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MASTER

RESIDENTIAL CONSUMER'S HANDBOOK
FOR WOOD-FIRED APPLIANCES

by

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Chapter 1

INTRODUCTION

Since initiating research on domestic wood heating equipment six years ago, the authors have been asked hundreds of times to answer the question: "What is the best unit on the market?" This book is intended to help people answer that question. The answer, however, may not come in the form expected by the reader. First, the particular unit, best for a given situation, depends on many factors, including existing wood heating equipment in house, house size, location of house, objectives of user, etc. Secondly, when the particular type of unit is selected, one finds that most units within that type have about the same peak performance. A much more important factor is how the stove is operated.

This report first describes the types of appliances for heating with wood. Advantages and disadvantages in each category of wood heating units are given. Second, information on properly sizing and selecting a unit for safety is given. Third, efficiency and heat output performance measurements are described. A table giving measured values of these parameters for a number of wood heating units of each type is presented. Finally, a few tips on efficient and safe operation are given.

Chapter 2

TYPES OF APPLIANCES

This section describes the types of wood heating appliances on the market. It gives their characteristics along with advantages/disadvantages.

Fireplace

A fireplace is normally considered to be a bricked up hole in the wall where a fire can be built. Fireplaces were first used primarily for heating and cooking; in more recent years they have been relegated for more aesthetic purposes.

As the cost of energy continues to increase, the fireplace is once again being used as a heating appliance. It is expected that a fireplace will heat the home in which located, as well as provide a romantic atmosphere on a cold winter evening.

You as the consumer must now decide which of the two basic types of fireplaces you want in your home: masonry or manufactured.

As the name implies, the masonry fireplace can be constructed of brick, stone, or rock. The chimney will also be constructed of masonry materials. The firebox consists of the walls (sides and back), hearth, and the physical materials that directly surround the firebox. The firebox is generally lined with firebrick. A common example of a masonry fireplace is shown in Figure 1.

Masonry fireplaces heat the room in which they are located by direct radiation from the flames, hot coals, and firebox. Because a basic fireplace is an open combustion chamber appliance, there is no control of the amount of air entering the firebox. Thus, a large volume of air is drawn into the firebox, and then exhausted up the flue. This is wasted heat. The volume of air can be many times the amount needed for combustion of the wood.

Figure 1 Typical Masonry Fireplace

Therefore, masonry fireplaces typically have an overall efficiency of up to only 10%. The efficiency drops as outside air temperature goes down because of extra energy needed to heat the colder air.

Many modifications are being made and new equipment is currently being designed to increase the efficiency of masonry fireplaces. Systems have been developed to circulate the room air through the passageways in the firebox itself as well as through andirons to provide convective heat transfer as well as radiant heat transfer to the room. Glass doors in front of the firebox have also been utilized. These features all attempt to reduce the amount of heated room air lost up the chimney as well as the flue temperature. Excess air levels are still high even when these modifications are in place. In fact, the glass doors significantly reduce the radiant heat transmitted from the fire to the room; consequently, the overall efficiency and heat output are lower.

Masonry units are not as efficient as the best manufactured units.

Manufactured fireplaces are made of metal and insulating materials and are installed in the home as a prefabricated unit, whereas masonry fireplaces are generally constructed on the site. Manufactured fireplaces come in many styles and configurations, most of which are either conventional fireplace styles or freestanding fireplace or fireplace stove styles.

The conventional style manufactured fireplaces are often called "zero-clearance" fireplaces. "Zero-clearance" means that the fireplace can be installed directly in contact with combustible materials. As shown in Figure 2, the "zero-clearance" fireplace has an appearance very similar to a masonry fireplace once it is installed. Our tests show that the more efficient models can attain efficiencies as high as 10% to 30%. A few units appearing on the

Figure 2 Zero-Clearance Manufactured Fireplace

market this year have peak efficiencies approaching 50%. These units have extra high temperature glass and utilize gasket sealing of glass and doors.

Free-standing fireplaces and fireplace stoves get their name from the fact that they are not installed into a wall as in a conventional fireplace but are out in the room. Typical fireplace stoves are shown in Figures 3 through 7. Strictly speaking it is difficult to delineate between a fireplace stove and freestanding fireplace. Usually the units in this class have attributes of both fireplaces and stoves. They can be operated with fire exposed like a fireplace or the doors closed and the unit operated like a stove. We will refer to both type units as fireplace stoves. These appliances may sit on the floor or hang from the ceiling. The performance of a fireplace stove may be somewhat higher than other fireplaces. Typically, they will fall in a range of 35% to 60% efficiency. The higher efficiencies are obtained by units with solid doors or high temperature sealed glass doors (closed) that offer precise control of combustion air such as the units shown in Figures 4 and 6. The "Franklin" type fireplace shown in Figure 7 tends to have the lower efficiency because of air leakage.

Stoves and Heaters

The wood burning stoves and heaters are relatively new compared to the fireplaces. However, these appliances were used commonly in the kitchens in Colonial American homes for cooking and heating purposes. Today, these stoves are being widely used as an alternative (and often as the primary) heat source for homes.

Wood burning stoves are referred to as closed combustion chamber devices; that is, they are relatively airtight when compared to the open combustion chamber fireplaces.

Figure 3.A Free-Standing Fireplace Schematic

Figure 3.B Free-Standing
Fireplace

Figure 4 Fireplace Stove
with Side Loading Door

Figure 5 Fireplace Stove with
Flue in Rear

6 Fireplace Stove

Figure 7 "Franklin" Type Stove

On the market today, the consumer can choose from two types of wood burning stoves and heaters: the radiant stove and the circulator stove. Variants of these types are also available as described below.

Radiant stoves are those that heat by radiation of heat from their outer surfaces. These stoves are typically a plate steel or cast iron box lined with firebrick or other refractory materials. Many stoves in this category also incorporate blowers to provide forced convection heat transfer. Some use a heat exchanger in the flue area combined with blowers to provide extra heat. These radiant stoves usually contain no ash pan and the wood is burned directly on the firebrick. Figures 8 through 13 show the stoves that were tested for this handbook and are typical stoves that are presently available to the consumer.

Because of the heavy metals and firebrick used to construct the radiant stoves, they may weigh anywhere from 300 to 600 pounds. The radiant stoves under consideration here are "airtight" units; thus the air flow into the firebox can be controlled. The most common means of controlling the air flow is with manually adjusted air inlets, usually but not always located in the fuel loading door. Attempting to further control the flow of air and combustion products through the firebox area, many units have baffles built into the firebox. Unfortunately, the baffle arrangements do not always achieve their goal.

For the radiant stove and heaters, the wood is normally loaded into the firebox through the door or doors on the front or side of the appliance.

Circulator Stoves

Those wood burning appliances that heat primarily by convection of heat from the heater to the room are referred to as circulators.

Figure 8 Typical Radiant Stove with Glass
Doors to View Fire

Figure 9 Typical Radiant Stove with
Rear Flue and a Cutaway to
Show Firebricks

Figure 10 Radiant Stove

Figure 11 Radiant Stove with Single
Front Loading Door

Figure 12 Radiant Stove with
Ash Pan

Figure 13 Radiant Stove

Basically, the circulator consists of an inner metal firebox lined with cast iron or firebrick and a thin sheet metal outer jacket. Room air circulates between the firebox and the outer metal jacket transferring heat from the appliance to the room. This circulation may be natural or forced with a blower. Figure 14 shows a typical circulator stove and a schematic of how it works.

Wood is normally loaded through a door in the end or side of the appliance. The wood is placed on an iron grate or refractory brick for burning, and the ashes fall into an ash pan below the grate. Combustion air normally flows into the ash pan region and then up through the grate to the combustion zone. This air flow is usually controlled by a bi-metallic strip type thermostat.

Fireplace Inserts

Fireplace inserts are more recent additions to the line of wood burning appliances. These appliances are closed-chamber devices that combine the efficiency of the wood burning stoves with the space saving and aesthetic qualities of fireplaces.

The first fireplace inserts were actually radiant stoves that were installed inside the firing chamber of a fireplace. However, due to their lack of radiating surface exposed to the room, these units were fairly inefficient. Specifically designed circulators soon replaced the radiant stoves as an insert. Since the circulator units depended on the circulation of air to transfer heat, their efficiencies suffered very little when installed in the confines of a fireplace. The fireplace insert shown in Figure 15 is a typical insert.

There are already several different models of fireplace inserts to

Figure 14.A Typical Circulator Stove

Figure 14.B Typical Circulator Stove Schematic

Figure 15.A Fireplace Insert

Figure 15.B Fireplace
Insert
Schematic

choose from, and the number seems to be steadily growing. The number of variations on the basic fireplace insert theme is also growing. Many manufacturers offer glass doors on their units which allow viewing of the fire while maintaining control of the air flow into the fire chamber. Others offer increased heat transfer through the use of fans, fins or tubes and baffles which direct the air flow around the outside of the unit.

Fireplace inserts are ideal choices for those who wish to economize their existing fireplaces, without having to worry about where to put the unit. Its home already exists in your den wall. Also, flue connection is generally simpler than with the other wood burning appliances. Some inserts are designed to vent into the existing fireplace with no direct connection. Others require a connection between the insert and existing flue. This latter type is generally difficult to install.

Furnaces

One of the biggest problems with wood burning stoves and heaters is the distribution of heat to various parts of the house. It is not uncommon for the room in which the appliance is located to be overheated and the rest of the house to be cold. This is a basic problem with all types of space heaters and it led to the development of central furnaces.

A central furnace system consists of a heating unit and distribution network. The heating unit is generally located in the basement or utility room. The heat is then distributed about the home via a hot air duct system or a hot water system.

Furnaces offer a more convenient means of heating a home. They are controlled by a thermostat; such that the home remains at a constant

temperature. Oil, gas or electricity fired furnaces require very little, if any, attention from the homeowner; just set the thermostat and let the furnace take care of the heating.

As with other types of heating, the increased cost of fuels has encouraged the use of wood fired furnaces. The only difference in a wood burning furnace and other furnaces is the fuel being consumed.

The wood fired furnace can still be controlled by a thermostat; however, it requires the periodic charging with the wood and maintenance for the chimney. Many furnaces are termed multifuel furnaces because of their ability to operate on several different fuels. Figure 16 shows a typical wood fired furnace.

The performance of any furnace is limited by the heat loss from the distribution system. Typical efficiencies of wood burning furnaces are in the range of 40% to 60%. These numbers compare favorably with the use of oil or gas as a fuel.

If you really want to get serious about wood heat and you have a readily available wood supply, and the money to expend, then a furnace might be what you want. Remember that a wood fired furnace cannot be connected to an existing oil or gas flue.

Accessories

Several important accessories for wood burning equipment are discussed below.

Outside Combustion Air

Frequently, combustion air is provided to wood burning appliances directly from outside the home. The use of outside combustion air does very little towards saving energy. Air from outside the home must be heated

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Figure 16 Typical Wood Fired Furnace
with Additional Blower

to the flue gas temperature no matter whether the air passes through heated portions of the house or not. Outside air can reduce drafts and reduce the effects of drafts on thermostats.

Glass doors

The use of glass doors has become wide-spread. The primary objective of glass doors is to limit the flow of air into the fireplace and hence reduce the excess air level. However, research at Auburn University shows there are two problems with glass doors. First, most glass doors available do not significantly limit the air flow through the fireplace when there is a fire. Second, the glass doors reduce the radiant heat transfer from the fire by 50% or more. Thus, unless other means are made to retrieve the heat from the fire, the net heat output and efficiency of the fireplace decreases significantly when the glass doors are used.

Glass doors do provide a screen to contain sparks, and when there is no fire, the glass doors do limit the flow of air up the chimney; hence, the real value of glass doors is safety and control of air when the fire is left to die down.

Heat Exchangers

The efficiency of most wood burning appliances is usually limited more by the heat transfer process rather than by the combustion processes. Thus, a flue gas temperature can be decreased and the efficiency increased if additional heat is transferred from the appliance to the room. However, if too much heat is removed from the flue gases of an airtight appliance, creosote problems may be compounded. Usually heat exchangers added in the flue do not transfer much more heat than the equivalent area of bare flue pipe that they replace. Heat exchangers built into the upper area of the wood burning appliance furnace area can increase heat transfer considerably.

There are many special grates for fireplaces. Most of these can remove heat from the fire; however, if this heat is not transferred to the room, no net effect is noticed. In other words, quite frequently the heat reclaimed from the fire is pulled back into the fireplace and up the chimney by the room air being pulled by the chimney.

Fans

Any fan, whether made onto the appliance or not, will help to distribute the heat produced to various parts of the house. However, the use of a fan on a room heater or stove generally has little effect on the efficiency. Fans can increase the efficiency of fireplace inserts and furnaces (and any device that mainly depends on convection).

Catalytic Converters

Recently devices consisting of a porous structure plated with a catalyst have been incorporated in the flue area of wood burning appliances to help react unburned gases. These devices do not increase efficiency more than a few percentage points although some manufacturers have made larger claims.

Chapter 3

SIZE AND SAFETY CONSIDERATIONS IN SELECTION OF A UNIT

Size

The first decision regarding size is to determine how much of the home is to be heated. You can get a rough estimate on how large a unit you will need if you will determine the floor area of the room or rooms you wish to heat and calculate what percent of your total house area (heated) that is.

$$\frac{\text{ROOM AREA}}{\text{TOTAL HOUSE AREA}} \times 100 = \text{PERCENT FLOOR AREA}$$

Then, multiply that percentage by the present heating system "BTU/hr Output Rating" to find approximately how many BUT/hr you will need. For example, consider a 1500 ft² home with a 100,000 BTU/hr furnace. Suppose it is desired to heat 540 ft² with a wood stove. The stove requirement would be

$$\frac{540 \text{ ft}^2}{1500 \text{ ft}^2} \times 100,000 \frac{\text{BTU}}{\text{hr}} = 36,000 \frac{\text{BTU}}{\text{hr}}$$

This number gives you an estimate of how much heat you will need from your stove. Remember, this is an average heat output over several hours. Most stoves will put out more heat than this, but for a much shorter time period. So, look for a unit that will supply the estimated heat requirements for a relatively long time period (say 4 to 8 hours). This will cut stove attending time, and also your wood consumption.

Note that most stoves with air control dampers can be adjusted so that a large wood load can be placed into the firebox, which provides a moderate

amount of heat all night. However, this practice can lead to excessive creosote build-up and possible fire flashback if someone were to suddenly open the firebox door. You should not select a huge stove just to be able to load it down and choke off the combustion air for long, smoldering fires.

Safety

Only units tested by recognized safety listing organizations such as Underwriter's Lab should be purchased. Carefully examine the label on the appliance to see if the unit has been properly tested for safety.

It is paramount that the unit be installed according to the manufacturer's instructions provided with the unit. These instructions should be reviewed before purchase for suitable detail and clarity.

Chapter 4

PERFORMANCE

Description of Performance Parameters

There are two basic concepts that determine the efficiency and heat output of a wood burning appliance; namely, the combustion process and the heat transfer. The combustion process is gauged by the completeness of combustion (i.e., the absence of unburned fuel and hydrocarbons in the flue gases) and by the amount of air consumed by the appliance. The heat transfer process determines how well the energy released in the appliance is transmitted to the living area. In other words, the combustion process determines how well the energy stored in the wood is released, while the heat transfer process determines how much of the energy released is made available to the home.

To understand the factors that affect efficiency and heat output, one must first understand just what these terms mean. The heat output of an appliance is simply the amount of heat that the appliance actually makes available to the living area it is intended to heat. The heat output is normally expressed in terms of energy per unit time (i.e., BTU/hr). When sizing and selecting an appliance, the heat output is the most important bit of information. Closely related to the heat output is the firing rate. The firing rate is merely the rate at which wood is being consumed. Normally, this is expressed in lbm/hr.

The overall energy efficiency of the appliance is defined as the ratio of the heat output to the total heat released. The total heat released includes the heat that escapes up the chimney and is wasted as well as that heat that is used to heat the living area.

Efficiency and heat output can be discussed in terms of three parameters: the amount of excess combustion air or air/fuel ratio, the flue gas temperature, and the presence of unburned fuel in the flue gases. When combustible materials or fuel remain in the flue gases, part of the energy stored in the wood is being thrown away. This is called incomplete combustion; most wood burning appliances experience some degree of incomplete combustion. Incomplete combustion can be detected by the amount of smoke and creosote emitted from the appliance.

A combustion process requires a specified amount of oxygen or air. Any extra air present during the combustion process is called excess air. To heat one pound of air one degree Fahrenheit requires approximately 1/4 BTU; thus, any excess air absorbs part of the energy released from the wood to heat it from room temperature to the flue gas temperature. This means that the more excess air consumed by an appliance, the more energy lost to the heating of this excess air.

The temperature of the flue gases leaving the appliance also affects the efficiency of the appliance. The hotter the gases passing up the flue, the more energy is being thrown away; therefore, the poorer the overall efficiency. Improved heat transfer to the room results in lower flue gas temperatures.

Efficiency decreases rapidly as incomplete combustion increases. Efficiency also decreases as the excess air increases, and for a given amount of excess air the efficiency decreases as the flue gas temperature increases. Airtight wood burning appliances operate in the range of -25% excess air to about 100% excess air whereas open fireplaces generally operate well above 500% to 600% excess air.

Measurement of Performance

Detailed performance measurement standards have been developed by the Wood Heating Alliance (1). A brief synopsis of these measurements is given below.

The efficiency of wood burning appliances using large amounts of excess air are best measured in a calorimeter room. This room is carefully controlled so that the net heat output to the room can be directly measured. By measuring the amount of wood consumed in the same period, the efficiency can be calculated.

The efficiency of air-controlled, wood burning appliances is more easily measured by determining the amount of energy lost in the flue gas. This is accomplished by measuring the composition and temperature of the flue gas at various times during a firing cycle. With this measurement, it is possible to calculate the energy delivered to the room by subtracting the energy lost in the flue gas from the energy input to the appliance (wood burning rate).

References

1. Test Standard for Rating Wood-Fired, Open Combustion Chamber, Heating Appliances and Test Standard for Rating Wood-Fired, Closed Combustion Chamber, Heating Appliances, Wood Heating Alliance (formerly the Fireplace Institute), February 1979.

Chapter 5

TYPICAL RESULTS

Table 1 gives typical performance results for the appliances described in this report. The appliance number and figure number in this report are the same.

It is important to note that these data were taken without any special effort to optimize results. Hence, the efficiency of some units reported will be closer to the maximum possible level than others. However, all of the results represent typical performance of the given appliance and are representative of the performance one obtains in actual field use.

Table 1

APPLIANCE DESCRIPTION	APPLIANCE NUMBER (same as figure number)	AVERAGE EFFICIENCY with 70°F OUTSIDE TEMPERATURE	AVERAGE EFFICIENCY with 0°F OUTSIDE TEMPERATURE	AVERAGE AIRFLOW TO UNIT, CFM	AVERAGE NET HEAT OUTPUT with 70°F OUTSIDE TEMPERATURE	AVERAGE NET HEAT OUTPUT with 0°F OUTSIDE TEMPERATURE	AVERAGE POUNDS OF WOOD BURNED PER HOUR
Fireplace (Masonry)	1	10	3	326	31,000	8,000	38
Fireplace (Manufactured)	2	34 31	17 19	230 238	33,000 42,000	17,000 25,000	12 18
	3	54	52	21	36,000	35,000	8
	4	50 56	47 54	38 47	52,000 90,000	49,000 87,000	13 20
	5	53 44	51 42	21 18	41,000 37,000	40,000 36,000	9 11
	6	42	40	20	37,000	36,000	11
Stove or Heater	8	58 64	55 61	38 36	56,000 63,000	53,000 60,000	12 12
	9	43 55	42 54	18 16	60,000 52,000	59,000 51,000	18 11
	10	39	36	15	13,000	12,000	4
	11	64 58	62 56	11 12	26,000 29,000	25,000 28,000	5 6
	12	41 50	40 49	21 20	72,000 49,000	71,000 48,000	22 12
	13	47 42	46 41	23 19	51,000 37,000	49,000 36,000	13 11
Circulator	14	40 33	38 32	34 38	39,000 109,000	37,000 106,000	31 41
Insert	15	46	43	60	77,000	73,000	21
Furnace	16	42	41	12	25,000	24,000	7
		46	45	15	27,000	26,000	7

Chapter 6

OPERATION

For a given wood burning appliance, the single most important factor governing efficiency is the manner of operation. This section gives some tips on achieving maximum operating efficiency while avoiding problems which might result from this type operation.

The air/fuel ratio used for combustion must be controlled so that only air required for complete combustion is used. The homeowner can determine this point of operation by adjusting air until a slight smoke haze appears in the exhaust.

One problem that often occurs in operating wood burning appliances in an air-controlled mode is creosote. Creosote consists of products of incomplete combustion. These products in a gaseous and solid form become liquids if the temperature of the stack is reduced below about 300°F. In liquid form, they adhere to the flue pipe surface and eventually solidify. To avoid creosote either burn the wood completely or maintain stack temperature above 300°F.

However, it is not practically possible to always avoid creosote formation in operating an air-controlled appliance. To eliminate creosote, the appliance should be operated with dry wood (to get a large heat release rate) at high excess air levels about 1 hour each day.

There is a common misconception that green wood and soft woods such as pine produce more creosote. Many investigators including the authors have demonstrated that this is untrue.

Chapter 7

CONCLUSION

This manual describes the various types of wood burning appliances and accessories on the market. The characteristics of the various types of units are given to allow one to assess the best unit for a given application.

Tips on selecting a unit are given. The most important overall considerations are shown to be the size (heat output) and safety features of the unit.

Performance parameters, particularly heat output and efficiency, are defined. Test values for these parameters for several appliances of each type are given. This summary of results will allow one to evaluate the various types of appliances and design features. This table also shows that the performance of units in a given category is very similar. Hence price, quality of construction, appearance, and type of appliance, rather than efficiency, become the most important parameters in selecting a stove in a given category.