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

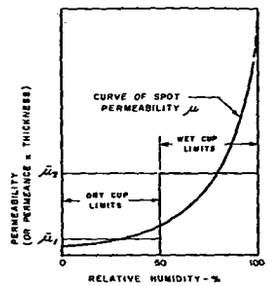

Fig. 3 .... Relation between Dry and Wet Cup Tests and the Spot Permeability for a Material such as Wood

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.

Method of test E96-53T of the American Society for Testing Materials 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 Standard* C355-54T 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 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 area) (unit time). 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:

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

where

WVT rating = weight of vapor transmitted, grains per (sq ft) (hour).

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.

Water-proofed building papers are listed in *Federal Specifications* UU-P-147, May 24, 1948, according to water-vapor resistance required as:

Class A. For uses where a high degree of water-vapor resistance is required.

Class B. For uses where a lower degree of water-vapor resistance and of water resistance is required.

Class C. For uses where a moderate degree of water-resistance is required.

Class D. For uses where low resistance to water vapor is required.

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

Detail requirements in these specifications are given as follows, the specified WVT Test being a dry method at 73 F.

Class A paper shall have a minimum tensile strength in each direction of either 35 lb per inch width, or 20 lb per inch width, as specified in the invitation for bids. Paper of both strengths shall have a minimum water resistance of 24 hr, and a maximum water vapor permeability (WVT) of 4 grams per (square meter) (24 hr) i.e. 0.576 perm.

Class B paper shall have a minimum tensile strength in each direction of either 35 lb per inch width, or 20 lb per inch width, as specified in the invitation for bids. Paper of both strengths shall have a minimum water resistance of 16 hr, and a maximum water-vapor permeability (WVT) of 6 grams per (square meter) (24 hr) i.e. 0.864 perm.

Class C paper shall have a minimum tensile strength in each direction of either 35 lb per inch width, or 20 lb per inch width, as specified in the invitation for bids. Paper of both strengths shall have a minimum water resistance of 8 hr.

Class D paper shall have a minimum tensile strength in each direction of 20 lb per inch width. The paper shall have a minimum water resistance of 10 min., a minimum water-vapor permeability (WVT) of 35 grams per (square meter) (24 hr) i.e. 5.04 perms.

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

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 hrs) (sq m)	by same method*	1	16.7
grains / (hr) (sq ft)	by same method*	0.0597	1
Perms by same method*	method A & B, 73.4 F	0.144	2.41
	method C & D, 90 F	0.0840	1.41
	method E, 100 F	0.0344	0.575

Nominal Test Conditions		% Relative Humidity on the Two Sides of Specimen:	
Method	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 method cannot be reliably converted to another method.

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

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 occur also in summer. It is often seen on basement concrete walls and floors that are cooled by the earth and which being massive, 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 fos-

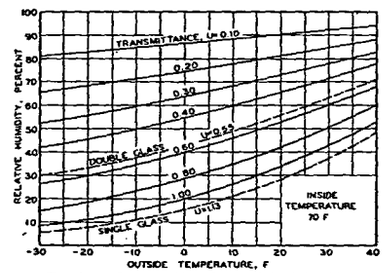

Fig. 4 .... Relative Humidity at Which Visible Condensation Will Appear on Inside Surface

ters 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 giv-