or condensing temperature, would be 80 F. In the second case, the vapor would be superheated and the dew-point, or condensing temperature, would be about 60.2 F. When the vapor in a space is cooled, either by contact with cold surfaces, or otherwise, to a temperature below its dew-point temperature, some of the vapor will be condensed and form either free water or frost, depending upon the temperature. In condensing, the vapor will give up heat and be deposited as either free water or frost, depending upon the condensing temperature.

Surface Condensation

If water vapor comes in contact with surfaces of materials which have temperatures below its dew-point temperature, condensation will take place. This process is seen in the accumulation of moisture on surface of a glass of cold water, or on cold water pipes. In cold storage systems con-

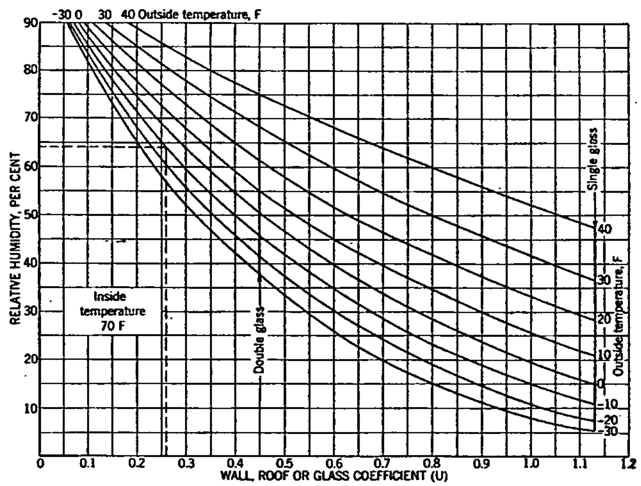

Fig. 5. Permissible Relative Humidities for Various Transmission Coefficients

densation occurs on the cooling surfaces. In the winter, condensation collects on interior surfaces of windows, cold closet walls or attic surfaces, and sometimes it occurs within cold sections of the structure. The extent of condensation in these places depends upon the surface temperature of the material and the dew-point temperature of the vapor in contact with these materials.

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 insulation of exposed parts of the structure. Limiting maximum relative humidities for walls, roofs or glass, having transmission coefficients up to 1.2 Btu for outside temperatures, from −30 F to 40 F, and for 70 F inside temperature, may be obtained from Figure 5.

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

$$W = \mu A\ (P_1 - P_2) \tag{7}$$

where

W = total moisture vapor flow, grains per hour through the wall.
μ = permeability, grains per (hour) (square foot) (unit vapor pressure differential).
A = area of the wall, square feet.
P_1 = vapor pressure on the humid 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 permeabilities (μ_1, μ_2, μ_3, etc.) of the individual materials according to the formula:

$$\mu = \frac{1}{\dfrac{1}{\mu_1} + \dfrac{1}{\mu_2} + \dfrac{1}{\mu_3} + \cdots \dfrac{1}{\mu_n}} \tag{8}$$

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

There are several methods for determining the vapor permeability of materials. While a lengthy discussion of these methods cannot be under-