In the winter, visible condensation may collect on interior surfaces of windows, cold closet walls, or attic surfaces. Sometimes condensation occurs within cold sections of the structure, but is concealed and may not be evident until paint failure troubles develop, or framing eventually deteriorates.

In residences and public buildings, the surface condensation problem is usually more important from the viewpoint of its nuisance and deteriorating effect on the structure, than it is from the standpoint of addition to the cooling load. In cold storage plants and refrigerating processes, it often has a material effect on the structure, the cooling load and the operating efficiency. For residences and other similar buildings, condensation is usually dependent upon surface temperatures and upon the dew-point temperature of the air in contact with these surfaces.

For any set of temperature and humidity conditions there is a definite relation between the condensation possibilities and the thermal resistance of exposed parts of the structure. In Fig. 6 the limiting maximum inside relative humidities may be obtained for walls, roofs, or glass having transmission coefficients up to 1.2 Btu, with outside temperatures from −30 F to 40 F, and for 70 F inside temperature.

Vapor Transmission Through Materials

The condensation of moisture within buildings is not limited to visible surfaces such as wall surfaces and glass surfaces. Vapor will pass through certain materials very readily, and may penetrate into exterior or cold walls and come in contact with material within these structures having a temperature below the dew-point temperature of the vapor, and thus form moisture or frost within the wall. This moisture tends to accumulate over long periods of time without being observed. It is this accumulation of interior and unobserved condensation that causes the greatest difficulty in many long-range processes. The property of a material to transmit vapor is known as its *vapor permeability*.

The term *permeability* has usually been applied to the rate of transmission of moisture for the thickness of the material considered or tested, rather than for unit thickness. It has been suggested[16] that the term *permeability* be limited to a moisture transfer rate based on unit time, unit area, unit vapor pressure difference, and *unit thickness*, and that the term *permeance* (similarly to use of conductance in heat transfer) be used with other than unit thickness. This recommendation is followed in this chapter. The designation *Perm* as the unit of permeance having a value of one grain per (square foot) (hour) (inch of mercury vapor pressure across the specimen) has been suggested.[16]

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

$$W = \mu A\,(P_1 - P_2) \qquad (7)$$

where

W = total moisture vapor flow, grains per hour through the wall.
μ = permeance, grains per (hour) (square foot) (unit vapor pressure differential).
A = area of the wall, square feet.
P_1 = vapor pressure on the warm side of the wall, and
P_2 = vapor pressure on the other side of the wall, both in units consistent with the pressure units of the transmission coefficient.

The overall moisture transfer coefficient for a wall consisting of a combination of several materials in series may be calculated by combining the permeances (μ_1, μ_2, μ_3, etc.) of the individual materials according to the formula:

$$\mu = \frac{1}{\frac{1}{\mu_1} + \frac{1}{\mu_2} + \frac{1}{\mu_3} + \cdots \frac{1}{\mu_n}} \qquad (8)$$

In the application of Equation 8 it is assumed that the permeance is directly proportional to the vapor pressure drop between two different

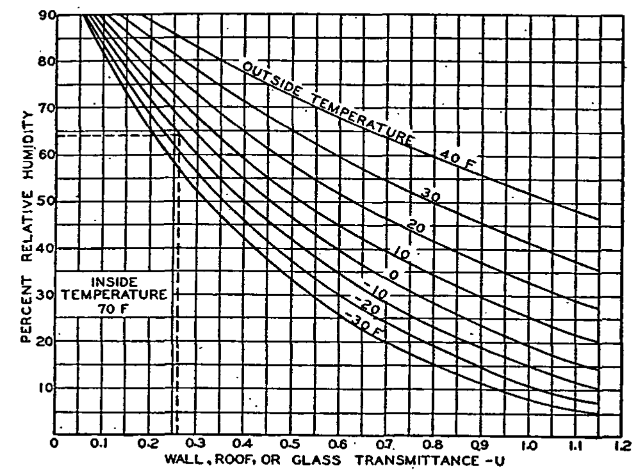

Fig. 6. Relative Humidities at Which Condensed Moisture Appears on Inside Surface
For Various Outside Temperatures and Values of Transmittance U Based on 70 F Inside Temperature

planes, and that the resistance to vapor is additive for several materials in series. This theory may apply so long as the vapor remains in the vapor state. In most cases, however, there is a change in temperature throughout the structure and the vapor may change to a liquid or even a solid, and thus completely change the mechanism by which it is transferred through the material. Furthermore, many materials are hygroscopic and vapor is absorbed somewhat in proportion to the relative humidity, and not directly proportional to the pressure of the vapor in contact with the material. A further point to be considered is that the vapor pressure or dew-point temperature drop per degree of temperature drop is much greater in high temperature than it is in low temperature ranges. Due to the uncertainties as to the exact mechanism for the transfer of vapor through various types of structures, the *application of a theory which parallels the theory of heat transmission should be used with caution.* The expression *per inch of mercury* does not imply that vapor transfer is proportional to vapor pressure difference.

There are several methods for determining the vapor permeance of materials. While a lengthy discussion of these methods cannot be undertaken here, it may be said that there is not complete agreement in the results