8 at the percentage CO_2, moving horizontally to the curve for the type of fuel, and then moving, vertically downward to the weight of products per 1000 Btu, the reader can determine the flue gas rate in pounds per hour for any fuel.[6]

Any of the described methods of determining available draft may be used, but a graphical solution to the problem may be obtained for an 8 × 8-in. chimney from Figs. 2, 8, and 10. This solution can be best explained by a numerical example.

Example 4: Determine whether a 13-ft, 8 × 8-in. nominal-size flue is sufficient for a coal-heating unit rated at 0.03 in. of water draft at 400 F inlet temperature, fuel rate being 10 lb per hr of bituminous coal, with 10 percent CO_2.

Solution: From Fig. 8 a flue gas rate of approximately 180 lb per hr is obtained. The available draft for a 180 lb per hr gas flow, and an inlet temperature of 400 F, obtained from Fig. 10, is 0.056 in. of water. This indicates that the chimney is adequate.

The selection of chimney areas for liquid- and solid-fuel-burning devices is difficult because of the variability in efficiency of different models, the possibility that soot on the lining will restrict the chimney area, and the variation in combustion air requirements of different solid fuels. Figs 2 and 10 show that a given chimney produces a maximum available draft and a maximum efficiency for some intermediate mass flow rate for any selected inlet flue gas temperature. For mass flow rates lower than optimum, the greater cooling of the gases in the chimney causes lower available draft, whereas, for mass flow rates above the optimum, the greater friction losses reduce the available draft. A chimney for a given heating system should probably be designed to operate at its point of maximum efficiency and maximum available draft for its full rated output. A chimney would have an accelerating effect[13] on the combustion rate of a solid-fuel burning device if the chimney were operating to the left of the optimum point in Fig. 10, because an additional increment in mass flow rate would increase the available draft a small amount and tend to increase the mass flow still more. On the other hand, a chimney operating to the right of the optimum point in Fig. 10 would tend to decelerate the combustion rate for any small increase in mass flow rate.

Data are not complete for the selection of proper chimney areas for heating plants of different capacities, but some information on the effect of cross-section areas on the capacity of masonry chimneys is provided by tests[9,20] on several chimneys with liners having nominal outside dimensions: 9-in. diameter, 12-in. diameter, 9 × 9-in., and 9 × 13-in. These tests showed that, for flue gas rates up to 200 lb per hr, and entering flue gas temperatures from 200 to 1000 F, the 9-in. round liner provided an available draft equal to, or greater than, that produced by the other three larger liners. When the flue gas rate was increased to 320 lb per hr, the three larger liners produced a little more draft than the smallest one for entering flue gas temperatures above 600 F. Other data[19] show that metal chimneys with an internal diameter of 6 in. should not be used for mass flow rates greater than 130 lb per hr.

Table 5 shows approximate values of the mass flow rates and flue-gas velocities at the chimney inlet that produce the maximum available draft for masonry chimneys[9] of several conventional sizes and with an effective height of 15 ft. This table shows that a 9-in. round chimney is best suited to mass flow rates from 130 to 170 lb per hr; a 9 × 9-in. chimney performs best for flow rates from about 200 to 300 lb per hr. and 9 × 13-in. and 12-in. round chimneys are best suited to flow rates above 300 lb per hr. These results were obtained with clean chimneys, so that conclusions about chimney areas require some modification if soot deposits are taken into consideration.

Soot deposits in chimneys reduce the effective area of the liner and may, in some cases, entirely close the passage. Soot deposits are likely to be greater in the horizontal passages in the heating plant, the breeching, and the smokepipe than in the vertical chimney liner. An increase in the liner diameter of one inch above that required for a clean chimney will probably make adequate allowance for soot deposits in all but the worst cases. Where smoky combustion is likely to occur and the mass flow rates on a clean chimney basis approach those listed in Table 5, the next larger commercial size liner should be used. Smoky combustion with oil-burning devices, particularly with vaporizing oil burners, is likely to be caused by inadequate draft, which is often due to insufficient chimney height. For coal, inadequate chimney height or chimney area may be a contributing cause, but smoky combustion with coal is related to fuel characteristics and firing methods. Therefore, an increase in chimney area will usually not cure smoky combustion of a coal-burning device, but can be expected to lengthen the interval between cleanings.

New standard sizes of clay flue linings were developed by the industry and approved by the American Standards Association, in order to effect economies that can be derived from coordination of the dimensions of building materials. These linings are known as modular clay flue linings, and the dimensions and tolerances are summarized in *ASA Standard* A62.4-47. As the effective areas of these liners are somewhat smaller than those of the corresponding linings used previously, they cannot be used in certain municipalities where building codes specify minimum areas based on the older dimensions.

DRAFT REQUIREMENTS OF APPLIANCES

Typical flue-gas temperatures and drafts required at rated output for several kinds of domestic heating appliances[21] are contained in Table 6. Chimney height and chimney area for cast-iron boilers are specified in the *I = B = R Testing and Rating Code* of the Institute of Boiler and Radiator Manufacturers.

Mechanically-fired devices such as oil burners and stokers are equipped with blowers, and the chimney is not required to overcome the resistance of the fuel bed or burner. Nevertheless, a draft in the firebox of about 0.03 in. of water is desirable so that any leakage will be into the firebox rather than outward from it.

Insufficient draft for natural-draft appliances is likely

Table 5. . . . Approximate Flue Gas Flow Rates for Maximum Available Draft in Masonry Chimneys

Nominal External Liner Dimensions, In.	Internal Area of Liner Sq. In.	Flue Gas Temperature at Chimney Inlet, F					
		200	600	1000	200	600	1000
		Mass Flow Rate, Lb/Hr			Flue Gas Velocity at Chimney Inlet, Fpm		
9 (dia)	38.5	170	150	130	175	250	300
9 x 9	49	215	306	334	175	400	600
12 (dia)	78.5	290	Above 320	Above 320	150	—	—
9 x 13	77	295	Above 320	Above 320	150	—	—

with installations in attics or in one-story basementless houses. Automatic oil-burning space heaters, floor furnaces, and warm air furnaces employing natural-draft vaporizing burners require a draft of 0.06 to 0.08 in. water for outdoor temperatures of 60 F. Coal-burning heaters and furnaces which attain design rating at 0 F outdoor temperature would require about the same draft. For such requirements, data from Fig. 3 and Table 2 show that an effective chimney height, above chimney inlet, should be a minimum of 8 to 12 ft. Because temperature drop and friction loss in the flue pipe cannot be calculated accurately,[8] and the resistance of various chimney connections is uncertain, the minimum calculated heights should have a generous factor of safety applied to allow for these and other uncertainties. Where ample height cannot be provided, forced or induced draft should be provided. Extreme care should be used in the application of forced draft to avoid producing a pressure in combustion chambers, because they are not usually designed to prevent the outward leakage of toxic gases which might result.

Induced draft by means of motor-driven fans or blowers will solve low-draft problems, but would usually be employed for residential systems only as a last resort. Operation of a blower entails some cost, introduces maintenance requirements, and may be dangerous in event of power failure unless suitable protective devices are used. Induced draft fans designed to resist effects of high temperature and corrosion are available. Fans not carefully designed or modified to meet these conditions should not be applied to this service.

RECOMMENDATIONS OF THE NATIONAL BOARD OF FIRE UNDERWRITERS

For general data on the construction of chimneys, refer to the *National Building Code*, recommended by the National Board of Fire Underwriters, Article X, Section 1001 to 1006, in which the following are some of the important provisions listed in the 1951 edition:

1. *Flue Connections Required.* Every heating apparatus or heat producing appliance requiring a flue connection shall be connected with a flue conforming to the provisions of this article. This shall not include electric appliances; gas appliances, except as specifically required in this article; or oil fired appliances especially designed for use without flue connection.

2. *Use of Nonconforming Flues.* Flues not conforming to the requirements of this article for chimneys, metal smokestacks or vents for gas appliances, shall not be used unless listed by Underwriters' Laboratories, Inc., installed in full compliance with the listing and the manufacturer's instructions, and approved for such use by the building official.

Table 6 . . . . Drafts Required by Typical Residential Heating Devices or Appliances

Device	Draft, In. Water	Stack Temperature[c] F
Space Heater, Oil-Burning, Pot Burner	0.06 to 0.08	1000
Warm Air Furnace, Oil-Burning, Pot Burner	0.06	860
Warm Air Furnace, Hand-Fired	0.06[b]	900
Floor Furnace, Oil-Burning, Pot Burner	0.06	860
Mechanical Oil Burner, Less than 5 gph	0.03[a]	—
Mechanical Oil Burner, More than 5 gph	0.05[a] or less	—
Cooking Stove, Solid-Fuel	0.04[b]	400
Space Heater, Coal-Burning	0.06[b]	900

[a] Draft in firebox. [b] For chestnut sized anthracite.
[c] 18 in. from heater.

3. *Smoke Pipe Connections.*

a. No flue shall have smoke pipe connections in more than one story of a building, unless provision is made for effectively closing smoke pipe openings with devices made of noncombustible materials whenever their use is discontinued temporarily, and completely closing them with masonry when discontinued permanently.

b. Two or more smoke pipes shall not be joined for a single connection, unless the smoke pipes and flue are of sufficient size to serve all the appliances thus connected.

c. The smoke pipe of a heating appliance shall not be connected into the flue of an incinerator which has the rubbish chute identical with the smoke flue.

4. *Construction of Chimneys.*

a. Chimneys hereafter erected within or attached to a structure shall be constructed in compliance with the provisions of this section.

b. Chimneys shall extend at least 3 ft above the highest point where they pass through the roof of the building, and at least 2 ft higher than any ridge within 10 ft of such chimney.

c. Chimneys shall be wholly supported on masonry or self-supporting fireproof construction.

d. No chimney shall be corbeled from a wall more than 6 in.; nor shall a chimney be corbeled from a wall which is less than 12 in. in thickness, unless it projects equally on each side of the wall; provided that in the second story of 2-story dwellings corbeling of chimneys on the exterior of the enclosing walls may equal the wall thickness. In every case the corbeling shall not exceed 1 in. projection for each course of brick projected.

e. No change in the size or shape of a chimney, where the chimney passes through the roof, shall be made within a distance of 6 in. above or below the roof joists or rafters.

5. *Chimneys for Heating Appliances, Low Heat Industrial Appliances and Portable Type Incinerators.*

a. Chimneys for stoves, cooking ranges, warm air, hot water and low pressure steam heating furnaces, fireplaces, and low heat industrial appliances, other than chimneys for incinerators of nonportable type, shall be constructed of solid masonry units or of reinforced concrete. The walls shall be properly bonded or tied with corrosion-resistant metal anchors. In dwellings and buildings of like heating requirements, the thickness of the chimney shall be not less than 4 in. In other buildings the thickness shall be not less than 8 in., except that rubble stone masonry shall be not less than 12 in. thick.

b. Every such chimney hereafter erected or altered shall be lined with a flue lining conforming to the requirements below.

c. Flue linings shall be made of fire clay or other refractory clay which will withstand the action of flue gases and resist, without softening or cracking, the temperatures to which they will be subjected, but not less than 2000 F. Flue linings may be of cast iron of approved quality, form and construction.

d. Required clay flue linings shall be not less than $\frac{5}{8}$ in. thick for the smaller flues, and shall increase in thickness for the larger flues.

e. Flue linings shall be installed ahead of the construction of the chimney as it is carried up, carefully bedded one on the other in Type A, Type B, or fire clay mortar with close fitting joints left smooth on the inside.

f. Flue linings shall start from a point not less than 8 in. below the intake, or, in the case of fireplaces, from the throat of the fireplace. They shall extend, as nearly vertically as possible, for the entire height of the chimney, and be extended 4 in. above the top of cap of the chimney.

g. Cleanouts for flues or fireplaces shall be equipped with cast-iron doors and frames arranged to remain tightly closed when not in use.

h. When two or more flues are contained in the same chimney, at least every third flue shall be separated by masonry at least 4 in. thick bonded into the masonry wall of the chimney. Where flue linings are not so separated, the joints of adjacent flue linings shall be staggered at least 7 in.