quired to cover a range of conditions of both temperature and humidity.

Experience to date shows that the effect of temperature is quite moderate and, for some purposes, differences in temperature at which tests are run may be ignored. Corrections for temperature have been made with some success in the case of certain materials by the use of an equation based on activation energy[8] which states:

$$\mu = \mu_0 e^{-(E/RT)} \quad (8)$$

where, in appropriate units,

μ_0 = permeability at $T = \infty$.
R = gas constant.
E = activation energy.
e = Naperian base of logarithms = 2.718.
T = absolute temperature.

Applications of this equation may be limited to materials such as resins, rubbers, and polymers in which the water molecules enter and move through the molecular structure by a process known as activated diffusion. It may serve also as a useful approximation in other cases.

By use of Equation 8, spot permeability curves for a variety of temperatures can be constructed from a curve for one temperature, provided only that two tests at different temperatures can be run, from which E, the activation energy, can be evaluated. In this way it becomes possible to describe the permeability of a material with reasonable completeness from the results of as few as five single tests at carefully selected conditions.

No method has yet been found, other than by direct testing for a particular set of conditions, of predicting the effective permeabilities for conditions of temperature gradient along with a humidity (or vapor-pressure) gradient, from data obtained under other conditions, even though this is the general situation in practice. A very considerable amount of information is available on the permeances and permeabilities of various materials, but these are frequently obtained at different conditions so that the results cannot be compared directly, nor do they often give a coverage of a range of conditions to permit construction of basic curves of spot permeability or permeance.

Since dry-cup and wet-cup tests are much easier to carry out than tests at intermediate humidities, many of the data available have been obtained in this way. In the absence of data obtained from tests duplicating the conditions of temperature and relative humidity in service, the permeance of a piece of material may be judged adequately for many purposes if it is tested by both dry and wet methods. It is obvious that any statement of permeance of a specimen should include the conditions of test.

ASTM Designation E96 describes procedures for testing for water-vapor transmission of materials in sheet form under five different test conditions. These include the dry-cup and wet-cup methods, based on 50 percent relative humidity outside the cup, at either 73.4 or 90 F, and a fifth condition at an elevated temperature of 100 F with relative humidities of 0 and 90 percent on either side of the sheet. Standard T448m-49 of the Technical Association of the Pulp and Paper Industry covers the determination of water-vapor transmission of paper and paperboard, and calls for the dry-cup method at 73.4 F, based on 50 percent relative humidity outside the cup. *ASTM Designation* C355 covers tentative methods of test for water vapor transmission of materials used in building construction.

Unfortunately, there is no general agreement as yet to report results as coefficients of permeance, or of permeability

Table 2 .... Conversion Factors for Vapor Transfer Units

Multiply Number of → / *by* / *to Obtain* ↓		*WVT Units* grams / (24 hrs) (sq m)	*WVT Units* grains / (hr) (sq ft)
grams / (24 hr) (sq m)	by same method*	1	16.7
grains / (hr) (sq ft)	by same method*	0.0597	1
Perms by same procedure*	procedures A & B	0.144	2.41
	procedures C & D	0.0840	1.41
	procedure E	0.0344	0.575

Nominal Test Conditions ASTM E96		*% Relative Humidity on the Two Sides of Specimens:*	
Procedure	*Temperature-F*	*In cup*	*Outside cup*
A	73.4	0	50
B	73.4	100	50
C	90	0	50
D	90	100	50
E	100	0	90

* Data obtained by one procedure cannot be reliably converted to another procedure.

To convert $\frac{\text{grams}}{(24\text{ hr})(\text{sq m})(\text{mm Hg})}$ to perms multiply by 1.52.

where appropriate, as adopted in this chapter, or to use the same basic units. Test data are frequently reported in terms of weight transmitted per (unit time) (unit area). Such data may be called *water-vapor transmission data* or WVT data, and values are either high or low depending on the difference of vapor pressure chosen for the test. When this difference is known, WVT data can be converted to permeance, care being taken if conversion of the basic units (weight, area, and time) is also required. The following formula applies:

$$\text{Permeance} = \frac{\text{WVT rating}}{\Delta p} \quad (9)$$

where

WVT rating = weight of vapor transmitted, grains per (hour) (sq ft).
Δp = vapor-pressure difference in the test, in inches of mercury.

Permeance is expressed in perms.

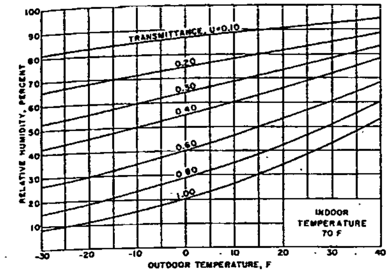
Table 2 presents the conversion factors applicable to the commonly used units and test methods. Table 1 presents some data on typical building materials showing, in each case, the source and method and, where applicable, the thickness tested.

It should be noted that a paper may be *water-proof*, i.e., possess water resistance, and still have low water-vapor resistance.

Water vapor barriers may be classified as structural, membrane, or coating barriers.

Structural barriers include rigid sheets, such as reinforced plastics, aluminum, stainless steel, and rigid insulation types which are relatively impervious to water vapor flow due to their physical structure and composition. These barriers usually are fastened in place by mechanical means, and have provision for vapor sealing at joints.

Membrane barriers include metal foils, laminated foil and treated papers, coated felts and papers, and plastic films or sheets. Such barriers are flexible and are supplied in roll form or as an integral part of a building material such as insulation. Accessory materials are required for sealing joints.



* See Chapter 24 for typical transmittance values.

Fig. 4 .... Relative Humidity at Which Visible Condensation Will Appear on Inside Surface

Coating barriers may be of the semi-fluid, mastic type, the fluid, paint type (arbitrarily called surface coatings), or the hot melt type. Their basic composition may be asphaltic, resinous or polymeric, with or without pigments and solvents as required to meet design conditions. Application may be by spray, brush, trowel, roller, dip or mop, depending upon the type of coating and surface on which it is to be applied.

VISIBLE CONDENSATION

Just as moisture collects on the outer surface of a glass of cold water, so does it also condense on other cold materials. In winter, visible condensation may collect on cold closet walls and attic roofs and is commonly observed on frosted window panes. Although condensation, if liquid, may enter an unpainted surface as fast as it forms and thus be unseen, any condensation on a visible surface will for convenience here be called *visible condensation* to distinguish it from *concealed condensation*. Within residences and public buildings, visible condensation in winter may damage decorative finishes and window sash.

Interior visible condensation occurs when any surface is colder than the dew point of the near-by air. The temperature of any such surface—wall, roof, or glass—is dependent upon the air temperature inside and outside the building and the heat transfer coefficient U of the surface structure. Based on a value of 1.65 for the inside surface conductance, Fig. 4 shows the relative humidity in a room at 70 F at which visible condensation will appear at various U values. The curves for single and double glass at their usual U values are included. It should be noted that U values as commonly used are an average for a large area within which there may be spots, such as the studs in an insulated wall, where the transmittance is higher. The inside surface temperature of a wall will, in general, be lower at the bottom due to such things as stratification of inside air and the effects of air leakage and of convection in walls with air spaces. Since condensation appears at any sufficiently cold spot, values from Fig. 4 can be applied only with caution. As a result, the limit of relative humidity for a non-homogeneous wall is lower than might be inferred from its average U value.

Normally, glass is the most likely spot in a heated room for appearance of condensation, but an uninsulated wall surface shielded from radiation by furniture, may be equally cold. In some cases where condensation is barely avoided, the surface, being but little warmer than the dew-point temperature, is exposed to moisture damage—such as swelling, mold or discoloration.

Visible condensation may also occur in summer. It is often seen on basement concrete walls and floors that are cooled by the earth. Being massive, they tend to hold a constant temperature from day to day while the weather dew-point temperature rises. When no water vapor is released in the space the dew point tends to equal that of the outdoors (though it is likely to lag when there is slight ventilation). At times the dew-point temperature rises above the temperature of walls and floors with resulting condensation. If the basement is decorated the trouble may be serious. As an operating problem, the solution may be to reduce ventilation at times of high weather dew point, to warm the walls, or to dehumidify the space. Warming the walls, a slow process at best, is generally accomplished in favorable climates by excess ventilation. In a climate having low temperature at night, it may be feasible to ventilate only at night and thus reduce the moisture content of hygroscopic materials which will then act as desiccants to retard the dew-point rise during the day. In basement walls and floors insulation should be applied in the concrete or on its outside. Insulation placed on the inside of such walls eliminates visible condensation but fosters concealed condensation. The control of the latter will be discussed. A practical and fully effective technique for such control has, however, not been developed. Usually, sub-surface dwellings designed for occupancy should be dehumidified.

A similar situation is seen in dwellings with concrete floor slabs laid on the ground where such slabs are not a part of the heating system. In a northern climate where high dew-point temperatures occur in summer, condensation or very high relative humidity may damage rugs which are themselves contributors to the trouble since they reduce the floor slab temperature. Slab floors above grade are not so serious a problem as floor slabs on grade but their response to air temperature change is slow. Faster warming is accomplished by the removal of rugs and abundant ventilation at proper times. In their design, floor slabs should have as low specific heat and as high thermal resistance as is consistent with other requirements. Suitable insulation below the slab, especially well-drained gravel, will help somewhat. A top surface cover of insulating value that is unaffected by water on its lower side would be desirable in the less favorable northern climates.

The avoidance of interior visible condensation is partly a construction 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.

CONCEALED CONDENSATION IN HEATED BUILDINGS

Water vapor produced in a building necessarily raises the vapor pressure above that outdoors thus providing the force that causes its diffusion into exterior walls. The amount of vapor-pressure rise in the building depends on the amount of vapor produced and inversely on its chance to escape.