TABLE 8. APPROXIMATE AIR REQUIREMENTS FOR THEORETICALLY PERFECT COMBUSTION OF FUELS[a]

Type of Fuel	Air Required for Perfect Combustion: Lbs per Lb Fuel	Air Required for Perfect Combustion: Cu Ft per Unit[b] Fuel	Approximate Precision, Per Cent	Exceptions
Solid	Btu per lb × 0.00073	Btu per lb × 0.0097	3	Fuels containing more than 30% water
Liquid	Btu per lb × 0.00071	Btu per lb × 0.0094	3	Results low for gasoline and kerosene
Gas	Btu per lb × 0.00067	Btu per cu ft × 0.0089	5	Gases of 300 Btu per cu ft or less

[a] Values in table taken from page 276 of *Gaseous Fuels*, 1948, published by *American Gas Association.*
[b] Units for solid and liquid fuels in pounds, for gas in cubic feet.

2. *Fuel Oil* (Pounds air per gallon): Commercial Standard No. 1, 102.6; No. 2, 105.5; No. 5, 112; No. 6, 114.2.

3. *Gaseous Fuels* (Cubic feet of air per cubic foot): Natural, 10.0; Mixed Natural and Manufactured, 8.0; Manufactured, 4.7, Propane, 23.8, Butane, 31.0.

COMBUSTION EFFICIENCY FROM THE FLUE GAS ANALYSIS

Excess Air

A commonly employed index of efficiency of combustion is the relation existing between the amount of air theoretically required for perfect combustion and the amount of air actually supplied. Since the difference between air supplied for combustion and theoretical air required is characterized as excess air, its percentage may be calculated by use of the following equation.

$$\text{Percent excess air} = \left(\frac{\text{Air supplied} - \text{Theoretical air}}{\text{Theoretical air}}\right) \times 100 \qquad (5)$$

The amount of dry air supplied per pound of fuel burned may be obtained from Equation 6 which has reasonable precision for most solid and liquid fuels. Values for CO_2, CO and N_2 are percentages by volume from the flue gas analysis, and C is the weight of carbon burned per pound of fuel, corrected for carbon in the ash.

$$\text{Pounds dry air supplied per pound of fuel} \times \frac{3.04 N_2}{(CO_2 + CO)} \times C \qquad (6)$$

Because excess air calculations are almost invariably made from Orsat analysis results, and theoretical air requirements are not always known, another convenient method of expressing the relation of Equation 5 is as follows:

$$\text{Percent excess air} = \frac{100(O_2 - CO/2)}{N_2 \times 0.264 - (O_2 - CO/2)} \qquad (7)$$

As measurement standards for gaseous fuels are almost universally expressed in cubic feet, Equation 8 may be employed for computing excess air on a percentage basis for gases.[21]

$$\text{Percent excess air} = \frac{(U - CO_2)}{CO_2} \times 100\,\frac{P}{A} \qquad (8)$$

TABLE 9. APPROXIMATE MAXIMUM THEORETICAL CO_2 VALUES, AND CO_2 VALUES FOR VARIOUS FUELS WITH DIFFERENT PERCENTAGES OF EXCESS AIR

Type of Fuel	Maximum Theoretical or Ultimate Percent CO_2	Percent CO_2 at Given Excess Air Values: 20%	40%	60%
Coke	21.0	17.5	15.0	13.0
Anthracite	20.2	16.8	14.4	12.6
Bituminous Coal	18.2	15.1	12.9	11.3
No. 1 and 2 Fuel Oil	15.0	12.3	10.5	9.1
No. 6 Fuel Oil	16.5	13.6	11.6	10.1
Natural Gas	12.1	9.9	8.4	7.3
Carburetted Water Gas	17.2	14.2	12.1	10.6
Coke Oven Gas	11.2	9.2	7.8	6.8
Mixed Gas (Natural and Carburetted Water Gas)	15.3	12.5	10.5	9.1
Propane Gas (Commercial)	13.9	11.4	9.6	8.4
Butane Gas (Commercial)	14.1	11.6	9.8	8.5

where

U = ultimate carbon dioxide, percent of flue gases resulting from perfect combustion.
CO_2 = carbon dioxide content of flue gases, percent.
P = dry products from perfect combustion, cubic feet per cubic foot of gas burned.
A = air theoretically required for complete combustion, cubic feet per cubic foot of gas burned.

As the ratio of P/A is approximately 0.9 for most city gases, a value of 90 may be substituted for $100\,\frac{P}{A}$ in Equation 8 for rough calculation.

Carbon-hydrogen ratios of different fuels vary considerably, hence the maximum or ultimate CO_2 attainable also varies. Where they are unknown, theoretical maximum CO_2 values may be calculated from a flue gas analysis by use of Equation 9.

$$\text{Maximum theoretical } \%\, CO_2 = \frac{\%\, CO_2 \text{ in flue gas sample} \times 100}{100 - \left(\frac{O_2 \text{ in same sample}}{0.21}\right)} \qquad (9)$$

Approximate maximum CO_2 values for perfect combustion of several common types of fuel are shown in Table 9 together with values of CO_2 that will be attained with different amounts of excess air. Desirable values to be attained in practice depend upon the fuel, the method of firing, and other considerations. In general, fuels burned in suspension, such as gas, oil, and pulverized coal, can be burned with a lower amount of excess air than fuels burned on grates.

To produce heat efficiently by burning any common fuel a number of basic requirements must be met: (1) adequate heat absorbing surface of proper shape and construction is necessary in the appliance, (2) heat transfer surfaces must be clean, (3) a minimum amount of excess air must be present, (4) air employed for combustion and combustible gases must be properly mixed, and (5) flue gas losses must be reduced to a safe minimum.

If insufficient heating surface is employed, or if heat transfer surfaces are covered with soot, ash, or scale, flue losses will generally be excessive