where

$\overline{KE}$ = average kinetic energy, Btu per pound.
v = specific volume, cubic feet per pound.
$(h_v^{3/2})_{av}$ = arithmetic average of the 3/2-powers of all measured velocity pressures, inches of water at 60 F.

If the velocity pressure were uniform over the section, Equations 24 and 25 could be combined to give

$$\overline{KE} = \left(\frac{V}{13{,}430}\right)^2 \qquad (26)$$

But, it is interesting to note that if the velocity varies *parabolically* from zero at the walls to maximum at the center as it does in the case of purely viscous flow in a circular duct, *then the average kinetic energy is twice that given by* Equation 26.

Example 19. If 2000 cfm of air flow through an 8 in. diameter circular duct, find the average kinetic energy per pound of air.

Solution. The cross-sectional area of the duct is 0.349 sq ft; hence the average flow velocity is 5730 fpm. If the velocity were uniform over the section, the average kinetic energy would be $(5730 \div 13{,}430)^2 = 0.182$ Btu per pound. But it is more likely that the actual distribution of velocity would approximate that characteristic of viscous flow; hence the average kinetic energy would be more nearly $2 \times 0.182 = 0.364$ Btu per pound.

Gravitational Energy

The potential energy due to elevation Z (feet) above any convenient datum is simply $Z \div 778.3$ Btu per pound of fluid. In the case of moist air,

$$\overline{PE} = \frac{\overline{Z}\,(1 + W)}{778.3} \qquad (27)$$

where

$\overline{PE}$ = average potential energy, Btu per pound dry air.
$\overline{Z}$ = average elevation, feet.
W = humidity ratio, pound water per pound dry air.

Enthalpy

No further discussion of enthalpy is required. It may be well to emphasize, however, that enthalpies have been figured on the basis of one pound of dry air.

Heat and Shaft Work

Between any two sections 1 and 2 in an apparatus through which steady flow occurs, there may be heat *absorbed* from outside, ${}_1q_2$, Btu per pound of dry air, and shaft work *removed* to outside, ${}_1l_2$, Btu per pound of dry air. If heat is actually rejected to outside, ${}_1q_2$ is intrinsically negative; and if shaft work is actually put in from outside, ${}_1l_2$ is intrinsically negative.

Steady-flow Energy Equation

A complete energy accounting takes the form of Equation 28 which is usually referred to as the steady-flow energy equation.

$${}_1q_2 = (h_2 + \overline{KE}_2 + \overline{PE}_2) - (h_1 + \overline{KE}_1 + \overline{PE}_1) + {}_1l_2 \qquad (28)$$

where

${}_1q_2$ = heat *added* from outside *between* sections 1 and 2, Btu per pound dry air.
h_2 = enthalpy of the mixture *at* section 2, Btu per pound dry air.
$\overline{KE}_2$ = average kinetic energy *at* section 2, Btu per pound dry air.
$\overline{PE}_2$ = average potential energy *at* section 2, Btu per pound dry air.
h_1 = enthalpy *at* section 1, Btu per pound dry air.
$\overline{KE}_1$ = average kinetic energy *at* section 1, Btu per pound dry air.
$\overline{PE}_1$ = average potential energy *at* section 1, Btu per pound dry air.
${}_1l_2$ = shaft work withdrawn *between* sections 1 and 2, Btu per pound dry air.

In Equation 28 all quantities are *per pound of dry air*. If Equation 25 is used in computing average kinetic energy, the result will be in Btu per pound of dry air if v is taken as volume per pound of dry air. If Equation 26 is used, multiplication by $(1 + W)$ as in Equation 27 is required though this is a refinement seldom justified.

Thermodynamic properties of water at saturation are given in Table 2 for the range −160 to +212 F.

U. S. STANDARD ATMOSPHERE

The so-called U. S. Standard Atmosphere is an essential standard of reference in aeronautics and as such has become important to the air conditioning engineer who frequently has to simulate atmospheric conditions at high altitudes in connection with aeronautical research. In defining this standard it is first assumed that temperature T varies linearly with altitude Z above sea level, at any rate up to the lower limit of the isothermal layer at 35,332 ft. Thus,

$$T = T_0 - 0.0019812\,Z \qquad (29)$$

or

$$\frac{dT}{dZ} = -0.0019812 \text{ (degree Centigrade per foot)} \qquad (30)$$

The second assumption is the validity of the perfect gas laws, namely,

$$Pv = RT \qquad (31)$$

A horizontal disc of air having unit cross-sectional area (1 sq ft) and vertical thickness dZ (ft) weighs dZ/v (lb). This accounts for the difference of pressure dP (lb per sq ft) between the upper and lower faces of the disc; hence, using Equation 31

$$dZ = \frac{RT\,dP}{P} \qquad (32)$$

Equations 30 and 32 can be combined to eliminate Z and then integrated to obtain the relation between pressure and temperature, namely,

$$\frac{T}{T_0} = \left(\frac{P}{P_0}\right)^{0.1903} \qquad (33)$$

The values $T_0 = 288\,K$ and $P_0 = 29.921$ in. Hg are parts of the definition of the standard atmosphere.

Values of pressure and temperature are listed in Table 5 for altitudes in the standard atmosphere from −1,000 to 50,000 ft above sea level. Values for altitudes below the lower limit of the isothermal layer conform