converted to pressure units by fundamental calculations involving the specific gravity of the fluids used and the design principles involved.

MEASUREMENT OF AIR MOVEMENT

The problem of measuring air movement may be divided into three main parts: when confined in ducts, when circulating in free spaces, and when entering or leaving such space through openings such as grilles. Other gases might be measured by the same methods, but emphasis here will be on air measurements[5].

For determining the velocity, and therefore the volume of air flowing in a duct, such as in the test of a fan or a complete ventilating system, the Pitot tube as described in the A.S.H.V.E. Code[6] is probably most often used. At low velocities the velocity pressure head is so low that it becomes difficult to get accurate gage readings. The velocities used in many ducts are below the lower limit of determination with gages available. The relation between velocity and velocity pressure may be used to determine the range of gage required.

$$V = 1096.5 \sqrt{\frac{h_v}{d}} \tag{3}$$

where

V = velocity, feet per minute.
h_v = velocity pressure, inches of water.
d = density of air, pounds per cubic foot.

Air flow in a round duct is seldom uniform. In general, the velocity is lowest near the edges, and maximum at or near the center. In order to obtain higher velocities and more uniform flow across the measuring section, it is sometimes possible to reduce the duct to a smaller cross-section at the Pitot station by use of a long transition piece. In any case, a large number of readings along two diameters should be taken, with 20 being quite desirable. These should be taken at the centers of equal annular areas for correct determination of volumes[7]. For small pipes it is sometimes necessary to construct a Pitot tube smaller than the standard size. Such a small Pitot tube should be geometrically similar to the standard tube. Pulsating or disturbed flow will give erroneous results and every effort should be made to remove disturbances in the Pitot tube section.

Many forms of Pitot tubes other than the one described have been used and calibrated[8]. A double-ended tube, one end pointing down-stream, and one up-stream, is sometimes used for low velocities, but it should be carefully calibrated for accurate results[9]. A special form of this tube design consists of two straight ⅛ in. tubes soldered together, closed at

[5]For technical data refer to Fluid Meter Reports, Parts 1—1937, 2—1931, and 3—1933 (*American Society of Mechanical Engineers*).
[6]Loc. Cit. Note 2.
[7]Loc. Cit. Note 2.
[8]Technical Notes No. 546 (*National Advisory Committee for Aeronautics*, November, 1935).
[9]The Characteristics of Double Pitot Tubes, by F. R. Ingram, E. Diez-Canseco and L. Silverman (A.S.H.V.E. JOURNAL SECTION, *Heating, Piping and Air Conditioning*, November, 1942, p. 708).

the end, and with a 0.04 in. hole in each tube opposite the line of contact. This tube is useful in exploring velocities on exhaust inlets, such as on hoods placed around grinding wheels.

The rounded approach orifice or nozzle of the general type described in the A.S.H.V.E. Unit Heater[10] and Unit Ventilator[11] Codes is an accurate air measuring device. When it is well made, the coefficient closely approaches unity. The discharge from such a nozzle is uniform[12] and provides a good location for calibration of air velocity instruments[13].

The Venturi meter is like the nozzle except for the addition of a downstream transition section that reduces the pressure drop through the measuring apparatus.

The thin-plate square-edged orifice has a decided advantage over the nozzle and Venturi meter in cost. Its coefficient is approximately 0.60. The exact value depends on the location of the connections, the pressure drop, the diameter ratio of orifice to pipe, and the sharpness of the edge[14].

Another method of air measurement uses the thermal electric principle where by means of a measured amount of current, heat is put into the air stream. The temperature rise is measured, and with the specific heat of the air mixture known, the weight of air flowing may be calculated. Heat should be applied uniformly to the mass of air passing, and the small temperature difference must be determined accurately.

Air Currents in Free Spaces

One of the instruments useful in determining the velocity of air currents in free spaces is the Kata-thermometer. It is essentially an alcohol thermometer with a large bulb. The stem has two marks, one corresponding to 95 F, and the other 100 F. The instrument is heated in water above 100 F, then dried and the time in seconds required for it to cool from 100 to 95 when placed in the air current gives a measure of the non-directional velocity. It is important to wipe the Kata-thermometer dry before taking the reading. Each Kata has its own factor etched on the stem, and this factor must be used with its cooling formula or chart for obtaining the velocity. The Kata-thermometer is useful in exploring ventilated spaces to determine whether the proper air movement and distribution are being maintained. It is also used in determining the cooling power of the atmosphere, since it loses heat by radiation and convection when dry, and by radiation, convection, and evaporation when the bulb is equipped with a wetted cloth covering[15].

Another instrument for measuring low velocity air currents is the heated thermometer anemometer[16]. This consists of an ordinary mer-

[10]Standard Code for Testing and Rating Steam Unit Heaters (A.S.H.V.E. TRANSACTIONS, Vol. 36, 1930, p. 165).
[11]Standard Code for Testing and Rating Steam Unit Ventilators (A.S.H.V.E. TRANSACTIONS, Vol. 38, 1932, p. 25).
[12]Discharge Coefficients of Square Edged Orifices for Measuring the Flow of Air, by H. S. Bean, E. Buckingham and P. S. Murphy (*Bureau of Standards Journal of Research*, Vol. 2, 1929, p. 561).
[13]A.S.H.V.E. RESEARCH REPORT No. 1140—The Use of Air Velocity Meters, by G. L. Tuve, D. K. Wright, Jr. and L. J. Seigel (A.S.H.V.E. TRANSACTIONS, Vol. 45, 1939, p. 645).
[14]Flow Measurement by Nozzles and Orifice Plates (*A.S.M.E.* Power Test Codes, Chapter 4 of Part 5, 1940).
[15]Temperature, Humidity and Air Motion Effects in Ventilation, by O. W. Armspach and Margaret Ingels (A.S.H.V.E. TRANSACTIONS, Vol. 28, 1922, p. 103).
[16]The Heated Thermometer Anemometer, by C. P. Yaglou (*Journal Industrial Hygiene and Toxicology*, Vol. 20, October, 1938, No. 8).