difference between the element and the stream becomes a measure of velocity by calibration. In the *hot-wire anemometer*, a very fine heated wire is employed as a resistance-thermometer element whose temperature may be determined accurately.[23, 24, 25] In the *heated-bulb thermometer* type, a heating wire is wound around the bulb of a mercury-in-glass thermometer, and the temperature difference between this thermometer and a similar unheated one serves as an index of air speed.[26] The *heated-thermocouple anemometer* is calibrated to give velocity in terms of the differential *emf* between heated and unheated thermo-junctions exposed to an air stream.[27, 28] Combined measurements of air temperature and velocity are particularly useful for air distribution studies, and automatic recording potentiometers or resistance-thermometer devices facilitate spatial traverses. A correct calibration of thermal anemometers requires consideration of the effects of temperature, humidity, and pressure upon the air properties which influence convective heat transfer.[27] With sensing elements of simple shapes for which convection data are known, thermal anemometers may be designed, both thermally and electrically, for desired characteristics. Directional sensitivity is controllable. Thermal anemometers are convenient and practical for low velocities.

Cup Anemometer

The cup-type anemometer is almost universally used for measuring wind speeds. It consists of three or four hemispherical cups mounted radially from a vertical shaft. Wind from any point of the compass will cause the cups and shaft to rotate. The instrument is usually so constructed that wind speeds may be recorded or indicated electrically at some remote point.

Measurement of Velocities at Inlets and Outlets of Ducts

In the field it is often desirable to make volume measurements at the face of the supply openings. For accuracy, the instrument and its application should be checked on a similar approach and grille in the laboratory before use in the field.

Tests have shown that the propeller-type anemometer can be used successfully on most of the common types of supply grilles.[29, 30] The core area is divided into equal squares, and the anemometer is held against the face of the grille for the same length of time in each. To obtain the air volume in cubic feet per minute, the average corrected velocity in feet per minute thus obtained is multiplied by the average of the gross and net free area of the grille (core) in square feet.

On exhaust openings, the anemometer traverse is made as described previously. The air volume may be determined by multiplying the corrected velocity in feet per minute by the gross core area of the grille in square feet, and by a coefficient for average conditions of 0.85.[30]

When a propeller-type anemometer is held in a stream of varying velocities, it tends to indicate higher than the true average, that is, the speed of the propeller is nearer to the top velocity in its area than it is to the minimum velocity. This is the main reason for the large difference in ratings of unit ventilators by the anemometer method, and by air volume measurements in a duct approach to the inlet.[31]

Deflecting vane anemometers can be also used within their range at the face of supply grilles when properly applied. In principle, it is a case of finding the velocity at many points, and using the average thus found with the correct discharge area at that cross-section. The deflecting vane anemometer equipped with a jet on the end of a rubber tube has been found especially convenient and accurate on supply grilles.[32] On modern air conditioning grilles, the core area is used without a correction coefficient when the jet is held one inch away from the face of the grille. At this distance, the constriction due to the thin bars has disappeared, since the small air jets have reunited and the air stream has not yet spread beyond the core dimensions. With deflecting grilles the exploring jet should be turned to the angle giving a maximum reading. With suitable traversing tips and calibration, this instrument may also be used on exhaust grilles if proper grille factors are applied.[33] Those contemplating such measurements should consult the references cited.

MEASUREMENT OF AIR CURRENTS

The measurement of air current velocities within an enclosed space is usually a tedious undertaking. However, useful data can be obtained with any of several instruments now available, if they are maintained in calibration, and the user understands their operation and limitations.[34] Thermal-type anemometers, when calibrated for low air velocities, are well suited for this service.

The Kata Thermometer

Another instrument useful for studying air currents in free spaces is the Kata thermometer. This is essentially an alcohol thermometer with a very large bulb, and with only two scale divisions etched on its stem. On the *Low Kata* these divisions are 95 and 100 F; on the *High Kata* they are 125 and 130 F. In use, the instrument is heated, usually in a water bath, until the alcohol has risen sufficiently above the upper calibration on the stem. It is then thoroughly dried, and placed at the point at which the air velocity is to be measured. The time in seconds required for the temperature to drop from the upper to the lower scale division is observed. From this cooling time and the calibration factor inscribed on each Kata thermometer, the air velocity can be calculated or determined from a chart. The Kata thermometer 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.[35] To minimize the effect of radiation, the Kata thermometer is also made with a silvered bulb.

Smoke is a qualitative tool which is very useful in studying air movements. Satisfactory smoke can be obtained from titanium tetrachloride (which, however, is very irritating to nasal membranes) or by mixing potassium chlorate and powdered sugar (a nonirritating smoke) and firing the mixture with a match. This latter process evolves considerable heat, and it should be confined in a pan away from flammable materials. The titanium tetrachloride smoke lends itself to spot determinations, particularly for leakage through casings and ducts, as it can be easily handled in a small pistol-like ejector. The fumes of aqua ammonia and of sulfuric acid, if permitted to mix, form a white precipitate which is useful for some purposes. Two bottles, one containing ammonia water and the other acid, are connected to a common nozzle by means of rubber tubing. Air is forced over the surfaces of the liquids in the bottles by means of a syringe, and the two streams, upon mixing at the nozzle, form a white cloud.

A satisfactory test smoke may also be made by bubbling an air stream through ammonium hydroxide and then through muriatic acid.[36] Smoke tubes, smoke candles, and smoke bombs are available for studying airflow patterns.

Infiltration or Air Change Measurement

The total air leakage into an existing building caused by wind and temperature difference forces can be determined with considerable accuracy by determining the decrease in concentration of a tracer gas. Hydrogen and helium have both been used rather successfully as tracer gases in conjunction with a sensitive thermal conductivity comparator.[37, 38] About one percent of tracer gas by volume is introduced into the room or building, and the tracer gas is thoroughly mixed with the air. The decrease in concentration of the tracer gas is observed at regular time intervals with a thermal conductivity meter as infiltration dilutes the mixture. The following formula is used to calculate the infiltration from the observed concentration measurements:

$$C = C_o e^{-\frac{kt}{v}} \tag{5}$$

where

C_o = initial tracer gas concentration, percent.
C = concentration of tracer gas after t minutes, percent.
v = volume of room or building, cubic feet.
k = infiltration rate, cubic feet per minute.
e = 2.718.

Closets and cupboards should be left open during such infiltration tests so the entire space will have the same rate of change of tracer-gas concentration.

HUMIDITY MEASUREMENT

Psychrometers

Any instrument capable of measuring the humidity or hygrometric state of the air is a hygrometer. A psychrometer is a particular kind of hygrometer which consists of two mercury thermometers, one of which has a cloth wick or *sock* applied to its bulb. For use, the wick is wetted with distilled water and ventilated with air moving at a recommended rate of 900 fpm or more, relative to the instrument.[39] In the simpler and more common type, known as the sling psychrometer, the two thermometers are mounted side by side on a frame fitted with a handle by which the device can be whirled through the air. The motion is arrested for reading the thermometers, and continued until the thermometer readings become steady. Due to evaporation, the wet-bulb thermometer will indicate a lower temperature than the dry-bulb thermometer, and the difference is known as the wet-bulb depression. Charts and tables are available showing the relation between the thermometer readings and the humidity.[39, 40, 41] Data are usually based on a total pressure of one standard atmosphere. For precise work, a correction is necessary for barometric pressure and is usually made by multiplying the observed relative humidity by the ratio of the observed to the standard atmospheric pressure.

For air temperatures below 32 F, the water on the wick may either freeze or supercool, and its state must be known and a proper table or chart used, since the wet-bulb temperature is different for ice and for water. Some operators remove the wick from the wet-bulb for freezing conditions and dip the bulb in water a few times, allowing the water to freeze on the bulb between dips and to form a film of ice. Since wet-bulb depression is slight at low temperatures, precise temperature readings are essential.

In the ventilated or aspirated psychrometer, the thermometers remain stationary, and a small fan or blower or a syringe is used to move the air across the thermometer bulbs. Various designs have been employed in the laboratories, and several commercial models are available.

The Dew-Point Hygrometer

In the usual form of these instruments, means are provided for cooling, and observing the temperature of, a surface which is exposed to air. The temperature at which visible condensation occurs on the surface is considered the dew point of the air. With the dew-point temperature known, the relative humidity and other properties of the air can be determined from tables and charts (See Chapter 3). A bright surface or metallic mirror is usually employed to improve the visibility of the dew deposit, and various means are used to cool the mirror from the back, including evaporation of ether or another refrigerant, or a stream of air passed through dry ice. Dew-point temperatures, in some cases, are observed by means of thermometers in fluids in contact with the back of the mirror, but in modern instruments thermocouples are used, and are soldered or welded to the mirror itself. The dew-point apparatus is not so commonly used as the psychrometer, probably because it is less convenient. It is usable, however, for higher temperatures than the wet- and dry-bulb psychrometer, and should be considered for dew points near or above the boiling point, as in the case of flue gases. Special apparatus for high precision has been constructed, in which the photronic cell and a light source are used for dew or frost detection instead of visual inspection.

Organic Hygrometers

Many organic materials change in dimensions with changes in humidity and this action has been utilized in a number of simple and effective humidity indicators, recorders, and controllers. See also Chapter 43 Automatic Control. Motion caused by the changes in dimension, through a suitable linkage, causes a pointer to move across an indicating dial, moving a pen across a recording chart, or actuating a pneumatic or electric control mechanism.

Common organic materials employed are human hair, animal membrane, animal horn, wood, and paper. Unfortunately, although the field has been well explored, no organic material has been found which can be relied upon to consistently reproduce its action over an extended period of time. Such devices require initial calibration and frequent recalibration or setting, especially if they are exposed to extremes of either high or low humidity. In spite of this they are highly useful because they read directly in terms of humidity, they are simple and inexpensive by comparison with most other types, and the inconvenience of recalibration is often less than that of providing distilled water and servicing the wicks of wet- and dry-bulb psychrometers.

Electrolytic Hygrometers

The dampness, and therefore the electrical resistance of a salt film, varies with the humidity of the atmosphere to