide data based on different standards, including 1) ASTM D 726, Test Method for Resistance of Nonporous Paper to Passage of Air and 2) ASTM E 283, Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen. For this reason, caution should be exercised when evaluating and specifying air barriers. In addition, conventional wall elements may act as air barriers. For example, when joints are caulked or taped, either sheathing or gypsum board can serve as an air barrier.

Vapor Diffusion and Vapor Retarders

As stated previously, water vapor will naturally diffuse from an area of higher vapor pressure to one of lower vapor pressure. When a vapor pressure differential occurs across a wall section, the water vapor diffuses through the wall elements in proportion to each element’s vapor permeance. A vapor retarder is a material with low vapor permeability, intended to interrupt water vapor diffusion.

Vapor retarders are often made of materials similar to air barriers. While some air barriers will also inhibit vapor transfer, all vapor retarders can be air barriers if they are installed continuously and thoroughly sealed, with no tears, gaps or holes. Some manufacturers cite test data based on ASTM E 96, Test Methods for Water Vapor Transmission of Materials. However, this test does not account for fastener penetrations, electrical outlets, or joints in the retarder. Materials that qualify as vapor retarders have a perm rating of one or less.

Thermal Bridging

Thermal bridging occurs when materials with a low thermal resistance penetrate materials with higher thermal resistance. Heat flowing through a wall will take the path of least resistance, causing the heat to “funnel” through areas of low resistance. An example of this phenomenon occurs in a steel stud wall where the R-value of the batt insulation is on the order of 100 times that of the steel. Because the insulation is placed between the studs, the steel then acts as a “bridge” through the insulation, allowing the heat to bypass the insulation. Thermal bridging, in this example, can lead to local cold spots at the steel stud locations, resulting in condensation in those areas even though analysis of the wall as a whole may not indicate a high potential for condensation. Continuous insulation or insulated sheathing on the exterior of the studs helps break the thermal bridge and keeps the steel studs at a temperature closer to that of the building interior, reducing the chances of local condensation. It is also important that all walls are completely insulated without gaps that could result in thermal bridging.

REDUCING CONDENSATION POTENTIAL

The possibility of condensation can be reduced by:

- Lowering the humidity of the air if the high humidity is inside the building. This may be accomplished by adequate ventilation if the high humidity is caused by conditions inside the building.
- Increasing the temperature of the surface on which the condensation occurs by increasing the interior temperature, increasing the heat resistance of the wall or minimizing thermal bridging in the construction. This is usually accomplished by adding insulation behind the interior finish.
- Promoting drying by increasing the movement of air over the surface on which condensation is likely to occur.
- Adding an air space to increase the wall’s drying potential; this is a good redundant measure to help the wall system recover from the presence of moisture.

- Installing an air barrier or vapor retarder in locations appropriate to the climate and building use where analysis indicates a probability of condensation.

CONDENSATION ANALYSIS TOOLS

Traditionally, hand-calculation procedures, such as the steady-state dew point analysis, have been used to estimate the potential for condensation within a wall. The dew point analysis looks at temperatures and vapor pressures across a wall section at a set of interior and exterior climate conditions. Currently, however, computer programs are widely available for condensation analysis. Contrary to the dew-point analysis, computer aided analysis tools have the advantage of considering dynamic effects. These programs use up to a full year of specific weather-related input for temperature ranges, humidity and rainfall. They also include material property databases for common construction materials, as well as the ability to add custom material data. One such program, that is publicly available via the internet, is WUFI [Ref. 3].

WUFI-ORNL/IBP Research and Education version for USA and Canada is publicly available at the following URL: www.ornl.gov/ORNL/BTC/moisture [Ref. 3]. Proper application of WUFI-ORNL/IBP requires experience in the field of hygrothermics and basic knowledge of numerical calculation methods.

WUFI-ORNL/IBP is a menu-driven program which allows realistic calculation of one-dimensional heat and moisture transport in walls. It is based on the latest findings regarding vapor diffusion and liquid transport in building materials and has been validated by detailed comparison with measurements obtained in the laboratory and in outdoor tests.

WUFI provides the user with a wide range of output options for each user-defined monitoring position, including temperature, water content in each construction layer, heat fluxes and profiles across the wall section of temperature, relative humidity and water content at discrete points in time.

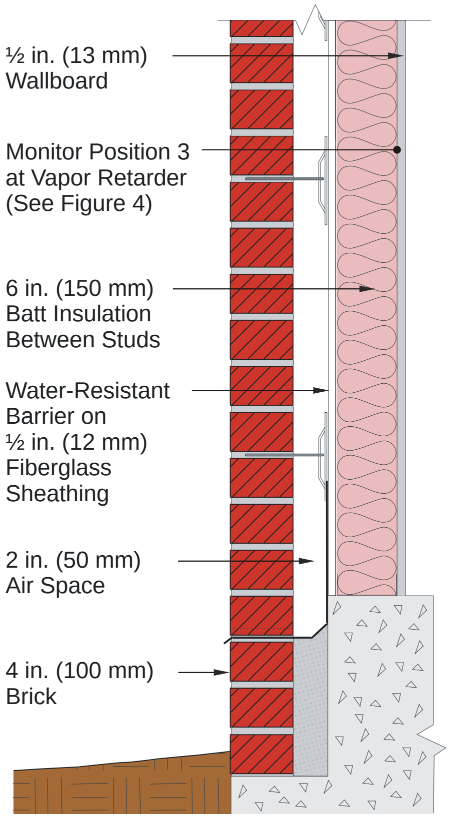

Figure 2

Example Wall Section - Minneapolis

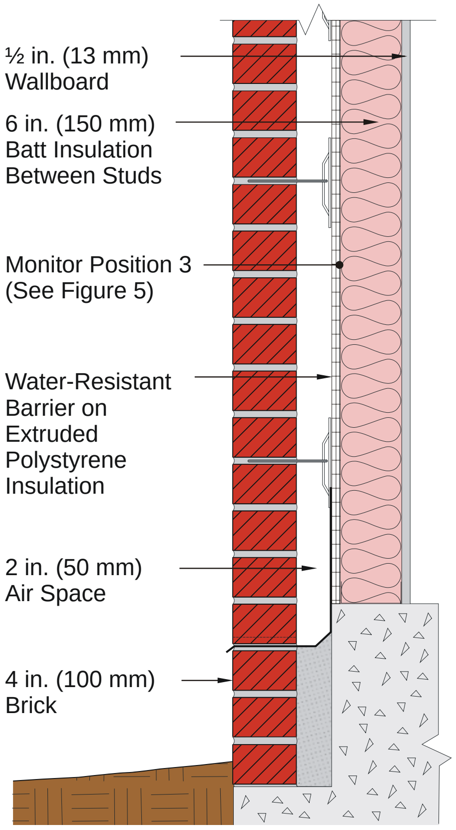

Figure 3

Example Wall Section - San Antonio

Because WUFI does not include the effects of air movement on heat and moisture transfer, the program does not adequately evaluate the drying capabilities of an air space in the wall system. The presence of an air space can reduce the moisture content of adjacent wall components. In addition, since WUFI is a one-dimensional tool, the potential effects of thermal bridges are not accounted for.

Example

Brick veneer steel stud wall systems, such as shown in Figures 2 and 3, were evaluated using WUFI in two climates: Minneapolis, Minnesota and San Antonio, Texas. Each was evaluated for a full year, and example results are shown in Figures 4 and 5. These figures show relative humidity at specific positions within the wall over the course of a year. In Minneapolis, the wall includes a polyethylene vapor retarder between the batt insulation and the interior gypsum wallboard. In cold weather, this prevents interior moisture from entering the wall system and condensing within the wall. In San Antonio, this interior vapor retarder is replaced with extruded polystyrene insulation on the exterior of the steel studs. The joints are sealed to intercept exterior moisture and prevent it from condensing within the wall as it moves closer to the cooler, dryer interior under summer cooling conditions. For the Minneapolis wall section Monitoring Position 3 is at the the batt insulation/vapor retarder interface, and for the San Antonio wall section Monitoring Position 3 is at the extruded polystyrene insulation/batt insulation interface.

It is important to note that condensation occurs when relative humidity reaches 100 percent. Figures 4 and 5 show that the wall systems in Figures 2 and 3 do not reach the level where condensation will occur. Therefore, the example wall sections are appropriate for the given locations.

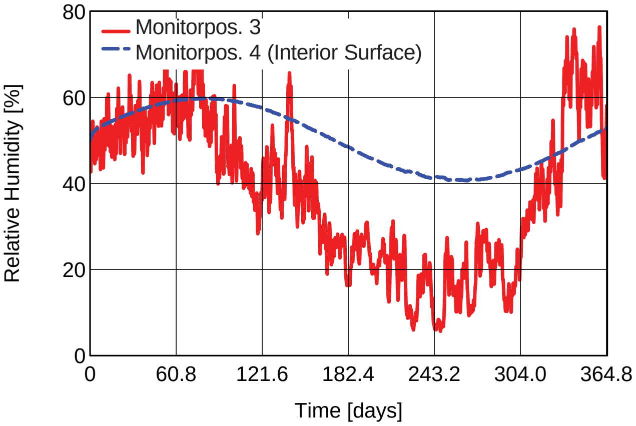

Figure 4

Relative Humidity Profile of Brick Veneer/Steel Stud Wall in Minneapolis, Minnesota

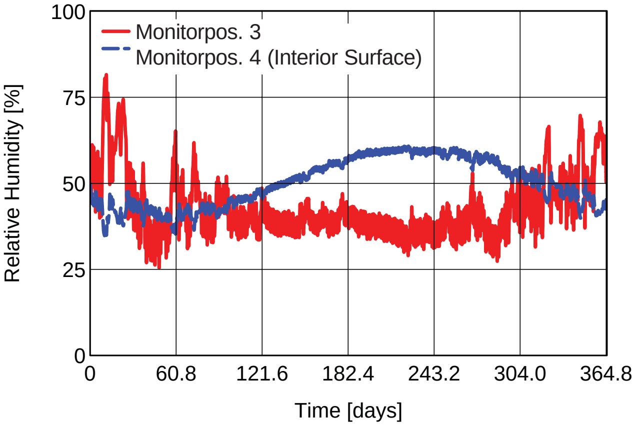

Figure 5

Relative Humidity Profile of Brick Veneer/Steel Stud Wall in San Antonio, Texas

SUMMARY

Proper design of brick masonry walls must consider the potential for condensation. This includes reducing the influences of air leakage, vapor diffusion and thermal bridging. Prevention and control of condensation can be achieved through proper design, which can be aided by contemporary analysis tools, as well as material selection and placement. Incorporating these tools and methods into design will add to the durability of brick and longevity of the building.

The information and suggestions contained in this Technical Note *are based on the available data and the combined experience of engineering staff and members of the Brick Industry Association. The information contained herein must be used in conjunction with good technical judgment and a basic understanding of the properties of brick masonry. Final decisions on the use of the information contained in this* Technical Note *are not within the purview of the Brick Industry Association and must rest with the project architect, engineer and owner.*

REFERENCES

1. *Handbook of Fundamentals*, American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., Atlanta, GA, 2005 Edition.
2. *Masonry Structures: Behavior and Design*, Second Edition, The Masonry Society, Boulder, CO, 1999.
3. WUFI-ORNL/IBP, Oak Ridge National Laboratory, ORNL's Buildings Technology Center, Oak Ridge, TN, 2005.