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EFFECT OF WOOD STOVE DESIGN ON PERFORMANCE

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by

A.C.S. Hayden* and R.W. Braaten**

ABSTRACT

Using an indirect stack loss method to measure efficiency and performance characteristics, the Canadian Combustion Research Laboratory (CCRL) has carried out a series of experiments on wood-fired space heaters (stoves). A good stove design should allow the heater to run a majority of the time at a reasonably low-excess air level and flue gas temperature without producing excessive emissions of incomplete combustion products.

Results on five different stove types show that a fireplace or non-airtight stove is very inefficient and can have high emissions, while a well-designed and well-constructed airtight stove may have efficiencies as high as 77%. In particular, sidedraft designs and, to a lesser extent, horizontal baffle designs appear to offer potential for higher efficiencies and lower emissions than other stove types.

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L'influence du type de poêle à bois sur la performance

par

A.C.S. Hayden* et R.W. Braaten**

RESUME

En utilisant une méthode indirecte de perte de chaleur pour mesurer rendement et caratéristiques de performance, le Laboratoire canadien de recherche sur la combustion a conduit une série d'expériences sur les chaufferettes de chambre à bois (poêles à bois).

Un bon modèle de poêle à bois permit a la chaufferette de fonctionner une majeure partie du temps à un niveau raisonnablement bas d'excès d'aur et de basse température de gaz de fumée sans produire d'excessives émissions de produits de combustion incomplète.

Les résultats sur cinq types différents de poêle démontrent l'inefficacité des foyers ou les poêles non-étanches, lesquelles peuvent produire des émissions élevées, tandis qu'un poêle étanche bien déssiné et bien construit peut donner des rendements aussi élevés que 77%. En particulier, les dessins de cloison horizontale et de tirage de côté semblent offrir le potentiel pour des rendements superieurs et pour des émissions plus basse que les autres types.

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INTRODUCTION

With the realization that the principal domestic heating fuels - oil and natural gas - are finite and becoming increasingly expensive, homeowners are looking to other means to heat their homes. One result has been a dramatic increase in interest in the use of domestic wood heating, particularly stoves for space heating. This has led to searches by consumers for an efficient wood stove, but most consumers have quickly become dismayed by the wide variety of claims made by manufacturers and retailers. Each unit is touted as "the most efficient on the market" or "capable of heating 'x' square metres" or some other similar statement. However, there is very little controlled and objective data to support these claims.

At the same time, there is increasing concern over emissions from widespread use of wood burning. These emissions can cause environmental problems downstream from the dwelling, as well as creating potential fire safety hazards for the house and the occupants when they condense within the venting system to form creosote. Because these incomplete products of combustion also represent an efficiency loss, reducing them can increase the utilization of energy available from the wood.

Experiments have been conducted on a number of stoves representing five basic design types. Typical results from the five types are presented and the effects of combustion design on performance, related to both efficiency and emissions, are discussed.

EFFICIENCY

Appliance efficiency is the measure of the ability of the wood stove to extract heat from the fuel and supply it to the house. It is the ratio of the heat supplied to the house to the heat in the wood. Conversely, it is 100% minus all the heat losses up the stack while the wood is burning.

It is not to be confused with combustion efficiency, the measure of completeness of combustion. In most oil and gas furnaces combustion is effectively complete. Only small amounts of carbon monoxide, hydrocarbons and soot are emitted and combustion efficiency is nearly always greater than 99.6%. For wood-fired appliances, combustion is not nearly so complete. Many incomplete products of combustion are emitted, and combustion efficiency may be lower than 94%.

Appliance Efficiency

It can be measured either directly using a calorimeter room or indirectly using a sophisticated heat loss method. Detailed discussions of these techniques are presented in Reference 1. The heat loss method requires determination of the following losses; the sensible heat loss, hydrogen loss, loss due to incomplete combustion and loss due to moisture in fuel.

The Canadian Combustion Research Laboratory (CCRL) has chosen to use the indirect method for the following reasons: it helps to explain why a particular stove performs well or poorly; it does not alter stove performance when it is being used; it can be portable and it gives detailed information on emissions and creosote potential.

Stove performance data is obtained continuously over a burning cycle using electronic flue gas analyzers for CO_2. CO, O_2, HC and NO_x, a dewcell for moisture, particulate sampling system for solids, Cr-Al thermocouples for temperatures and an electronic digital scale to record burning rate. A data logging system makes complete scans of all the data every ten seconds and stores it on magnetic tape. A detailed profile of the performance of the appliance is thus easily constructed and analyzed using the digital computer.

STOVE TYPES

Wood space heating appliances (wood stoves) can be divided into two major classifications, airtight and non-airtight, the latter including fireplaces. Airtights, where combustion air is closely controlled, can be further subdivided into several types depending on the flow of gases within the combustion chamber of the stove. The five types of appliances reported in this paper are described briefly in the following paragraphs.

The open fireplace, either freestanding or built-in, is the most common type of wood-fired appliance, although it has a very low heating efficiency. Field tests reported by CCRL show that a conventional built-in fireplace can acually increase oil consumption while the fireplace is being used, because of the high draft generated.(1) In the present paper, results for a freestanding fireplace, shown in Figure 1, are presented. This type has no controlled combustion air delivery, the only effective combustion air control being a damper downstream of the appliance. Obviously, the unit is not airtight. There is no internal baffling to aid in combustion or heat transfer.

The second type of appliance is the airtight updraft (box) stove. It has controlled combustion air, but no effective internal baffling within the combustion chamber, so that the flame, as well as any volatiles have direct access to the exit from the stove, as shown in Figure 2.

The third is the airtight horizontal baffle stove, shown in Figure 3. This type has an essentially horizontal (not angled upward) baffle running from the rear of the stove toward the front to at least mid-length. Combustion air is controlled at the front, where the wood tends to burn. "Smoke" and other incomplete products of combustion are released from the back of the stove, remote from the flame, and then are forced forward under the baffle toward the flame, where they can be re-ignited and burned if brought into contact with the flame. The flue gases then travel back over the baffle to the flue exit.

The next appliance is the <u>airtight downdraft stove</u>, shown in Figure 4. In this design, combustion air is controlled and the wood sits on a grate. When the fire is lit, a vertical damper is opened at the top, making the stove behave like an updraft, to promote rapid combustion. When a hot bed of embers is developed, this damper is closed; the flue gases are forced back down near or through the bed before going up and out the flue.

The final type is the <u>airtight sidedraft stove</u>, shown in Figure 5. There is a vertical baffle, with an opening 4-6 cm high at the bottom and an open-and-shut damper at the top. The latter is open when combustion is initiated, as with the downdraft. When enough heat has been developed to sustain adequate draft, the damper is closed. The flame moves horizontally, parallel to the fuel bed, out the baffle opening. Smoke and volatile matter released remote from the flame are pulled down under the vertical baffle. If the flame is adequate at that point, the incomplete products of combustion may be ignited and burned before passing up and out the flue pipe.

COMBUSTION PARAMETERS AFFECTING PERFORMANCE

In a wood stove, three performance parameters give a good indication of how effective a particular design is in achieving the desired goals of high appliance efficiency and low emissions.

Excess air, measured by oxygen and/or carbon dioxide concentration in the flue gas, is the first parameter. The greater the excess air, the greater the sensible heat loss (dry flue gas loss) from the appliance and the lower the appliance efficiency (1).

The second parameter is stack temperature. The greater the temperature of the flue gases leaving the stove, the greater the heat loss and the lower the appliance efficiency.

Excess air and stack temperature together determine the conventional sensible heat loss of a stove.

The third parameter is the amount of incomplete products of combustion, chiefly carbon monoxide and unburned or partially burned hydrocarbons. Energy in these products has not been released and is carried up the stack as a heat loss. It is here that potential hazards from wood stove operation originate, either as creosote, as toxic carbon monoxide (CO) or as other undesirable emissions to the environment. In tests conducted by CCRL, carbon monoxide and hydrocarbon emissions tend to track quite well over the burning cycle so that comparison of CO emissions between stoves allows determination of the relative degree of completeness of combustion of different designs.

Reducing the amount of incomplete products of combustion requires both adequate air at the proper location and high enough temperatures to ensure ignition. In general, attempts to lower this loss tend to increase sensible heat losses due to greater excess air and increased stack temperature. For a given stove, there is usually an optimum firing rate. Above this firing rate, the sensible heat loss increases faster than the unburned combustible loss decreases; below this optimum rate, the inverse occurs.

A good combustion design will allow a stove to operate the majority of the time under conditions where both losses are minimized. That is, the stove operates at relatively low excess air and low stack temperatue without producing excessive creosote and other undesirable emissions.

EXPERIMENTAL RESULTS

Table 1 presents mean test results for the five types of appliances in the form of excess air, stack temperature, carbon monoxide emissions (representing incomplete products of combustion) and appliance efficiency. The CO emissions are presented both in terms of mass per unit mass of fuel burned and in terms of mass per unit heat output. The latter probably represents a more realistic comparison of emissions if these appliances are to be considered heat sources. It is analogous to the emissions standards for automobiles in grams of pollutant per kilometre of distance travelled, a measure of output performance.

Excess air levels range from over 1800% with the freestanding fireplace to a very low 60% with the downdraft. Surprisingly, even with that high excess air, the fireplace emits a significant amount of carbon monoxide. On a heat output basis, with the low-appliance efficiency of only 24%, the fireplace has three times the CO emissions of the worst airtight stoves, the updraft and the downdraft types, and six times those of the sidedraft, which has the lowest emissions.

From Table 1, stove design is seen to have a significant effect on both efficiency and emissions. The sidedraft, using relatively sophisticated combustion techniques, has just over half the emissions of the updraft, while showing a large 16% improvement in efficiency to 76%, the highest of any type.

The horizontal baffle type shows the next lowest emissions, with an efficiency only 4% below the sidedraft.

Although the downdraft had a good efficiency (in the same range as the sidedraft and the horizontal baffle) it achieved this by operating at the low excess air level of only 60%. This resulted in emissions above that of the updraft on the basis of heat output. The high emissions may be partially explained by the fact that the stove was operating near the low end of its output range, in order to be representative of actual usage in a Canadian home. Other tests conducted by CCRL indicate that this particular stove is most comfortable operating at a burn rate of at least 10 kg of wood per hour, giving a heat output of as high as 90 MJ/h, continuously. When one considers that the average demand for heat by a house in Ottawa over a heating season (2) is only 15 MJ/h it is evident that this stove is greatly oversized for domestic applications.

Even though these results indicate potentially superior performances for well-baffled designs over updraft designs, tests reported elsewhere (3) indicate that the performance of different stoves within a specific type can vary widely, depending on how well the particular design utilizes the potenial performance advantages of its type.

From a field trial reported previously (1) performance profiles were generated for a house heated with an electric boiler and a well-designed combi-fire sidedraft stove where the door could be opened to view the flame. Using the technique developed at CCRL (2) the profiles were integrated over the heating season to give yearly consumption. In this case, the sidedraft yielded a seasonal efficiency of 65% relative to the electric heating system. This is as high as the accepted seasonal efficiency for conventional oil or gas central heating systems.

CONCLUSIONS

1. Current well-designed sidedraft stoves have greater potential for high efficiency and low emissions than other types of airtight stoves presently available.

2. Next to the sidedraft, a good horizontal baffle stove appears to offer the best overall performance.

3. The available downdraft stove offers little overall performance advantages over the poor performing updraft (box) airtight stove designs.

4. Updraft (box) stoves having no internal baffling have high emissions and the lowest efficiencies of any of the airtight stove types.

5. Fireplaces are very inefficient and can have high emissions per unit output.

6. Performance of a specific stove depends on how the design utilizes the potential performance advantages of the stove type.

7. Reduced emissions of incomplete combustion products through design improvements will lead directly to reduced creosote formation.

8. Well-designed and well-constructed airtight or combi-fire wood stoves of the sidedraft or horizontal baffle type can be an effective complement to an existing heating system by reducing the central system demand for premium fuels.

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2. Hayden, A.C.S., Braaten, R.W. and Brown, T.D. "Oil conservation in home heating"; J Eng Power 99:3:413-418;1977.

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Stove Type	Excess Air %	Stack Temperature °C	Carbon Monoxide Mass Emissions Factor		Appliance Efficiency %
			/mass fuel	/heat out	
Freestanding Fireplace	1860	92	200%	610%	24
Updraft (box)*	450	152	180%	200%	62
Horizontal Baffle*	230	110	140%	150%	73
Downdraft*	60	117	190%	200%	72
Sidedraft*	160	122	base	base	77

Table 1. Typical performance data for five wood stove types.

* airtight design

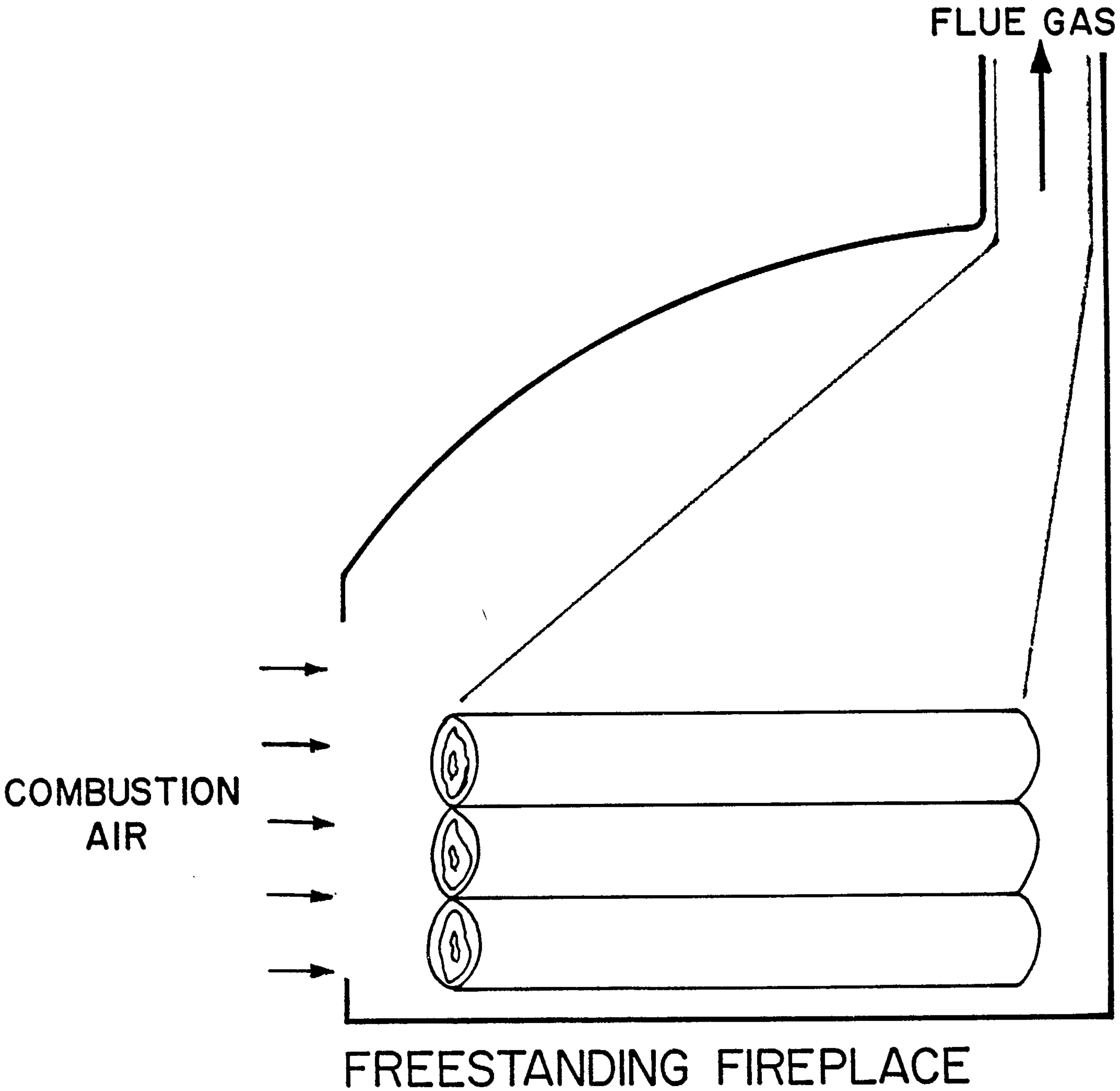


Figure 1. Schematic of non-airtight freestanding fireplace.

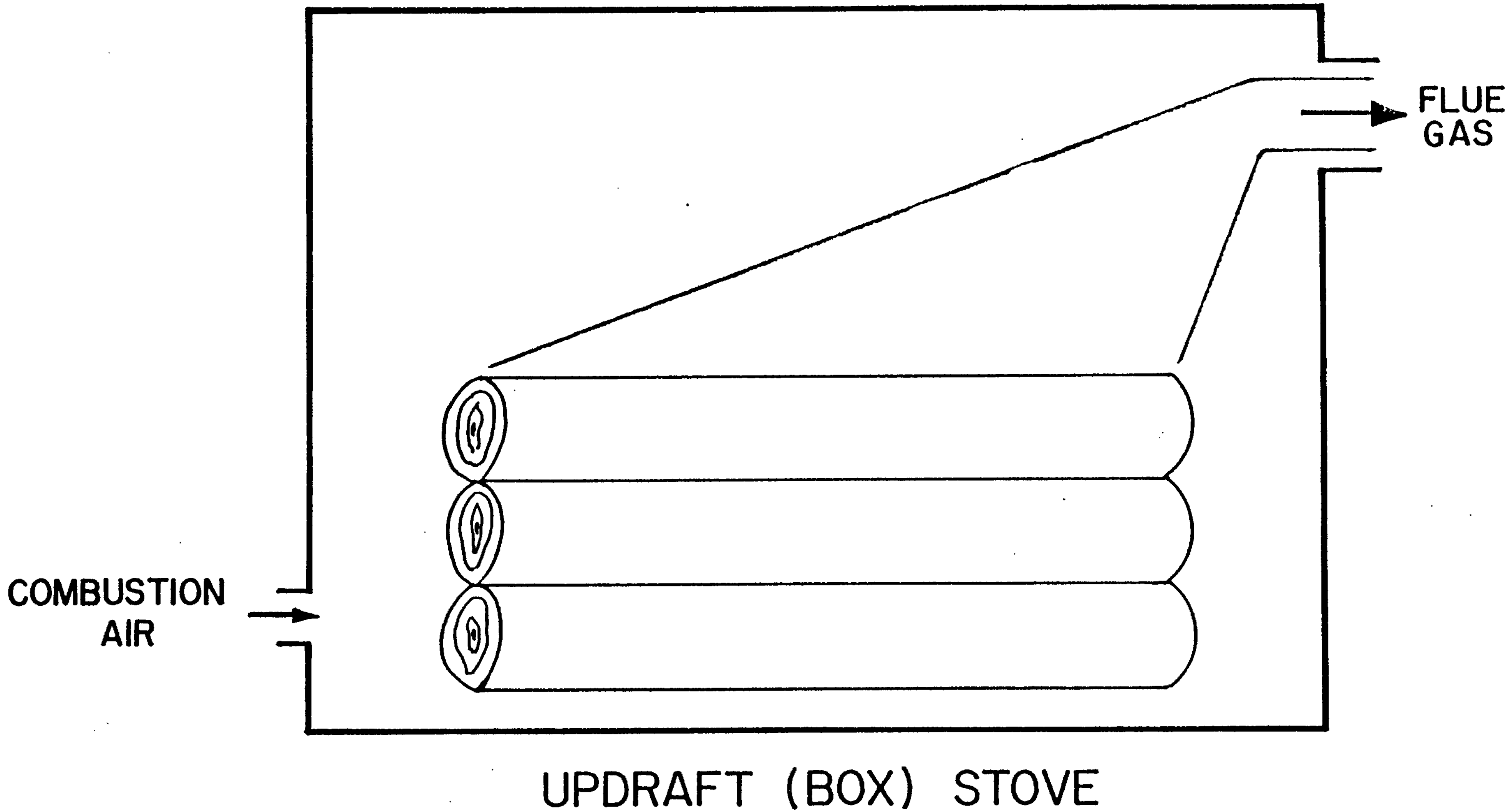


Figure 2. Schematic of airtight updraft (box) stove.
(no significant internal baffling)

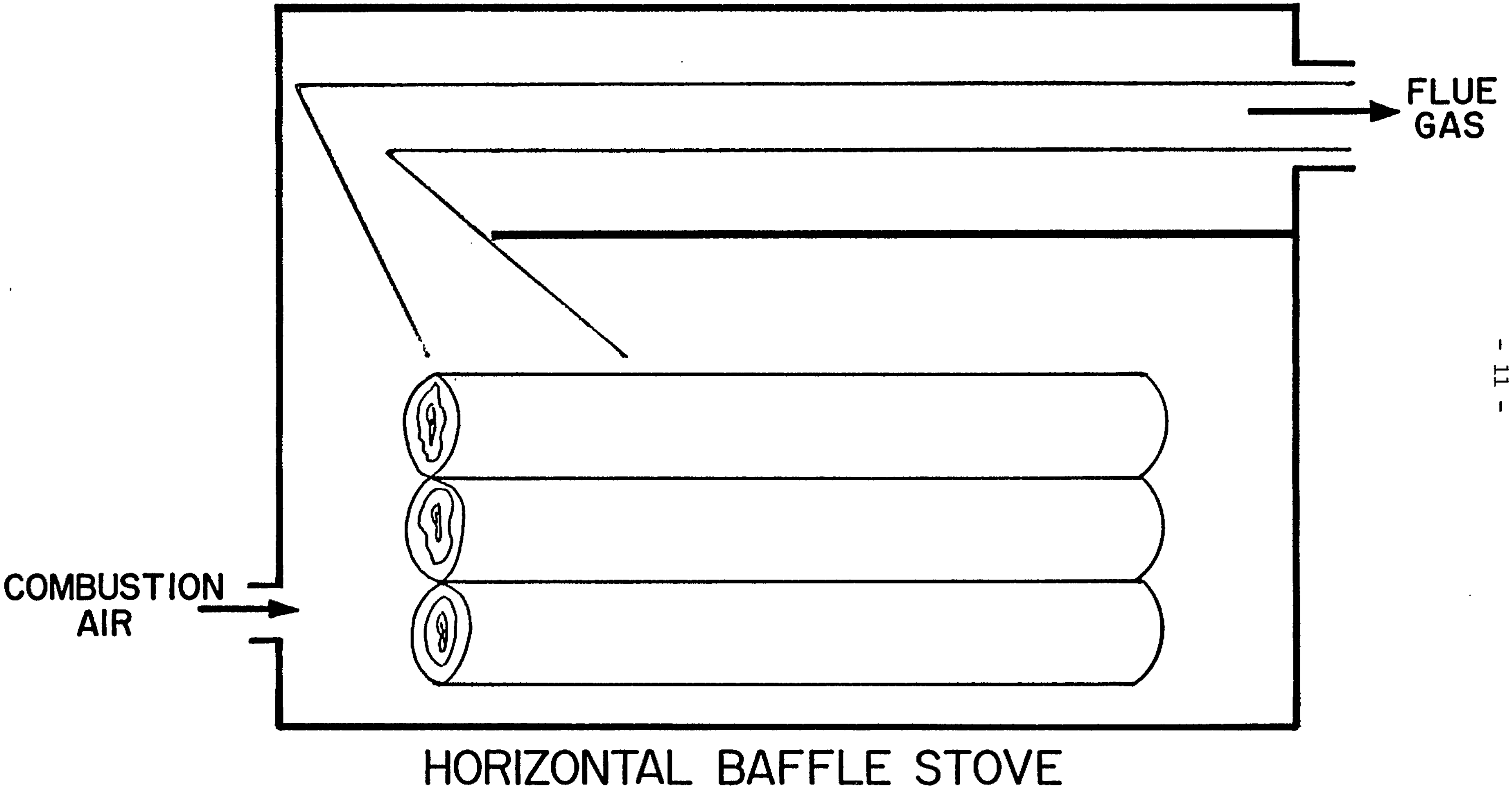
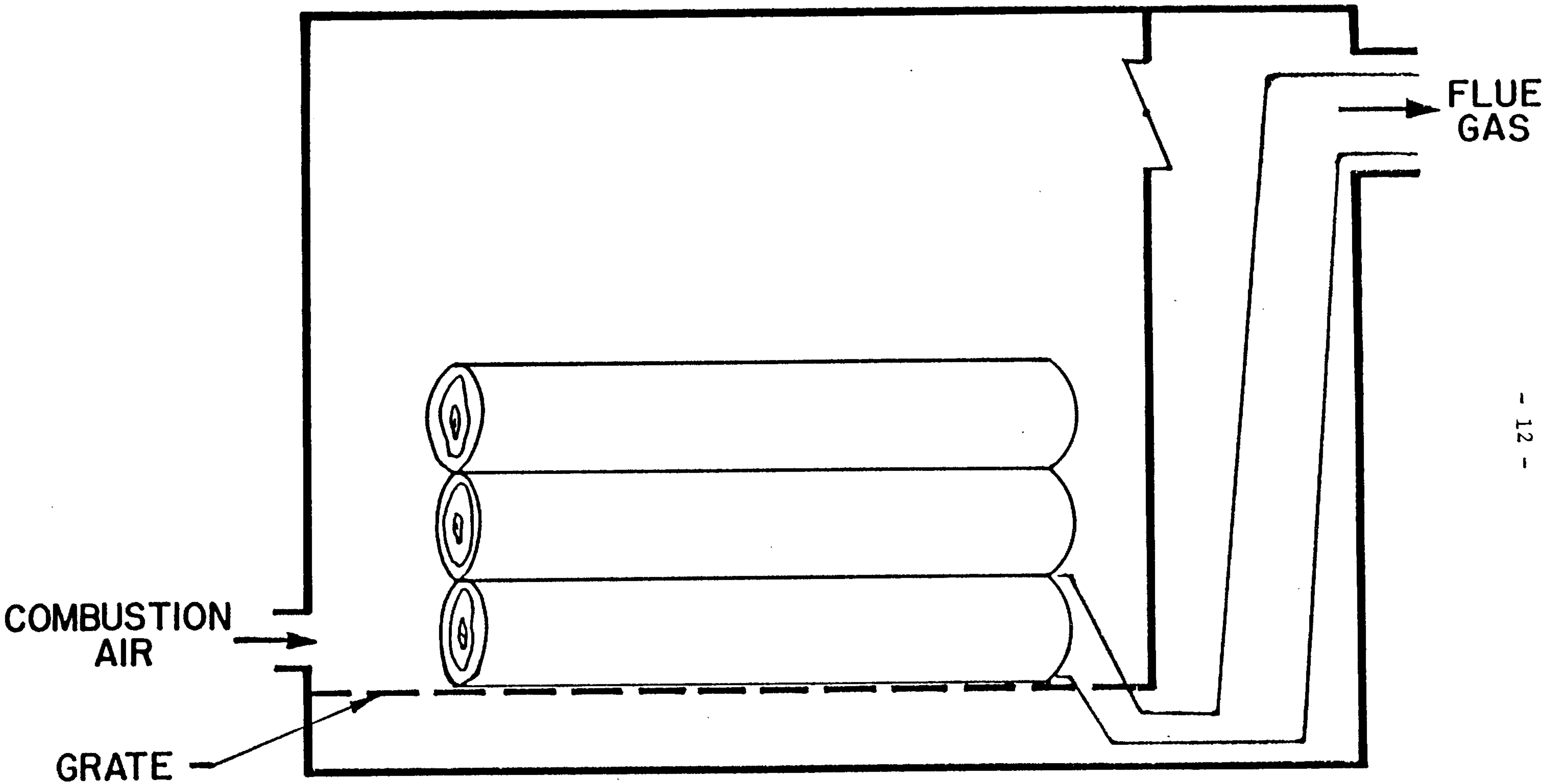


Figure 3. Schematic of airtight horizontal baffle stove.



DOWNDRAFT STOVE

Figure 4. Schematic of airtight downdraft stove.

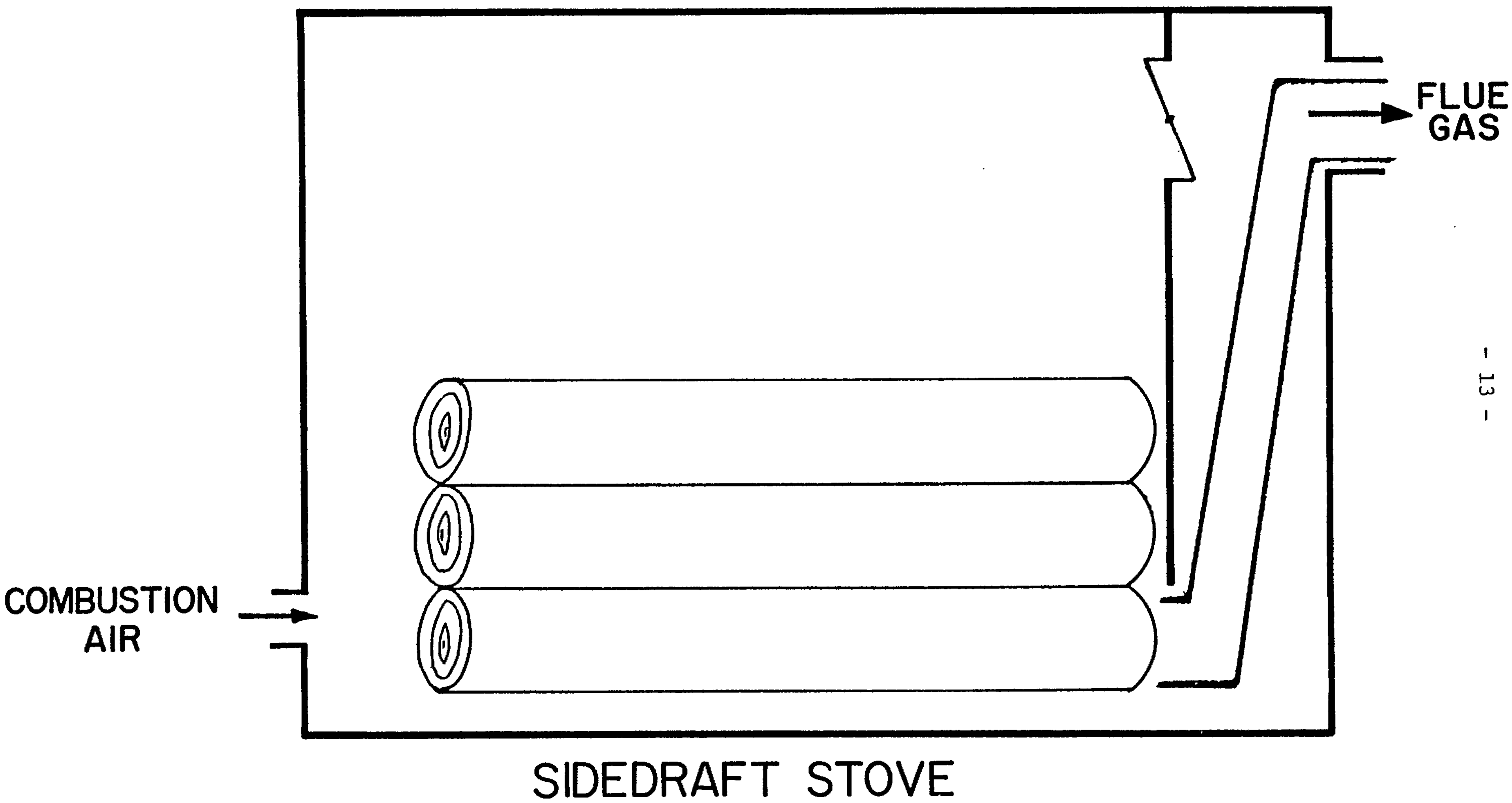


Figure 5. Schematic of airtight sidedraft stove.

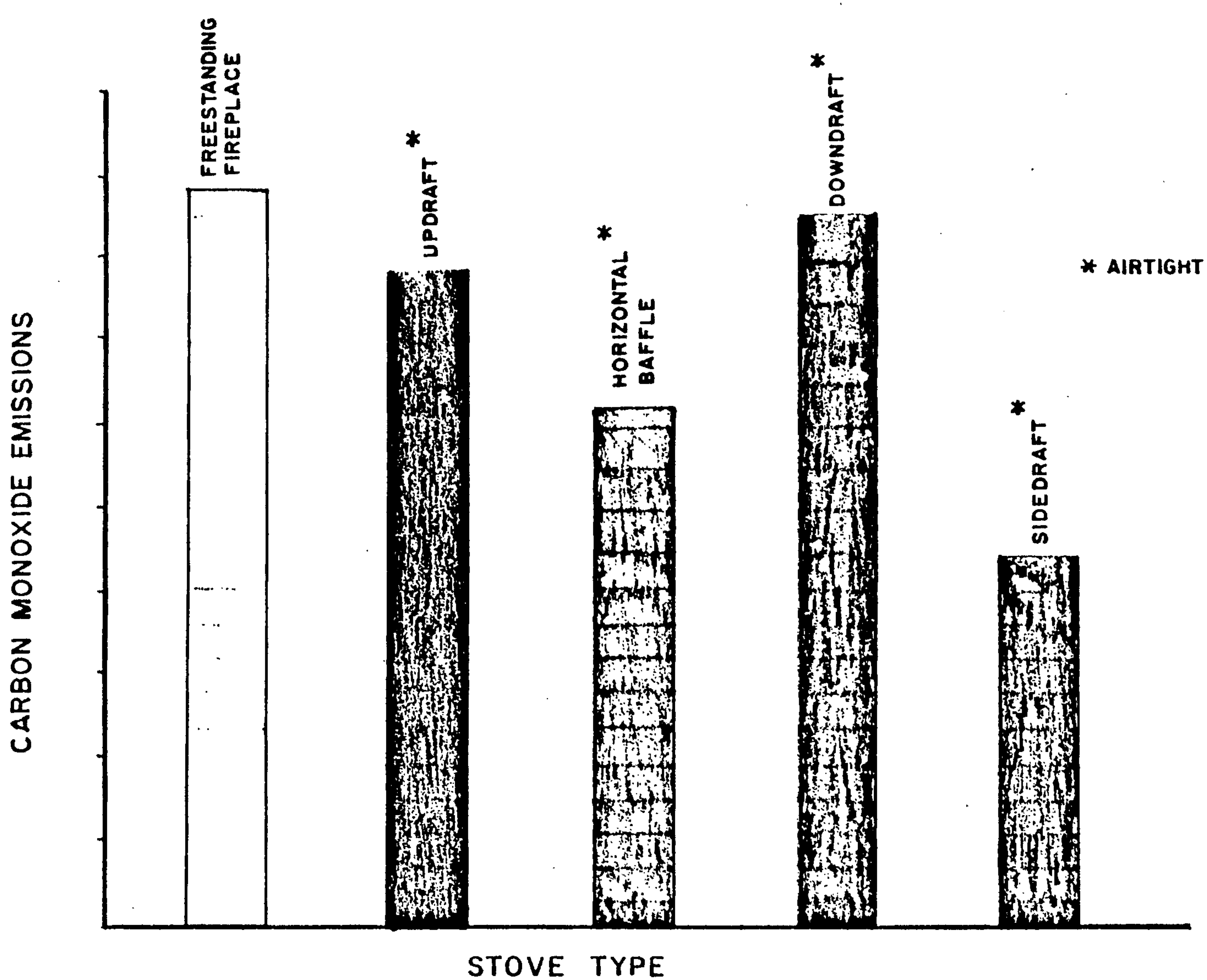


Figure 6. Relative carbon monoxide emissions of different stove types.

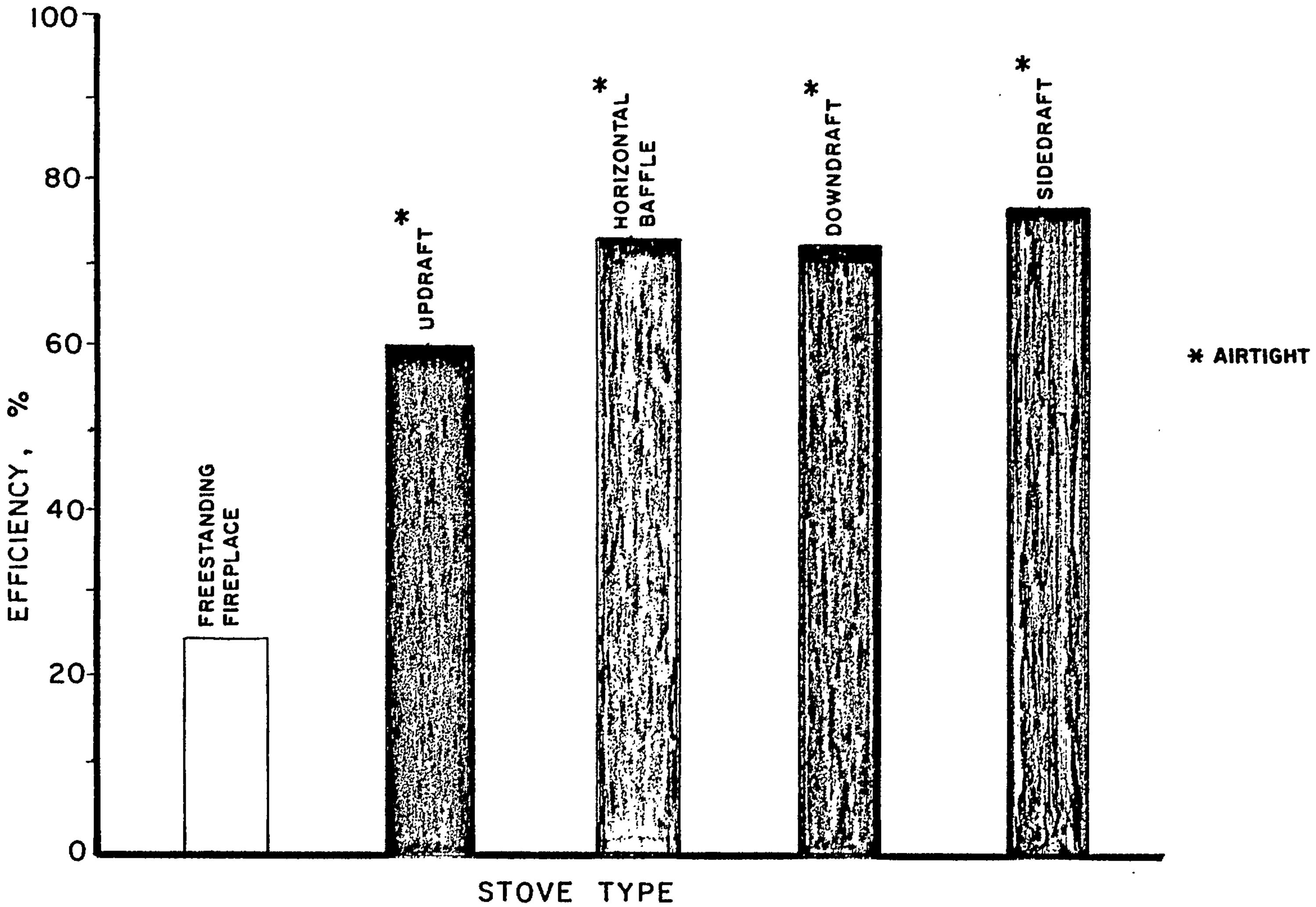


Figure 7. Appliance efficiency of different stove types.