The Moisture Balance: Fundamentals

Anton TenWolde

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INTRODUCTION

Just as indoor temperature is the result of a balance among heat gain, heat loss, and heat storage, so is indoor humidity the result of moisture gain, moisture loss, and moisture storage. In formula **this** can be simply expressed as:

$$Q_g - Q_r = Q_s \qquad (1)$$

where

Q_g = water vapor gain, kg/s (lb/h)

Q_r = water vapor removal rate, kg/s (lb/h)

Q_s = moisture storage rate, kg/s (lb/h)

WATER VAPOR GAIN

Moisture gain may include water vapor from respiration, plants, washing and cleaning, baths and showers, wet building foundations, and a variety of other sources. Crawl spaces, in particular, have been found to be a significant contributor to indoor humidity. Water vapor also enters with the ventilation air and air infiltration. In humid, warm climates this can provide a major source of moisture. This paper focuses on moisture removal from the building and the role of moisture storage in various materials inside a building. The other two papers in this session by Jeff Christian and William Rose discuss the specifics of water vapor gain from various moisture sources.

WATER VAPOR REMOVAL

Water vapor leaves a building through ventilation and air leakage, diffusion through the exterior walls and ceiling, or by removal with a dehumidifier or air-conditioner. Removal by diffusion is usually relatively insignificant. **Table 1** compares moisture removal by ventilation and diffusion for a 1200 ft^2 (110 m^2) house during winter. **Table 1** shows that vapor diffusion removes more water vapor from the building than does ventilation only if the ventilation rate is less than 0.1 air changes per hour (ACH) and the permeance is greater than 10 perm. This represents an extremely unlikely case of a very airtight building with an unrealistically permeable exterior envelope: a permeance of 10 perm for the entire envelope is extremely difficult to achieve. In a more realistic example, an older, fairly airtight home may have ventilation rates of 0.5 to 1 ACH and a water vapor permeance of the envelope of around 1 perm, e.g. gypsum board, a kraft (not polyethylene) vapor retarder, and a very permeable exterior sheathing and siding. In that case, **Table 1** shows that ventilation removes 24 to 47 times more water vapor than escapes by diffusion through the envelope. For a newer, airtight home with polyethylene vapor retarders the ratio is likely to be larger. With ventilation rates between 0.1 to 0.35 ACH and a polyethylene, or equivalent, vapor retarder, ventilation removes between 50 and 170 times more than does diffusion. Thus, the often heard statement that vapor retarders "lock in" the moisture and are responsible for high indoor humidity and moisture problems is erroneous, unless the vapor retarder also functions as an air barrier and significantly lowers the building ventilation rate. However, vapor retarders can play an important role in preventing moisture problems in the building envelope. Another misconception is that attic or roof ventilation are crucial to indoor humidity control. Attic ventilation requirements are meant to relieve moisture problems in the roof, not in the occupied space below. Attic ventilation affects indoor humidity only to the extent that it changes ventilation and air flows in the rest of the building.

Anton Tenwolde is a Research Physicist with the USDA, Forest Service, Forest Products Laboratory in Madison, Wisconsin 53705.

Table 1. Comparison of moisture removal rates by ventilation and water vapor diffusion.

Moisture Removal by Ventilation

Ventilation rate	Moisture Removal	Comment
0.1 ACH[1]	6.3x10^{-5}kg/s (0.5 lb/h)	Airtight house
0.35 ACH	21x10^{-5}kg/s (1.7 lb/h)	ASHRAE recommended ACH[2]
0.5 ACH	30x10^{-5}kg/s (2.4 lb/h)	
1.0 ACH	59x10^{-5}kg/s (4.7 lb/h)	

Moisture Removal by Vapor Diffusion

Permeance of walls and ceiling	Moisture Removal	Comment
10 perm	13x10^{-5}kg/s (1.0 lb/h)	Gypsum board, latex, no sheathing
1 perm	1.3x10^{-5}kg/s(0.1 lb/h)	Kraft paper facing, or plywood
0.1 perm	0.13x10^{-5}kg/s (0.01 lb/h)	Polyethylene vapor retarder

Assumptions:

Indoor conditions: 21°C (70°F), 50% RH
Outdoor conditions: -7°C (20°F), 50% RH
House dimensions: 12 m by 9 m (40 ft by 30 ft)

[1] ACH = air change per hour

[2] ASHRAE Standard 62-1999, Ventilation for Acceptable Indoor Air Quality

The extent to which ventilating the building lowers humidity greatly depends on the outside absolute humidity, which is a strong function of temperature. **Figure 1** shows that building ventilation is much more effective with low outdoor temperatures than with mild outdoor conditions. Therefore, ventilation offers a greater opportunity for indoor humidity control in cold winter climates than it does in mild coastal climates or warm winter climates. In those climates, dehumidification may be needed if low indoor humidity is desired or large moisture sources are present. In cold climates, too much ventilation causes uncomfortably dry indoor air, in addition to unnecessary heat loss (TenWolde, 1994).

MOISTURE STORAGE

Moisture storage moderates swings in indoor humidity in a similar way that thermal mass prevents excessive temperature swings. Many building materials and material used in furnishings and other objects in the house have the ability to adsorb moisture directly from the air. These hygroscopic materials include wood, paper, cotton, wool, and concrete. The amount of moisture stored in these materials generally depends primarily on the relative humidity (RH)

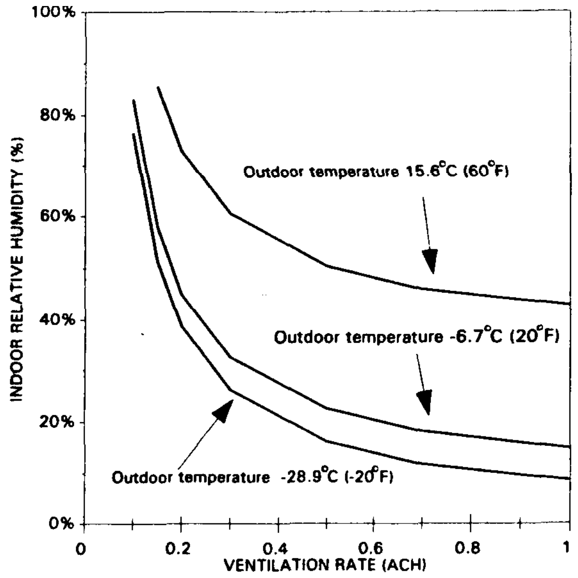

Figure 1. The effect of building ventilation on indoor humidity using three different outdoor temperatures.

Assumptions:
Indoor temperature: 21°C (70°F)
Outdoor RH: 50%
Water vapor release: 10x10^{-5}kg/s (20 lb/day)
Floor area: 111 m^2 (1200 ft^2)

of the air near the material. When the RH increases, the hygroscopic material adsorbs moisture, and when RH decreases the material gives off (desorbs) moisture. How much moisture is adsorbed and how quickly depends on the amount of hygroscopic material, the exposed surface area, and the kind of finishes on the surface. For example, the interior paper facing of gypsum board can rapidly exchange moisture with the indoor air because of the large exposed area, but the rate of moisture exchange is slowed if an oil paint or vapor retarder paint is used on the interior.

Figure 2 shows the effect of moisture storage on interior humidity (TenWolde 1988). It compares the measured indoor humidity during winter in a house in Madison, Wisconsin, with the results from a computer model for indoor humidity (FPLRH) with and without consideration of moisture storage. The moisture storage time constant used in the calculations was 3 days, and the average water vapor generation rate was 4.9x10^{-5}kg/s (0.39 lb/h). The calculated RH values with moisture storage are much closer to the measured RH values than the values calculated without moisture storage. Moisture storage also clearly inhibits rapid fluctuation in RH that would occur without the presence of moisture storage materials. TenWolde (1988, 1994) found that the average storage time constant for three homes in Madison Wisconsin was about 3 days; this means that after three days the house reaches about 63% of its final response to a sudden change in conditions. Note, however, that these houses had a concrete slab foundation and no basement. TenWolde (1994) also found that manufactured houses have a much shorter response time constant, between 9 and 24 hours. Thus, moisture storage in these homes had an effect on short-term indoor humidity levels, but did not affect seasonal indoor humidity. However, none of these homes had basements. Quirette (1984) states that a basement may contribute as much as 5 1 (approximately 1 gallon) of water per day to the seasonal humidity balance in a building, based on theoretical calculations.

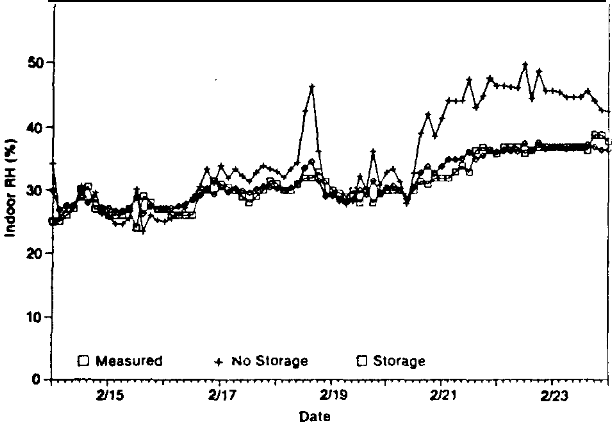

Figure 2. Comparison of measured indoor relative humidity in a home in Madison, Wisconsin, during winter, with calculated results, with and without moisture storage, using the FPLRH computer model. Source: Ten Wolde (1988)

Moisture storage has beneficial as well as deleterious effects. Storage is largely responsible for condensation in the early Fall, when outdoor temperatures decline suddenly. However, moisture storage also significantly reduces the potential for intermittent condensation during winter. When dehumidistats are used to control a ventilation system, moisture storage influences how often and how long the system will run, and how quickly it responds to a change in occupancy and moisture release. The presence of moisture storage in the building means that a dehumidistat generally does not function well as an occupancy sensing ventilation control but a dehumidistat can be effective for condensation and indoor humidity control during winter (TenWolde 1994).

CONCLUDING REMARKS

The most important parameters that determine indoor humidity are the water vapor gain rate from various moisture sources, ventilation rate, outdoor temperature and RH, and dehumidification rate (if a dehumidifier or air-conditioner is operating). The presence of a vapor retarder has only a minor effect on the building moisture balance and indoor humidity levels. In buildings without a basement, moisture storage affects short-term indoor humidity levels, but does not influence seasonal averages. Buildings with a basement may experience seasonal as well as short-term moisture storage effects.

REFERENCES

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