which the film is exposed, and at least two types of instruments based on this fact have been developed. The Dunmore hygrometer was originally designed for use in radiosondes or small balloons, and means were devised whereby the device transmits humidity data back to earth in the form of a radio signal. In the more usual form, this hygrometer consists of a dual winding of small wire on a nonconducting tube. The whole is coated with an electrolytic film, usually containing a salt such as lithium chloride, which forms an electric connection between the windings. Means are provided for determining the electrical resistance of the film, which is an indication of the humidity. In the radio-sonde, variations in the resistance of the film affect the frequency of an oscillating circuit. These hygrometers are usually calibrated by comparison with a wet- and dry-bulb psychrometer. For calibration for some purposes, particularly for use at subzero temperatures, means have been provided for producing atmospheres of known humidity.[illegible] Advantages of instruments of this type for some scientific and industrial purposes are becoming apparent, and some forms of them are on the market.

The Weaver-type hygrometer is particularly useful for determining the humidity of air or other gas in pipes or closed vessels at various pressures and temperatures. It consists of a threaded plug carrying a central electrode insulated from the plug, except for a gelatinous electrolytic film. The film is exposed to the air or gas from the pipe or vessel, and provision is made for determining its electrical resistance. The hygrometer, or detector, is mounted in a manifold equipped with valves whereby the film can be alternately exposed to the test gas, and to a standard gas having a known absolute humidity. The pressure of the standard gas is varied until contact with it establishes the same resistance in the film as the test gas, and the humidity of the test gas is then determined by computation based on the gas laws.

Chemical Hygrometry

The humidity of an atmosphere can be measured directly by extracting and weighing the water vapor from a known sample. For precise laboratory work, powerful desiccants such as a sulfuric acid and phosphorus pentoxide are used for the extraction process, while for some purposes, calcium chloride, lithium chloride, or silica gel are satisfactory. Freezing the water vapor out of a measured stream of air or gas with solid carbon dioxide, and weighing the resulting ice, is a similar operation. A thermal conductivity method for gas analysis can be used for temperatures above 212 F, or for very low humidities.[illegible]

MEASUREMENT OF MEAN RADIANT TEMPERATURE

Because if its effect on human comfort, it is sometimes desirable to measure the radiation exchange between a person and his surroundings. The radiant environment of a space is usually expressed in terms of its mean radiant temperature (MRT), which is defined in Chapter 1.

The Vernon globe thermometer[illegible] is commonly used to measure mean radiant temperature. This instrument consists of a 6-in. diameter hollow copper sphere coated with flat black paint and having a thermocouple or thermometer bulb at its center. The temperature assumed by the globe at equilibrium is the result of a balance between the heat gained or lost by radiation and the loss or gain by convection. In terms of heat-transfer relationships:

$$T_w^4 = T_g^4 + 0.103 \times 10^9 \sqrt{V}\,(t_g - t_a) \qquad (8)$$

where

T_w = mean radiant temperature, Fahrenheit absolute (black-body equivalent).
T_g = globe temperature, Fahrenheit absolute.
V = air velocity, feet per minute.
t_g , t_a = globe ambient air temperature, Fahrenheit.

It will be noted from the above equation that the air temperature and the air velocity around the globe must also be determined. It is the velocity measurement which presents the greatest problem in the use of the globe thermometer.

A *two-sphere radiometer*[illegible] has recently been developed which may be used for the measurement of MRT. This instrument utilizes two spheres approximately 2 in. in diameter, one of which is gold-plated, and the other black. The two spheres are heated electrically to the same temperature, thus eliminating differences in convection. The difference in energy required by the two spheres to maintain temperature equilibrium is measured, and from this difference, the MRT of the space may be calculated.

Several instruments have been developed to evaluate the combined effect of radiation and convection on human comfort. Among these are the eupatheoscope[illegible] and the thermal integrator.[illegible]

HEAT TRANSFER THROUGH BUILDING MATERIALS

Thermal Conductivity

The thermal conductivity (k value) of an insulation, as defined in Chapter 9, is a unit heat-transfer factor. Practically universally accepted for the conductivity determination of flat insulation is the guarded hot plate, which is described in ASTM test method C-177.[illegible] In its simplest form it consists of an electrically heated plate and two water-cooled plates. Two identical specimens or slabs of a material are required for a test, and one is mounted on each side of the hot plate. A cold plate is then pressed against the outside of each specimen by a clamp screw. The heated plate is divided into two portions: the central or measuring section, and the outer or guard section. During tests the two sections are maintained as nearly as possible at the same temperature. The purpose of the guard section is to minimize errors due to edge effects. The electric energy required to heat the measuring section is carefully observed and converted to Btu per hour. From this heat quantity, the area of the test section, the temperature gradient, and the specimen thickness, the thermal conductivity of the material can be calculated. Hot plate apparatus accommodating specimens on the order of one foot square and an inch or more thick is common. The apparatus at the National Bureau of Standards takes specimens 8-in. square, while plates as large as 3-ft square have been used. The thermal conductivity of cylindrical or pipe insulation (Chapter 27) is determined in a similar manner except that an equivalent thickness must be calculated to account for the cylindrical shape.[illegible]

Recently there has been considerable development of transient state conductivity apparatus utilizing a slender probe.[illegible] These instruments are commercially available and have the advantages of rapidity and requiring a small test specimen. While useful as research and development tools, the probe has not been generally accepted as have the guarded hot plate and pipe insulation apparatus.

Wall Conductances

The thermal conductances (C values) of many walls can be satisfactorily estimated from the conductivities of their components and their dimensions, but some walls are complicated by the inclusion of metal, for instance, and tests for conductance are required. The apparatus is required to accommodate large specimens representing actual construction. The guarded hot box apparatus was developed for this purpose. Test specimens for the apparatus at the National Bureau of Standards are 5 ft long and 8 ft high, while others require different sizes, some larger, others smaller.

The guarded hot box is described in the *ASTM Standard Test Code for Built-up Sections* C-236-54T.[illegible] The apparatus consists essentially of three boxes: a cold box, cooled by a refrigerating machine; a hot box, heated electrically; and a metering box also heated electrically. Each box has an open side to be placed against the specimen. The cold box is clamped against one side of the specimen, and the hot box against the other. The hot box encloses the metering box and is kept at the same temperature to minimize heat exchanges to or from the metering box, except through the specimen. The electric energy necessary to heat the metering box is measured, converted to Btu per hour, and divided by the area and the temperature difference through the wall, from surface to surface, to yield the conductance of the wall. The transmittance or U value of the wall is then computed by means of the surface coefficients from Chapter 9.

A heat-flow meter is sometimes useful for measuring steady heat flow through a wall or other building member.[illegible] In essence, this meter consists of a plate or slab of material of known thermal resistance having attached thermocouples on both sides. For use, the device is pressed against or cemented to the wall to be tested. At steady state, the temperature difference through the slab, measured with the thermocouples, with the known thermal resistance of the slab, indicates the heat flow through the slab and hence, through the wall covered by it. For best results, such meters are calibrated by means of a guarded hot plate or other suitable apparatus. The chief precaution is to assure that the heat flow is steady at the time of measurement.

COMBUSTION ANALYSIS

There are two approaches to the problem of measuring the capacities of fuel-burning devices, such as boilers and furnaces. The direct or calorimetric test consists in measuring the change in enthalpy or heat content of the fluid, air or water, heated by the device and multiplying by the flow rate in pounds per hour to arrive at the capacity in Btu per hour.[illegible] The indirect test consists in determining the heat lost in the flue gases and deducting it from the heat evolved by combustion of the fuel.[illegible] A heat balance consists in the simultaneous application of both tests to the same device. The indirect test almost invariably indicates the greater capacity, and the difference is credited to radiation from the boiler or furnace casing and *unaccounted for loss.*

In the case of some small equipment, the expense of the direct test is not considered justifiable, and the indirect test is relied upon with an arbitrary *radiation and unaccounted for* factor.[illegible]

Flue-Gas Analysis

The Orsat apparatus is commonly used for analyzing flue gases. In its ordinary form, it consists of three pipettes and a means for isolating a sample of flue gas in a graduate. After measuring, the sample is expelled from the graduate into the first pipette where the carbon dioxide is extracted by potassium hydroxide. The sample is then remeasured and successively passed into the second and third pipettes, where the oxygen and the carbon monoxide are respectively extracted by potassium pyrogallate and cuprous chloride.

For field testing and burner adjustment, simpler portable devices are available for carbon dioxide determination only. From curves, based on typical hydrogen content of several common fuels, efficiencies may be estimated from the carbon dioxide value obtained. More elaborate laboratory equipment is sometimes provided for precise determination of carbon monoxide content by burning the carbon monoxide to carbon dioxide in presence of a catalyst.[illegible] In large plants, carbon dioxide recorders are used to obtain a continuous indication of the plant's efficiency.[illegible]

SMOKE DENSITY MEASUREMENTS

Ringelmann charts are widely used for evaluating the density of smoke discharged from chimneys or stacks, and smoke ordinances are based on them in some cities. Each chart is composed of a series of crossed black lines on white paper which, at a distance of about 50 ft, is visually compared with the smoke under observation. Four charts are used with different degrees of blackness as shown in Table 1. The smoke density is specified by Ringelmann numbers from 1 to 4.

Table 1 .... Ringelmann Smoke Chart Spacings

Number of Card	Thickness of Lines, mm	Distance in Clear Between Lines, mm
1	1.0	9.0
2	2.3	7.7
3	3.7	6.3
4	5.5	4.5

The photoelectric cell is used in some apparatus developed for smoke density recording in large plants. The same device is included in the testing equipment for domestic oil burners described in *National Bureau of Standards, Commercial Standard* CS75-42.[illegible] Under Laboratory Tests this publication contains the following section: "Smoke Determination.—After combustion has reached equilibrium, the amount of smoke in the flue gases, when viewed lengthwise through 4 feet of the smoke pipe in accordance with the *Underwriters' Laboratories, Inc., Standard for Domestic Oil Burners* (Subject 296), March 1934 and subsequent revisions, shall not reduce the output of a standard photoelectric cell from 9 microamperes, with a clear smoke pipe, to less than 8 microamperes." The Commercial Standard also requires that during a test after installation, the burner shall operate without visible smoke at the chimney top.

A method of evaluating smoke produced by pot-type oil