

rooms, taking radiant as well as convective effects into account. Prominent among these are the eupatheoscope, the globe thermometer, the thermal integrator and the heated globe.^{54, 55}

Shielded Thermometer

In the presence of high radiant heat, an unshielded thermometer may give an erroneously high reading of air temperature. The error is minimized by using a whirling psychrometer since, with the considerable rotating velocity of the bulb, there is a high convection coefficient and the absorbed radiant heat will be given up with only a small excess temperature over that of the surrounding air. An aspirating psychrometer, with the thermometer bulbs enclosed in bright metal tubes, will also read the air temperature with minimum error. A simple shielded and ventilated thermometer may be employed. This consists of an ordinary thermometer with its bulb immersed in an aluminum tube attached to the inlet of a small motor-driven fan (such as a drug-store model hair dryer). The aluminum tube shields the thermometer against direct thermal radiation and ventilation minimizes temperature rise within the tube.

Mean Radiant Temperature

For adequate assessment of heat exposures around hot furnaces, molten metal and other sources of radiant heat, the mean radiant temperature (MRT) of the surroundings as well as the ambient air temperature, is required. A simple device for estimating mean radiant temperature is the Vernon globe thermometer, consisting of a 6 in. diameter hollow copper sphere, coated with flat black paint and containing a stem thermometer with its bulb at the center of the sphere. In the presence of significant radiant heat, this instrument, after reaching equilibrium, will indicate a temperature above that of the air. This excess temperature is such that the radiant heat gain by the sphere is just balanced by the convective heat loss. In terms of heat transfer relationships:

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

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.

Thus, the mean radiant temperature can be calculated from the readings of globe temperature, air temperature and air velocity. Commonly, about twenty minutes are required for the globe thermometer to reach equilibrium.

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.⁵⁶ 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.⁵⁷ 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.⁵⁷

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.

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

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.^{58, 59} In large plants, carbon dioxide recorders are used to obtain a continuous indication of the plant's efficiency.⁶⁰

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.

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 CS75-42.⁶¹ 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 burners was developed for the *Institute of Cooking and Heating Appliance Manufac-*