Moisture in building materials may have a marked effect upon the transmission of heat through them. It has been commonly assumed that moisture when present in a material will remain more or less stationary and will increase the conductivity largely by adding to the path available for heat flow. On this basis, the effect of moisture on heat flow can be accounted for quite simply by the use of suitable coefficients of conductivity in the usual heat-flow equations. The data presented in Chapter 9 on moist soils are of this type.

Evidence to date indicates, however, that in porous materials partially saturated with water there is likely to be a migration of moisture to the cold side under the influence of the temperature gradient. This can occur by a process of evaporation, vapor flow, and condensation within the material, a substantial amount of heat being transferred as latent heat of the vapor, particularly in the case of open fibrous materials. The transmission of heat through moist materials becomes complex whenever conditions are such as to produce any appreciable migration of the moisture, and, consequently, calculations by the usual heat-flow theory alone, are an approximation.

MOVEMENT OF MOISTURE IN MATERIALS

Moisture is caused to migrate in granular media or in porous solids by gradients in hydrostatic pressure, vapor pressure, capillary forces, concentration of salts, temperature, or electrical potential. Neither the various mechanisms nor the particular potentials involved are entirely unrelated. They are frequently combined in most complex ways not at all well understood. A temperature gradient in a moist material usually produces a vapor-pressure gradient with consequent vapor migration. Whether the temperature gradient is able to produce migration by other mechanisms is still being debated. There is a relationship between vapor pressure and capillary force, and with a condition of capillary-force gradient but uniform temperature, there will also be a vapor-pressure gradient. At high relative humidities small capillaries may be completely filled and larger capillaries partially filled, so that movement of liquid water may occur in combination with vapor movement. There is some evidence that under special conditions vapor movement and liquid movement through capillaries may occur simultaneously but in opposing directions.

VAPOR TRANSMISSION THROUGH MATERIALS

The equation presently used in calculating water-vapor transmission through materials is based on a form of Fick's Law, and is as follows:

$$w = -\mu \frac{dp}{dx} \tag{1}$$

where

w = weight of vapor transmitted through a unit area in unit time.
p = vapor pressure.
x = distance along the flow path.

and hence:

$\frac{dp}{dx}$ = vapor pressure gradient.
μ = permeability.

The close parallel with Fourier's equation for heat flow will be noted. The actual transmission of vapor through a material is extremely complex, so that the coefficient, μ, is not a simple one but is actually a function of relative humidity and temperature, and may vary along the flow path through the material in question.

Integrating Equation 1 from $x = 0$ to $x = l$ and from p_1 to p_2, and rearranging, the following is obtained:

$$w = \frac{\int_{p_1}^{p_2} \mu dp}{p_1 - p_2} \times \frac{(p_1 - p_2)}{l} \tag{2}$$

Let

$$\frac{\int_{p_1}^{p_2} \mu dp}{p_1 - p_2} = \bar{\mu} \tag{3}$$

Then,

$$w = \bar{\mu}\,\frac{p_1 - p_2}{l} \tag{4}$$

where

l = length of flow path (or thickness of material).

If Equation 1 had been integrated, assuming the coefficient μ to be independent of vapor pressure (and temperature) along the flow path, Equation 4 would have been obtained, but with $\bar{\mu}$ replaced by μ. The coefficient $\bar{\mu}$ is therefore an average permeability coefficient applicable to the varying conditions along the flow path of length l, while the coefficient μ is the *spot* or *differential* permeability.

Equation 4 may be rewritten and units assigned:

$$W = \bar{\mu} A \theta \frac{\Delta p}{l} \tag{5}$$

where,

W = total weight of vapor transmitted, grains.
A = area of cross-section of the flow path, square feet.
θ = time during which the transmission occurred, hours.
Δp = difference of vapor pressure between ends of the flow path, inches of mercury.
l = length of flow path, (or thickness of specimen), inches.

The basic units given are those now favored by the building industry. The permeability μ or $\bar{\mu}$ is therefore expressed in a unit of grains-inches per (square foot) (hour) (inch of mercury vapor pressure difference).

Whenever it is convenient to deal with a material of a stated or implied thickness other than the unit thickness to which μ or $\bar{\mu}$ refer, use may be made of the permeance coefficient M, where $M = \mu/l$. The designation *perm* for the unit of permeance is now widely used, and is a convenient substitute for the unit, 1 grain per (square foot) (hour) (inch of mercury vapor pressure difference).[2] The corresponding unit of permeability is *perm-inch*, since it is the permeance of unit thickness. The corresponding flow equation is:

$$W = MA\theta\Delta p \tag{6}$$

Resistance to vapor flow provided by a sheet or board is the reciprocal