than lost heat. They may, therefore, be omitted from calculations of heat losses, or added to item 1. If there is CO in the flue gases, small amounts of unburned hydrogen and hydrocarbons will probably also be present. The small losses due to incomplete combustion of these latter gases would also be included in item 7.

Symbols used in Equations 12 to 16 inclusive are:

- h_1 = heat loss in the dry chimney gases, Btu per pound of fuel.
- h_2 = heat loss in water vapor from combustion of hydrogen, Btu per pound of fuel.
- h_3 = heat loss in water vapor in combustion air, Btu per pound of fuel.
- h_4 = heat loss from incomplete combustion of carbon, Btu per pound of fuel.
- h_5 = heat loss from unburned carbon in the ash, Btu per pound of fuel.
- w_g = weight of dry flue gas per pound of fuel (from Equation 10), pounds.
- c_p = mean specific heat of flue gases at constant pressure (c_p ranges from 0.242 to 0.254 for flue gas temperatures from 300 F to 1000 F),[3] Btu per pound.
- t_g = temperature of flue gases at exit of heating device, Fahrenheit.
- t_a = temperature of combustion air, Fahrenheit.
- H_2 = percentage of hydrogen in fuel by weight from ultimate analysis of fuel burned.
- 1091.8 = enthalpy of saturated water vapor at a temperature of 70 F, Btu per pound.
- M = humidity ratio of combustion air, pounds of water vapor per pound of dry air.
- w_a = weight of combustion air per pound of fuel used, pounds, from Equations 2, 4, 5, 6, 7 and 8.
- CO, CO_2 = percentages of CO, CO_2 in flue gases by volume.
- C = weight of carbon burned per pound of fuel corrected for carbon in ash, pounds.

$$C = \frac{WC_w - W_a C_a}{100W} \qquad (17)$$

where

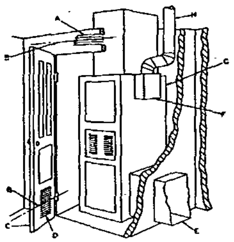
- C_w = percentage of carbon in the fuel by weight from the ultimate analysis.
- W_a = weight of ash and refuse, pounds.
- C_a = percent of combustible in ash by weight (combustible in ash is usually considered to be carbon).
- W = weight of fuel used, pounds.

Flue-gas losses for solid and liquid fuels, listed as items 2, 3 and 4 of the heat balance, may be determined with sufficient precision for most purposes from curves shown in Fig. 4,[3] if CO_2 content and temperature of flue gases are known. Values of the losses plotted for fuel oil were computed from the ultimate analysis of a typical fuel oil used in domestic burners, while those presented for the several ranks of coal were computed from the typical ultimate analyses shown in Table 1. The curves for medium-volatile bituminous coal may be used for high-volatile bituminous coal with negligible error.

Utilization of gaseous fuels, for numerous reasons, is generally a more simple process than is the case with either solid or liquid fuels. Accordingly, the determination of a practical heat balance is also a more simple procedure in that items 5 and 6 do not generally apply to gas installations. A series of typical alignment charts is combined in Fig. 5

Table 10 .... Average Flue Gas Dew Point for Various Fuels[a]

Type of Fuel	*Average Dew Point Temperature, F*
Anthracite	68
Semi-Bituminous Coal	84
Bituminous Coal	93
Oil	111
Natural Gas	127
Manufactured Gas	137
Propane Gas (2500 Btu/cu ft)	119
Butane Gas (3200 Btu/cu ft)	124
Butane-Air Gas Mixture (535 Btu/cu ft)	121



A. Ventilating air outlet register for appliance room, 1 sq in. free area for each 1000 Btu per hr appliance input located above relief opening of draft hood. Register must not be blocked by drapes or other furnishings.

B. Both registers must either face same large ventilated interior space or extend to such space by means of ducts. Vertical distance C/L to C/L of registers should be not less than 3½ ft.

C. Suggest room access door be not less than 6 ft high by a width sufficient to provide for installation or removal of appliance. At least 2 ft horizontal clearance should be provided in front of appliance when closet door is open, or 18 in. when door is closed.

D. Combustion and ventilation air inlet register for appliance room, 1 sq in. free area for each 1000 Btu per hr appliance input, located at or below combustion air inlet to appliance. Register must not be blocked by drapes or other furnishings.

E. Air circulated by appliance must be handled by ducts which are sealed to appliance casing and are entirely separate from means provided for supplying combustion and ventilation air.

F. Spacing between draft hood and wall at least 6 in. (unless approved for closer spacing). If flue products may be directed toward wall, 12 in. spacing recommended.

G. No part of appliance casing closer than 6 in. to wall (unless approved for closer spacing).

H. Flue should terminate above peak of roof and above nearby walls to assure satisfactory flue performance.

Fig. 6 .... Illustration Showing Air Openings Necessary to Supply Air for Combustion When Appliance is Installed in Confined Space

for use in determining flue losses of items 2, 3 and 4 from common types of gas burning appliances. To determine flue losses place a straight edge extending from the corrected temperature reading to the percent CO_2 recorded. Percent flue loss is indicated where the straight edge intersects the flue loss column. The operating efficiency of a gas appliance

Table 11 .... Permanent Openings for Air Supply to Spaces Containing Fuel-Burning Equipment

	Fuel-Burning Equipment	*Free Area of Ventilating Opening*[a] Air Inlet	Air Outlet
Gross output capacity exceeding 250,000 Btu per hr	Equipment in a large enclosure having adequate air infiltration	None required	None required
	Equipment in a large enclosure having unusually tight construction	Total free area communicating with outdoor air not less than ½ sq in. per (1000 Btu) (hr) furnace input	Total free area communicating with outdoor air not less than ½ sq in. per (1000 Btu) (hr) furnace input
	Equipment in a small enclosure in a building having adequate air infiltration	Opening in party wall or door, (above draft hood) with free area of not less than 1 sq in. per (1000 Btu) (hr) furnace input	Opening in a party wall or door, (below combustion air inlet to appliance) with free area of not less than 1 sq in. per (1000 Btu) (hr) furnace input
	Equipment in a small enclosure in a building of unusually tight construction	Grilled opening connecting directly with outdoors, through duct if necessary; free area not less than ½ sq in. per (1000 Btu) (hr) furnace input	Grilled opening connecting directly with outdoor air, through duct if necessary. Area and location same as above.
Gross output capacity not exceeding 250,000 Btu per hr	Equipment in an enclosure having adequate air infiltration	Total free area equivalent to not less than the combined area of the flue outlets of all fuel-burning equipment in the space	None required
	Equipment in an enclosure having unusually tight construction	Total free area equivalent to not less than twice the combined area of the flue outlets, of all fuel-burning equipment in the space	None required

[a] Operation of exhaust fans, kitchen ventilation systems, fire places, etc. may require special consideration. For residential closet installations see Fig. 6.

can then be computed with sufficient precision by application of Equation 18.

Percent Combustion Efficiency =

$$\frac{\left(\begin{array}{c}\text{Gross Btu of fuel}\\ \text{gas per cubic foot}\end{array}\right) - \left(\begin{array}{c}\text{total flue losses per}\\ \text{cubic foot fuel gas}\end{array}\right)}{\text{Gross Btu of fuel gas per cubic foot}} \times 100 \qquad (18)$$

Reference to Table 9 will show that ultimate CO_2 percentage values of fuel gases vary. While personal errors involved in CO_2, temperature, and chart determinations, would doubtless more than offset any inaccuracies due to universal use of the alignment charts shown, precise laboratory work may require a more exact method. For more complete information the reader is referred to *Combustion*, 3rd Edition, and *Gaseous Fuels*, (published by American Gas Association) and particularly to tables covering various properties of different commercial gases included in these publications.

CONDENSATION AND CORROSION

Sulfur dioxide or sulfur trioxide, formed by the combustion of sulfur in fuels, are the principal corroding substances in flue gases. They become active whenever sufficient moisture is present for the formation of sulfurous or sulfuric acid,[14] and they lower the dew points of flue gases appreciably. Therefore, unless heating equipment is designed for operation at flue-gas temperatures below the dew point, which is seldom the case, it is always advisable to maintain temperatures above this value in all parts of the appliance. Excessive spot temperatures in the combustion chamber or elsewhere, on the other hand, are also destructive in that they may result in rapid oxidation of ordinary heating surfaces. *American Standard Requirements* for gas furnaces, floor furnaces, and recessed heaters, for example, specify that minimum spot heating surface temperatures during normal operation must neither fall below 178 F (50 F above average dew point) nor exceed 830 F to 1230 F on any portion of the heating surface, depending on the type and thickness of the metal. In any event it is usually desirable to maintain flue-gas temperatures within the limits indicated not only throughout the appliance, but in its connecting vent, flue, or chimney as well. Otherwise, excessive condensation and corrosion problems, with resultant customer dissatisfaction, will in all probability be the result. Average dew-point temperatures of flue gases resulting from the combustion of various fuels, when burned with the amount of excess air normally supplied to insure complete combustion, are shown in Table 10.

SOOT

The deposit of soot on the flue surfaces of a boiler or heater acts as an insulating layer over the surface, and reduces the heat transmission to the water or air. The *Bureau of Mines Report of Investigations* No. 3272[15] shows that the loss of seasonal efficiency is not so great as has been believed, and usually is not over 6 percent because the greater part of the heat is transmitted through the combustion chamber surfaces. The *Bureau of Standards Report BMS 54*[16] points out that, although the decrease in efficiency of an oil fired boiler, due to soot deposits, is relatively small, the attendant increase in stack temperature may be considerable.

The soot accumulation clogs the flues, reduces the draft, and may prevent proper combustion. Soot can probably be most effectively removed by a jet of compressed air, by means of a brush, or a vacuum cleaner. However, it has been found that copper chloride, lead chloride, tin chloride, zinc chloride, common salt and some other salts are partially effective in removing soot from furnaces and boilers when properly used.[17] A discussion of instruments and methods of evaluating smoke will be found in Chapter 44.