

and partly an operating problem. It is accomplished by reducing the interior dew-point temperature or by raising the surface temperatures that are below the dew-point, or both. The dew-point temperature may be lowered by giving attention to the sources of the moisture, and in winter, may be controlled by ventilation, or possibly by some moisture absorption process. The temperatures of the inside room surfaces in winter may be increased by adding insulation to outside walls, by double glazing of windows, by circulating warm air over the surface, or perhaps by direct heating of the surface. The most expedient method of overcoming a surface condensation difficulty will depend upon special conditions surrounding the problem.

VAPOR TRANSMISSION THROUGH MATERIALS

The condensation of moisture within buildings is not limited to visible surfaces. Vapor permeates through certain materials very readily and may penetrate exterior or cold walls and contact material therein having a temperature below the dew point of the vapor. At these places the vapor will condense to form liquid water or frost. Such concealed condensation may, if excessive, cause serious damage which is particularly insidious when it continues without detection. An accumulation of hidden condensation often causes great difficulty in long-range processes.

The principal mechanism by which water vapor passes through solid materials is a process of diffusion, the net transfer requiring a difference of vapor pressure. Various writers have suggested the possibility that adsorbed moisture (which is neither vapor nor liquid) moves from a region of high concentration to one of lower concentration without the benefit of a vapor pressure difference, but this action has not been conclusively demonstrated and probably is negligible in the problems here considered. The property of a material which enables it to transmit vapor is known as its vapor *permeability*. Other forces which play an important part are capillarity and gravity (when the vapor changes to liquid at any point in its path), and the hygroscopic adsorption of moisture (which, for many materials, is nearly proportional to relative humidity).

The term *permeability* has frequently been applied to the rate of vapor transmission for the thickness of the material considered or tested, but this use is not consistent with the use of *conductivity* (thermal) which relates to a property of the material based on unit thickness. It has been suggested² that the term *permeance* (similar to *conductance* in heat transfer) be used when referring to any specimen of definite thickness, or an assembly of such pieces. This recommendation is followed in this chapter. The term *permeability*, as used herein, defines a property of the material and is numerically equal to the permeance of a unit thickness.

The theory covering water vapor transmission through materials leads to the following formula,

$$W = MAT \Delta p \quad (1)$$

where,

W = total weight of vapor transmitted through the specimen, grains.

A = area of the specimen, square feet.

T = time during which the transmission occurred, hours.

Δp = the difference of the vapor pressure across the specimen, inches of mercury.

M = the permeance of the specimen, in perms, or grains per (square foot) (hour) (inch of mercury vapor pressure difference).

The basic units in Equation 1 are favored by the building industry. The designation *perm* for the unit of permeance has been proposed² as a convenient substitute for the unit, 1 grain per (square foot) (hour) (inch of mercury vapor pressure difference), and this recommendation is followed herein.

The weight of vapor transmitted is unquestionably proportional to area and time, but is not always proportional to the vapor pressure difference. Proportionality is a useful relation when applied with caution in a limited range, but the expression *per inch of mercury* does not sanction an unrestricted extension of this relation. In other words, the permeance of a specimen is not a constant under every condition. This fact must be considered but is generally not an obstacle in the solution of many practical problems.

Vapor resistance is the reciprocal of permeance, and theory indicates that the vapor resistance of a homogeneous specimen is proportional to its thickness. Permeance, therefore, is inversely proportional to thickness, and:

$$M = \frac{\mu}{t}$$

$$\text{or, } \mu = Mt$$

(2)

where,

M = the permeance of the specimen, perms.

t = the thickness of the specimen, inches.

As defined by Equation 2, μ is the permeability of the material or the permeance per unit thickness. Using consistent units, permeability is expressed in *perm-inches*, a perm-inch being equal to one grain per (square foot) (hour) (inch of mercury per inch of thickness.)

Equations 1 and 2 may be combined to give:

$$W = \mu AT \frac{\Delta p}{t} \quad (3)$$

where,

μ = the average permeability of the material. (The spot permeability in thin elements may be progressively different throughout the thickness.)

The overall vapor resistance of an assembly (like a wall) of materials in series is the sum of the resistances of its component parts provided condensation does not take place within the assembly. Expressed in the more usual terms, the permeances (M_1, M_2, M_3 , etc.) of the individual pieces may be combined by use of the formula

$$M = \frac{1}{\frac{1}{M_1} + \frac{1}{M_2} + \frac{1}{M_3} + \dots + \frac{1}{M_n}} \quad (4)$$

Equation 4 holds for materials that are reasonably homogeneous and in a condition of *steady state* where the transmission at all points is a vapor diffusion process as, for example, in a vapor transmission test. Actually, the conditions of moisture movement through a building wall are generally different. A steady state, where the entering and leaving moisture are equal, rarely exists, and frequently, the moisture in some portion of the path is liquid, in which case forces of capillarity and gravity are usually