of the permeance, and correspondingly, the over-all vapor resistance of an assembly (like a wall) of materials in series is the sum of the resistances of its component parts. The over-all permeance of the assembly may be found from the permeances of the individual components[3, 4] in a manner paralleling that used in calculating the over-all coefficient of thermal conductivity from the individual conductances:

$$M_t = \frac{1}{\left(\frac{1}{M_1} + \frac{1}{M_2} + \frac{1}{M_3} \cdots + \frac{1}{M_n}\right)} \tag{7}$$

This simple theory for vapor flow, as in the case of the corresponding

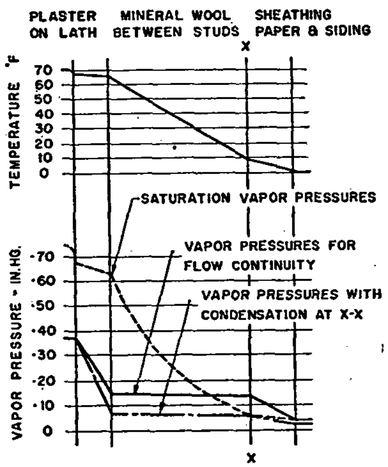

FIG. 2. TEMPERATURES AND VAPOR PRESSURES UNDER VAPOR FLOW CONDITIONS IN THE INSULATED FRAME WALL OF EXAMPLE 1.

simple heat-flow theory, assumes conditions of unidirectional, steady-state flow. Useful calculations can be made for an assembly or subassembly for which the inflow and outflow of vapor are equal (a condition at which no condensation occurs) if a permeance applicable to actual conditions can be assigned to each component part. Over-all permeances, vapor pressures and vapor flow can be calculated, and in conjunction with thermal calculations, relative humidities can be determined, and the imminence of condensation predicted. (See *Example 1*, and Fig. 2. See also Chapter 13, Cooling Load, for use of vapor-flow calculations.)

Example 1: A wood frame wall is exposed to inside conditions 70 F. and 50 percent relative humidity (0.37 in. Hg vapor pressure) and outside conditions 0 F. and 80 percent relative humidity (0.03 in. Hg vapor pressure). The wall consists of painted plaster on gypsum lath on the inside over 2 x 4 in. studs, mineral wool fill between studs, 1 in. wood exterior sheathing, paper, and pine lap siding. Check for possible condensation.

To simplify the example, consider the paint, plaster and lath as a single element having a permeance $M = 1.0$ perms and a thermal conductance $C = 2.4$, and the exterior sheathing, paper, siding and paint as another single element for which $M = 2.0$ perms and $C = 0.50$. From Table 1 the value for the permeability of mineral wool fill may be found as $\bar{\mu} = 116$ perm-inches. The thermal conductivity for mineral wool, $k = 0.27$.

Solution: In this particular wall, insulated, and with moderate warm-side relative humidities, condensation is unlikely to occur until the sheathing is reached. To check directly for condensation on the warm side of the exterior sheathing (designated as plane X − X in Fig. 2 for convenient reference) proceed as follows:

Calculate according to the method of Chapter 9 the temperature at plane X − X. This is found to be 9 F. The saturation vapor pressure at this temperature is 0.06 in. Hg. If condensation is imminent or occurring at X − X, the vapor pressure there will be 0.06 in. Hg. Calculate the permeance for the portion of the wall from the warm side to X − X, and the vapor flow rate to X − X as follows:

$$\text{Permeance of wall to X − X} = \frac{1}{\frac{1}{1.0} + \frac{3.625}{116}} = 0.97 \text{ perms.}$$

Vapor presssure drop to X − X = 0.37 − 0.06 = 0.31 in. Hg.

Vapor flow to X − X = 0.97 × 0.31 = 0.30 grains per (sq ft) (hr).

Calculate the vapor flow rate from X − X to outside as follows:

Permeance of wall from X − X to outside = 2.0 perms.

Vapor pressure drop from X − X to outside = 0.06 − 0.03
= 0.03 in. Hg.

Vapor flow rate to outside = 2.0 × 0.03 = 0.06 grains per (sq ft) (hr).

It is apparent that continuity of vapor flow is not possible, since at the highest vapor pressure at X − X permitted by the temperature, there is indicated a greater flow to plane X − X than from it to outside. Condensation is indicated at a rate of 0.30 − 0.06 = 0.24 grains per (sq ft) (hr).

Whether this condensation rate will be serious must still be decided, since it might readily be absorbed by the sheathing during the condensation period without excessive wetting. When the temperature at X − X is below freezing, as in this case, the condensation will be in the form of frost which may accumulate until released over a short period upon a rise in outside temperature.

Condensation will be reduced or avoided if the permeance of the warm side of the wall can be reduced so that the flow to X − X is limited to 0.06 grains per (sq ft) (hr). Permeance required for this is $\frac{0.06}{0.37 - 0.06} = 0.19$ perms or less. A more resistant paint film on the plaster, reducing the paint-plaster-lath permeance to 0.19 perms would accomplish this.

When the critical plane for condensation is unknown, or for a more informative graphical representation of the situation throughout the wall, temperatures and vapor pressures may be calculated and plotted as in Fig. 2. The vapor pressures throughout the wall, for continuity of flow, are calculated in a manner similar to the temperatures; the external vapor pressures are given, and the vapor pressure drops across each element are taken in proportion to resistance to vapor flow.

The curve for saturation vapor pressures at the various temperatures throughout the wall is also shown in Fig. 2 and is seen to fall below the curve for vapor pressures with continuity of flow, toward the outer portions of the wall. This indicates that with the given temperatures and vapor pressures, continuity of flow is not possible and that condensation will occur. Condensation on the sheathing is indicated as a definite possibility, and the new vapor pressure curve can be constructed for this condition, as shown. This new curve does not rise above the saturation-vapor-pres-