Short Course on Masonry Heating Systems

by:

Norbert Senf

Masonry Stove Builders / Lopez Labs

RR 5, Shawville, Que. J0X 2Y0

V 819.647.5092   F 819.647.6082

e-mail: mheat@travel-net.com

Presented at

All Fuels Expo 96

Burlington, Vermont

February 2, 1996

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Introduction:

What is a masonry heater?

A masonry heater allows wood to be burned for home heating in a unique way. It's main distinction is the ability to store a large amount of heat. This means that you can rapidly burn a large charge of wood without overheating the house. The heat is stored in the masonry thermal mass, and then slowly radiates into your house for the next 18 to 24 hours.

This results in a number of benefits. If you burn wood fairly rapidly, it is a clean fuel. It has a low ash content and almost no sulfur content. If you try to burn it too slowly, however, the fire will change from flaming to smoldering combustion. The burning process is incomplete and produces tars. Atmospheric pollution increases dramatically. The ratio of emissions between complete and incomplete combustion with wood can be as high as 100 to 1.

These characteristics of wood combustion become very important if we are planning a wood fired heating system for an energy-efficient house. The average energy demand of this newer type of house is often quite low. For most of the time, it may require only 1 to 2 KW of heat. For most conventional woodstoves, this is below their "critical burn rate", or the point where they start to smolder. In other words, woodburning and energy efficient houses don't really suit each other very well, unless you have some way to store heat so that your stove can operate in the "clean" range all of the time.

Masonry heaters fill the bill very well. If you need even a very small amount of heat, such as between seasons when you simply want to take off the chill, you simply burn a smaller fuel charge–yet you still burn it quickly. The large surface is never too hot to touch. You have a premium radiant heating system with a comfort level that is second to none.

Brief history

The first controlled use of fire by man predates our own species, and is now believed to have occurred 1.4 million years ago by Homo erectus. Agriculture, in contrast, is only about 10,000 years old. Although chimneys were known in Han China 2,000 years ago, they only came into general use among our British forebears around the sixteenth century. Interestingly, of the northern European cultures only the British and French have an open fireplace tradition. Since our North American heritage is mainly British and French, we share this tradition. Not surprisingly people in both countries, peasant and nobleman alike, used to basically freeze in the winter. In our harsh North American climate, the open fireplace was replaced for primary heating by the closed combustion iron stove in the 18th century. The open fireplace is commonly found to this day as a main heat source in the milder climate of the British Isles.

We still carry this ancient relationship with fire in our consciousness, even though few people are still aware that the words "hearth" and "heart" share a common origin.

Other northern and middle European cultures had a somewhat different development that led to a masonry heating tradition. Several different heater types evolved in separate regions. Four types are commonly recognized in North America, and will be described later.

Wood Combustion Fundamentals

Combustion chemistry

From high school chemistry, we recall that all chemical compounds are formed by a combination of about a hundred chemical *elements*. The elements can neither be converted into each other nor split into simpler substances by chemical means. The elements are represented by symbols. The symbols of interest to us for the combustion chemistry of wood are carbon (C), hydrogen (H), and oxygen (O).

Wood combustion is a complicated process consisting of several main chemical reactions and a very large number of intermediate reactions. Depending on the conditions in the firebox, many alternate paths are available to the reacting compounds. As you know, when wood is burned the range of possible products that can leave the stack is very wide.

Elementary analysis

Wood has a complicated chemistry, but it can be broken down into an elementary analysis as follows:

Carbon	(C)	41.0%
Hydrogen	(H_2)	4.5%
Oxygen	(O_2)	37.0%
Water	(H_2O)	16.0% (Air dried)
Ash		1.5%

The brackets give the molecular formula. For example, C refers to 1 atom of carbon, which for carbon also happens to be one molecule. H_2 refers to one molecule of hydrogen, which consists of two atoms. There is also about 1% Nitrogen, which we will ignore.

The atomic weights of the different elements are as follows, and refer to the atomic weight of Hydrogen, the lightest element, which is 1.

H	1
C	12
O	16

Thus we get the molecular weight of carbon dioxide, CO_2, as 44 and carbon monoxide, CO, as 28.

44 grams of CO_2 and 28 grams of CO both have the same number of molecules, and therefore the same volume. A liter of CO_2 therefore weighs 44/28=1.57 times as much as a liter of CO at the same temperature.

Combustion reactions

During complete combustion, the following chemical reactions take place:

$C + O_2 = CO_2$

$2H_2 + O_2 = 2H_2O$

During incomplete combustion, we get the following:

$2C + O_2 = 2CO$

The CO can itself be combusted as follows:

$2CO + O_2 = 2CO_2$

As wood is heated, it releases hydrocarbons in the form of volatiles or gases, and they are given the general molecular formula C_mH_n. The products from complete combustion of hydrocarbons are CO_2 and H_2O (water vapor or steam). During the charcoal phase, we’re combusting C without any H_2, so we get CO_2 or CO, but no H_2O.

All of these reactions are exothermic, ie., they result in a conversion of chemical energy into heat, namely:

1kg C	+	2.67kg O_2	=	3.67kg CO_2	+ 32,000 BTU or 9.6 kWh
1kg C	+	1.33kg O_2	=	2.33kg CO	+ 9,500 BTU or 2.9 kWh
1kg CO	+	0.57kg O_2	=	1.57kg CO_2	+ 9,500 BTU or 2.9 kWh
1kg H_2	+	8.0kg O_2	=	9.0kg O_2	+ 135,000 BTU or 40.5 kWh

Once the chemical composition of a fuel is known, the above formulas can be used to calculate the heat content.

If we oven dry the wood, then it becomes 98.5% combustibles. We've taken out the water, and everything except the ash (and nitrogen) is combustible. The elementary analysis now becomes:

C................................50.0%
H_2 .... 6.0%
O_2 ....42.0%
Ash...............................2.0%

Combustion air

The theoretical combustion air requirement can be calculated from the chemical composition of the fuel.

With complete combustion and dry air:

Air_{th} = 8.8 C + 26.5 H_2 - 3.3 O2 m^3/kg. This is also known as stochiometric air.

Example

Let's run through an example:
Calculate the theoretical air requirement for wood combustion as well as the actual combustion air if the exhaust gas contains 10% CO_2:

For wood with the following analysis:
C = 41%
H_2 = 4.5%
O_2 = 36%
N_2 = 1%
H_2O = 16%
Ash = 1.5%

Using our formula, stochiometric, or theoretical air, becomes:
Air_{th}................. = 8.8 x 0.41 + 26.5x0.045 + 3.3 x 0.36
= 3.60 m^3/kg

Excess air

In reality, more than the theoretical amount of air is required, since some air passes through the firebox without taking part in the combustion. This is called excess air.

Excess air = CO_2max./CO_2measured
The maximum CO_2 possible in wood fuel flue gas is 20.9%

Returning to our example, the excess air is therefore n = 20.9/10 = 2.09, ie., 209% excess air.

Efficiency

Combustion efficiency measures how much of the wood's chemical energy is released during the burn. This is typically around 96 - 99% for most good masonry heaters. The chemical loss consists of unburned carbon monoxide and hydrocarbons that exit the chimney.

Heat transfer efficiency measures how good the appliance is at delivering the released energy to your house instead of out the chimney (stack). One way to define it is in terms of stack loss, something that can be measured with combustion testing equipment.

For wood, we will ignore the fact that the wood changes continuously in chemical composition as it goes from cordwood to charcoal, and assume an average composition. We've already dealt with the chemical loss due to incomplete combustion. There are three other types of stack loss.

Latent heat loss

This results from the fact that you are boiling off the water content of the wood into water vapor. It takes about 2,000 BTU to turn a kg of liquid water at 212ºF to a kg of gaseous water at 212ºF. Note that this loss does not involve a change of temperature, but rather a change of state from liquid to gas. It is termed latent heat, as opposed to sensible heat which is something you can sense as a temperature change. This is an unavoidable loss, unless you use a condensing chimney to reclaim the latent heat, as in a high efficiency gas furnace.

For wood that is at 20% moisture content, this ends up being about a 13% loss. One source of confusion with efficiency numbers and claims by manufacturers is that in Europe the latent heat loss is not counted. This means that if you see European literature on a stove claiming 80% efficiency, you have to subtract 13% to get a North American number.

Stack temperature

The gas leaving the chimney is above ambient temperature, which represents an efficiency loss. With 20% moisture wood and 200% excess air, you have to keep the gas temperature in the chimney above about 180ºF to prevent condensation, which is undesirable unless your chimney is built specifically to handle it. You also need to maintain draft.

Excess air

If you are moving excess air through the system, it ends up at the stack temperature. Therefore, the more excess air, the higher the loss. With a masonry heater, we can pretty much pick whatever stack temperature we want in the design process. The main challenge is controlling excess air. Wood needs 200% to 300% excess air, or complete combustion will be hard to achieve and we will see elevated CO levels in the stack.

It is interesting to note that the theoretical maximum efficiency possible with a non condensing woodburning system burning wood at 20% moisture is about 80% overall efficiency.

Overall efficiency = Combustion efficiency × Heat transfer efficiency.

A very good real world number for a masonry heater is about 75% overall.

Emissions and flue deposits

If we cut back enough on combustion air, we will see a rise in emissions. The emissions question revolves around the subject of incomplete combustion. Incomplete hydrocarbon combustion gives rise to carbon monoxide (CO), soot (C), free hydrogen (H_2) and numerous tars and other organic compounds.

As chimney service professionals, you are all intimately familiar with certain of these compounds. At one end of the scale we have soot, which is pure carbon. It is a non volatile fluffy solid. At the other end of the scale we have complex organic chemicals. Some of these are volatile, which means we don’t see them as they leave the chimney. Others are semi-volatile. They either condense after they leave the chimney into extremely small tar droplets, or smoke, or they condense before they leave the chimney and form a flue deposit. You all know that the most dangerous kind of flue deposit is shiny creosote, which is the most flammable because it is closest to the volatile end of the scale. It’s pretty hard to light soot - it’s more like trying to light a charcoal barbecue. This shouldn’t surprise us, since charcoal and soot are different forms of the same chemical, carbon.

The woodsmoke that enters the atmosphere is considered to be a serious health hazard. I have seen one medical reference claiming that it is 40 times as harmful as cigarette smoke. If you turn down the air on an airtight woodstove enough, your woodfire goes from a flaming fire to a smoldering fire. Your emissions can increase by a factor of a hundred, i.e., 10,000%. Smoldering combustion should be avoided at all costs, because, aside from the pollution it inflicts on the environment, it gives woodburning a bad name.

Emissions are of great interest to the masonry heater builder. A masonry heater is by far the cleanest way to burn cordwood on a domestic scale, i.e. in batch mode from a cold start. Because we have heat storage at our disposal, we can use whatever burn rate we want.

Carbon monoxide (CO)

Carbon monoxide deserves a special mention. We have already seen how it arises from incomplete combustion and can contribute to stack loss and to emissions. CO is also a fuel, since we saw earlier that it contains 9,500 BTU of chemical energy per kilogram. At the tail end of a wood fire, during the charcoal stage, we are seeing CO combustion. We’ve already seen that charcoal is pure carbon, or C. It can burn either completely to CO_2, or partially to CO. The CO can then either burn to CO_2 or exit the chimney as a pollutant.

It is a potential safety hazard with all combustion appliances, including masonry heaters. Most masonry heaters have flue dampers, and if you close it before the fire is out, you can die from CO poisoning. CO is colorless, odorless, and potentially lethal. It is particularly dangerous because the ratio between low concentrations when you first start feeling physical effects such as headache and between fatal concentrations when you black out is only about 1:100. Fortunately, reliable CO detectors have recently become available at low cost. Everybody who has any combustion equipment in the house should have a CO monitor. As a masonry heater builder you need to tell your clients, in writing, to install a CO detector in the portion of the house that has the heater.

Combustion testing

Demonstration of a TESTO 342 combustion analyzer

This is a combustion gas analyzer that is manufactured in Germany and used there by many sweeps, stove builders and furnace technicians. I believe that before you are allowed to build a masonry heater in Germany you have to get an OK from the Bezirgsschornsteinfegermeister, or district master chimney sweep, who will check out the venting setup and make sure that clearances are followed.

This particular instrument consists of the following:

- a flue gas probe
- a connecting hose
- a sample conditioning system
- a handheld battery powered analyzer
- an optional small remote controlled printer

It measures stack oxygen, stack CO, stack temperature and stack pressure (draft). The CO measurement is accurate to 20 PPM and you can use it to measure ambient CO in a house. It is programmed for 16 different fuels, including wood at 20% moisture, and can calculate stack loss directly. You can get an optional infrared remote printer that gives you a printed report.

I'll describe briefly what you would do to use it:

It is not designed for homeowner use and you have to read the manual carefully before using it, because it is a sensitive, not to mention expensive, piece of gear that will break if you don't follow the instructions.

Once you push the on button, it goes through a calibration phase. A pump turns on and pumps ambient air through the two electrochemical measuring cells. After about a minute, you follow the prompts on the LCD screen and adjust the oxygen number to read 21.0, which is ambient. It then jumps to a fuel selection sub-menu. Assuming you are just measuring one fuel, you don't have to change this.

You then insert the flue gas probe into the flue. Next, you turn on the pump and can read various screens full of information. You can program it to give up to 5 different screens. You then stop the pump and pull the flue gas probe out into fresh air. After you are done either printing out or writing down the reading, you need to turn the pump back on in order to flush out the measuring cells.

Table 1. Test summary from a typical Lopez Labs test

RUN No.	HK-D12
Wood Moisture................	16.4
Total Weight....................	47.9
Kindling Weight................	2
Number of Pieces...........	8
Fuel Surface/Vol.............	3.96
Run Length......................	1.5
Av. Stack Temp...............	401
Av. O2%..........................	12.76
Av. CO%..........................	0.12
Stack Temp. Factor........	0.78
Stack Dilution Factor......	2.57
Burn Rate dry kg/hr........	11.39
Boiling of Water Loss.....	12.25
CO Loss %......................	2.03
HC Loss %......................	0.20
Dry Gas Loss %.............	14.83
Filter Catch gm.	0.0319
g/kg Condar................	**0.53**
g/kg CO........................	**17.93**
Combustion Effic...........	**97.76**
Heat Trans. Effic............	**72.92**
Overall Efficiency..........	**71.29**

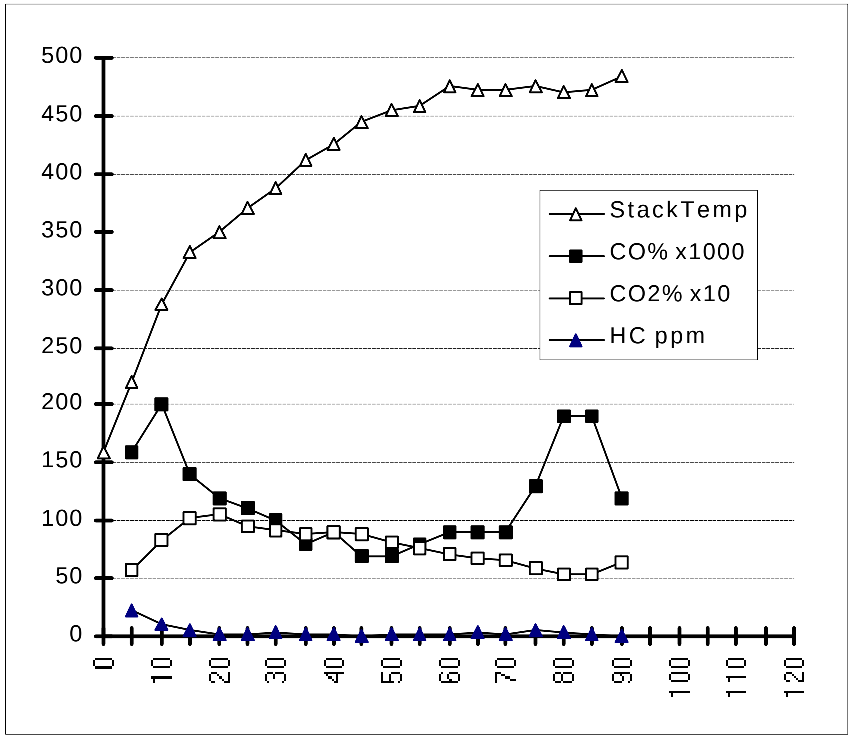


Figure 1. Flue gas analysis curves for a 1½ hr test run

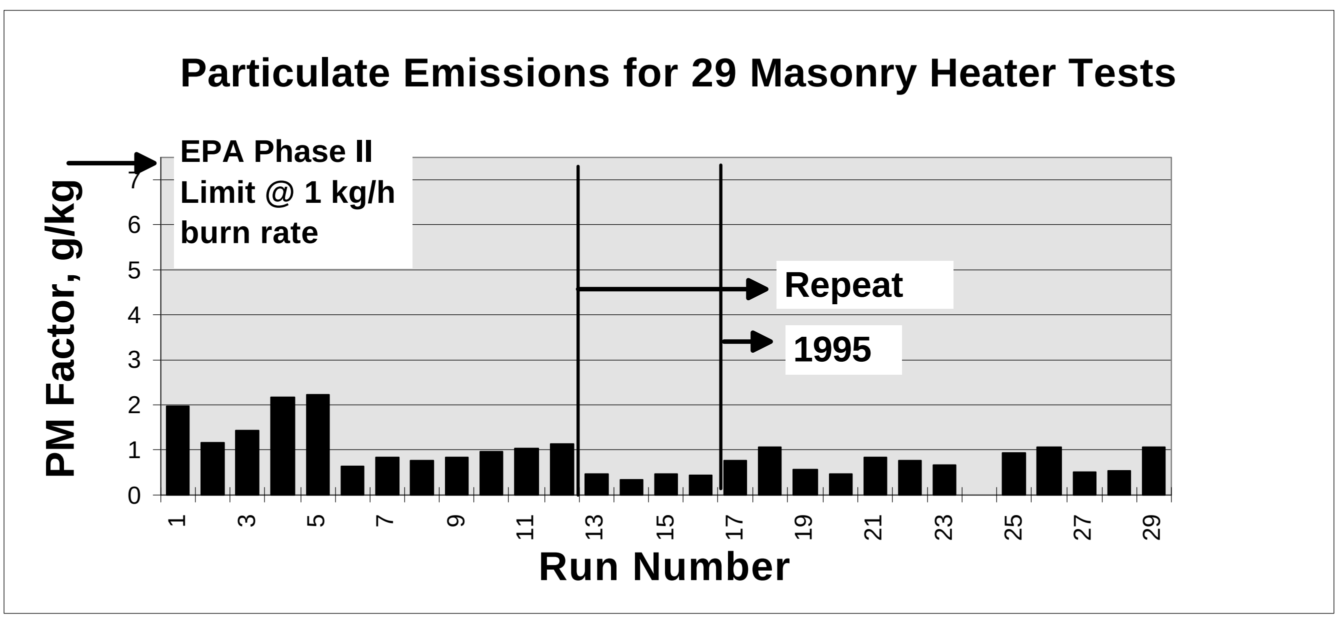


Figure 2. Lopez Labs 2 yr test results on one masonry heater

Masonry Heater Operating Principles

Burn cycle

Most North American heaters, as mentioned, are at the large end of the traditional scale. Most heaters are fired once per day. Burn cycle varies with owner lifestyle. With a typical couple where both people are away at work all day, the heater usually gets fired in the evening. Most heaters double as fireplaces, so heater owners get to see a real wood fire every night. The house is warm in the evening, overnight, and in the morning. As the house sits unoccupied, it slowly cools. A backup system can give the house a small boost just before its occupants arrive after work, and the cycle is repeated.

Options

Bakeovens can be incorporated into many heater types, and are getting very popular. Other common options are domestic hot water and heated sitting benches. With properly engineered heat exchangers, hot water heating systems such as radiant floors can also be driven.

Safety

CO danger has already been mentioned. It is worth repeating that reliable, inexpensive CO detectors have recently become available and should be mandatory equipment for owners of any combustion appliances. In the province of Ontario, they will soon become mandated in the provincial building code.

Maintenance and servicing

A properly designed, built and operated masonry heating system requires little service beyond a yearly checkup by a qualified chimney service person. A small amount of fly ash may need to be vacuumed from the channels. Our neighbour has a contraflow heater that we built for him in 1981, and he has never serviced it. There is no flue deposit at all, there is probably some fly ash, and all of the hardware is in mint condition after 15 years of normal use.

I have once seen creosote deposits in a masonry heater. The owners ran out of firewood the first winter and were cutting green trees and burning them right off the stump.

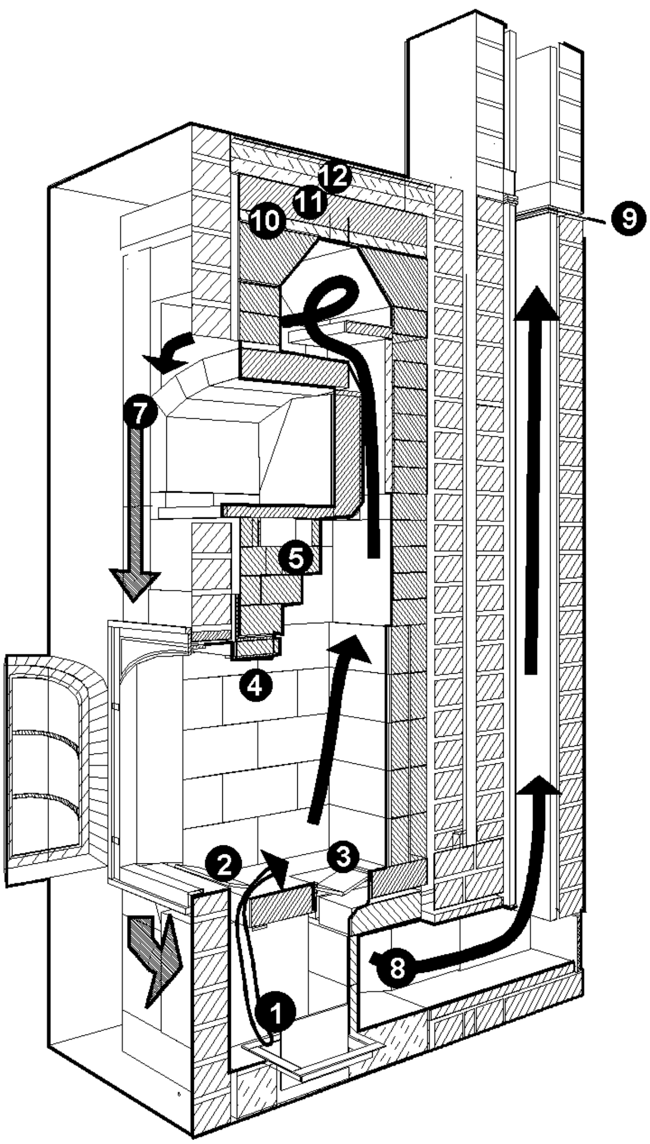
Some Masonry Heater Design and Construction Principles

Principal heater types

Among North American heater masons, there are generally regarded to be 4 principal heater types:

- Grundofen (German and Austrian)
- Contraflow (Finnish)
- Kakelugn (Swedish)
- Russian

The most commonly built type of heater is the contraflow, illustrated below:



1. Insulating Base Slab with Outside Air Damper
2. Combustion Air Inlet
3. Ash Drop
4. Firebox Lintel with Heat Shield
5. Bakeoven Floor Heat Bypass
7. Heat Exchange Channel
8. Exhaust Gas (to Chimney)
9. Chimney Damper
10. Hi-Temp Insulating Board
11. Refractory Capping Slab
12. Insulating Concrete

Figure 3. Cutaway illustration of a contraflow heater.

There are a number of ways of constructing a masonry heater:

- Factory prefabricated heater (Tulikivi, Biofire). The complete heater including facing is assembled on site from prefabricated components.
- Factory prefabricated heater core (Tempcast, Envirotech). Heater core is assembled onsite from factory components. Heater facing is installed onsite.
- Hybrid cores (Heat-Kit, AlbieCore). Factory components are combined on site with standard refractory modules (firebricks). Heater facing is installed onsite.
- Handbuilt. Can be built from purchased plans (Maine Wood Heat Co.) or custom designed.

It should be noted that the first three options are relatively new. Until quite recently, all masonry heaters were handbuilt onsite and often custom–designed.

Heat output calculation

We will look at two ways of calculating masonry heater output:

Using the German system, we can first calculate what our heating output requirement is in BTU/hr or in KW. Next, we pick one of the four heater types. Table 2, below, gives us a design surface temperature, which is assumed as a constant. If we know the surface temperature, then it is a simple matter to look up the corresponding heat output, in BTU/ sq. ft. or kW/m^2. The required output is then $kW/m^2 \times m^2$, i.e., we simply calculate the required masonry heater surface area.

A second method of calculating heat output is simpler and somewhat more practical for North America. We tend to build whole house heaters almost exclusively, whereas most of the traditional European heaters were room heaters. In other words, most of the categories of smaller heaters simply don’t exist here.

For contraflow heaters, we can base our heat output calculation on several assumptions:

- Essentially, we try to build he highest output heater that we can. Oversizing is not an issue the way it is with airtight stoves, since heat output on a masonry heater is easily downsized simply by burning a smaller fuel charge. The charge itself is still burned at a high rate:
- the heater shape is somewhat fixed and less flexible than a heater without a glass fireplace door.
- we use the largest practical wood charge, about 60 lb. This gives us the largest practical firebox, 22½".
- we use the heaviest practical construction (“extra heavy” in the German system). This gives us the minimum practical sidewall thickness for a double skin contraflow heater, or about 6". Another way to look at it is that we are essentially trying for the highest surface temperature on a heavy heater.

Using the above rules of thumb, we end up with a heater that burns a 60 lb. wood charge and has about an 18 hr. cycle (time constant). If we assume a 75% overall efficiency, then 60 lb. of 20% moisture wood translates into about 300,000 BTU, or about 90 kWh of heat output.

Next, we can custom tailor our heat output by varying the firing cycle of the heater. We can burn 60 lb. once, twice, or three times per day. Three times per day is unusual, so we have a practical maximum output of 300,000 BTU × 2 or 600,000 BTU/day. Averaging this, we get 600,000/24 or 25,000 BTU/hr. (7.6kW) maximum design output.

In modern energy efficient housing, it is usually unnecessary to built a larger heater. There should alway be a backup heating system. If it kicks on for, say, 5% of the heating season then it avoids the extra expense of an extra large heater.

Where it is necessary to have more output, there are several choices:

- Use a shorter firing cycle (8 hrs)
- Use a backup system
- Custom design a larger heater
- Use a standard heater with add-on storage. This is known as a heat battery. Make sure that it won’t invalidate the core manufacturer’s warranty. Heat batteries are usually custom designed to fit the situation.

Channel sizing and calculation

We will look at the German system for Grundofen calculation.

Terminology

Masonry heater terminology can sometimes be confusing. Many North American terms are borrowed from other languages due to the fact that there is no masonry heater tradition among English speaking peoples. There is some confusion in particular with German terms. The common term in Germany for a masonry heater is Kachelofen or “structural clay tile faced stove”. The term Grundofen (plural Grundöfen) is better, and literally means “ground stove”. This is to distinguish it from the Einsatzofen, or “insert stove”. The Einsatzoven consists of a metal stove insert and a Kachel or structural clay tile facing. North American stovemasons don’t consider this to be a true masonry heater, because it is mainly a convection system as opposed to a heat storing, radiant system. From our point of view, the more accurate German term for masonry heater is Grundofen. Very few stoves in North America use Kachel facings, so the term Kachelofen is not really accurate.

Design and Construction Sequence

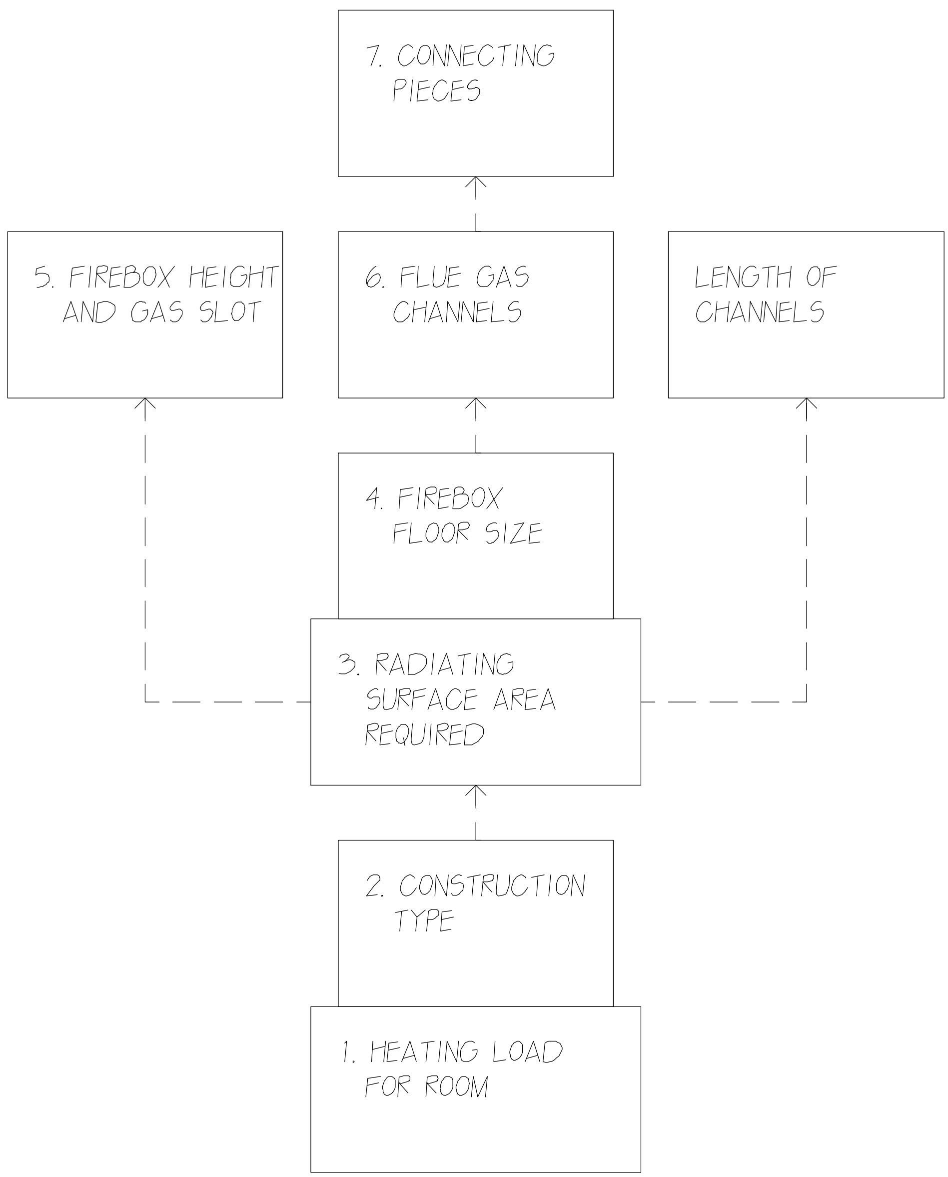


Figure 4. Construction sequence for Grundofen system

Construction Type

Table 2. Grundofen construction types and their characteristics

Type	Heavy	Medium	Light
Prevailing climate usual for this type of construction	Heating intervals particularly long, very low temperatures	Heating intervals of medium length, low temperatures	short heating periods, mild temperatures
Heat storage capacity	Highest mass	Medium construction	Light construction
	Highest storage capacity	Good storage capacity	Adequate storage
Usual mode of operation	One large burn daily	One burn daily with one reloading	One burn daily with several reloadings
Type of heating cycle	A relatively long warmup time is followed by very long, steady heat output	A normal warmup time is followed by a long heat output	Room is warm after short warmup, but cools quicker unless stove is reloaded
Mass per KW output, kg	350	230	175
Average surface temperature, ^{o}F	147	176	194
Rated output, kW/m^2	0.7	0.93	1.16

Table 3. Cross sectional area of Grundofen heat exchange channel, cm^2/kW - cordwood fired

Construction Type	First Channel	Last Channel
Heavy	130 to 150	90
Medium	110 to 130	90
Light	100 to 130	80

Refractory materials

Refractory means having the ability to withstand heat. Knowledge of refractory materials is not normally required for installers of factory made heaters. Installers are usually factory trained to install specific models of heaters, and are not necessarily stovemasons. For core-only systems, masonry skills are required to install custom facings. Sometimes the core is installed by a factory trained installer and the facing is done separately by a local mason.

A stovemason is capable of designing and handbuilding custom heaters to the customer's requirements. We've taken a brief look at how masonry heaters are designed and sized, and how some of the internal components are laid out.

Refractory materials is a large subject area. As chimney professionals, you are familiar with some of these.

Fired clay masonry units

An example of a fired clay masonry unit is an ordinary clay brick. It is composed of clay and has been fired in a kiln. It is different from a concrete brick, which is composed of portland cement and inert aggregate and is hardened by chemical action instead of by heat.

A firebrick is usually lighter in color than a common clay brick, which is usually red. The red color comes from iron, which is a common impurity in clay. Iron and other impurities such as lime lower the melting point of the clay. Fireclay is similar to ordinary clay except that it has fewer impurities. This gives it a higher melting point and allows it to withstand higher temperatures after it has been fired.

When you are looking for a good firebrick for use in building masonry heaters, you don't really care what temperature the brick is rated at. Even the lowest rated firebrick is capable of withstanding much higher temperatures than it will ever see in a masonry heater firebox. A super heavy duty industrial firebrick is not necessarily what you are looking for. These bricks are designed to be heated to high temperatures and <u>kept</u> there. This is a key point. In a masonry heater, although the firebrick doesn't have to withstant an extremely high temperature, it gets heated and cooled <u>rapidly</u> and <u>often</u>. This is termed thermal cycling, and is your main enemy as a stove mason. It is related the thermal shocking, which means changing the temperature of a material rapidly.

This can be illustrated by an example that you are all familiar with, the red clay flue liner. As chimney professionals you see a lot of cracked red clay flue liners. These liners are often made from fireclay, so they actually have no problem at all when it comes to handling high temperatures. You can heat them cherry red with no adverse effects, but you have to do it slowly. If you heat or cool them rapidly, they crack. They can take heat but they can't take thermal shock.

Clay flue liners crack because of their geometry. Clay has a coefficient of thermal expansion, which means that it expands by 1% for every 100 degrees Centigrade temperature rise. Fired clay is not very flexible, so if you heat a flue liner unevenly parts of it will expand faster than other parts, causing it to crack. Because the liner is relatively thin, it is easy to get hot spots.

A second property of clay that affects its thermal cycling properties is its chemical composition. The two main constituents of clay are silica and alumina. Pure alumina is white and has a very high melting point. Porcelain is an example of a high alumina clay. Silica can cause problems in refractories. It undergoes a reversible change in crystal structure known as a quartz inversion at 573ºC accompanied by a change in volume.

Castable refractories

Castable refractories are used to make what amounts to high temperature concrete. An example from the chimney lining trade would be the various pumped liner systems. Castable refractory, like ordinary concrete, consists of an aggregate and a binder. In concrete, the binder is portland cement and the aggregate is sand and gravel. In castable refractory, the most common binder is calcium aluminate cement, also known as fondue cement or lumnite. You can buy it in a 90 lb bag just like portland cement, and it has some similar properties and uses. In fact, non-soluble refractory mortar, which has become mandated in NFPA 211 and some state building codes for joining flue liners, is basically a mixture of calcium aluminate cement and sand. The aggregate in castable refractory usually is crushed firebrick or some other refractory mineral substance.

Refractory mortars

Refractory mortars are tyically used for setting refractory standard modular unit masonry (firebricks). Non-soluble mortars have already been mentioned, and are used for joining flue liners and joining large precast refractory modules.

Firebricks, if they are not going to be exposed to water as in a chimney flue, are normally set in clay mortar, either heat setting or air setting. Heat setting mortar consists solely of clay, and sets only after the clay has been taken up past its fusing temperature. This will never happen in a domestic scale masonry heater, except perhaps in portions of the firebox and only if low melting point clays (plastic earthenware clays) were used. Air setting refractory mortars such as Sairset from A.P.Green consist of fireclay with sodium silicate added. Sodium silicate is also known as water glass. It is used by potters as a deflocullant, which means that it keeps clay particles in suspension, giving the clay a slimey feel. It is also the material that you buy as stove gasket glue in small bottles. It's about $10 per gallon at A.P. Green. It sets by drying, and remains somewhat water soluble after it has set. This is a problem in chimney flue liners, but not in masonry heaters since they never get wet.

Setting firebricks

As mentioned, firebricks are normally set in refractory clay mortar, either heat set or air set. Airsets are commonly used on masonry heaters but non-airsets also to some degree. Firebricks can be trowelled or dipped. Sairset comes in the bucket at trowelling consistency. All commercial refractory work is done by dipping. It is extremely fast, since firebricks are very dimensionally consistent and can therefore be set with very thin joints. In order to dip firebricks, you need to thin the refractory mortar by adding water. It has the right consistency when a dry firebrick laid flat on the surface sinks about halfway.

Insulating Refractories

There are a number of types of insulating refractories. They include:

- insulating castable refractories
- ceramic blanket and ceramic paper
- refractory insulating board or millboard

Other Refractories

Soapstone is a unique refractory and masonry material. Compared to a pound of concrete, a pound of soapstone can store approximately 20% more heat. Its main distinctive thermal property is that it has about 4 times the conductivity of concrete or about 6 times the conductivity of soft clay brick. Another way of saying this is that its R value is 1/4 that of concrete. It is somewhat similar to a metal in this respect. This means that a soapstone heater of equivalent mass will heat up faster on the outside surface and reach a higher surface temperature, due to the high conductivity. On the other hand, the higher rate of heat transfer to the room also means that it cools down faster than other masonry materials. Understanding the thermal properties of soapstone gives the heater mason an additional way to handle unusual design requirements when they arise. For example, we use soapstone heat transfer plates in castable refractory bakeoven floors to even out cool spots. A nice feature of soapstone is that it can be carved quite easily.

Expansion joints

The quickest way to go out of business in the masonry heater business is to build heaters that crack their facings. When fired, the interior of a heater, particularly the firebox, heats up first and expands. If the proper expansion joints are not left at appropriate locations between the heater core and the facing, the facing <u>will</u> crack. This is guaranteed, and has put a lot of new heater builders out of business over the years. You can wrap the core with mineral wool, but this will compromise performance unless it is very thin. Don't use an airspace filled with sand, either. Expansion joints are fairly simple once you learn exactly where you need to put them.

Hardware

Metal hardware for masonry heaters should be designed for long service. Firebox doors and frames should be cast iron. Only ceramic glass should be used.

Finishes

Finished can be almost anything within the entire huge range of masonry. Most popular in North America are brick, stucco, stone and tile. Some examples are given in the slideshow.

Codes and Standards

If you are building a masonry heater, your client typically will have to deal with a local building inspector and also his/her insurance company. The insurance company will usually want to know that you are installing a “listed appliance”, and/or that you have a building permit.

A listed appliances carries a label from a recognized testing laboratory stating that it has been safety tested for clearances to combustibles in accordance with the applicable UL (Underwriters Laboratories) standards. The clearances will be spelled out on the tag. Listing is possible with factory-made heaters, but not practical for site-built units. These fall under the building code, which carries provisions for clearances to combustibles for masonry fireplaces and chimneys.

Very few code jurisdictions currently recognize masonry heaters specifically. One exception is the state of Washington. The nearest applicable provisions are usually the masonry fireplace and chimney sections of the locally recognized code, which often references NFPA 211 (the National Fire Protection Association standard).

Masonry fireplaces codes typically specify the following:

<u>Clearances to combustibles from:</u>

- the firebox opening
- cleanouts
- the masonry itself

<u>Materials and minimum thicknesses for</u>

- the firebox
- a non-combustible hearth extension
- other surfaces

If a prefabricated non-masonry chimney will be used, it may be necessary to find a connector listed for attachment to masonry.

To address the lack of specific standards for masonry heater construction in North American building codes, an ASTM task group was formed about 10 years ago. ASTM is the world’s largest consensus standards organization. It differs from UL in that standards development is an open process and anybody has the right to have their particular concerns addressed before a standard can be voted on.

ASTM Standard Guide E 1602 - 94 was passed in 1994 and is titled “Construction of Solid Fuel Burning Masonry Heaters”.

Highlights of the ASTM Standard Guide for Construction of Solid Fuel Burning Masonry Heaters

<u>Scope</u>

- Provides dimensions for sitebuilt masonry heater components.
- Provides clearances that have been derived by experience.
- Does not apply to components that have been safety tested and listed.

<u>Definitions</u>

Gives definitions for masonry heater specific terminology.

<u>Significance and Use</u>

- “4.1 This guide can be used by code officials, architects, and other interested parties to evaluate the design and construction of masonry heaters. It is not restricted to a specific method of construction, nor does it provide all specific details of construction of a masonry heater. This guide does provide the principles to be followed for the safe construction of masonry heaters.”
- Not intended to be a complete set of construction instructions.
- “4.3 ... construction shall be done by or under the supervision of a skilled and experienced masonry heater builder.”

<u>Requirements</u>

- Clearances to combustibles
- Minimum dimensions and materials for various heater elements
- Other construction details

<u>Typical Masonry Heater Types</u>

- Lists 5 masonry heater types with example illustrations

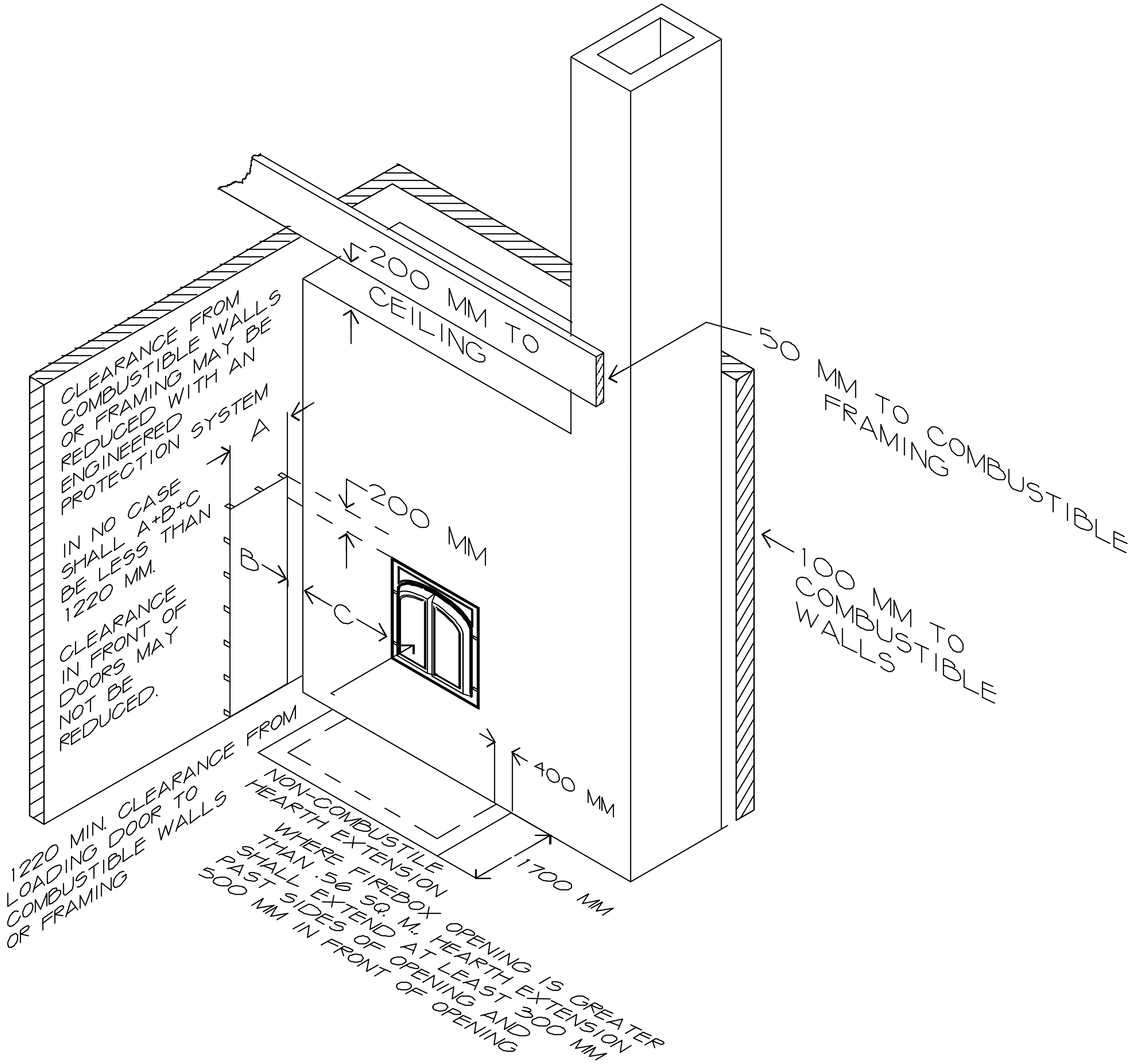


Figure 5. ASTM clearances to combustibles for masonry heaters

Slide Show

Examples of heater design and construction
Manufactured vs. handbuilt systems
Marketing examples

Practical Demonstration

Layout and construction of the bottom end of a contraflow heater
Firebrick techniques

Question Period and Discussion