The Masonry Heater Reference Manual

Masonry Heater Association Of North America ®

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The Masonry Heater Association of North America

Administrator:

Richard Smith
2180 S. Flying Q Lane
Tucson, AZ. 85713
Phone 520-883-0191
Email: execdir@mha-net.org

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Illustration Credits

Figures 1, 2, 3, 5	John Fisher
Figures 13, 16, 17,18	Tempcast Enviroheat Ltd.
Figure 10	Heikki Hyytiäinen
Figure 24, 25	Alex Chernov
Figure 26	Chris Prior

1. Introduction

This manual has been prepared by the Masonry Heater Association (MHA) of North America to provide a technical reference for the construction of masonry heaters and to form a component of its professional certification program for heater builders. The overall objectives of the Association's efforts in this area are to recognize the specialized skills of qualified masonry heater builders, to standardize the fundamental principles of masonry heater design and construction practices, and to increase the public awareness of the benefits of using masonry heaters for home heating and enjoyment.

Masonry heater building as a commercial activity has a short history in North America of only about 30 years, and has drawn considerably from the rich European tradition of masonry heater design. The members of MHA have studied the available literature on classic European designs from Germany, Austria, Finland,

Russia and other countries, and have consulted with recognized European experts in the field.

Among the many types and variations of masonry heaters across Europe, the **ASTM E 1602.-03**
Standard Guide for Construction recognizes four typical designs, as follows:

- **The Kachelofen (Figure 1)**,

Of German origin and perhaps the most recognized of masonry heaters, takes its name from the structural tiles, or kacheln, that cover its surface. Each kachel has a hollow back and when laid on its face resembles a square or rectangular ceramic cooking dish; in fact, the origin of the kachel is the clay pot.

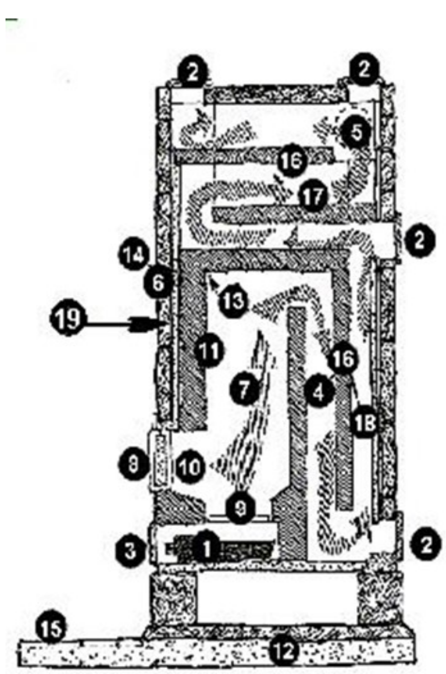


Figure 1.
Kachelofen

1. *Ash Box*
2. *Clean Out*
3. *Ash Box Door*
4. *Downdraft Channel*
5. *Exhaust Gas Outlet*
6. *Exterior Wall*
7. *Firebox*
8. *Firebox Door*
9. *Firebox Floor or Grate*
10. *Firebox Opening*
11. *Firebox Wall*
12. *Heater Base*
13. *Gas Slot*
14. *Kachel/Brick*
15. *Hearth Extension*
16. *Heat Exchange Area*
17. *Horizontal Channel*
18. *Updraft Channel*
19. *Expansion Joint*

- The back of the kachel can be left empty when put in position or filled with firebrick to increase the mass in that area of the heater. Kachelöfen (pl.) are compact in size and mainly used as room heaters. They are not often built in North America. The Grundofen, also of German origin, is similar internally to the Kachelofen but uses standard bricks/or natural stone rather than kachel on its surface.
- The gas flow path from the rather tall firebox in Kachelöfen and Grundöfen is a relatively short downdraft channel behind the firebox leading to an updraft channel leading to three or four horizontal channels directly above the firebox. In this way, these stoves achieve a large heat transfer surface in a compact size.

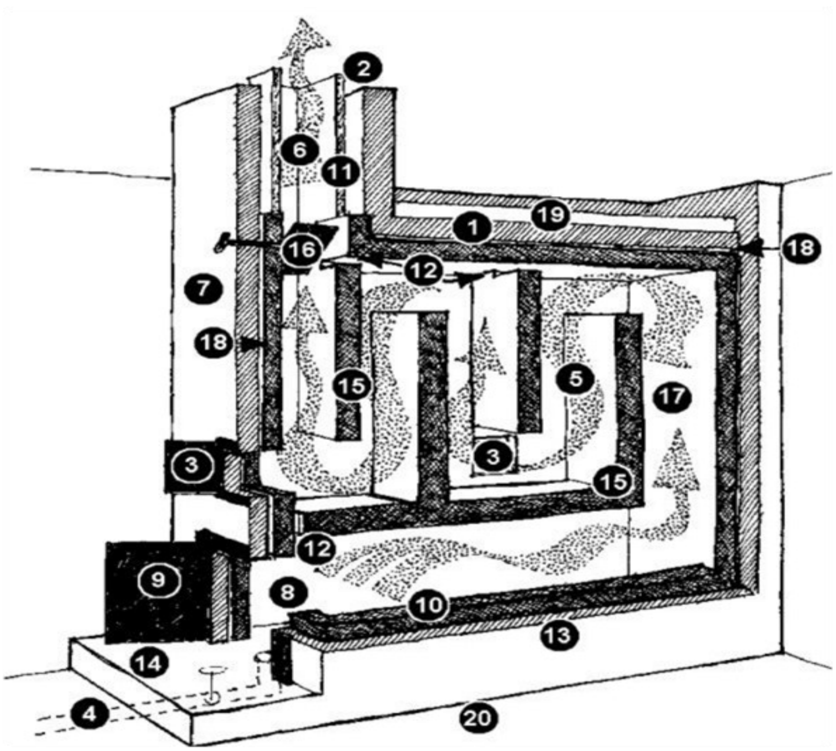


Figure 2.
Russian heater

1. Capping Slab
2. Chimney
3. Clean Out
4. Outside Combustion Air
5. Downdraft Channel
6. Exhaust Gas
7. Exterior Wall
8. Firebox
9. Firebox Door *10.* Firebox Wall
11. Flue Liner
12. Gas Slot
13. Brick
14. Hearth Extension
15. Heat Exchange Area
16. Shut Off Damper
17. Updraft Channel
18. Expansion Joint
19. Insulation Joint
20. Heater Base

- **The Russian heater (Figure 2),**

is characterized by a long, low firebox with its rear exit leading to a series of vertical or horizontal channels formed by baffles above the firebox. It is also rarely built in North America.

- **The Swedish tile heater (Figure 3)**

Has a tall firebox which exhausts into downdraft channels on either side of the firebox. At the level of the firebox floor, these channels empty into two updraft channels that come together at the exhaust outlet, usually at the top rear of the stove.

Figure 3. Swedish Kakelugn

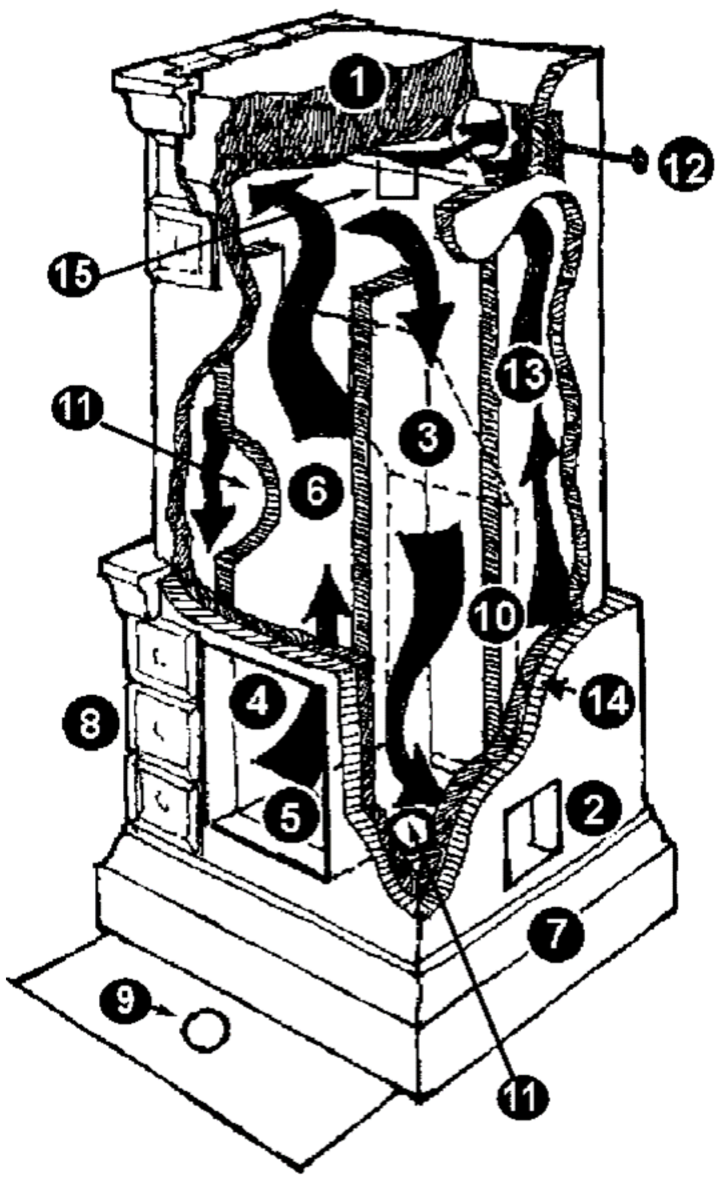


Figure 3.
The Swedish tile heater

1. *Capping Slab*
2. *Clean Out*
3. *Downdraft Channel*
4. *Firebox*
5. *Firebox Floor or Grate*
6. *Firebox Wall*
7. *Heater Base*
8. *Kachel*
9. *Hearth Extension*
10. *Heat Exchanger Area*
11. *Horizontal Channel*
12. *Shut Off Damper*
13. *Updraft Channel*
14. *Expansion Joint*
15. *Gas Slot*

- **The Finish Contraflow heater (Figure 4 and Figure 5)**

Has a tall firebox that exhausts into downdraft (or contraflow) channels on either side. The channels are shallow but as wide as the firebox is deep, providing a large swept heat transfer surface. The downdraft channels extend down to below hearth level where a horizontal channel directs the exhaust into the base of the chimney which is at the rear or off to one side of the heater.

Despite the considerable European influence, and particularly that of the Finish contraflow tradition, masonry heater design has evolved over the past three decades to produce a distinctly North American type that accommodates its housing characteristics and customer preferences.

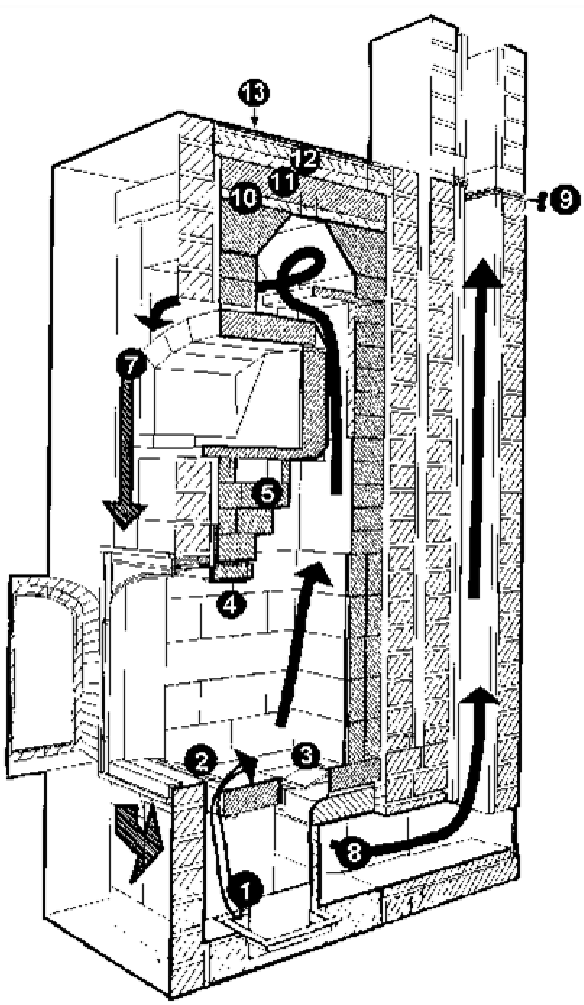
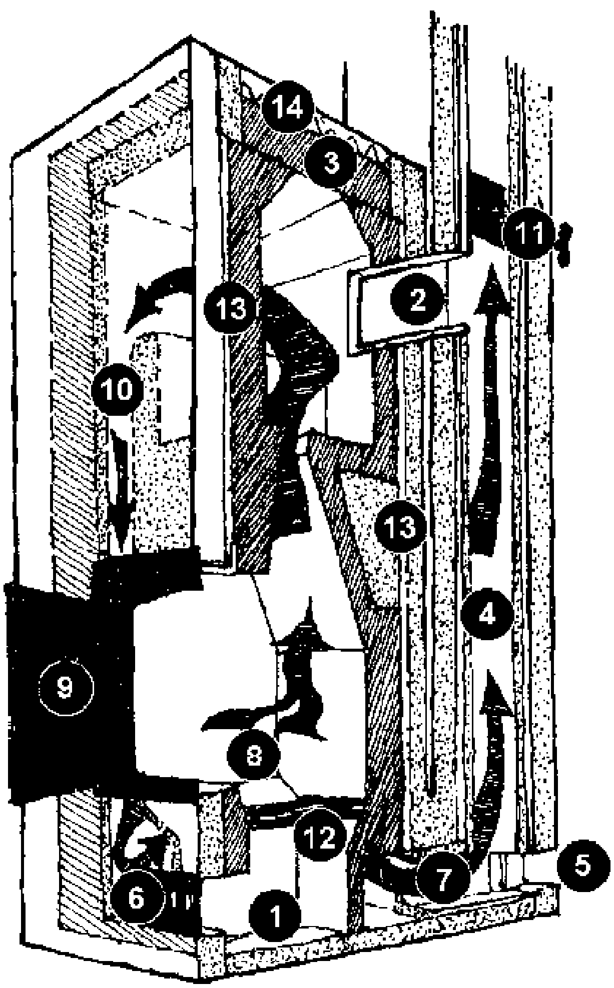


Figure 4.
A heavy contraflow heater with an integral bake oven

1. Insulating Base Slab with Outside Air Damper
2. Combustion Air Inlet
3. Ash Drop
4. Firebox Lintel with Heat Shield
5. Bake Oven Floor Heat Bypass
7. Heat Exchange Area
8. Exhaust Gas (to Chimney)
9. Sliding Chimney Damper
10. Hi-Temp Insulating Board
11. Refractory Capping Slab
12. Insulating Joint
13. Reinforced sealing cap

North American masonry heaters take some design cues from the massive, decorative masonry fireplaces that have been characteristic in U.S. and Canadian housing. This trend results in heaters that are bigger and heavier and with larger fireboxes than European designs.
North American heaters are viewed as whole house heaters, unlike the European masonry stoves that are used more often as room heaters. North American heaters usually have glass panels in their doors to permit viewing of the fire, another design element that responds to customer desires for a look reminiscent of conventional masonry fireplaces.

Fortunately for North American masonry heater designs, ceramic glass was made available in the late 1960's. Ceramic glass has replaced tempered glass for applications where temperatures may exceed **500 degrees F** (260 C).



Standard tempered glass expands when heated and shrinks when cooled. This makes it susceptible to thermal shock and shattering. Ceramic glass has near zero thermal expansion, which makes it very resistant to thermal shattering.

The custom-built masonry heater that has emerged in North America is the primary focus of this manual. This North American type could be referred to as an "extra-heavy glass doored contraflow masonry heater": we will refer to it in this manual with the shorter form extra-heavy contraflow or X-HC.

European masonry stoves may be available as kits supplied by manufacturers who provide complete instructions for construction and technical support to assemblers. These kits are not covered in any detail here because their construction techniques and material use tends to be product-specific and training is normally provided by factory representatives.

Figure 5.
A heavy contraflow heater with bypass damper and under-fire air

1. *Ash box*
2. *Bypass Damper*
3. *Refractory Capping Slab*
4. *Chimney Flue*
5. *Clean Out*
6. *Ash box Door with Combustion Air Inlet*
7. *Exhaust Gas (to Chimney)*
8. *Firebox*
9. *Firebox Door*
10. *Heat Exchange Area*
11. *Pivoting Chimney Damper*
12. *Grate*
13. *Expansion Joint*
14. *Insulating Joint*

- Two other masonry heater technologies have emerged in North America that are not yet included in **ASTM 1602.3** should be mentioned.

- **Bell Heaters**

Were brought to North America by Alex Chernov in 2002. Having it's history in Russia, the system of Free Gas Movement was introduced by V. E. Grum-Grzhimallo at the beginning of the 20^{th} century and further developed by I.S. Podgorodnikov I.S. Another Russian engineer and mason, Igor Kuznetsov and his trained masons have built 4,000 such stoves since the 1960's.
The fundamental difference with Bell heaters is that, rather than flowing through channels, heat exchange occurs in chambers where slow moving gases are allowed to stratify with only the cooler "ballast" gases at the bottom entering either a second chamber or the chimney.

See **Figure 6.**

- **Rocket Mass Heaters**

Rocket mass heaters have recently evolved from the rocket stove, which is primarily a high efficiency, low cost wood fired cooking stove. Small pieces of wood are fed vertically by gravity into the open end of a J-shaped combustion chamber. The hot gases then enter an insulated vertical secondary combustion chamber, then are pulled downward into horizontal ducting that can allow the heat to be absorbed and slowly released into the desired space. More recent developments have utilized a batch fed horizontal firebox, and by adding a door, their designs are moving towards building code acceptance. But, since they are most popular with natural and alternative building designs and the materials and methods of construction are usually by the owner builders themselves, only limited testing has been done to date to insure that they will eventually be accepted by any building code or emissions standard in the near future.

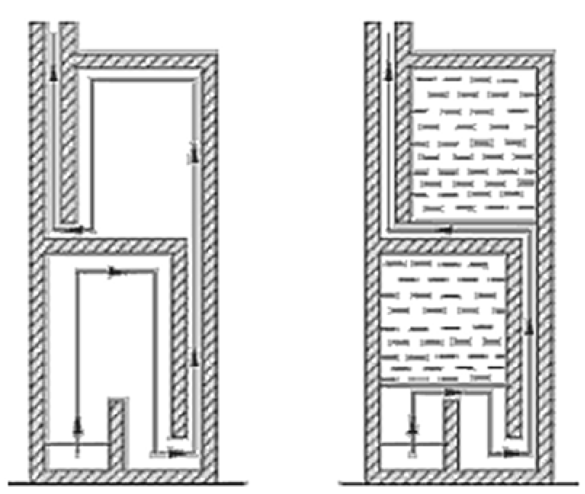


Figure 6

A generic Double Bell masonry heater

2. MHA Masonry Heater Definition

A masonry heater is a site-built or site-assembled, solid-fueled heating device constructed mainly of masonry materials, in which the heat from intermittent fires burned rapidly in its firebox .

The heat is stored in its massive structure for slow release to the building.

It has an interior construction consisting of a firebox and heat exchange channels, or chambers, built from refractory components.

Specifically, a masonry heater has the following characteristics:

- A mass of at least **1,760 lbs**. (800 kg).
- Tight fitting doors that are closed during the burn cycle, except when the door is primary air control.
- An overall average wall thickness not exceeding **10 inches** (250 mm).
- Under normal operating conditions, the external surface of the masonry heater, except immediately surrounding the fuel loading door (s), does not exceed **230° F**. (110° C). (*except within **8 inches** (203mm) surrounding the fuel loading doors)*,
- The gas path through the internal heat exchange channels downstream of the firebox includes at least one **180°** change in flow direction, before entering the chimney,
- The length of the shortest single path from the firebox exit to the chimney entrance is at least twice the largest firebox dimension,
- A maximum chimney flue size of **8 inch X 12 inch** (200 mm X 300 mm) nominal, or **8 inch** (200 mm) i.d. round.
- The body of the masonry heater does not penetrate an exterior vertical wall of the building.

3. Design Characteristics and Components

- **General**

A masonry heater is a site-built or site assembled heating device constructed mainly of masonry materials in which the heat from intermittent fires burned rapidly in its firebox is stored in its massive structure for slow radiant heat release to the building over a period of time.
It has an interior construction of a firebox etc. and consists of a firebox and heat transfer channels built from custom-cast refractory components, standard refractory brick units or, more commonly, a combination of both.
These components form the heater core, which is then surrounded by a Wythe of brick, solid block or stone. To make the heater compact, yet with sufficient heat transfer surface area, most heaters are of the contraflow design. In the contraflow design, the exhaust gases rise up and out of the firebox, and then flow down either side of the core through heat transfer channels to the heater base, and exhausts into the chimney at floor level.

An even more compact version of a contraflow design is possible by returning the exhaust gas upwards to a top vent. This configuration eliminates an additional chimney footprint, and is derived from the Swedish 5 tube heaters and is known as a five run design.

- **Under-fire versus Over-fire Air**

It has been common in European heater design to provide combustion air to the fire up through a metal grate in the floor of the firebox. While this design is appropriate if coal is the principal fuel burned in the heater, most masonry heaters in North America are used to burn wood. Fireboxes designed for wood burning should be designed to supply air for combustion at or above the coal bed level.

Research conducted by and for MHA has demonstrated that higher efficiency and lower emissions are achieved by using over-fire air.

(see MHA News, Spring 1994, Recent Laboratory and Field Testing of Masonry Heater and Masonry Fireplace Emissions).

A grate in the floor of the firebox may be provided so ash can fall to an ash dump below, but the ash dump access door should be reasonably well sealed to prevent air leakage up through the grate. The grate and ash dump are not an operational necessity, so the firebox may have a flat floor without a grate.
Some heater masons design their combustion air systems so that either over -fire or under-fire air can be used at different stages of the burn cycle. Over-fire air is used during the early part of the burn to produce clean combustion of the volatile gases and under-fire air is used during the coal bed phase to burn the charcoal rapidly and completely. Rapid completion of the combustion cycle is seen as advantageous so that the chimney damper can be closed off earlier, reducing losses of stored heat.

(See the discussion of chimney dampers for alternative strategies).

In an effort to meet increasingly tighter emission regulations, other firebox air systems have been tried. Adopted from Austria, the “eco-firebox” employs a double wall construction with an air space for pre-heating combustion air and delivering it to the firebox evenly around its’ perimeter. This design has been shown to emit fewer particulate emissions than earlier designs.

- **Gas Slot**

A gas slot is a small gap somewhere above the firebox that allows some exhaust to bypass the downward flow through the heat exchange channels and instead flow directly into the chimney, or, depending on the design, into heating channels above the firebox.
Its function was to prevent the explosion of accumulated combustion gas. The gas slot may have been thought necessary for European coal- fired heaters or wood-fired heaters with under-fire combustion air. However, the fuel gas/air/temperature conditions necessary for an explosion are unlikely to occur in the designs common in North America, considering their unrestricted and usually over-fire combustion air supply.

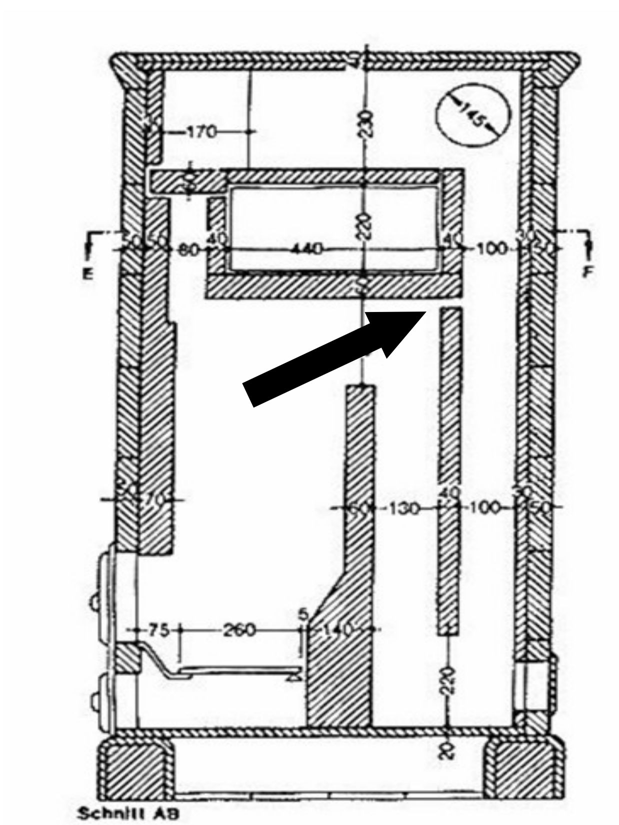


Figure 7.
Gas Slot

The heater designs that used the gas slot typically had a downdraft channel behind the firebox, leading back up to horizontal channels above the firebox. This configuration makes the construction of a gas slot a relatively simple.

It is a matter of leaving a gap at the top of the firebox into a heat transfer channel directly above.

A gas slot passage into the chimney would be a challenge to install in X-HC heaters. The reason being is because there may be a horizontal distance of four or more brick thicknesses between the firebox and chimney flue through which this small gas passage would have to be routed.
This high level connection between the heater and chimney could also present differential expansion problems.
Field experience has demonstrated that a gas slot is not a necessary feature of the X-HC masonry heater.

From **ASTM E 1602** Construction "Guide:"

5.7.3 Gas Slot *— When required, a gas slot shall have a cross-sectional area of at least 1/30 of the firebox floor area and a height of 30 mm (1 1/4 in.)*
Refer to ***Figs.1 and 6*** *for typical locations.*

- **Bypass Damper**

An internal passage from the top of the firebox directly into the chimney, bypassing the heat exchange channels has been a common feature of masonry heaters. A cast iron or steel damper is installed in the passage so gas flow through the passage can be controlled. In operation, the damper would be fully opened at start up and fully closed once draft is established.

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The need for a bypass damper assumes that when the heater is not in operation, (standby condition), air flow in the heater and chimney can be either stalled or downward.
Downward or stalled flow presents an obstacle to getting combustion heat into the chimney to produce the necessary strong draft for a rapid burn. This stalled or downward flow occurs when the air pressure in the room containing the heater is negative relative to atmospheric pressure acting on the opening at the top of the chimney.

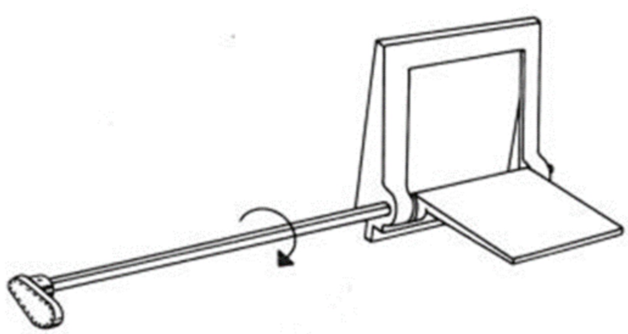


Figure 8.
Bypass Damper

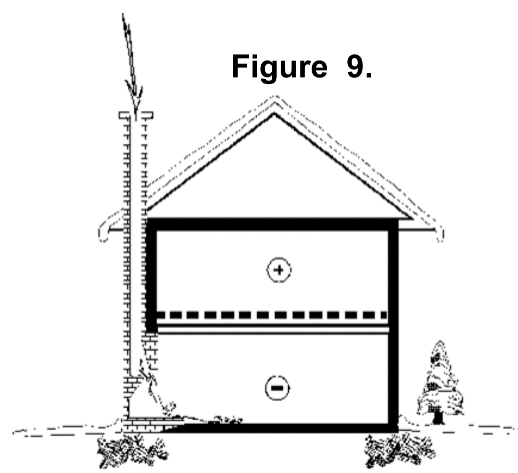
- ## House pressurization issues

There are three distinct scenarios under which this negative pressure condition can exist.

- **The first scenario**

Requires that three factors be present: The outdoor temperature is below room temperature in the house; the heater is installed low in the house, below the neutral pressure plane; and the temperature of the air in the chimney flue is below that of the house. This usually occurs because the chimney runs up outside the building envelope, and is cooled by the outdoor air.
Where these three factors are present, the stack effect in the house creates a negative pressure low in the house that exceeds chimney draft. The key factor is the location of the chimney outside the building envelope where excessive heat loss can cool the air in it to below the temperature inside the house.
Where the masonry heater is served by a chimney that is fully enclosed by the building envelope, the first condition leading to stalled or downward air flow is unlikely to occur, even if the heater is installed low in the house, below the neutral pressure plane. This is because inside chimneys always develop slightly more draft than the house develops stack effect.

Figure 9.

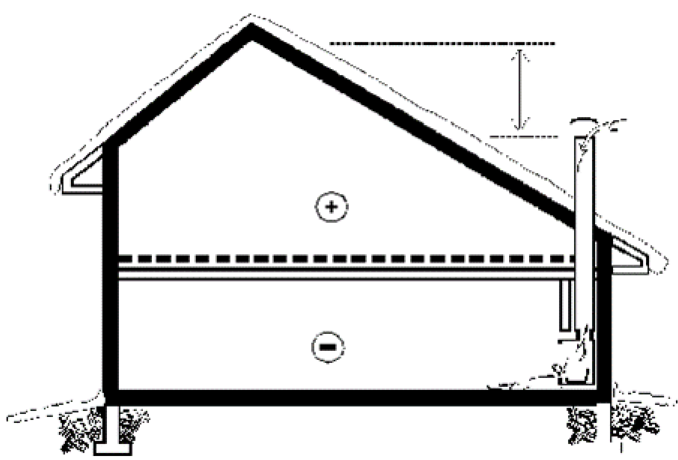


When it is cold outside the air in a chimney at standby can cool so that the chimney produces less draft than the house produces in stack effect. If the heater is located below the neutral pressure plane, a backdraft will result.

- **The second scenario**

A standby backdraft or stall can occur is when the effective stack height of the house exceeds the effective chimney height. A chimney that exits a single story section of a two or three story house may not be able to overcome the negative pressure low in the house while in standby mode.
Either the average temperature in the chimney falls below room temperature or the top of the chimney is not as high as the highest part of the house envelope. In either case, when it is cold outside and the chimney is in standby mode, the house can perform as a better chimney than the chimney.

Figure 10.



At standby, a tall house can outperform a short chimney and suck outdoor air backwards through the system.

- **The third scenario**

Requires that when an exhaust system removes enough air from the house to cause the house pressure to fall well below atmospheric pressure. The resulting depressurization acting on leaks around doors or air inlets to the heater, draws air downward through the heater and chimney. Although in most houses such episodes of significant depressurization are of short duration, the backdraft thus created can become stable because the cold air cools the chimney assembly and prevents it from producing standby draft. The normal but slight negative pressure low in a house in cold weather can be enough to sustain the backdraft after the exhaust system is turned off. This condition is not one that can be managed or improved by the use of a bypass damper. It can, however, be managed in one of two ways. The user can be instructed not to operate the exhaust system while firing the masonry heater.

This approach can be effective for moderate levels of depressurization. For example, where there is no exhaust system with a capacity in excess of **150 cfm** (75 L/s), depressurization, even in a tightly-constructed house will not reach significant levels.
A better solution for larger exhaust capacities is to install an interlocked, fan-forced make-up air system that operates to bring outdoor air into the house when a large exhaust system is turned on, neutralizing the house pressure.

In addition to these three negative pressure scenarios, it would also be good practice to consider the proximity of any return air vents, associated with a forced air system, to a masonry heaters' location. Ten feet from the loading door might be considered a realistic minimum starting distance.

The bypass damper, therefore, is a component of masonry heaters that is used to compensate for problems in the interaction between the heater chimney, and the house in which they are installed. Where these problems do not exist, there should be no need for a bypass damper because standby airflow in the heater and chimney should be upward. Specifically, where the chimney is fully enclosed within the building envelope and penetrates the envelope at its highest point a bypass damper should not be a necessary component of a masonry heater. Even where a standby stall or backdraft is a problem, an alternative priming strategy could be to open a window and apply heat to a chimney cleanout located at or near its base. The open window neutralizes the negative pressure caused by stack effect, and heat from a small amount of burning paper, a propane torch or hair dryer produces enough draft to produce upward flow so a fire can be started without fear of smoking.

- **Chimney Damper**

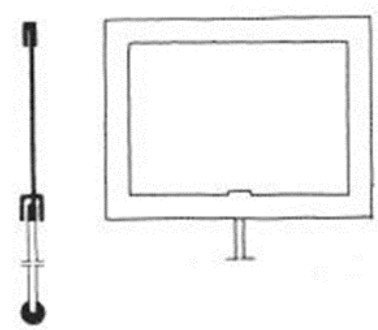
A chimney damper is used to minimize flow up the chimney after the fire is out in order to preserve the stored heat in the system. The damper is a flat metal plate normally installed in the chimney at eye level or higher in the room containing the heater. The plate slides in or out to open or close the flue. An alternate method is to use a pivoting damper that rotates around a control shaft. The damper is almost always designed and installed so that it does not entirely close off the chimney flue in case combustion gases remain in the system when it is closed. Complete sealing of the flue could permit carbon monoxide in combustion gases to enter the living space.

From the **ASTM E 1602 - 03** Construction Guide:

5.8 Shut-off Damper (s)

"*One or more shut off dampers may be installed near the juncture of the heater and chimney or in the chimney. Each damper shall have external controls and be constructed of cast iron or steel of at least **12 gauge**, 2.5 mm (0.10 in.) in thickness. To reduce the possibility of toxic gases escaping into the room, the cross-sectional area of the damper's opening shall be not less than **5%** of the interior cross- sectional area of the flue."*

Figure 11.
Sliding Chimney Damper



In other words, the damper must not close off more than 95 per cent of the chimney flue area.
An alternate strategy for conserving stored heat is to control the flow of air through the system at the heater rather than at the chimney. Very tightly fitted or gasketed doors and a combustion air control that can be tightly closed would function roughly the same as the chimney damper by minimizing flow through the system. Although it is possible that convection currents of warm and cold air might circulate within the stalled or almost stalled chimney, heater doors and air controls are never completely airtight, so some flow will occur. A small amount of upward flow due to leakage would minimize convection currents and therefore heat loss in the chimney.

- **Heat exchange channels**

In an X-HC heater, the heat transfer channels are shallow and wide. They are typically as wide as the firebox is deep and as shallow as possible while providing sufficient gas flow area. Excessive restriction in gas flow area should be avoided because, at least in theory, it could effectively suppress the fuel firing rate and produce incomplete combustion.
Some designers create a slight narrowing of the heat transfer channel towards the end of its run at the bottom of the heater. This narrowing is intended to increase contact of the gases with the walls and therefore increase rate of heat transfer as the exhaust gives up its heat.
The objective is to produce more even heating of the heater surface. Yet if the flow area is too restrictive, combustion performance could suffer.

One way to evaluate channel flow area is to work backwards from the chimney flue area.
The standard clay flue tile with nominal outside dimensions of **8 in. x 12 in (**20 cm x 30.5 cm), or inside dimensions of about **6 1/4 in. x 10 1/4 in.** (15.8 cm. x 26 cm.), is the most common liner size used for chimneys serving masonry heaters. Decades of field experience has shown that these liners have sufficient flow capacity to serve open woodburning fireplaces with hearth openings between **24 in. x 24 in.** (61 cm. x 61 cm.) and **24 in. x 36 in.** (61 cm. x 91.5 cm.).

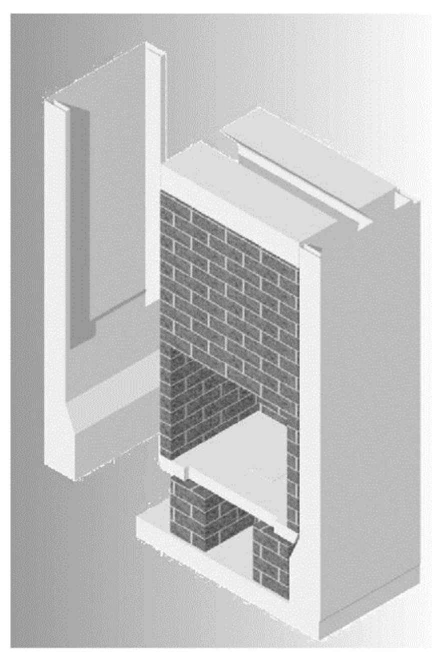
The high gas flow rates typical of open fireplaces would indicate that the nominal **8 in. x 12 in. (**20 cm. x 30.5 cm.) clay flue tile would provide more than adequate flow area for the closed, yet rapid combustion produced in a masonry heater. Experience with masonry heaters is consistent with this assumption.

The net free area of the **8 in. x 12 in.** (200 mm x 300 mm) flue tile is about **65 sq.in.** (419.5 sq. cm.) To match that free area, contraflow heat transfer channels that are 18" wide would be **65 ÷ 2 ÷ 18 = 1.8 in.,** or (419.5 ÷ 2 ÷ 45.7 = 4.6 cm.) in depth. However, to account for friction losses in the channels, and the two changes of direction (at least) in the gas flow path, adding at least 50% in flow area is advisable.
Therefore, it is common for X-HC heaters to have heat transfer channels in the **3 in. to 4 in.** (75 mm to 100 mm.) minimum depth range for a combined free area of between **108 sq.in. and 144 sq.in**. (700 sq. cm. and 930 sq. cm.).

In general, the internal passages should have a larger free area for gas flow when the heater is served by a short chimney; i.e. less than **20 ft.** (6.1 m) because a shorter chimney will produce less draft. Where limited draft is available, slightly larger internal passages help to allow acceptable gas flow and to keep the firing rate high.

Figure 11.

Heat exchange channels



The heat exchange channels or chambers can be built with standard refractory bricks. This will produce a thick wall if standard bricks are used for the facing; i.e. **2 1/4 in**. firebrick + **4 1/2 in**. face brick = **6 3/4 in.** , (57 mm. + 115 mm. = 172 mm) total thickness.

A thinner and more responsive heat exchange channel wall can be built by using pre-cast refractory sections or fire brick splits laid on edge.

NOTE: Facing brick and firebrick dimensions may very in size from one geographic region to another.

Average wall thicknesses of more than **8 in., (**200 mm.) are not advised because the surface temperature (and therefore heat output) may be too low and the heating cycle may be too long to be practical.

Table 1 shows the heat transfer rate at **68°F** room temperature from vertical radiant panels of various temperatures.

Note: that if the walls of a masonry heater were so thick that its surface temperature never exceeded **80°F**, it would not provide acceptable heating performance.

Table 1.

Total Heat Output from a Vertical Radiant Panel at Different Surface Temperatures

Surface Temperature °F	Total Heat Output Btu / hr. / ft^2 of Surface	Total Heat Output in (kW) For 100 ft^2 of Surface
80	33	1.0
120	105	3.1
160	200	6.0

4. Heater sizing

The sizing of a masonry heater is an imprecise science, as is the sizing of any hand-fed wood burning appliance. The sizing or output of wood stoves, for example, can be roughly divided into large, medium and small sizes.
The appropriate wood stove for a given application depends on the size and heat demand of the space and the objectives of the customer. Once any type of wood burning appliance is selected, its heat output can vary depending on the species and moisture content of the fuel and the way the unit is fired.

North American Masonry heaters are designed to be whole house heaters rather than room heaters, and they tend to be located centrally in the house.

In this location the heat can spread effectively to influence the temperature in a large portion of the building.
Even the largest masonry heater can be operated so that it does not overheat a small house or a house located in a mild climate zone.
Simply by using smaller fuel loads and/or firing the heater at longer intervals its heat output can be controlled by the user. In practical terms, there is no such problem as oversizing a masonry heater.
The more important issue in designing a masonry heater is to achieve a suitable heat release rate to the room so that the heating cycle extends over the desired period of time.
There are two primary factors that determine the heat output characteristics of a masonry heater.
They are **firebox size** and **mass.**

- **Firebox size**

The total amount of heat available to the room from burning one load of wood depends on the size of the wood load (in effect, firebox size), less the chemical and heat losses from the chimney. The typical firebox size is **18 in.** wide, **18 in**. deep and about **20 in.** in height, (46 x 46 x 56 cm.). A **22 in**. wide firebox is becoming increasingly common to meet the specific performance needs of North Americans and their housing.
These dimensions are compatible with standard firebrick size of **4 ½ x 9 x** between **2 ¼ and 2 ½ inches.**

The firebox size has only a general relationship to heat output, in that a larger firebox can accommodate more wood, and therefore, more heat per load. A simple calculation can be used to estimate the heat output from a load of wood, as follows.

Assumptions:

Firebox size: 18d x 18w x 20h (inches)

Wood species: Douglas Fir

Wood energy content: 8600 Btu/lb. Wood moisture: 20%

Calculations:

Moisture correction: 8600 x .8 = 6880 Btu

Weight of sample wood load: 40 lb.

Heater efficiency (assuming a well designed X- HC heater with over-fire air): 65%

Output from one load: 6880 x 40 x .65 = 178880 Btu

Average output, low demand (over 24 hours):
178880 ÷ 24 = 7,453 Btu/h (2.2 kW)

Average output, high demand (over 8 hours):
178880 ÷ 8 = 22,360 Btu/h (6.5 kW)

These simple calculations demonstrate that the same masonry heater could be used to deliver a low heat output to a home during mild weather or to meet the needs of a very efficient home, or when fired three times daily, used for a less efficient home or a home in a very cold climate zone. Note that the output would be increased significantly if a hardwood fuel was used, or by increasing the weight of wood per load. Also, the range of heat output can be lowered even further by reducing the amount of wood used per load.

When designing a prototype heater, the initial power output estimates can be made by simply stacking the proposed fuel in the proposed firebox shape and size and weighing the resulting load. This procedure assumes a fuel moisture content within an acceptable range.

Calculating firebox sizes for custom heaters of the Grundofen type

Heaters of the Grundofen type can be configured in both vertical and horizontal firebox types. For optimum emissions performance, firebox size is adjusted to fit the design wood load. The following sizing tables are used in Austria, and are derived from in-field emissions measurements conducted by the Austrian Stonemason's Guild

Table 2.
Firebox sizing table, Metric

Fuel Load (kg)	Firebox inside surface area (cm2)	Optimum Firebox floor area (cm2)	Maximum Firebox floor area (cm2)	Minimum Firebox floor area (cm2)
5.0	4500	500	550	450
6.0	5400	600	660	540
7.0	6300	700	770	630
8.0	7200	800	880	720
9.0	8100	900	990	810
10.0	9000	1000	1100	900
11.0	9900	1100	1210	990
12.0	10800	1200	1320	1080
13.0	11700	1300	1430	1170
14.0	12600	1400	1540	1260
15.0	13500	1500	1650	1350
16.0	14400	1600	1760	1440
17.0	15300	1700	1870	1530
5.0	16200	1800	1980	1620
5.0	17100	1900	2090	1710
5.0	18000	2000	2200	1800
5.0	20250	2250	2475	2025
5.0	22500	2500	2750	2250
5.0	24750	2750	3025	2475
5.0	27000	3000	3300	2700
5.0	31500	3500	3850	3150
5.0	36000	4000	4400	3600

Table 3.
Firebox sizing table, imperial

Fuel Load (lb.)	Firebox inside surface area (in2)	Optimum Firebox floor area (in2)	Maximum Firebox floor area (in2)	Minimum Firebox floor area (in2)
11.0	698	78	85	70
13.0	837	93	102	84
15.0	977	109	119	98
18.0	1116	124	136	112
20.0	1256	140	153	126
22.0	1395	155	171	140
24.0	1535	171	188	153
26.0	1674	186	205	167
29.0	1814	202	222	181
31.0	1953	217	239	195
33.0	2093	233	256	209
35.0	2232	248	273	223
37.0	2372	264	290	237
40.0	2511	279	307	251
42.0	2651	295	324	265
44.0	2790	310	341	279
50.0	3139	349	384	314
55.0	3488	388	426	349
61.0	3836	426	469	384
66.0	4185	465	512	419
77.0	4883	543	597	488
88.0	5580	620	682	558

- **Mass**

The mass of the heater determines the percentage of total heat energy from the fuel load that is absorbed (i.e. heat transfer efficiency) and the rate at which the stored heat is released to the room.
If the mass of a heater is correctly matched to its firebox size, it will absorb the heat of combustion effectively, producing moderate flue gas heat losses, a moderate surface temperature and its heat output will be spread over a suitable period of time, usually about 18 to 24 hours for an X-HC.

If a heater has too little mass for its firebox size, it will have high flue gas heat losses, high surface temperature and will release its stored heat relatively quickly to the room.

On the other hand, a heater with too much mass for its firebox size will produce a low flue gas temperature and release its heat too slowly to the room.

Firebox (fuel load) size and masonry mass work together to produce the heating characteristics of a masonry heater.

The **ASTM Guide** for the Construction of Masonry Heaters requires that surface temperature not exceed **230°F**, (110°C). A more typical (and desirable) average surface temperature of a heavy contraflow masonry heater is about **150°F**, (65°C)

The area of heated surface of a masonry heater is also sometimes used in the calculation of heat output. However, X-HC are built compactly so that when the firebox size and heat exchange channel configuration are combined with the correct wall thickness, the surface area is a by-product. In other words, it is not advisable to manipulate surface area independent of firebox size and wall thickness to create the desired heat output. The objective is to achieve a balance between firebox size and mass; when this is done, the surface area will be correct. The typical surface area of an X-HC is 86 to 108 sq. ft.
(8 to 10 square meters).

Table 4.

Adapted from Kachelgrundofen (ceramic stoves) A Guide for the Practitioner, by Heinz Maresch, Published by Informationstelle Kachelofen, 1972. To accommodate the bigger and heavier heaters common in North America, the Extra-Heavy column has been added to the original table.

	Extra heavy	Heavy	Medium heavy	Light
Wall Thickness (cm.)	15 to 18	12.5 to 14	10.5 to 12	8 to 9.5
Wall Thickness (in.)	6 to 7	4.9 to 5.5	4.1 to 4.7	3.1 to 3.7
Mass per kW (kg.)	350	260	170	130
Mass / 1,000 btu / hr. (lb.)	225	166	110	83
Av. Surface Temp. (°C)	65	65	80	90
Av. Surface Temp, (°F)	140-150	150	176	194
Rated Output (W / m2)	< 700	700 to 850	850 to 1100	1100 to 1280
Rated Output (Btu / ft2)	< 222	222 to 270	270 to 350	350 to 400

- **Length of heat exchange channels**

For heaters of the Grundofen type, the minimum temperature of the flue gases as they exit the heater and enter the chimney should be **356 F.**, (180 C.)

Table 5, or **Table 6** are used to determine the total length of heat exchange channels to be used for a given design wood load.

Table 5.

Channel length, Metric

Fuel Load (kg)	Minimum Channel Length (m)	Maximum Channel Length (m)
5.0	2.9	3.0
6.0	3.2	3.3
7.0	3.4	3.5
8.0	3.7	3.8
9.0	3.9	4.0
10.0	4.1	4.2
11.0	4.3	4.4
12.0	4.5	4.6
13.0	4.7	4.8
14.0	4.9	5.0
15.0	5.0	5.1
16.0	5.2	5.3
17.0	5.4	5.5
18.0	5.5	5.6
19.0	5.7	5.8
20.0	5.8	5.9
22.5	6.2	6.3
25.0	6.5	6.6
27.5	6.8	6.9
30.0	7.1	7.2
35.0	7.7	7.8
40.0	8.2	8.3

Table 6.
Channel length, Imperial

Fuel Load (lbs.)	Minimum Channel Length (in.)	Maximum Channel Length (in.)
11	115	119
13	125	129
15	135	139
18	146	150
20	154	157
22	162	166
24	170	174
26	177	181
29	185	189
31	191	195
33	198	202
35	205	209
37	211	215
40	217	221
42	223	227
44	229	233
50	243	247
55	256	260
61	269	272
66	280	284
77	303	307
88	324	328

5. Masonry units and Mortars

A wide range of masonry units can be used in the construction of masonry heaters. Their correct selection and use is essential for good performance and long service life of the final product. The masonry units used are of two distinct types:

- **First**

Refractories that are resistant to high temperatures because of their low thermal expansion characteristics and high melting temperatures. This is why they are used in the construction of the core, the hottest part of the heater.

- **Second**

Other masonry, stone or ceramic units used in the construction of the outer shell or facing. The correct mortar to use in a given situation is governed both by the type of masonry unit and where it is used in the heater.

- **Standard refractory units**

Standard refractory units are firebricks measuring **4 1/2 x 9 x 2 ½ in.,** (11.5 x 23 x 5.7 cm.).

The actual thickness of firebricks from various suppliers may be up to **2 1/2 in,** (6.4 cm.). Firebrick splits are also used frequently. As its name implies, a split is half the thickness of a standard firebrick, or about **1 1/4 in.**, (3 cm.).

By using standard firebricks and splits lying flat, (referred to as stretchers), or on edge, (referred to as shiners) and by cutting them to create custom shapes, virtually all the structures required for a masonry heater core can be built.

Larger sizes (a.k.a. Tiles or slabs), different shapes of firebrick, and silicone carbide kiln shelves are also available from manufacturers of refractories and can make good economic choices for some types of heater builds.

There is no particular need to select the highest temperature rated firebricks because a masonry heater is a relatively low temperature application for refractories. The ability of the firebrick to tolerate thermal cycling is a more important characteristic for firebricks used in masonry heater cores. Smooth, straight surfaces and consistent shape and dimension are also important properties.

- **Refractory mortar**

Refractory bricks are set using a clay mortar, also referred to as refractory mortar. There are two kinds of refractory mortars permitted for use to meet code.

Water soluble air-setting refractory

This type of mortar consists of clays, aggregates and sodium silicate (water glass or liquid glass) as a binder. It comes premixed and is the preferred mortar for heater core construction as very thin setting joints can be achieved between:
1/16 in. and 1/8 in., (1mm – 3mm).

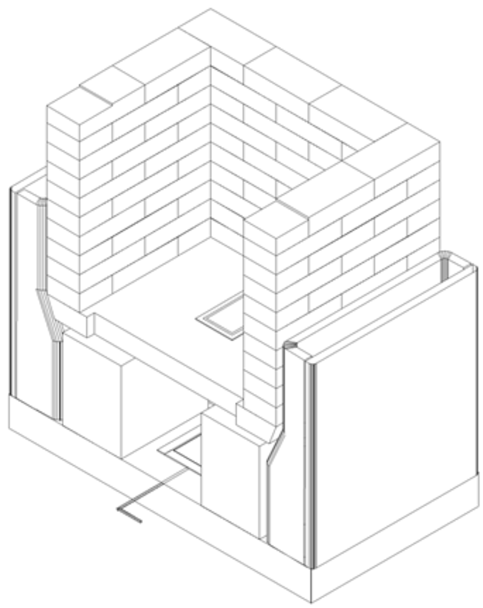
Non water soluble (hydraulic setting) refractory mortar

The other type, comes as a dry powder and consists of aggregates and binders (proprietary blends of Portland cement, calcium aluminate, lime, calcium carbonate, and polymers).When mixed with water it sets extremely quickly and is the preferred refractory mortar for joint thicknesses greater than 1/8” (3mm), or when constructing in cold or wet environments.

Figure 12.

. Use of Standard Firebrick

This double wall firebox is built up from standard firebricks, some of which are cut to produce the desired firebox dimensions.



- **Setting firebrick**

Firebrick are not laid in a bed of mortar as in normal masonry construction.
The dimensional consistency of firebrick can vary, but they should be **set** with the thinnest joints possible; just enough to fill all voids between the units.
Mortar joint size should be uniform but may vary from **1/16 in. to 3/8 in**.,
(1 mm. to 10 mm), depending on brick quality, or available refractory mortar type and consistency. Firebrick may be mortared by troweling or dipping. Dipping is generally the preferred method because it is faster. When the mortar is thinned to the correct consistency, delivers the right amount of mortar to the brick.
Pre-blended commercial refractory mortars are at troweling consistency when received, and require thinning if bricks are to be mortared by dipping. Use enough water to thin the mortar so that a standard dry firebrick sinks about half its thickness when placed on its surface.

- **Specialized refractory shapes**

Custom refractory shapes can be created to simplify, speed and make more precise the field assembly of the core.
A castable refractory is mixed and poured into a carefully designed mold to form custom shapes. Castable refractory is somewhat like heat resistant concrete. Whereas concrete is a mixture of a binding powder (Portland cement) and an aggregate (sand and crushed stone).
The binder used in castable refractory is usually calcium aluminate cement, and the aggregate is normally crushed refractory brick or some other refractory mineral.

- **Castable refractory**

Is usually purchased in bags in pre-mixed form. As a point of interest, the non-water soluble refractory mortar, which has become mandated in **NFPA 211** and some state building codes for joining flue liners, is a mixture of calcium aluminate cement and sand.

- **Custom shaped refractory units (firebrick)**

There are a wide variety of firebrick shapes available from refractory suppliers. They can be used in various places. Such as where a large slab is needed, like a base or capping slab. There are shapes that are angles, arches, tapers. They can be useful in the core where it would require too much cutting of standard units.

Custom shapes can also be useful for heat transfer channels because they can form a strong, stable, unified shape while helping to keep the overall wall thickness within the desired range. Creating good quality custom refractories is not a simple job. The mold must be exactly right to produce the desired shape; an inexperienced person may not succeed on the first attempt. Also, the mixture consistency is critical, as is the need to vibrate the form to remove air bubbles from the mix. Thorough testing with prototype shapes is advised before use inside a client's heater.

- **Other masonry units**

The shell of the heater can be made from virtually any stable masonry units including clay or cement brick, solid or paver block, or natural stone. Unless the heater is being built in a region with a high probability of seismic activity, standard Type N masonry cement is sufficient. Otherwise, higher strength Type S mortar is also acceptable, especially if required by the locally enforced seismic building code.

The facing, however, must be carefully planned and built because each face is essentially a free-standing wall. The shell does not rest against the core because an expansion and slip joint is installed between them. The key point here is that considerable skill is required of the mason if the shell is to be constructed of irregularly shaped units such as natural stone.

In general materials expand or contract when their temperature changes, with expansion or contraction occurring in all directions. The effects of this expansion or contraction of individual masonry units or steel components is cumulative. Therefore, extra care should be taken to allow for movement in particularly long runs of masonry units or steel components, both vertically and horizontally.

- **Soapstone**

Soapstone is unique in its aesthetic and refractory properties. It is the only naturally occurring refractory material (hydrated silicate of magnesium).
It stores about 10 - 20% more heat per pound than firebrick, and conducts heat 3 to 7 times as fast, depending on the relative properties of each material.
This makes it ideal for heat collection in oven applications, heat exchange channels and also for responsive radiation in facing applications.

It is not as durable as firebrick at high temperatures in the firebox.
Also, it could hinder startup combustion by conducting necessary heat from the firebox and throat.

Soapstone facing is usually about **2.36 in**., (60 mm) thick. Modules are typically set in soapstone mortar (one-part water, three parts water-glass, and soapstone powder to the consistency of refractory mortar).
The head joints are pinned with a U- shaped clip and the bed joints are splined. Alternatively, the modules can be set with thin-set mortar or refractory mortar.

Soapstone is easily milled, carved and polished. It lends itself to all sorts of ornamental uses (mantles, keystones, beaded trim, or sculpted shapes). It is pleasant to touch or lean against and develops a beautiful patina with use. It is non- absorptive and therefore easily cleaned. Its neutral gray color and smoothness compliment the colors and textures of other masonry materials, including plaster.

6. Managing Thermal Expansion

Although the refractory quality of firebrick is due partly to its low thermal expansion rate, firebrick does expand slightly when heated. A large assembly of firebricks, such as a heater core, will expand enough to crack the heater facing if an allowance for expansion is not provided.
Therefore, an expansion joint must be installed between the heater core and facing to result in a successful heater with a long service life.

To allow free movement of the core, air space or a slip joint, depending on the direction of the movement, is provided. However, since creating and maintaining a small but consistent air space during construction would be very difficult, expansion joints are usually constructed using a mineral fiber mat of the sort used in the fabrication of fiberglass structures. Corrugated cardboard can also been used, and was the standard for many years with great success.

Note that the air spaces between the mat fibers, or the corrugated cardboard, give the allowance for expansion and that the use of the mat just makes creating the air space easier. This means that the mat must not be crushed during the assembly of the shell, or the expansion joint will be lost.
A thin layer of mineral wool, or even a slurry of clay or soapstone dust have also been used successfully as slip joints.

There are some challenges in designing and installing an effective expansion joint:

- provide enough space for the expansion of the core so it does not crack the shell
- keep the joint thin and with minimal insulating properties to allow heat transfer through the joint so that heat storage performance is not compromised
- install the expansion joint only where it is needed, not necessarily over the entire surface of the core.

Because masonry heaters do not conform to a strict formula of size, structure or material usage, precise dimensions and locations for the core-to-shell expansion joint cannot be given. The zone of the most intense and rapid heating, typically the area just above the firebox, is also the location of the most densely-packed refractory assembly where the expansion of several units is combined.

Some allowance for expansion is also desirable in other locations within the heater. For example, if the firebox is constructed of a double layer of firebricks, it is wise to leave a slight allowance for expansion between the inner and outer walls, particularly where a row of brick butts against the adjacent wall.

And, of course, any metal parts, such as door frames and dampers, must be designed and installed to permit expansion since metal expands considerably more when it is heated than does brick.

Natural stone facings may require some special considerations such as setting uniformly (smaller) sized units in higher heat transfer areas and also paying attention to the grain direction in sedimentary types of stone. To reduce the chance of spalling, the stones' grain should be installed parallel to the heat transfer direction.

Some refractory materials for controlling expansion include, but are not limited to, various thicknesses of mineral wool, ceramic paper, ceramic blanket, fiberglass (mats, tapes, and rope), and silicone caulking.

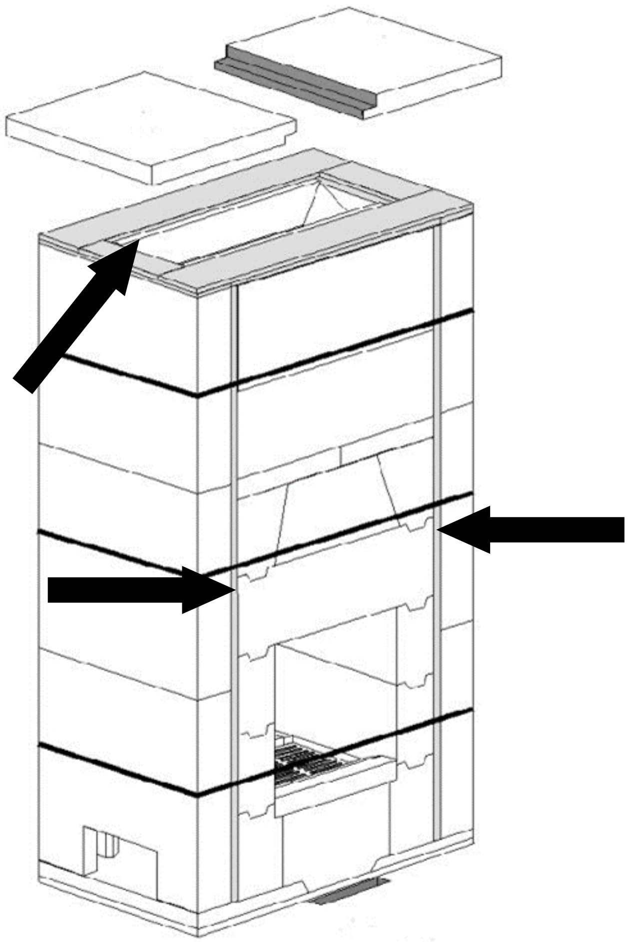


Figure 13.

. Typical Expansion joint locations for contraflow heaters

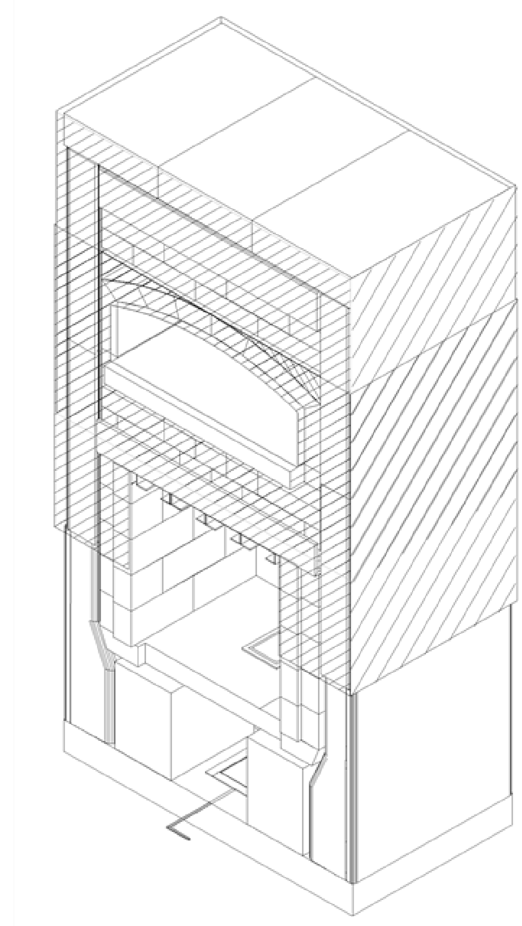


Figure 14.

Installing the Slip / Expansion Joint

The shaded area is where the fiberglass mat, or corrugated cardboard, is used to form a slip / expansion joint. This is a bond break between the facing and the core. This allows the core to slide up and down as it heats and cools. No slip joint is required at the bottom because the expansion is cumulative with the height of the core.

7. Footings and foundations

The footings and foundations for the support of a masonry heater must conform to local building code requirements for load -bearing walls and chimneys of masonry construction. These requirements vary depending on soil types and seismic risk conditions.

- **ASTM E 1602- 94:**

5.1 Foundation — Masonry heater foundations and foundation walls shall meet local building codes for standard masonry fireplaces and shall be designed with consideration given to the mass and size of the heater.

Because of their large footprint and limited height, masonry heaters do not put more force on footings than do other masonry structures like walls and chimneys.
A typical loading is in the range of **3 to 5 psi**., therefore, no special footings are usually required for heaters.

Unlike standard masonry fireplaces, masonry heater cores are typically isolated from their supporting foundation, in order to limit the flow of heat conduction in the downward direction.
There are several materials that possess the proper compressive strengths necessary to accomplish this goal.
Foam glass, vermiculite board, and calcium silicate board, are only three examples that have been used successfully.

8. Clearances to combustible materials

Clearances for factory-built, certified heater kits must conform with the terms of the certification of the product. Since these kits are beyond the scope of this manual, no further discussion of clearances for certified and labelled kits will be offered.

As a radiant heating device, a masonry heater needs to be constructed and located so that adjacent combustible materials are protected from overheating.
The issue of minimum clearances is a sensitive one for heater masons because building officials may not be familiar with masonry heaters and may challenge the clearances proposed by the mason.

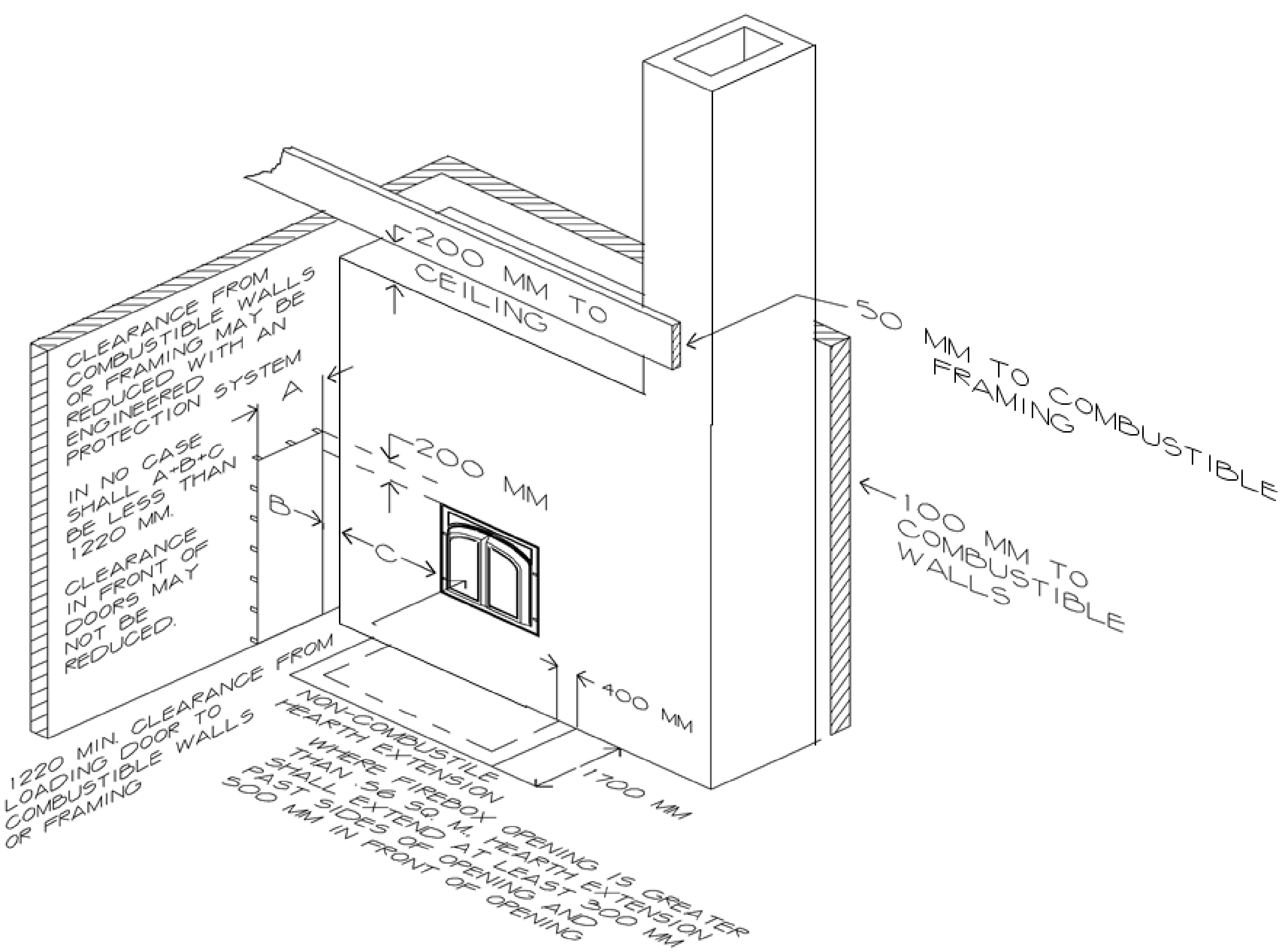
The most authoritative reference for custom-built masonry heater clearances is **ASTM E 1602.** The clearance requirement provided in the **Section 5** of the standard presented below in italics.

Note: Clearances from combustible walls or framing may be reduced with an engineered protection system, other than in front of fuel-loading doors.

Clearance to Combustibles

- **4 in.** (100 mm) to combustible framing from masonry heater
- **8 in.** (200 mm) to ceiling
- **8 in.** (200 mm) minimum extent of side wall heat shield above firebox door.
- **12 in.** (300 mm) hearth extension (sides).
- **20 in.** (500 mm) hearth extension (front).
- **48 in.** (1200 mm) in front of fuel-loading doors to combustible framing.
- Extent of mandatory heat shield in front of masonry heater; required **only** when clearance to combustible material from fuel loading door **((8) + (9))** is less than **48 in.** (1200mm).
- **4 in.** (100 mm) minimum clearance from side wall of masonry heater to heat shield (if used) or combustible framing.
- Distance from fuel-loading doors to side wall of masonry heater. **(7) +(8) + (9)** The sum of these must be greater than or equal to **48 in.** (1200 mm).

Figure 15.
ASTM E 1602 Figure 1



Note that the wording of **clause 5.1** mandates not only the wording in the standard, but also the illustration as requirements to be followed. This is significant, as you will see.

5.2.1 Clearance from Foundation

All combustible structural framing members shall have a clearance of not less than 50 mm (**2 in**.) from the masonry heater foundation.

In contraflow heaters in particular, the heat transfer channels route flue gases downward to the heater base below the firebox where they are collected in a masonry manifold connected to the chimney. This can mean that the base of a masonry heater can be considerably hotter than that of a conventional fireplace.
The potential for heat transfer from the lowest flue gas passage to the foundation creates the need for a minimum clearance requirement for the foundation.

5.2.2 Clearance from fuel loading door

Maintain a minimum clearance of **48 in**. (1200 mm) from combustible materials to fuel-loading doors, unless an engineered protection system as specified in **5.2.2.1** is provided.

In other codes the front is defined as that face of the appliance with the door (s) most commonly used for fire stoking.
Front clearance is usually given as **48 in.**,(1200 mm) but no provision for clearance reduction is offered because the (1200 mm) is not just for protection of combustibles but is the minimum considered necessary for proper access for loading and maintaining the fire.

In **ASTM E 1602**, however, no "front" clearance is given. Rather the clearance of **48 in**. (1200 mm) is from the fuel loading door.

5.2.2.1 *Clearance from fuel-loading doors to combustible materials may be reduced if the combustible material is protected by an engineered protection system acceptable to the authority having jurisdiction.*
*Engineered systems installed for the protection of combustible material shall limit the temperature of the combustible material to **90°F** (50°C) above ambient temperature. Base the system design upon applicable heat transfer principles, taking into account the geometry of the system, the heat loss characteristics of the structure behind the combustible material, and possible abnormal operating conditions of the masonry heater.*

As worded, the requirement must be interpreted as **48 in**., (1200 mm) in any direction.
This provision establishes a minimum clearance between the edge of the loading door to an adjacent wall oriented at right angles to the face of the heater.
This clearance may be reduced through the use of a recognized site-constructed shielding system or a shield listed for this purpose.

Fig. 1 clarifies that the shielding, if used, must extend along the wall until the minimum clearance to unprotected combustibles is exceeded.

Although it is not mentioned in the text, notice that **Fig. 1** contains the requirement that **"clearance in front of doors may not be reduced".**
Awareness of this feature of the standard may help to avoid misinterpretation in discussions with building officials.

5.2.3 Clearance from Rear, Side and Front Walls

*Clearance from a masonry heater to combustible structural framing and other combustible materials shall be not less than **4in**. (100 mm), unless an engineered protection system is provided.*

This is the key clearance requirement, yet it may be subject to interpretation because the standard guide provides no requirement for minimum wall thickness.
In other codes the side and rear clearance for masonry fireplaces is coupled to a minimum wall thickness.
For example, CABO One and Two Family Dwelling code requires a clearance of **2 in**. (50 mm) to the back and sides of a fireplace with a wall thickness of at least **10 in**. (250 mm) (or at least **8 in**. (200 mm) if firebrick lining is used.

The National Building Code of Canada requires a minimum clearance of 100 mm (**4 in**.) to the back and sides of a fireplace with a wall thickness of 190 mm (**7.5 in**.), including the thickness of a firebrick liner.

Given that some masonry heaters may have average wall thicknesses of less than, say, **8 in**. (200 mm) in order to achieve the particular performance objectives of the builder, some negotiation may be required with the building official in order to establish a minimum clearance.

Clearly, the best way to avoid compliance problems over side and rear clearance is never to locate a masonry heater against a combustible wall. The heating performance of the unit is likely to be enhanced by an open location in which all faces of the heater are freely exposed to the space to be heated.

5.2.3.1

Clearance from a masonry heater to combustible materials may be reduced by the use of materials or products listed for the purpose of reducing clearance to combustibles shall be installed in accordance with the conditions of the listing and the manufacturer's instructions and shall meet the criteria of **Section 5.2.2.1.**

Ideally, clearance reduction at the sides and rear would be unnecessary because minimum clearances would be far exceeded with the preferred open location of the heater. However, if side or rear shielding is required, the preferred type would be sheet metal suspended away from the wall about **1 in**. (25 mm) on non-combustible spacers and up off the floor so that cooling air may flow freely up both the front and back of the shield.
This type of shield serves to enhance the convection flow of air and therefore heat transfer to the room, rather than to the combustible wall. See the codes in force locally for details on shield construction and installation.

5.2.4 Clearance from the Ceiling

The clearance from the masonry heater capping slab to the ceiling shall be a minimum of **8 in**. (200 mm) Note that an additional requirement is found at:

5.7.2 Capping Slab

*Place a capping slab of at least **2 1/4 in**. (57 mm) in actual thickness above the upper most heat exchange channels.*

The capping slab is a critical component of the heater and must be built with care.
The slab has three key functions:

1. To seal exhaust gases inside the heater.
2. To accommodate expansion.
3. To resist heat transfer so a combustible ceiling does not overheat.

A **1 in**. (25 mm) sheet of high temperature rigid insulating board is used as a base upon which a **3 in**. (75 mm) layer of castable refractory is poured and bonded using stainless steel anchors.
This component assembly can be precast at the shop before shipping to the site. This part of the slab is sized to cover the top of the core down inside the heater facing.
All joints are sealed with hi-temp silicone sealant.

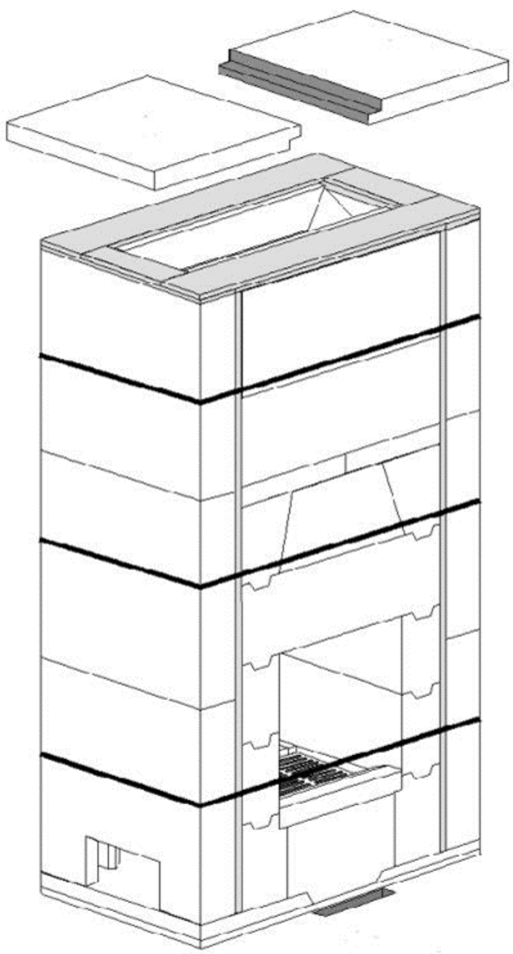


Figure 16. The capping slab

The core will expand upward inside the facing when the heater is fired, so it is necessary to install a crushing zone above the core to prevent displacement and damage.
The crushing zone is formed from a mix of vermiculite and Portland cement with enough water to make concrete consistency.
Start with a ***2 in**. (*50 mm) layer of a soft mix at six parts vermiculite to one part Portland. Finish with a **1 in**. (25 mm) layer of a firmer mix at four to one. The top of this capping slab design is a **1/2 in**. (12 mm) layer of cement/sand mortar reinforced with a sheet of expanded metal lath. This capping slab design has been shown to be effective in managing expansion, as well as sealing and insulating the heater top.

Another option that has also been used extensively starts with **4 in**. (100 mm) of castable refractory, topped with a crush and insulating zone of **4 in**. (100 mm) of mineral wool insulation and finished off with a **4 in**. (100 mm) thick reinforced concrete slab.

Note that both of these capping slab designs far exceed the minimum thickness of **2 1/4 in.** (57 mm) prescribed by **ASTM E 1602.** It is strongly recommended that the capping slab be carefully planned and installed and that it have sufficient insulation to control surface temperatures on the top of the heater.

The **8 in.** (200 mm) clearance at the top of the heater creates a height limit for the heater when installed in a standard **8 ft**. (2.4 m) room. According to most codes, this clearance could be reduced by half if a suitable shield were installed.

Decorative caps are sometimes necessary when the top of a heater can be seen from above. Cast concrete, natural stone slabs, tiles, or even dry set brick are examples of non-combustible materials that have been used successfully in these situations.

5.2.4.1 Extensions of Exterior Wythe's to Ceiling

When exterior masonry Wythe's of the heater are carried to the ceiling, insulate and vent the top of the heater above the heat exchange channels to reduce possible static heat build-up.

This requirement prohibits the creation of a sealed air space between the capping slab and ceiling when the walls of the heater outer shell are carried to the ceiling for aesthetic reasons. Venting may be accomplished by alternating bricks or half bricks with air space in the top row of the Wythe. Because this area is hidden from view and because such sheltered areas are often the site of ignition where insulation or clearance is inadequate, it is wise to err on the side of caution by incorporating extra insulation into the capping slab if the exterior Wythe's are carried to the ceiling.

5.2.5 Wing Walls

Wing walls may be added to a heater and used as room partitions. Wing walls located at the corners of a heater for the purpose of forming a room divider shall be a minimum of **4 in**. (100 mm) in length and a maximum of **4 in**. (100 mm) in thickness and be constructed with non- combustible materials.

Wing walls located more than **8 in**. (200 mm) from a corner of the heater shall be a minimum of **8 in**. (200 mm) in length and a maximum of **4 in**. (100 mm) in thickness and be constructed with non- combustible materials.

These limitations on wing wall dimensions are intended to permit the joining of a combustible partition wall to a heater so that the combustible materials of the partition do not overheat. The clause prescribes a stub of masonry wall projecting at least **4 in.** (100 mm) from a corner of the heater or at least **8 in**. (200 mm) from a side of the heater. The combustible partition is then fastened to the end of the masonry stub wall. Using this design, sufficient heat is dissipated in the short masonry wall to prevent overheating of combustibles.

5.3 Firebox Floor

The firebox floor shall be a minimum thickness of **4 in.** (100 mm) of non-combustible material and at least the top **2 in.** (50 mm) shall be refractory material.

This requires a floor of sufficient strength and heat resistance to provide a stable surface on which to build the fire.

5.4 Hearth Extensions:

5.4.1 Masonry heaters shall have hearth extensions of brick, concrete, stone, tile, or other approved non- combustible material properly supported. Remove wooden forms used during the construction of hearth and hearth extensions once construction is completed.
This clause provides no guidance on what constitutes proper support of a hearth extension. Follow the requirements of the building code enforced locally for hearth extension requirements. The requirement to remove combustible forms used in the construction of hearths and hearth extensions is well understood by responsible masons.

5.4.2 Fireboxes With A Glass or Metal Door the hearth extension shall be at least 500 mm (**20 in**.) (from the heater face). When a raised hearth of at least **8 in**. (200 mm) in height is used and the hearth is located at the base of the door, the hearth extension shall be at least **16 in**..(400 mm).

5.4.3 Where a firebox opening overhangs a floor, the hearth extensions shall also cover the area beneath the overhang and extend beyond the firebox opening as specified in **5.4.2.**

These requirements may conflict with the hearth extension requirements in the building code enforced locally. Regardless of the code that is consulted, all hearth extension requirements are designed to achieve the same objectives :
To provide a non-combustible apron in front of the loading door so that combustible flooring is not damaged or ignited by embers, coals or logs that may roll out of the firebox.
Therefore, to avoid the problem of challenge by building officials, follow the hearth extension requirements in the local building code.

9. Venting

Both metal and masonry chimneys can be used for the venting of masonry heaters.
A masonry heater does not put excessive stress on the chimney, so a masonry chimney conforming to the requirements of the local building code will suffice.
Similarly, if used, a metal chimney should meet local requirements for chimneys serving wood burning appliances.

ASTM E 1602 contains the following requirements for chimneys.

5.9 Chimney

Vent masonry heaters with a low-heat type masonry chimney approved by the authority having jurisdiction or with a factory-built residential type chimney that meets the "Type HT" requirements of UL 103.
(ULC S629 in Canada).

5.9.1 The chimney shall not be supported by the interior walls of the masonry heater unless specifically designed to do so.
The chimney can be built integrally with an exterior Wythe of the heater, provided the exterior Wythe is constructed of solid masonry and has a minimum thickness of **4 in**. (100 mm).

The limitation regarding the support of chimneys is based on the potential for differential expansion between the core and shell of the heater. This expansion can be accommodated within the heater through the use of expansion joints, but cannot be accommodated properly in a supporting structure for a chimney without some careful engineering.

5.9.2 Flue sizes shall be in accordance with the design specification of the builder or the designer of the unit.

At the gas volume and flow rates typical of the X-HC heaters built in North America, experience has shown that the standard clay flue tile of nominally **8 in. x 12 in**.
(200 mm x 300 mm) outside dimensions provides satisfactory performance.
Heaters that are much larger or smaller than the X- HC may require a flue of a different size. The equivalent round flue would be **8 in**. (200 mm) diameter.

5.10 Chimney Connector

The chimney connector shall be accessible for inspection and cleaning. Chimney connectors shall be airtight and fitted with airtight joints. Where differential movement can take place between a heater and chimney, make provision for this movement in such a way as to maintain the integrity of the connector joints. Materials and methods of construction shall comply with the requirements of the authority having jurisdiction.

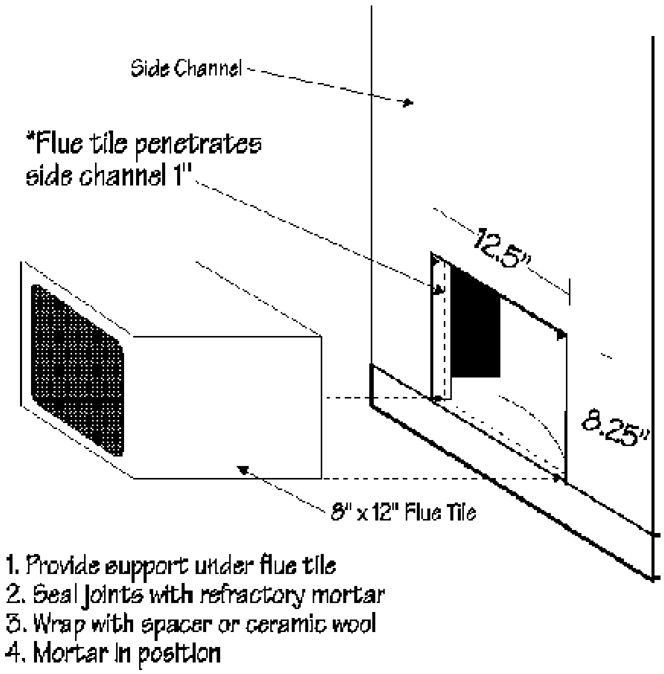


Figure 17.
Chimney connector
(typical Finish contraflow)

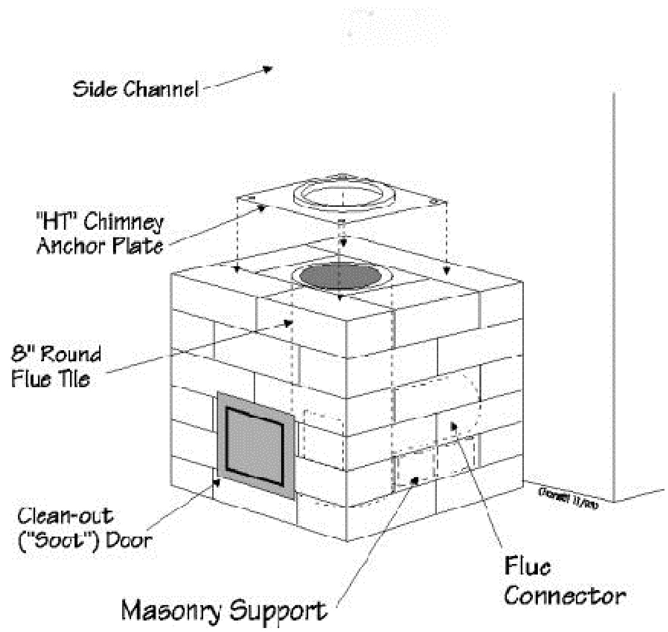


Figure 18.
Chimney connection for metal chimney to masonry chimney or top vent.

Note the opening in the left heat exchange channel prepared for fitting the chimney connector

Ideally, the heater and the masonry chimney serving it share a footing and foundation to reduce the potential for differential movement.

The connector at the base of a contraflow heater is normally formed from firebrick. When laying up the facing material around the connector (if applicable), corbel the assembly slightly so that the connector tunnel does not support the weight of the facing above.

Use at least **8 in**. (200 mm) of solid masonry above the connector tunnel.

The joint between a heater and metal chimney should accommodate a slightly flexible connection so that the seal is not put under strain. Such a connection can be achieved by using a telescopic connection, a section of flexible stainless steel liner, and/or gasketing that permits movement without leakage.

- **General recommendations for venting masonry heaters**

Since a masonry heater is a serious heating device, performance issues should be given priority over strictly aesthetic concerns. Principle among the performance issues is the need for strong draft to drive combustion air flow and produce rapid, turbulent combustion in the firebox. Also, the location and height of the chimney should be such that cold back drafting during standby conditions is prevented. Where possible follow these guidelines:

- Never use a chimney that runs up the outside of the building envelope, or even one that shares a wall with the building. Ideally, the chimney should run completely inside the envelope to avoid cold back drafting.

- The chimney should penetrate the highest part of the building envelope. Cold back drafting can occur in chimneys that penetrate either a single story of a two story house, or penetrate low on the eaves of a house with a cathedral ceiling. The ideal exit point for a chimney is at or near the peak of the roof. Note that the physics of chimney function strongly support the idea that the hearth should be at the heart of the home.

- The height of the chimney should exceed **15 ft**. (4.6 m) in height to provide strong enough draft. Higher is better. The top of the chimney should be at least as high as the minimums provided in building codes. If adjacent rooflines are close, exceed the building code minimums to prevent adverse pressures due to wind effects.

- Install a rain cap at the top of the chimney, preferably one with some amount of baffling. Research has shown that chimneys with good caps are much less susceptible to adverse wind effects.

10. Heating Water with Masonry Heaters

- **Introduction**

Heating wash water is one of the biggest items in the household energy budget, so energy conscious homeowners may express interest in using a masonry heater for water heating.
Part of the heat output of a masonry heater can be used to produce domestic hot water used for washing. Less common, but also possible, is to use the hot water for space heating with baseboard units or in a radiant floor system.

Hot water for space heating might be used to supplement convection heat circulation to a hard-to-heat room that is some distance from the heater.

A heat collector consisting of one or more loops of stainless steel high pressure boiler tubing is located in the firebox, or immediately after the firebox.
It is important to include the proper safety devices when installing a hot water system. If water in the collector is allowed to turn to steam, a powerful explosion can result. Also, the water in the tank can reach scalding temperatures, so a tempering valve may be needed.
Never take any shortcuts when designing or installing a domestic hot water system into a wood fired masonry heater.

- **Thermo-syphon Method**

The flow through the collector can take place in two ways: by thermo-syphoning (i.e. using natural convection), or by means of a small circulation pump.

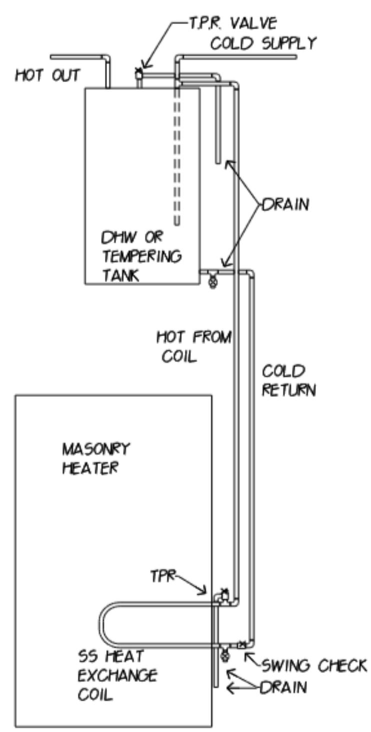


Figure 19.
Thermosyphon circulation method

A thermo-syphon system is the simplest and least expensive, but also has some drawbacks. It requires that the storage tank be located higher than the collector.
Best efficiency is obtained when horizontal distance to the tank is **4 ft**. (1.2 m) or less and the vertical distance is **6 ft**. (1.8 m) or more.
This arrangement is rarely convenient because the domestic hot water tank is usually located in the basement. In some cases a tempering or preheat tank can be mounted above the masonry heater and collector coil.

Note that the tank shown at the top of the illustration, (*on the previous page*), represents either the main hot water tank or a preheat or tempering tank.

The preheat tank is located for good thermo-syphoning and is plumbed to feed into the cold water inlet of the primary tank.

Heat transfer is less efficient with the thermo-syphon method because of the slower water flow through the collector tube (s). In order to achieve good efficiency, both lines from the coil to the tank should be insulated.
A minimum of **3/4” dia.** pipe must be used to ensure adequate flow.

- **Circulation pump method**

This method allows the most flexibility in locating the tank (s) and provides the greatest amount of heat transfer.
A small pump (0.07 - 0.15 l/s or 1 - 2 g/m) is used to circulate water between the collector and the tank.
A pump controller senses when the water from the heater is warmer than the water in the tank. Since a considerable amount of heat is stored in the firebox after a burn, water heating occurs for some time after the fire is out.

Two temperature sensors are used.

One sensor is placed at the hot water outlet from the heater.

The other sensor is placed at the tank where cooler water leaves the bottom of the tank on its way to the loop. A differential controller uses the temperature sensor information to determine when to turn the circulation pump on and off.

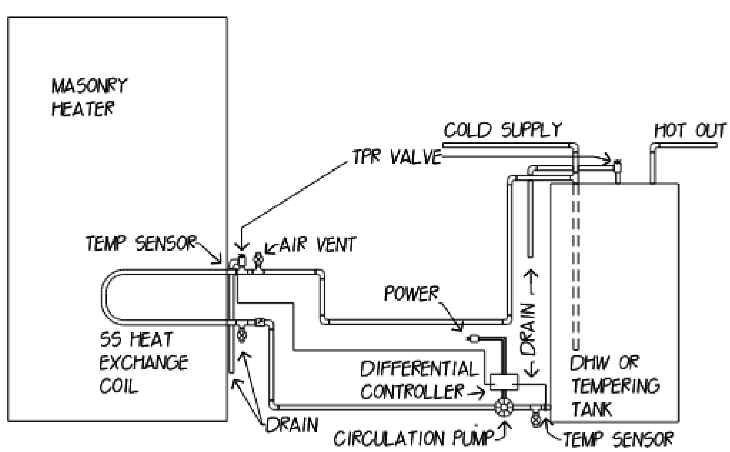


Figure 20.
Pumped circulation system

Each safety device shown is an important component of a well-designed system.

- **Design and safety devices**

If in doubt about any of the design and safety issues consult an experienced plumber to help with the design and installation of a hot water heating system.

Coil construction.

The material used for the coil in the firebox must be certified Schedule 40 stainless steel high pressure boiler tubing, rated at 16,000 psi (for 3/4" pipe). Both ends of the coil should be threaded. A minimum of 3/4" copper tubing should be used for the coil loop to the tank.

Temperature/pressure relief (TPR) valve.

In all cases, it is necessary to install a temperature/pressure relief (TPR) valve at the hot water outlet of the collector, near the heater.
A TPR valve is a standard plumbing item used on hot water tanks. In case of a temperature or pressure build-up, steam and/or excess hot water are safely diverted into the house drainage system. The valve should be accessible for servicing and testing.
The TPR valve at the collector is in addition to the TPR valve located at the hot water tank, and should not be used as a substitute for the tank TPR valve.

Tempering valve.

If hot water usage is low, water in the tank can reach scalding temperatures.
A tempering valve can be installed at the tank exit to mix cold water into the hot water line.

Preheat or tempering tank.

A second tank can be installed to increase the capacity of the hot water system. This is known as the tempering tank method. It is often useful in thermo-syphon systems (see above). For both types of systems, it has the advantage of being able to use more low-grade heat from the heater during periods of high usage.

During high usage, water in the tempering tank will be cold. For a thermo-syphon system, this creates a higher usage, water in the tempering tank will be cold.
For a thermo-syphon system, this creates a higher temperature differential for convection and increases flow in the loop and therefore heat transfer. For both types of systems, it allows low grade heat from the firebox to be used for a longer time after the fire is out, since the feed water to the coil is cold.

Swing check valve.

A swing check valve is a one way valve installed in either the thermo-syphon or the pumped loop. In both cases, a low resistance valve designed for horizontal installation should be used. It is installed near the heater at the water inlet side of the coil. The valve body is stamped with an arrow to indicate the direction of flow. With a pumped system, the swing check prevents reverse thermo-syphoning when the tank is lower than the heater and the heater is cold.

With either a pumped or a thermo-syphon system, the swing check valve can act as a secondary safety device. If a bubble of steam forms in the coil, it creates an immediate pressure rise in the system.
This pressure pulse will first reach the (now closed) swing check valve, where it will reflect. This reflection creates a momentary low pressure at the swing check valve, allowing some cold water to pass.
This mechanism can create a pumping action that helps to circulate water through the coil in case of an emergency, such as a power outage.

Drain fitting.

The collector loop should have a drain fitting to allow for servicing. Once a year, the loop should be flushed with water. In areas with hard water, the loop should be checked for scale build-up. This can be indicated by dislodged particles of scale coming out of the drain fitting during flushing. it may be necessary to use a cleaning solution to remove any scale build-up.

Electronic anti-scale systems are also an available option.

Air vent.

It is a good idea to install an air vent at the high point in the hot water loop circuit. You can use either an automatic vent or simply a gate valve to allow the manual purging of any air that becomes lodged at the high point. This is usually more necessary in a pumped system, since the tank is usually lower than the loop.

Power failures.

Since a masonry heater is typically fired for about 2 hours out of 24, the odds of experiencing a power failure during a full burn are reduced accordingly. However, if power failures are a regular occurrence in your area, consider installing a system to protect against power failure related problems.

If the water is supplied from a well, then water pressure will fall soon after a power failure. If water boils in the coil and is vented by the TPR valve, some air may get into the collector. If the collector gets hot enough, soldered connections can melt.
After an over pressure emergency of this type, the water supply should be shut off and the system checked for leaks. This can sometimes be done by restoring water pressure in a gradual way.

Battery back-up.

If the degree of risk warrants it , a pumped rather than a thermo-syphoning system driven with a 12 volt circulation pump. This pump could be powered with a 12 volt battery that is maintained by a trickle charger.

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11. Other options and accessories

Bake ovens and warming ovens

Bake ovens and warming ovens have become popular options for masonry heaters in recent years. Bake ovens should be capable of achieving a minimum temperature of **350 F** for at least two to three hours, otherwise they should really be considered as warming ovens. Ideally, a good bake oven should be able to achieve a temperature of **450 to 500 F.**

Black Oven

In a black oven, the flames pass directly through the oven. If the fire is not hot enough, black soot that is deposited in the early stages of the fire may not completely burn off, hence the name.

The black oven design shown in **(Figure 22)** for a contraflow heater is based on the Finnish domestic bake oven, which is a dedicated bake oven with heating as a secondary function.

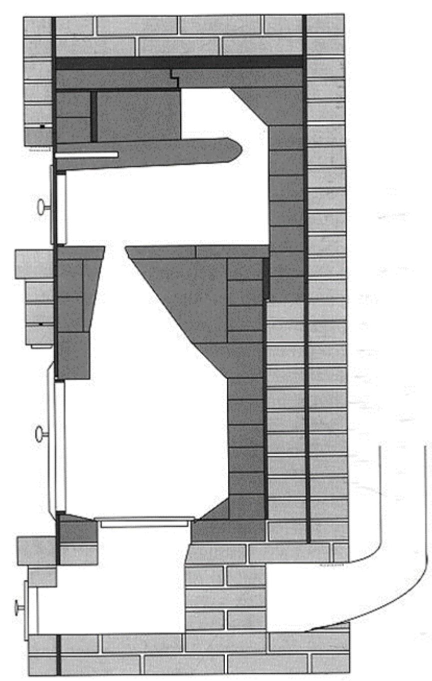


Figure 22.
Black oven in a contraflow heater

White Oven

In a white oven, the flames pass around the oven and do not enter the baking chamber.

It is somewhat difficult to build a good domestic white oven that achieves the necessary baking temperature and yet holds enough heat to last several hours. The oven wall thicknesses, particularly the floor, have to be correct and the heater needs to be designed to transfer the maximum amount of heat to the oven mass.

The special thermal properties of soapstone may be exploited to advantage in white oven design.

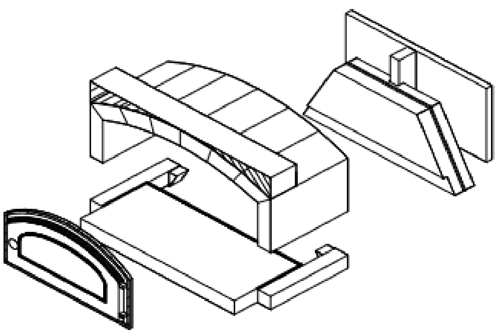


Figure 21.
Precast white oven components

Heated bench (hearth)

Heated benches are an increasingly popular option for masonry heaters.
On down-drafting heaters such as the contraflow, they are straightforward to design, because they tend to be self balancing.

Figure 23 shows a contraflow heater with a bench running along the front and extending over to the chimney located on the right hand side. A gas inlet for the bench is cut into the front of the left bottom downdraft channel. An extra connection is cut into the chimney flue liner, and this is where the gas exits the bench.
The bench runs in parallel with the normal connecting channel at the back of the heater.

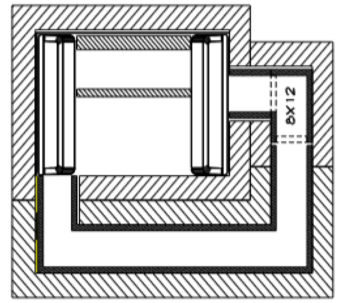


Figure 22.
Typical heated bench layout
Contraflow Heater with 8 in. x 12 in. chimney on the right side. Clean outs not shown

A typical heated bench is constructed from **8 x 12 in.** clay flue liners. Forty-five degree miters are cut into the liners to make the corners.
Thermal stresses are low at this end of the heater, so special expansion joint precautions are usually not taken. In order to get a relatively high temperature at the bench top, a popular method is to use a material such as 1-½” bluestone and to set it into a mortar bed directly onto the liner. One trick for making permanently gas tight head joints in the bluestone is to use Type 1 silicone. While the silicone is still wet, dry mortar mix is dusted onto the joints and pressed in, thus hiding the silicone.

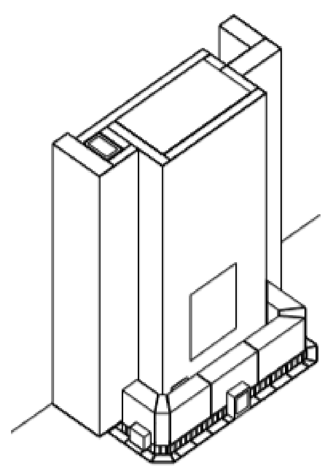


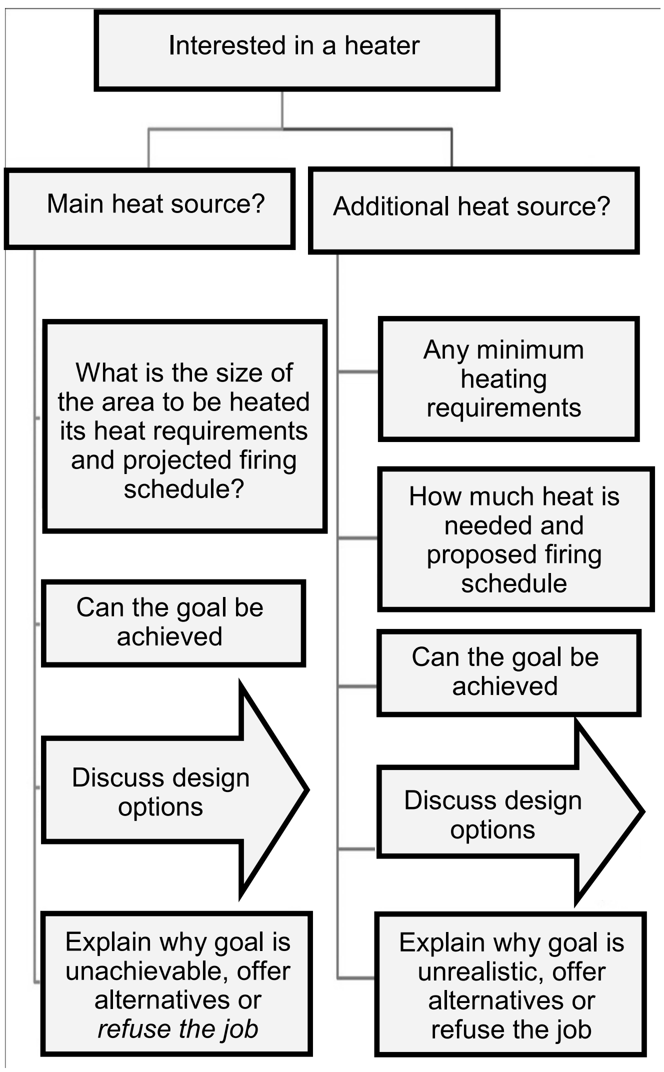
Figure 23.
Flue liner layout for heated bench with mitered corners An 8x8 liner has been notched into the bench for an ash box door. The 8x12 liners are raised 4” off the floor.

12. Communicating with your customer

Most of your customers will have little or no experience with masonry heaters, so they will depend on you for information. They will be more satisfied with their new heater if you make sure in advance that their expectations are realistic. The prospective buyer develops ideas about what they can expect from a masonry heater. These expectations fall into three general areas: beauty, comfort and heating performance.

Figure 24.
Builder / Customer Design Conversation

Provided by: Alex Chernov



Beauty and comfort are in the eye of the beholder and hard to measure so you can promote them without risk.
But heating performance expectations can be a problem if you are overly enthusiastic in your sales presentation about what the product will do. When purchasers' expectations are unrealistic, they are bound to be disappointed.

See the flow chart on the left in **Figure 24** to help understand the needs of the potential customer.

12.1 Masonry Heater Installation Guidelines

(Avoiding Common Pitfalls.)
Alex Chernov

Advice on predicting performance of a masonry heater

The only guarantee a heater builder can give confidently is a guarantee on the heat output of the heater. It is not recommended to guarantee heating of a certain area or space since this depends on many factors, some of which are subjective perceptions of the performance:

- Heat loss of the area.
- Firing schedule.
- Quality of firewood and its moisture content.
- Firing techniques and operator's knowledge.
- Client's perceptions of comfort level in the building.

A heater builder can find himself in a difficult situation when his clients do not perceive performance of their heater as meeting their expectations and/or promises of their heater builder. It can be very difficult to impossible to defend one's position if the promise was to "heat a certain area". Contrary to such meaningless promise, heat output of the heater is a factual characteristic that is easy to measure.

- It is recommended that rather than promising heating performance in terms of ability to heat a certain area, heater builders state heat output of the proposed heater and compare it with approximate heat loss of the area for illustrative purposes only. A heater builder is then makes recommendations, based on the comparison, not promises. The final decision of suitability of the heater for the place should always be made by the client, based on information, provided by the heater builder, not by the heater builder himself.

If a heater builder is required to propose a heater that meets certain heat output, it is advised to demand that the client provides a heat-loss statement.
This puts responsibility for providing factual information on the building into the client's hands, therefore, eliminating mistake in the assessment and taking responsibility for such mistake away from the heater builder. Performing your own heat-loss statement calculations, therefore, is not recommended. In absence of the heat loss statement, a heater builder can use Rule of Thumb for estimating heat loss of the buildings to illustrate capability of the proposed heater.

A statement must be made, however, that the calculations, performed in this case, are approximations for illustrative purposes only.

It is clear from **table 25**, that with minimum 5" of space between heater and a wall no heat output is lost if that space is open from sides. Reduction of such space or enclosure of the space from sides reduces the output of the wall up to 50%.

Heat output of a heater's wall, facing excessive masonry mass, is reduced significantly or can be practically lost with majority of the heat absorbed in the mass ,reducing surface temperatures of this mass to virtually ambient, at which point no heat transfer happens. With individual walls of a heater often taking 20-25% of overall surface area, reduced heat output from even a single wall results in a large reduction in overall heat output. Therefore, layouts, which call for the described solutions, must be avoided.

Figure 25.

Corrective Coefficients for Heat Output Calculations

Heater surface	Gap	Coefficient
Open	**Not applicable**	**1.00**
Facing a wall	**> 5"-wide gap open from both sides**	**1.00**
Facing a wall	**from 2 3/4" to 5"-wide gap open from both sides**	**0.75**
Facing a wall	**from 2 3/4" to 5"-wide gap closed from both sides, with air grill at the bottom and open on top**	**0.75**
Facing a wall	**closed from both sides, with air grills at the bottom and top**	**0.50**
Facing a wall	**closed from sides but open on top and bottom**	**1.00**

Source: A.E.Shkolnik "Heating buildings with Masonry Heaters", Moscow, 1986

Estimating heat loss

(The Alex Chernov method)

- Always ask client for the heat loss statement first.
- Demand that the client must provide heat-loss statement if you are expected to meet certain heat loss.
- Doing own heat-loss statement calculations is not recommended.
  If interested, there are multiple online tools available.

Rule of thumb for estimating heat loss

Heat loss estimated for the coldest day and for standard glazing conditions:

- Super-insulated houses (R30+ in walls): 10Btu hr. / ft ^{2}
- 2x6 walls with mineral or fiberglass insulation (R20): 20 Btu hr. / ft ^{2}
- 2x4 walls with fiberglass insulation (R10-13): 25-30 Btu hr. / ft ^{2}
- Un-insulated old houses: 50 Btu hr. / ft ^{2} and higher

Calculating Energy Output

Energy output of the heater depends on:

- Weight of wood in one full load.
- Number of loads per day.
- Energy content of the particular type of wood used.
- Efficiency of the heater, which is determined by size of the mass and heater design.
- water heat-exchanger (if applicable) can take part of the heat away.
- One lb. of wood on average has **8600 Btu's**
- One lb. of wood at **20%** moisture content has **8600 x 0.8 = 6880 Btu's**

Energy output of the heater in 24hrs equals:

6880 x heater efficiency x daily load in lbs. / 24hrs

Example:

6880 x 0.75 x 100/24 = 21500 Btu hr.

Maximum load for a reasonably-sized firebox of a residential heater is **75lbs.**
Maximum possible energy output of a heater, fired **twice a day** with **75lbs load**:

6880 x 0.75 x 100/24 = 32250 Btu hr.

Fuel load and size of the mass must be balanced!

Mass is too small for the load:
- Low efficiency
- High exhaust temperatures

Mass is too large for the load:
- Potentially poor chimney draft with all related problems from slow start to back drafting and smoke spillage.
- Condensation of the exhaust gases in the chimney or channels
- High emissions

Balancing heat output with mass

Rules of Thumb:

- A heavy heater, fired **two times a day**, on average will emit about 160 Btu / hr. from one ft ^{2} of its surface.

  Depending on thickness of mass, this number can be anywhere from **100 to 300Btu hr./ft ^{2}** .

  My opinion: for standard North American double-wall heaters we should have between **100-200 Btu / ft ^{2}**

Maximum amount of wood per mass in a heater:
- Fired once per day: **1 lb.** of wood **per 300lbs** of heater mass.
- Fired twice per day: **1 lb.** of wood **per 300lbs** of heater mass for each fire per day.

Making the sale

Although masonry heaters can be whole house heaters, a lot depends on the climate and on the house's layout and energy efficiency. It is rarely necessary or advisable to suggest that the heater will provide all the space heating required. It is preferable to say it will provide beauty, security and comfort while carrying a significant portion of the space heating load. It is usually a good idea to point out that most owners use other means to heat their houses in addition to the masonry heater. A whole house energy audit could help determine if a masonry heater is a good economic choice for a primary heating solution.

Information for the new owner

Once the heater is built, the new owners will need good information and possibly some support until they are familiar with its use and performance.

Verbal instructions are not enough. You will need to supply some operation and maintenance instructions that the user can refer to later. Clear and complete written instructions will mean fewer calls to you for ongoing support.

Following is a sample of operating and maintenance instructions that you can use as a template. Since there are variations in heater design, and masons have their own experience and preferences to share with their clients, these instructions may not be suitable in all cases. However, all such instructions should contain at least the general types of information offered here.

Operation and Maintenance of Your Masonry Heater

IMPORTANT:

Read and be sure you understand these instructions before operating your masonry heater.

Curing a New Heater

When your heater has just been built, it contains large amount of water. A lot of the water that went into the mortar is still in there.
Before you can use the heater to its capacity, it must be completely dried out. Otherwise, steam could form inside the masonry materials and damage the heater.
When the heater is completed, you can begin with several small fires. This can be done more than once a day, but fires must be at least six hours apart. Start by burning about 5 lbs. of wood.
Gradually increase the size of the load by about 3 lbs. each time. The gentle heating that results from these small fires heats all the masonry mass and gradually drives the moisture from the interior.
Break it in gradually.

IMPORTANT:

During the curing period, do **NOT** close the shut-off damper. This allows the moisture to escape up the chimney. Once the heater is cured, you can start heating with it.

Operation Summary

1. Open the chimney damper.
2. Open the combustion air control.
3. Stack the kindling and the wood load.
4. Light the fire and close the doors.
5. When the fire is almost out, close the combustion air supply. (if desired, suggest strategies for quickly consuming the coal bed)
6. When the fire is completely out (no coals) close the chimney damper.

CAUTION:

Do not close the chimney damper until the fire is out. When there are still blue flames on the coals, carbon monoxide is being produced. It is odorless and potentially lethal. Make sure that this is understood by anyone who operates the heater.

In addition to a number of smoke detectors, an inexpensive CO (carbon monoxide) detector alarm is a good safety device for any house with fuel- burning equipment, and we strongly recommend that you install one.

- **Operation Details**

Stacking Wood

- The maximum wood load is 50 lb. or roughly 2/3 of the height of the firebox.
- Lay the largest 2 pieces front to back, leaving a channel in between. This channel is needed to get air into the pile.
- Lay successive layers log cabin style, each layer with smaller pieces. Keep the pieces tight enough together so that kindling coals won't fall through.
- Surround crumpled newspaper, a few resinous pine cones, or a commercially available "fire-starter" with enough kindling to get the load burning from the top of the pile.

- Optional: After about 45 minutes, the fire changes from long yellow flames to the short blue flames of the charcoal fire, which requires much less air.
You may cut back the air supply by about two-thirds.
The fire will burn noticeably slower.

Firewood

You may use any type of cordwood, provided it is dry. Use a moisture meter if you're not sure. A freshly split piece should measure no more than 20% moisture with the probes inserted into the side of the piece. If you use scrap wood, such as hardwood pallets, be aware that such wood can be over dry and burn too hot. This overheating may damage the heater. If you will be using small pieces of very dry wood, mix in some pieces of wetter wood to slow the fire down.

A "top-down" method of firing

This method is inherently cleaner burning because rising gases are more likely to be consumed before escaping. In addition, the heat output is evened out over the firing, allowing longer, more even heat transfer into the mass. Also, a cleaner fire not only minimizes air pollution but also the build-up of soot on the heat exchange portion of the core. With top-down burning, a range of wood size diameters can be used.
For hardwood, largest wood size is about 6"-7" diameter. For softwood, the largest size is 7 - 8". These sizes are not critical.

It is advantageous for each layer of the load to be fairly even in size. If you have one big piece in a load, it will be the last to burn and you will have to wait much longer for the fire to be out so you can close the chimney damper.
The wood should have about 20% moisture. This means that it has been split and stacked inside for 6 months, or split and stacked outside, with a cover, for 8 - 10 months. If it has been stacked outside but not covered (even for years) it is NOT dry. Dry wood has checks or cracks in the end grain and two pieces make a characteristic ringing or hollow sound when struck together.

A moisture meter for wood and a noncontact (infrared) thermometer are good investments to help insure optimal heater/bake oven performance.

Maintaining your masonry heater

Ash removal

Masonry heaters have very low maintenance requirements. The most frequent maintenance task is the removal of ashes. This should be done before lighting each fire. Store ashes outside in a covered metal container away from combustible material because sometimes charcoal can stay hot for a long time.

This charcoal (i.e. biochar), as well as the finer wood ashes are very useful end products of wood energy ecology, and have much potential for becoming great assets in soil fertility / carbon sequestration / climate change science.

Check the cleanouts

Only with some use with the fuel you use can a suitable maintenance schedule become apparent. Therefore, it is important that you remove the cleanout doors in the heater and chimney frequent during the first heating season. Use a mirror and flashlight to view the area inside the cleanout opening. A light dusting of fly ash is of no concern, although a significant build-up should be removed to prevent blockage. If the deposits are dark and if they build up rapidly, you should call the heater builder, or an experienced chimney sweep to help you find out what is wrong.

If you see anything unusual

It is important that the door hinges and latches, as well as air controls and chimney dampers, function properly to control the flow of air into the heater. If you have questions about maintaining or repairing seals, dampers or joints, call your heater builder.

Please store these instructions in a safe place for future reference.

13. Glossary of Terms

The following definitions have been adapted from those presented in **ASTM E 1602.**

***Alumina –** (Al_2O_3) is an amphoteric oxide of aluminum, with a high melting point. Extremely abrasive at 9 on the Mohs scale. It is derived from bauxite. Corundum is crystalline aluminum oxide. As a general rule, the higher the percentage of aluminum oxide in refractory brick, the higher its temperature rating.

Approved — acceptable to the authority having jurisdiction.

Authority Having Jurisdiction - the organization, office, individual, or agent thereof, who is responsible for approving construction, materials, equipment, installation, procedure, etc.

***Bag walls**—The side walls of the secondary combustion chamber which flow the gases as they leave the chamber and enter the side channels.

***Black Oven**—Upper chamber oven having its bake chamber as part of the smoke path. Secondary combustion taking place within the bake chamber.

***Bypass Channel—**A mechanical device used to divert the flue gases from the heater directly into the chimney. Usually located between the secondary combustion chamber and the chimney, or between a manifold and chimney when used to by-pass a bench. The principle function of a bypass is to establish a draw before engaging a portion of extended smoke path.

Bypass damper — a valve or plate that provides a direct path to the chimney flue for the flue gases or portion thereof.

Capping slab — a horizontal refractory barrier covering the top of the heater that provides a seal, insulation and allowance for expansion of the core.

***Ceramic Blanket**—High temperature woven ceramic fiber blanket, used as an expansion and smoke gasket and non-load bearing insulating material above capping slabs.

Cleanout opening — an access opening in a flue passageway of the heater or chimney that is designed to allow access to the flue for purposes of inspecting for and removing accumulated deposits.

Convection—A means of heating, using air as the medium.

Damper — an adjustable valve or plate for controlling draft or the flow of gases, including air.

***Expansion Joint (slip joint)—**Gasket usually, but not necessarily, of fireproof material, placed between two materials with a different expansion coefficient. Or two similar materials, with a different expansion rate against time.

***Facing, Façade, Wrap**—A single Wythe masonry skin, enclosing a refractory core providing the heater's double skin. It can consist of any standard dense masonry material.

***Fire Tube**— Area of the core directly above the firebox where secondary combustion takes place. Found in cores with an undefined throat and upper chamber. Unlike the upper chamber, the fire tube does not rely upon compression and expansion of the gases to promote secondary combustion.

Firebox (fire chamber) — that portion of the masonry heater that is designed for containing and burning the fuel charge.

***Fly Ash—** Fine particles of ash that are drawn through the smoke path, often accumulating on its horizontal surfaces.

Foam glass— A light weight, rigid foam insulating material that is non-combustible, has a high compressive strength, and is composed of millions of sealed glass cells.

***Free Silica**— Fine crystals of silica suspended in the atmosphere in the form of dust. Caused by the working of silica containing products. A general and specific safety hazard for the Mason.

Gas slot — a small fixed opening that permits some unburned flue gases to bypass downdraft flue channels.

Hearth extension — the non-combustible surface applied to the floor area extending in front of and beyond each side of the fuel loading door of the heater; also applies to the floor beneath a heater or beneath an elevated overhanging heater hearth.

Heater base — that portion of the support for the heater between the heater and the foundation that is below the firebox or the heat exchange area.

Heat-exchange channel / chamber — a chamber or passageway between the firebox and the chimney flue in which heat in the flue gases is transferred to the surrounding masonry.

Kachel — a structural square or rectangular masonry heater tile with a hollow back.

Lintel — A horizontal beam used to traverse an opening. Can be of stone, iron, refractory concrete, firebrick slab, or common concrete.

***Lintel** — horizontal beam used to traverse an opening. Can be of stone, iron, refractory concrete, firebrick slab, or common concrete.

***Manifold** — The widened area of the smokie path directly beneath each side channel. There are three manifolds in a contra-flow core; left and right side manifolds and a rear manifold running beneath the back portion of the firebox.

Masonry heater — see MHA Masonry Heater Definition, **Section 2**.

***Mechanical bridge**—A solid contact between two otherwise separate, rigid materials, causing the possibility of one having a mechanical action on the other due to thermal expansion.

Mortar, masonry — a mixture of Portland cement (or equivalent), a plasticizer, sand and sufficient water to form a workable consistency

Mortar, refractory — mortar consisting of fire clay (heat setting) or fire clay and sodium silicate (air setting).

Mortar, soapstone refractory — a mixture of powdered soapstone and sodium silicate.

Non-combustible material — a material that, in the form in which it is used and under the conditions anticipated, does not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat.

Perlite — a naturally occurring volcanic glass that when heated, expands to form a light weight non-combustible aggregate with insulating properties.

***Prefabricated Refractory Core, Core kit** — Refractory core that is entirely factory made, consisting usually of castable refractory concrete modules. Can be installed by a non-specialized mason.

Radiant — The type of heat emitted from a heated surface using infrared radiation. Radiant heat is emitted at right angles to the heated surface.

Refractory Material — (**ASTM C71**) – non-metallic materials having those chemical and physical properties that make them applicable for structures, or as components of systems, that are exposed to environments above 1,000º F (538 º C).

***Shiners —** Brick that are laid face down i.e. on edge, rather than bed down.

Silicosis— An incurable lung disease contracted due to prolonged exposure to suspended crystalline silica. Note: In France it is said, "Une bonne fumiest mort a 50 Anne".

Soapstone — a variety of natural stone (hydrated silica of magnesium) that is suitable for high-temperature applications in masonry heaters. (Soapstone is between 4.8 and 7 times as conductive as low duty firebrick.)

***Sodium Silicate (Water Glass)** — Used as a bonder (hardener) in refractory mortars. Available in dry or liquid form.

***Soot Doors (Clean-outs)** — Openings giving access to the manifolds. Usually fitted with cast iron doors.

Thermal Break — A layer of insulating material placed between two dense conductive materials with the intention of impeding thermal transmission.

***Thermal Bridge** — A solid bridge allowing the conduction of heat from one dense material to another.

***Thermal Stress** — The detrimental effect of a material that is saturated, accumulating heat faster than it can transfer heat, resulting in cracking and warping.

***Thermosyphon** — The natural tendency for heated gas (air) or liquid to rise as it is displaced by cooler air.

***Throat** — Point at which the firebox ceiling narrows, compressing the gases. Usually precedes the upper expansion chamber.

Top Down Fire — Term used to describe the manner in which a fire is laid, with the largest wood on the bottom, medium pieces above that and finally, the paper and kindling laid on top. The fire is lit at the top and consumes the fuel load slowly from the top down.

Vermiculite Board- A molded refractory insulating material made by combining vermiculite (i.e. weathered mica clay) and a bonding agent usually sodium silicate.

Wing wall — a non-combustible lateral projection from the exterior wall of a masonry heater for use in bridging the space between a heater and a combustible partition wall.

An asterisk (*) indicates terms provided by Marcus Flynn of Pyromasse.ca

14. Certification Policies & Procedures

Of the Masonry Heater Association of North America (Revised /19)

1.Introduction

The MHA is a professional association of masonry heater builders that was formed to advance the technology of masonry heating in North America and to increase the knowledge and skills of professional heater masons. The MHA fulfills its mandate by sponsoring laboratory research into masonry heating technology and by publishing information of interest to practitioners. The MHA also maintains a professional training and certification program to recognize the competency of qualified heater builders.
This manual has been prepared to assist candidates in achieving and maintaining MHA certification, and to guide the administration of the program.
The requirements presented in this manual have been established by the MHA Board of Directors and it is its sole responsibility to apply and interpret them, primarily through its administrative designate. The manual may be amended from time to time to account for changing conditions.

2. Application for Certification

2.1 Application Procedure

To initiate the application procedure, a person must be a full voting MHA member **"in good standing"**, and apply in writing to the MHA administrator and provide:

(a) Completed application form
(b) Purchase a copy of the Masonry Heater Association od North America Reference Manual in the amount of US $150. (rev. 1/19)
(c) Pay an application fee of $150 this includes the cost of the written test. (rev. 1/19)

2.2 Administration

Upon receipt of a completed application form and fee, the administrator will supply the applicant with: Any additional documentation deemed necessary to prepare the applicant for the certification process. (rev, 1/19)

2.3 Certified Heater Mason Logo.

Any certified heater in good standing is allowed the use of the official Certified Heater Mason logo.
Contact MHA Executive Director to receive an electronic high resolution copy of the Certified Heater Mason logo.
(rev. 1/19).

3. Requirements for Certification

3.1 Professional Credentials Required

A candidate for MHA certification must demonstrate a working knowledge of relevant housing and fuel burning regulations, and sufficient knowledge of masonry work by providing proof* of successful completion of at least **ONE** of the following:

(a) A bricklayer apprenticeship program
(b) Certification issued by the Chimney Safety Institute of America (CSIA) (rev. 3/12)
(c) Certification issued by Wood Energy Technology Transfer Inc.
(d) Successful completion of a Level 1 HMED class or an equivalent professional credential deemed acceptable to the MHA (rev.3/12)

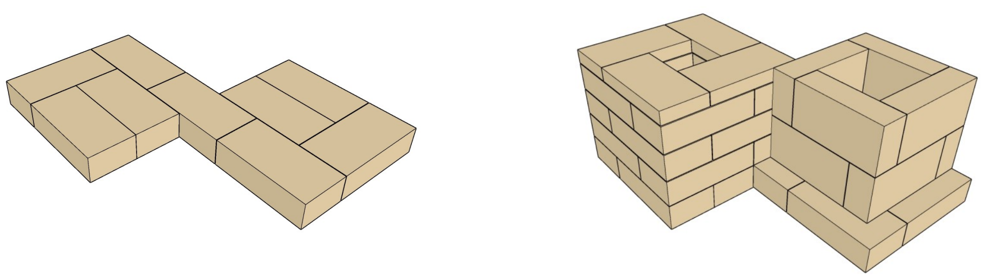
AND at least **ONE** of the following:

(e) 40 hours of work under the direct supervision of an MHA certified heater mason
(f) Successful completion of an MHA Hands-on Test, consisting of setting a combination of 38 full firebrick and 4 firebrick splits, using pre blended refractory mortar. The objective will be to build two adjacent square columns, in a 90 minute time period. Grading will be consistent with industry accepted standards for plumb, level, square, full joints, joint finish, and adherence to the time allotted. (rev. 1/19) *(see figure 26 below)*

Figure 26.

CAD drawing of the hands-on firebrick setting test (rev. 1/19)

Base Completed project



** Proof of certification or participation i.e. copy of certificate, diploma, letter of successful completion. Other credentials can be judged for their equivalence.*

3.2 Field Experience

A candidate must provide evidence of a working knowledge of masonry heater design and construction as set out in the MHA Occupational Analysis Manual. The required evidence must consist of verifiable documentation of **THREE** masonry heater construction projects professionally contracted and completed within the **past five ye**ars.
The candidate must have served as the lead mason on at least **TWO** of the required projects.

One of those 2 projects must have a firebrick firebox (rev.3/12) Required documentation for **EACH** of the three projects must consist of the following:

(a) 12 photos of the project: (rev. 3/12)
Photo's required:

- Foundation
- Base pad and first course
- Core at floor level
- Core at firebox level
- Completed core
- Facing with soot doors or 1 foot from floor
- Facing at lintel level
- Downward picture of channels just before capping slab
- Completed heater front
- Completed heater rear
- Chimney connection
- Full post break-in fire through door

(b) A thorough description of the heater including firebox dimensions, overall dimensions, wall thicknesses, main materials used, including scale drawings with plan sectionals.
(c) The name and address of the client, and the date of construction.

3.3 Examination

(a) The candidate must achieve a passing grade on the MHA examination. The passing grade is 80 percent. (rev. 1/19)
(b) The taking of the examination may be administered by the MHA or
(c) The examination may be proctored by an independent agency such as a public library which is deemed acceptable by the administrator. The MHA will pay the proctor for the service. All other costs related to the proctoring of the examination will be paid by the candidate.
(d) The candidate may take the examination before the other certification requirements are met, but certification will not be granted until all requirements are satisfied.

3.4 Summary of Certification Requirements

To achieve certification under the Heater Mason Program, the candidate must:
(a) Purchase a copy of the Masonry Heater Association of North America Reference Manual. (rev. 1/19)
(b) Supply a completed application form 2.1(a) (rev. 1/19)
(c) Pay the application fee of $150 2.1(c) (rev. 1/19)
(d) Provide proof of relevant professional credentials 3.1
(e) Provide documentation of three heater projects 3.2
(f) Achieve a passing grade on the MHA examination 3.3(a) (rev. 1/19)

4. Maintaining MHA Certification

4.1 Annual Certification Renewal

To maintain MHA certification in good standing, a certificate holder must be a MHA full voting member and pay an annual renewal fee of $50. The fee covers administrative costs, validation of renewal and information updates. Failure to pay the annual renewal fee will result in the withdrawal of certification after two payment notices have been sent and no response is received by the administrator within 90 days.

4.2 Continuing Education Requirement

Within each **three year period** after certification, the certificate holder must accrue MHA continuing education workshop points, or other relevant professional credentials deemed equivalent by the MHA. Points accrued must be a minimum of 8 to 9 each year or **25** or more for the **three year period**. (rev. 1/19)

In any **3 year period**, **CEU's** that are accumulated beyond the number needed to re-certify **do not carryover** to be used in the following **3 year period.** (Rev. 1/19)

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Continued Education Credits, **(CEU's),** are awarded by the following:

- The instructor of a MHA sponsored workshop would be awarded **1 CEU** per 3 hours of instruction.
- The assistant instructor of a MHA HMED class would be awarded **1 CEU** per 4 hours of instruction.
- Participation in a MHA sponsored workshop would be awarded **1 CEU** per 4 hours of instruction.
- The instructor of a non sponsored MHA workshop would be awarded **1 CEU** per 4 hours of instruction.
- Participation in a non sponsored MHA seminar or workshop would be awarded **1 CEU** per 5 hours of instruction.
- Holding an elected position in MHA warrants **2 CEU's** per year.
- Chairman of a MHA committee warrants **2 CEU's** per year.
- Documentation of a site built masonry heater with written description, firebox plan drawing, owner contact information and at least 9 photo's would be awarded **3 CEU's**

Photos required:

1. Foundation
2. Base pad and first course
3. Core at floor level
4. Core at firebox level
5. Completed core
6. Facing with soot doors or 1 foot from floor
7. Downward picture of channels just before capping slab
8. Completed heater front
9. Chimney connection

- Documentation of a site built masonry heater core with written description, firebox plan drawing, owner contact information and at least 5 photo’s would be awarded **2 CEU’s**

Photos required:

1. Base pad and first course
2. Core at floor level
3. Core at firebox level
4. Completed core

- A complete 3 dimensional CAD model can be used in lieu of photos 1 – 3. Finished core photo is required

- Documentation of a site built masonry heater core with written description, firebox plan drawing, owner contact information and at least 5 photo’s would be awarded **2 CEU’s**

Photos required:

1. Base pad and first course
2. Core at floor level
3. Core at firebox level
4. Completed core

- A complete 3 dimensional CAD model can be used in lieu of photos 1 – 3. Finished core photo is required

NOTE: Failure to comply with the continuing education requirement will result in withdrawal of certification after two notices have been sent and no response is received by the administrator within 90 days.

4.3 Leave of Absence

Any Certified Heater Mason leaving North America or becoming inactive as a working mason must remain a paid Associate Member of MHA and keep annual certification fees up to date.

15. Occupational Analysis:

The Design/Build Sequence for Masonry Heater Designers and Builders

Revised April, 2011.

GOAL

To convey the minimum process consideration required to plan and install a solid-fueled masonry heater.

TABLE OF CONTENTS

Introduction

Requirements for MHA Certification

1.A certified Masonry Heater Designer/Builder shall demonstrate proficiency in the skills listed in all sections of this manual

2.Proficiency in each skill area shall be determined through a combination of the following:

(i) verification of relevant past experience,
(ii) competency as certified by a current or previous employer or supervisor,
(iii) customer endorsements,
(iv) relevant educational credits,
(v) oral, written or practical testing.

See the Heater Mason Training and Certification Program Policies and Procedures Manual for detailed certification criteria.

How to Use This Occupational Analysis

This is the key document that outlines the special skills required of those who build masonry heaters. You must be able to demonstrate competency in each of the skills listed in all of the sections of the analysis. This MHA practical and written examinations use the skills listed in this analysis as a guide for their contents. You can use this analysis as a checklist of your own skills as you prepare for certification, and you can use it to assess employees or others whose competency in heater design and construction you are asked to evaluate.

1.Work Safely

1.1 Wear eye protection.
1.2 Wear foot protection.
1.3 Wear ear protection.
1.4 Wear protective clothing.
1.5 Wear hand protection.
1.6 Wear dust masks and respirators.
1.7 Wear a hard hat.
1.8 Lift and moving heavy objects.
1.9 Use forklifts, dollies, hand trucks and motor vehicles.
1.10 Secure loads.
1.11 Maintain a safe work environment.
1.12 Follow health and safety legislations.

2.Analyze customer expectations and give advice

2.1 Explain the operational and performance characteristics and limitations of masonry heaters.
2.2 Compare masonry heaters with other hearth and heating system options.
2.3 Determine the heating, fire viewing, and decor requirements of the customer.
2.4 Explain the characteristics of optional facing materials.
2.5 Prepare sketches showing location options.
2.6 Provide advice on the most effective locations for performance, aesthetics and safety.
2.7 Explain limitations of system locations such as outside walls and confined areas.
2.8 Identify and explain masonry heater and component options.
2.9 Discuss heating capacities of various masonry heater options.
2.10 Explain venting requirements.
2.11 Discuss the effects of a tight building envelope on the operation of a high-capacity exhaust system. Suggest this is redundant and be deleted: it’s covered in the back of the R. M.]
2.12 Discuss effective heat distribution of masonry heaters.
2.13 Discuss requirements and procedures for obtaining a building permit.
2.14 Determine information that may be required for insurance purposes.

3.Develop System Designs

3.1 Determine the type, size and configuration of a heater.
3.2 Determine associated components such as bake oven, facing options, water coils, heated bench, wing wall, etc.
3.3 Perform heat output calculations.
3.4 Specify footing and foundation and pad requirements including chimney and hearth extensions.

3.5 Determine code requirements for masonry heaters.
3.6 Determine requirements for clearance reduction systems.
3.7 Determine code requirements for chimneys

4. Design Masonry Heaters

4.1 Design a firebox.
4.2 Design heat transfer passages.
4.3 Design access requirements for cleaning internal passages.
4.4 Determine the need for a by-pass damper and/or chimney damper.
4.5 Design and construct a gas slot, if desired.
4.6 Assess the need for an outdoor combustion air supply.
4.7 Design a chimney to code requirements. Assess/determine the merits of masonry vs. metal chimney: cost, interior and exterior aesthetics, clearances.
4.8 Specify the core refractory components and mortars and expansion materials
4.9 Determine the facing material.
4.10 Design the layout of the heater facing material.
4.11 Specify metal components such as doors, lintels and dampers.
4.12 Design and construct a bake oven.
4.13 Design and construct a heated bench.
4.14 Design a capping assembly.
4.15 Allow for thermal expansion.

5. Prepare Job Cost Estimates

5.1 Evaluate material requirements.
5.2 Evaluate labor requirements.
5.3 Compile a list of necessary components.
5.4: Evaluate job site conditions and requirements.
5.5 Research and record prices.
5.6 Determine shipping costs.
5.7 Estimate the time required to complete the work.
5.8 Complete a cost estimate.
5.9 Provide a cost estimate to the client.

6. Review Installation Requirements and Prepare for the Installation

6.1 Interpret installation drawings and specifications.
6.2 Assess installation issues prior to work proceeding.
6.3 Review all installation requirements.
6.4 Obtain local building permits licenses etc.
6.5 Determine other trades are on schedule.
6.6 Gather all necessary components, tools and equipment.
6.7 Load materials, equipment and documentation into the service vehicle.

7. Uncrate and Inspect Components

7.1 Inspect unopened crates carefully and record visible damage.
7.2 Uncrate components carefully to avoid damage and injury.
7.3 Dispose of crate materials safely.
7.4 Compare parts list or packing slip to crate contents.
7.5 Confirm all components meet design specifications.

3.8 Determine access requirements for cleaning of internal passages.
3.9 Interpret manufacturer's instructions for factory-built masonry heaters.
3.10 Prepare clear and accurate sketches

4. Design Masonry Heaters

4.1 Design a firebox.
4.2 Design heat transfer passages.
4.3 Design access requirements for cleaning

16.
Conversion Factors

Multiply this	by this	to get this	Symbol
British thermal unit (Int.)	1055.06	joule	J
Btu per cubic foot	37.2591	kilojoule per metre3	kJ/m3
Btu per cubic foot °F	67.0661	kilojoule per cubic m °C	kJ/(m3°C)
Btu per pound	2.326	kilojoule per kilogram	kJ/kg
Btu per pound °F	4.1868	kilojoule per kg °C	kJ/kg °C
Centimeter	0.39370	inch	inch
Centimeter of water (4°C)	98.06378	pascal	Pa
Cord wood (stacked volume 128ft3)	3.6246	Cubic meter (stacked volume)	m3
Cord wood (solid volume 71-85 ft3)	3.6246	(solid volume 2.0 - 2.4 m3)	m3
Cubic centimeter	0.06102	cubic inch	In.3
Cubic centimeter	0.001	liter	L
Cubic foot	0.028317	cubic meter	m3
Cubic foot	28.31685	liter	L
Cubic foot per hour	28.31685	liter per hour	L/h
Cubic foot per minute	0.4719474	liter per minute	L/min.
Cubic foot per second	0.2831685	Cubic meter per second	m3/s
Cubic foot per second	28.31685	liter per second	L/s
Cubic inch	16.387064	cubic centimeter	cm3
Cubic inch	16387.064	cubic millimeter	mm3
Cubic meter	0.2759	cord	
Cubic meter	1.3080	cubic yard	yd3
Cubic meter	35.3147	cubic foot	ft3
Cubic meter	219.97	gallon	gal
Degree (angle)	0.017453	radian	rad
Degree (temperature)		See end of table	
Foot	0.3048	meter	m
Foot	304.8	millimeter	mm
Foot of water (4°C)	2.98898	kilopascal	kPa
Foot per minute	0.00508	meter per second	m/s
foot per second	0.3048	meter per second	m/s
Gallon (imperial)	4.54609	liter	L
Gallon (US)	3.785412	liter	L

Conversion Factors continued

Multiply this	by this	to get this	Symbol
Gallon per minute	0.075768	liter per second	L/s
Horsepower (boiler)	9.80950	kilowatt	kW
Horsepower (boiler)	33461	British Thermal Unit	Btu
Horsepower (electric)	746	watt	W
Horsepower (electric)	0.746	kilowatt	kW
Horsepower (550 ft lb./s)	0.74569	kilowatt	kW
Horsepower hour	2.68452	megajoule	MJ
Inch	2.54	centimeter	cm
Inch	0.0254	meter	m
Inch	25.4	millimeter	mm
Inch of water (4°C)	0.249	kilopascal	KPa
Joule	0.0009478	British Thermal Unit (international)	Btu
Joule	0.2778×10^{6}	kilowatt hour	kW h
Joule per liter	0.026839	Btu per cubic foot	Btu/ft.^{3}
Kilogram	2.20462	pound	lb. *(or)* #
Kilojoule per cubic meter	0.026839	Btu per cubic foot	Btu/ft.^{3}
Kilojoule per cubic meter	0.004309	btu per gallon	Btu/gal.
Kilojoule per kilogram	0.429923	Btu per pound	Btu/lb.
Kiloliter	35.315	cubic foot	ft.^{3}
Kiloliter	219.969	gallon	gal.
Kilometer	0.621371	mile	mi.
Kilometer per hour	0.277778	meter per second	m/s
Kilopascal	0.2953	inch of mercury(0°C)	—
Kilopascal	4.01474	inch of water(4°C)	—
Kilowatt	1.34048	horsepower (electric)	hp.
Kilowatt hour	3412	British Thermal Unit (international)	Btu
Kilowatt hour	3.6	megajoule	MJ
Liter	0.035315	cubic foot	ft^{3}
Liter	0.219969	gallon	gal
Liter per second	2.11888	cubic foot per minute	ft^{3}/ Mn.
Liter per second	13.1982	gallon per minute	gal/Mn.
Meter	39.370	inch	In.

Conversion Factors continued

Multiply this	by this	to get this	Symbol
Meter	3.28084	foot	ft.
Meter	1.0936	yard	yd.
Mile	1.609344	kilometer	km
Millimeter	0.03937	inch	in.
Ounce-force per square inch	0.430922	kilopascal	kPa
Pint	0.568261	liter	L
Pound	453.59237	gram	g
Pound	0.45359	kilogram	kg
Pound per cubic foot	16.01846	kilogram per cubic meter	kg/m3
Pound per cubic inch	27.67990	gram/cubic centimeter	g/cm3
Pound per cubic inch	27.67990	kilogram per liter	kg/L
Pound per cubic yard	0.593276	kilogram per cubic meter	kg/m3
Pound per hour	0.453592	kilogram per hour	kg/h
Pound-force per square foot	0.04788	kilopascal	kPa
Pound-force per square inch	6.894757	kilopascal	kPa
Quart	1.136522	liter	L
Quart (US)	0.946353	liter	L
Square centimeter	0.1550	square inch	in.2
Square centimeter	0.0001	square meter	m2
Square centimeter	100	square millimeter	mm2
Square foot	0.0929030	square meter	m2
Square inch	6.4516	square centimeter	cm2
Square inch	645.16	square millimeter	mm2
Square meter	10.7639	square foot	ft.2
Square meter	1.19599	square yard	yd.
Square millimeter	0.001	square centimeter	cm2
Square millimeter	0.001550	square inch	in.2
Square yard	0.8361274	square meter	m2
Ton - long (2240 pounds)	1.016046	metric ton	t
Ton - short (2240 pounds)	0.907184	metric ton	t
Watt hour	3.600	kilojoule	kJ
Watt hour	3.412	British Thermal Unit (international)	btu
Watt per square foot	10.76391	watt per square meter	W/m2
Yard	0.9144	meter	m

Temperature Conversions:

- **Celsius to Fahrenheit**

  Degrees Celsius **(°C X 1.8) + 32** = Degrees Fahrenheit

- **Fahrenheit to Celsius**

  Degrees Fahrenheit **(°F - 32) X .555** = Degrees Celsius

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From: Chris Prior MHA President.

To: the Certified Heater Masons 1/30/2019.

Recently adopted changes to the Heater Mason Certification Program

This purpose of this letter is to explain the changes that the board of Directors has just approved.

Overview:

Over the past two years an Education Sub-Committee made up with certified heater masons was given a goal to update, revamp and improve the Heater Mason's Certification Program that was 20 + years old. There have been minor changes to it over the years, but it was time for a major overhaul. Everyone on this committee worked very hard, and put forth an incredible amount of time into this project. I am very proud of the work that was done by them.

The stated goals were:

1. To bring our program in line with other well respected trade certification programs, and to make it as professional as possible, giving the program maximum credibility to regulators and officials.
2. Update and revise the Certification Manual and making it into a Resource Manual, that would be available for purchase by any full voting MHA member.
3. Revise the cost structure.
4. Redo the written test.
5. Revise and replace the Hands-on Test
6. Bring the re-certification and CEU procedures more inline with other professional trade programs

The format of the following changes is as follows:

- The section that was changed will be identified.
- The old language will be displayed in **RED** the effected language will be in **bold and underlined**.
- The new language will be displayed, followed by the reasoning behind the change.

Specific changes and the reasoning behind them:

1. Title of the manual.

    The Heater Mason's Reference Manual title is being changed to The Masonry Heater Reference Manual.

    Reasoning: This revised manual is literally now the "Bible" for masonry heater building information. It is such a valuable document, that it should be made available for purchase by any full voting member, as a member benefit.

    The cost of the new Masonry Heater Reference Manual will be set at $150.

- **An additional section was added to cover the new Certified Heater Mason's Logo:**

As we now have a "**Certified Heater Mason's Logo**", some language needed to be added to the (14. Certification Policies & Procedures) section of the Manual.

Added language, and copy of the Logo:

2.3 Certified Heater Mason Logo.

Any certified heater in good standing is allowed the use of the official Certified Heater Mason logo. Contact MHA Executive Director to receive an electronic high resolution copy of the Certified Heater Mason logo. (rev. 1/19).

Reasoning: With the addition of the new logo, it needed to be added to the pertinent section of the Manual.

- **Revised written test:**

The current written test language:

3. Requirements for Certification

3.3 Examination

(a) The candidate must achieve a passing grade on the MHA examination. **The passing grade is 70 percent**.

(b) The taking of the examination may be administered by the MHA or

(c) The examination may be proctored by an independent agency such as a public library which is deemed acceptable by the administrator. The MHA will pay the proctor for the ser vice. All other costs related to the proctoring of the examination will be paid by the candidate.

(d) **The fee for the administration of the examination is US $100** which must be received by the MHA before administrative arrangements are made.

The changes to the written test.

The test is and will remain as an open book test. It was determined that the current test of 75 questions had a number of questions that either, were not found in the text, or were misleading, or "gotcha" type questions. People that took the current test consistently got these 6 or so questions wrong. There was a time limit of 45 minutes to take the test, and a passing grade was 70%.

With the revisions, and additional content added to the manual, a new written test was compiled. The new test has **101 questions**, and the test questions are taken verbatim from the text of the manual, and follow the manual in consecutive order. With the new test, there is a time limit of **60 minutes** to take the test, and a passing grade was increased to **80%.** It will still be an **open book test**.

The revision to the Requirements for Certification:

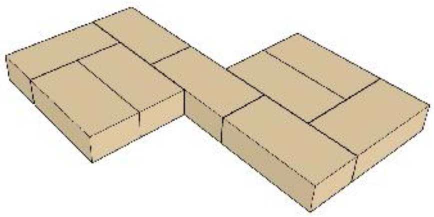
3.3 Examination

(a) The candidate must achieve a passing grade on the MHA examination.
The passing grade is **80 percent**. (rev. 1/19)

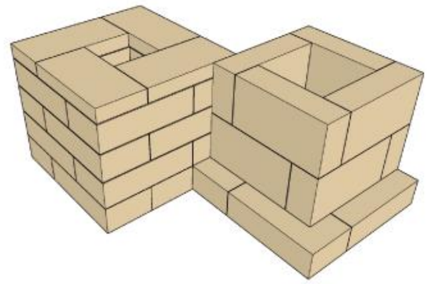
Figure 26.

CAD drawing of the hands-on firebrick setting test (rev. 1/19)

Base



Completed project



Reasoning: The old test did not test to see if a potential candidate possessed the specific skills associated with setting firebrick properly and accurately. This new test accomplishes this. It is also more representative as a key step towards certification for our specific industry, thus giving the certification program even more stature and credibility.

J Maintaining certification:

The current requirement

4. Maintaining MHA Certification

4.2 Continuing Education Requirement

Within each **five-year period** after certification, the certificate holder must accrue MHA continuing education workshop points, or other relevant professional credentials deemed equivalent by the MHA. Points accrued must be a minimum of **3 to 5 each year or 30 or more for the five-year period**. Continued Education Credits are awarded by the following: (Rev. 3/12)

The new requirement:

4. Maintaining MHA Certification

4.2 Continuing Education Requirement

Within each **three year period** after certification, the certificate holder must accrue MHA continuing education workshop points, or other relevant professional credentials deemed equivalent by the MHA. Points accrued must be a minimum of 8 to 9 each year or **25** or more for the **three year period**. (rev. 1/19)

In any **3 year period**, **CEU's** that are accumulated beyond the number needed to re-certify **do not carryover** to be used in the following **3 year period.** (rev. 1/19)

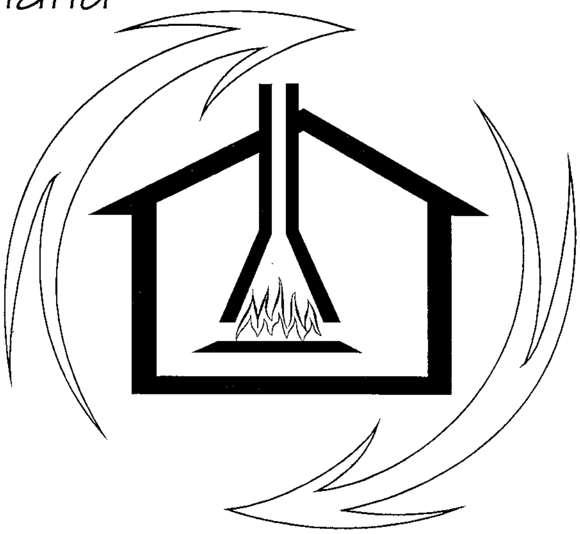
Reasoning: Research was done examining other industry trade association certification programs. The norm for a certification renewal term is three years. By changing to a three year term from our current five year term, this aligns our program with most other professional trade associations certification programs. The intent of this change is to raise the stature, credibility and professionalism of the Heater Mason's Certification Program. It will also make the program more efficient and less burdensome for both the administration of tracking the participants CEU accumulation, and for the members to accumulate and track their own CEU credits.

NOTES

The Fireplace in the house as a system

Heater Mason's Reference Manual edition

by John Gulland



The Fireplace in the House as a System
Heater Mason's Reference Manual edition

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Fax: (613) 757-0277
E-mail: john@gulland.ca
Internet: http://www.gulland.ca

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Contents

Preface

Snow hangs in the Spruce trees outside my third floor office window. Down on the main floor is the fireplace responsible for keeping this eight year old country home and office warm and comfortable, even when the wind howls and the temperature falls to minus thirty. The smell of wood smoke is not permitted in this house and the fireplace complies. It also delivers about seventy percent efficiency, keeping our wood consumption down to a reasonable three full cords each year. And it is beautiful in the bargain. I can't complain.

I don't mention this just to brag about the fireplace, but to point out that perfection is possible. And even better, it is predictable — I knew before the house was built that the fireplace would work perfectly. Twenty years in the hearth industry and exposure to the best housing researchers and their findings has taught me that when the design is right, the fireplace will work. At the time this house was built, some of the research was still going on; new ideas were just emerging and barely digested. Since then the theories have been confirmed through field testing and experience.

Starting fifty years ago or more, North American housing evolved to move the hearth from the central area — the heart of the home — to an outside wall and even put the back of the fireplace outside the wall in a chase. So began an unhappy chapter in the life story of fireplaces. To provide a straightforward explanation of the pervasive problems caused by outside chimneys (and fireplaces in outside chases) is one good reason why this book was needed.

Technological change created the need for this book. Over the past twenty years house construction has changed in response to buyer demands for greater comfort and lower energy costs. Sealed doors and windows, more insulation and near-continuous air barriers have made houses far more air tight and easier to heat than in the past. During the same period a remarkable transformation of woodburning technology took place. The amount of smoke emitted by a wood heater has been cut by up to ninety per cent while efficiencies have almost doubled. Meanwhile, all the old woodburning fireplace technologies remain, and that, as you will find in this book, is one of the problems.

This book is not about fire safety or the aesthetics of fireplaces. It deals with a neglected subject: how to make sure your fireplace gives comfort and satisfaction by working properly, not smoking and not annoying. A fireplace that misbehaves can be an endless source of frustration and embarrassment, but a great fireplace gives continuous pleasure. Read on and you will find out how to achieve fireplace perfection.

Whether your reason for picking up this book is personal or professional, I hope you find what you seek. And I wish you the warmth of a natural hearth.

John Gulland
January 1997

Introduction

People love fireplaces. Whenever potential home buyers are asked what features they would most like to have in their new home, a fireplace always figures prominently on their wish list. This is surprising, really, since fireplaces are so often a source of disappointment and annoyance to householders. The fireplaces in new homes disappoint by putting out less heat than expected; they annoy by spilling exhaust gases into the room when operating and spilling cold air and foul odors when they're not. Frustration with badly designed woodburning fireplaces could be one reason for the growing dominance of gas fireplaces in the hearth products market.

The other thing about fireplaces that breeds frustration is that everybody is an expert, but nobody seems to have the answers. Every bricklayer who has built one and every chimney sweep who has cleaned one have strong opinions as to what makes for a successful fireplace. And strong views are not limited to the professionals; just about anyone who has ever built a fire is happy to share their pet theory of fireplace function. If opinions counted for anything, all fireplaces would work perfectly.

The housing research of the 1970s and 1980s yielded the principle of the house as a system which suggests that the house functions as a system rather than as a number of unrelated parts and that its various subsystems, particularly those that move or contain air, behave in an interactive way. What a concept! It has become a corner stone of residential building science and it provided the enthusiasm to support further research. The house as a system principle forces us to look a the consequences of the equipment, material and installation decisions made in the process of house design and construction. It means, for example, that we must acknowledge when the specifications for a new house call for a woodburning fireplace and a downdraft kitchen range exhaust, that steps must be taken to ensure that these two devices will function in harmony. It also recognizes that wind, temperature and other environmental conditions influence the performance of the house and its components and so should be considered.

Laboratory and field research conducted in the 1980s on combustion venting, most notably by and for Canada Mortgage and Housing Corporation, began to shed light on how fireplaces interact with the house at a systems level. This research, combined with the insights of North America's most experienced and thoughtful hearth and housing specialists, produced a rich mixture of ideas that eventually gelled into the contents of this book. This is what the fireplace business has lacked all this time: an integrated theory of fireplace function supported by scientific fact.

A fireplace is literally the place within a house where a fire can be burned for heat and enjoyment. The enjoyment part mostly comes from viewing the fire as it burns. This simple definition, then, would include wood stoves and pellet burning appliances, most of which now include glass doors. No functional distinction will be made here between fireplaces and space heating stoves, so the system design and performance issues covered in the following pages apply equally to both.

Hearth products, the broad term that includes the appliances, venting systems and accessories that are combined to provide the visible fire in the home, are now available in bewildering variety. Aside from the fuel they burn, hearth appliances also vary in the way exhaust gases are vented to outdoors and these differences are the most significant for the behavior of the hearth in the house environment. To help in the analysis and discussion of the myriad types of hearth systems, here are five classifications based on venting strategy.

- **Chimney Vented.** This class includes masonry or factory-built woodburning fireplaces and heaters and is the primary emphasis in this book.

- **Vertically Vented Gas.** Included here are atmospheric gas and propane fireplaces, inserts and stoves with dilution device, usually a draft hood. Several of the principles covered in this book apply to this class.

- **Forced Draft, Low Temperature Vent.** Pellet stoves and fireplace inserts that may be vented vertically or horizontally (under favorable conditions) through pellet vent are in this class. A separate section of the book is devoted to pellet venting.

- **Sealed Combustion.** This includes direct vent gas and propane fireplaces and stoves with concentric exhaust and combustion air supply. It also includes fireplace inserts with non-concentric exhaust and air supply, both routed vertically through the original fireplace chimney. Direct vent appliances are, at least in theory, immune to many of the influences that cause chimney venting to fail. They are the right alternative for people who do not highly value the natural wood fire, but wish to incorporate a hearth in the home. Many people in urban areas will continue to choose sealed combustion hearths. Because the air supply and exhaust of these fireplaces flow independently of the house in which they are installed, this class of appliance is not covered in this book.

- **Unvented.** Unvented, or so-called vent-free, fireplaces and heaters are not discussed at all here. The reason is simple: their operational characteristics are incompatible with the house as a system principle. The idea of releasing the exhaust products from combustion equipment into the living space is a bad one. In fact, the evidence is mounting that gas and propane cooking ranges, which have long been used and favored by cooks, are not such a good idea either. Housing technologists now strongly recommend that homeowners operate a kitchen exhaust system while a gas range is used to prevent the build up of carbon monoxide and other air pollutants. Unvented fireplaces pollute the indoor air; on that point there can be no argument, although their makers say it is not enough to be concerned about. Nevertheless, anyone even slightly concerned about the quality of their indoor air should avoid unvented gas appliances.

If it is to be a valuable addition to a home, a fireplace should operate easily, make heat and never smoke or smell. The householder should never have to worry that the fireplace might act up. Fireplace perfection is possible and you will find the formula as you read on.

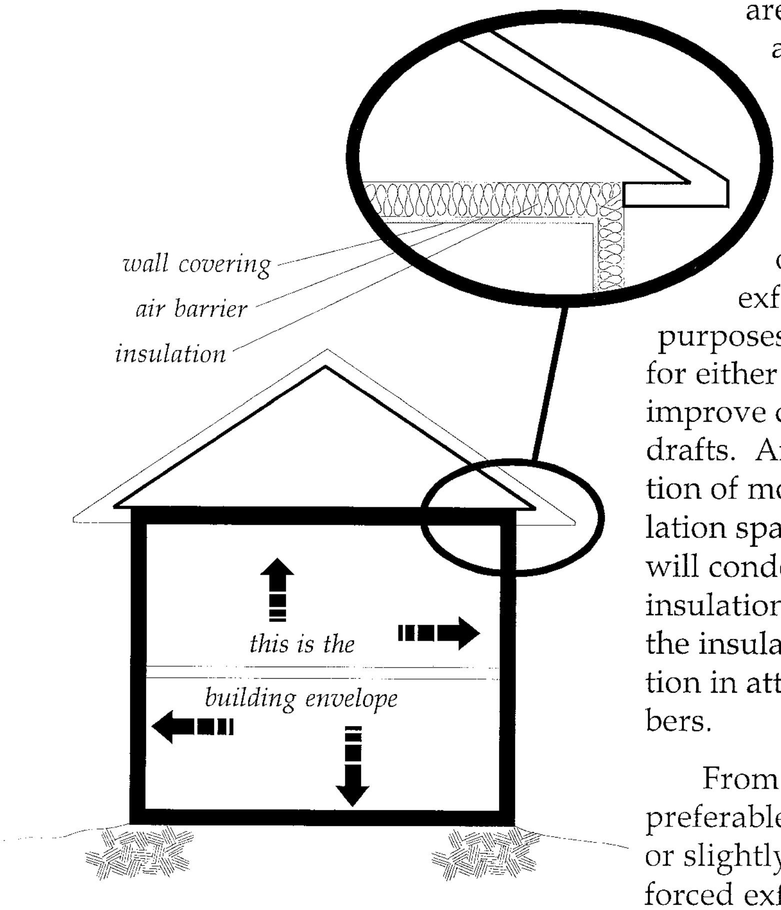
The purpose of this book is to support homeowners, builders, architects and hearth specialists who want to make sure that their fireplaces will function perfectly in the homes being built today.

Building envelope basics

The envelope of a building encloses the living space, including the basement, and isolates the interior of the building from the heat or cold, and wind outside. Uninsulated attics or crawl spaces are not considered to be within the building envelope.

In normal wood frame construction, the envelope consists of the lumber frame with insulation, usually fiberglass, placed between framing members. The insulation is intended to reduce conductive heat loss or gain through the envelope.

An air barrier covers the frame and insulation on the inside to reduce air leakage into and out of the envelope. The air barrier in warm to moderate climate zones is often formed by the wall covering such as drywall. In colder zones, a polyethelene sheet is normally installed behind the wall covering to further reduce air leakage. In tight home construction the joints in the air barrier are caulked to seal them, as are all joints at windows and doors. All penetrations of the air barrier, such as electrical outlets and fixtures, are carefully sealed to the air barrier.

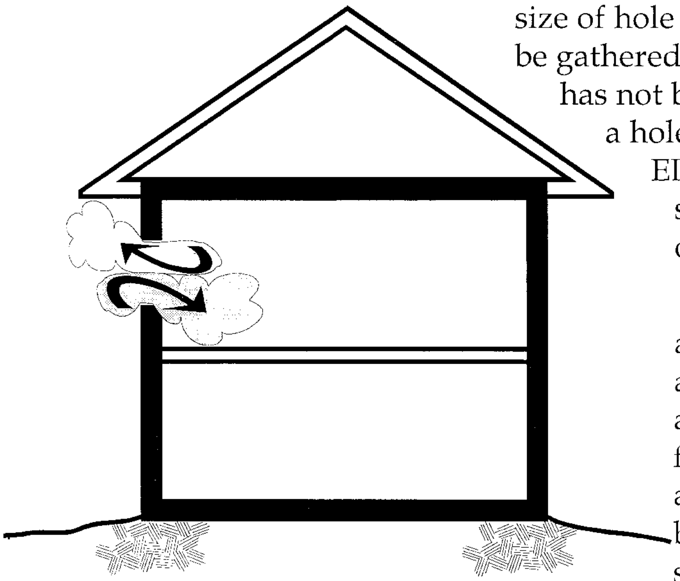


The building envelope is shown here and in the other illustrations in this book as a thick, dark line, because its relationship with the fireplace and chimney system is important, as you will soon discover.

The reduction of air leakage into or out of the building (infiltration and exfiltration respectively) has three main purposes. The first is to reduce energy costs for either heating or cooling. The second is to improve comfort in winter by reducing cold drafts. And the third is to prevent the migration of moisture-laden indoor air into the insulation space, where in winter, the water vapor will condense and become trapped in the insulation. This trapped moisture can damage the insulation and lead to structural deterioration in attics by initiating rot in wooden members.

From a building science perspective, it is preferable for the house pressure to be neutral or slightly negative in order to reduce the forced exfiltration of moist air into wall and ceiling insulation. The practice of pressurizing the house, even though it might assist in reliable chimney venting, is strongly discouraged by building scientists. For this reason, the pressurization of houses is not recommended here except in special circumstances and for short periods.

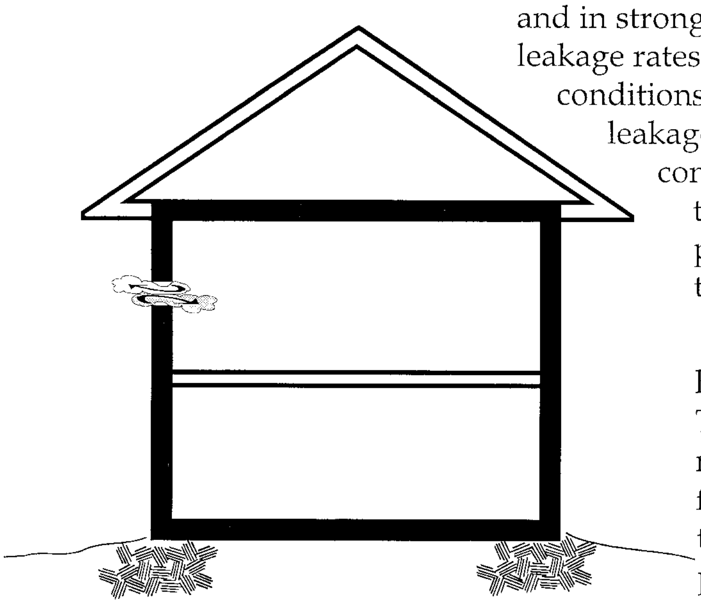
All building envelopes have leaks, but the range in the leakage rates of the existing housing stock is very wide. Leakage rate of a building is often expressed in terms of its equivalent leakage area or ELA which is the size of hole you would get if all the leaks in a house could be gathered together in one place. A large old house that has not been weatherized might have an ELA equal to a hole three feet in diameter. By comparison, the ELA of a modern house built with energy conservation in mind might be equal to a hole only seven inches across.



The ELA of a leaky old house can be equivalent to a hole 3 feet in diameter.

A large house will have a larger ELA than a smaller house built using similar methods and materials because of its larger surface area. A house with a complicated shape and features such as roof dormers is likely to have a larger ELA than a simple, box-shaped house because it is more difficult to seal. Therefore, small houses of simple design can be "tight" without the builder or owner being aware of it.

The leakage rate of buildings is often expressed in terms of air changes per hour (ACH) refers to the number of times in an hour that all of the air in a building is replaced with outdoor air. In winter and in strong winds old unweatherized houses can have leakage rates of up to 6 ACH. Under the same weather conditions, a very tight house may have a natural leakage rate of only 0.1 ACH. Building scientists consider 0.35, or about one-third ACH, to be the minimum ventilation rate necessary to provide fresh air for healthy living and for the control of moisture and odors.



The ELA of a modern energy conserving house can be equivalent to a hole only 7 inches in diameter.

Most tightly-constructed new homes have a natural ACH rate that is below 0.35. The difference between the natural ACH in new houses and 0.35 ACH creates the need for mechanical ventilation systems. Some of these systems cause continuous house depressurization, which causes problems for combustion systems vented by natural draft.

The most obvious indicator of house tightness in winter is indoor humidity. The water vapor produced by breathing, washing and cooking builds up to high levels in a tight house with inadequate ventilation and reveals itself as condensation of moisture on cold windows. Leaky houses, in contrast, tend to have low humidity in winter because the moisture created in the house is flushed out rapidly by the high infiltration rate of the cold, dry outside air.

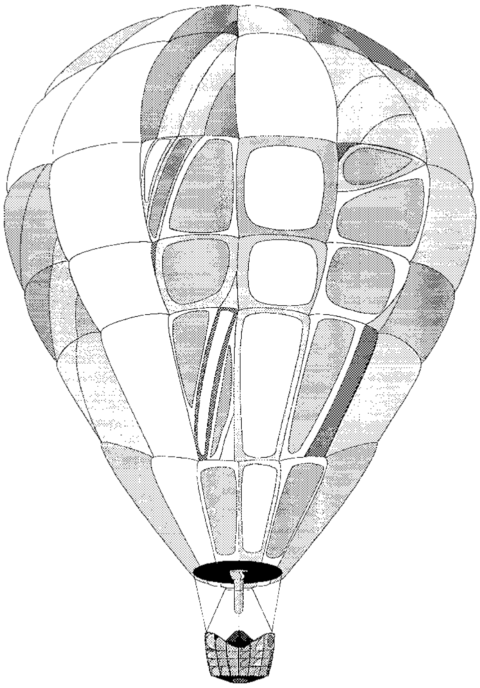
Builders in mild climate zones give less attention to air sealing of houses because heating costs are lower and leakage does not cause discomfort to the inhabitants. However, sometimes houses are built tight by accident when certain building materials are used. For example, if a builder uses high-quality doors and windows with gaskets, and the exterior is done in stucco or some other continuous surface, the house could end up being fairly tight without anyone involved being aware of it. If you live in a mild climate zone, you may encounter cases in which the tightness of the building envelope is a factor in the failure of a chimney vented system. And later on you will also learn that a leaky envelope is no guarantee of successful chimney venting.

Summary

- building envelopes are being constructed more tightly to increase comfort, to reduce energy consumption and air exfiltration to structural components
- pressurizing buildings is not considered to be good building science
- there is a wide range in leakage rate among the existing housing stock
- the natural leakage rate of tight houses is not sufficient for healthy living, which creates the need for mechanical ventilation systems
- condensation of moisture on windows in winter is the most obvious sign that a house is tight enough to need mechanical ventilation

8

Temperature difference



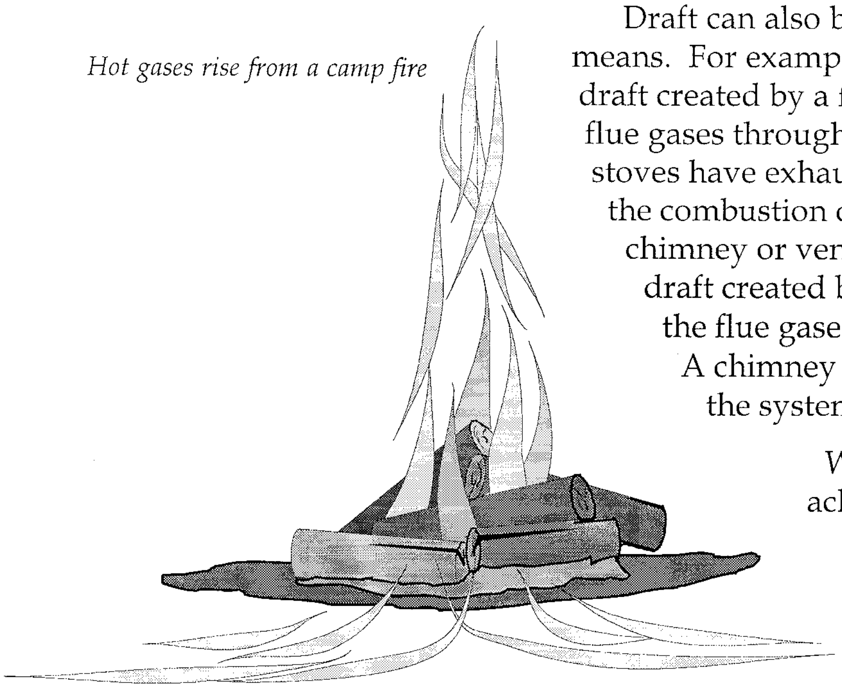
A balloon rises off the ground because of the buoyancy of hot air

Everyone knows that hot air rises. The behavior of a hot air balloon or the pattern of air and gas flow around a camp fire illustrate this natural law. Hot air rises because air expands when heated, becoming lighter or more buoyant than the cooler surrounding air. The tendency of hot air to rise is central to our discussion because it produces both natural draft in chimneys and stack effect in houses.

Draft is the pressure difference that is available to drive the flow of air and/or combustion gases through an appliance and its venting system. All combustion systems that are vented by natural chimney draft depend on the temperature difference that is maintained between the gases in the flue and the outdoor air for proper operation. The greater the temperature difference, the more draft is produced. If the temperature difference is not adequate, such as for example when a smoldering fire produces low flue gas temperature, the upward flow in the chimney becomes weak and unstable, and smoking can result.

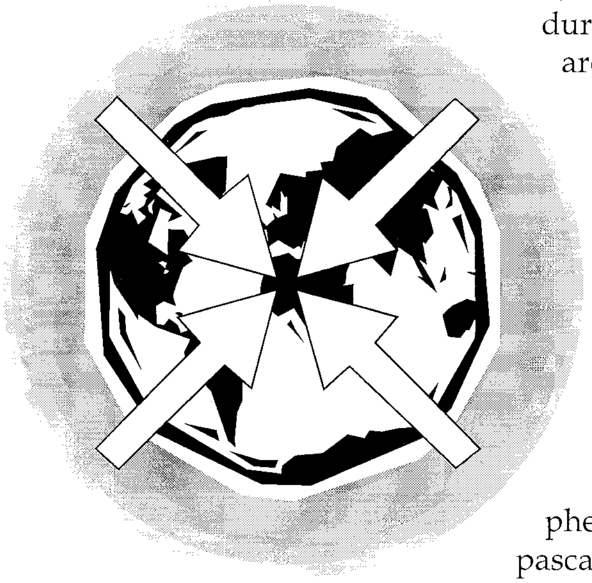
Conversely, very large temperature differences produce high draft levels. High draft can cause rapid deterioration of the internal components of fireplaces or wood stoves because of the higher temperatures that result from overfiring. Ideally, the chimney-to-outdoor temperature difference and the resulting draft should fall between the low levels that can lead to smoking and the high levels that waste energy and can lead to appliance damage.

Hot gases rise from a camp fire



Draft can also be developed by mechanical means. For example, *forced draft* is mechanical draft created by a fan located so that it pushes the flue gases through the chimney. Most pellet stoves have exhaust fans that draw gases out of the combustion chamber and force them into the chimney or vent. *Induced draft* is mechanical draft created by a fan located so that it pulls the flue gases through the chimney or vent. A chimney top exhaust fan induces draft in the system.

We will concentrate on here on achieving reliable venting by natural chimney draft. The other forms of draft, those developed by mechanical means such as forced draft and induced draft, are less affected by external influences. Note, however, that successful chimney venting is essential, not just when the appliance is operating, but also during standby periods when mechanical draft systems are inactive.

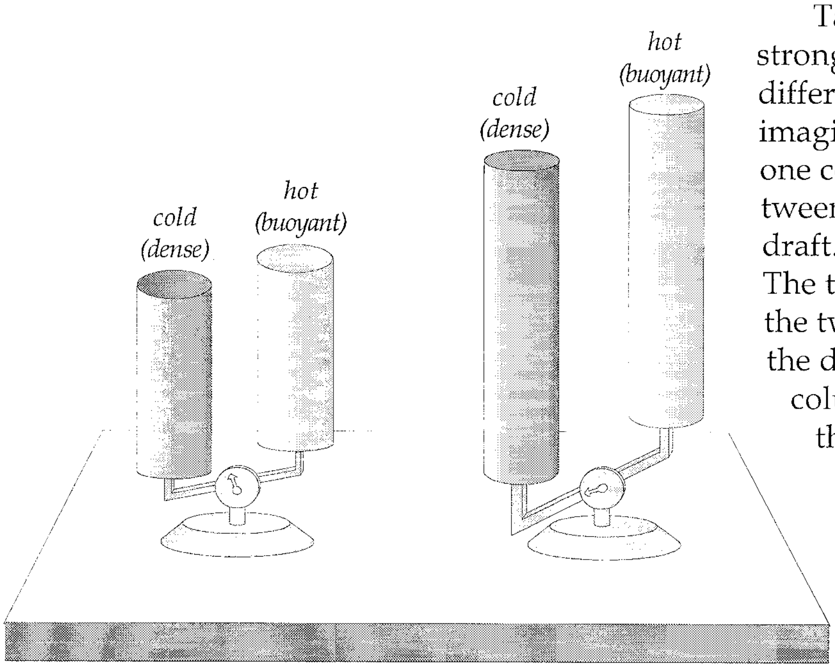


The weight of the blanket of air surrounding the earth produces an atmospheric pressure of around 100,000 Pa. By comparison, what we think of as strong chimney draft at only 50 Pa is a relatively weak force.

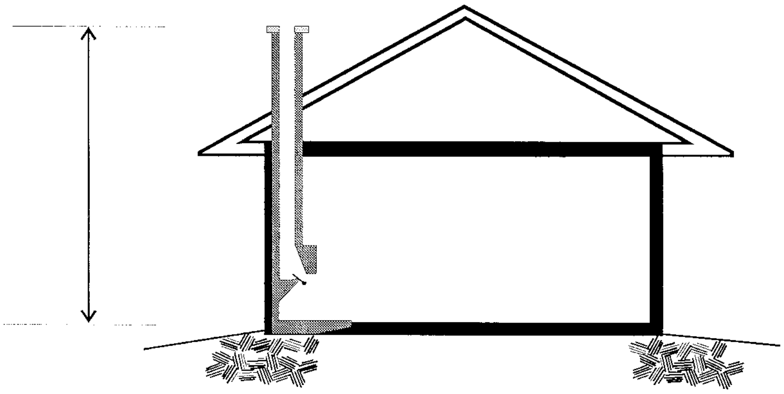
Natural chimney draft is a weak force. To put its relative strength into context, it is necessary to understand how draft occurs. Atmospheric pressure is created by the weight of the blanket of air surrounding the earth. An operating chimney represents a column of gas that is hotter, less dense and therefore lighter than the surrounding air. Draft is the difference between the pressure at the base of the chimney and atmospheric pressure.

Subject to the elevation above sea level, atmospheric pressure is about 100 kilopascals, or 100,000 pascals. High draft developed by a residential chimney full of very hot gases is only about 50 Pa, or 1/2000 of atmospheric pressure. Here is another example: when you are swimming and your ear goes four inches under the surface of the water, your ear drum is exposed to about 1000 Pa of pressure.

Taller chimneys usually produce stronger draft at a given temperature difference. To visualize why this is so, imagine two columns of air, one hot and one cold. The difference in weight between the hot and cold columns is the draft. Now make both columns taller. The total difference in weight between the two taller columns is greater than the difference in weight of the shorter columns. The taller the chimney, therefore, the more draft it will produce at a given temperature difference.



Taller chimneys produce more draft because the total weight difference between the taller columns of hot and cold air is greater than the weight difference between the shorter columns.



For adequate draft, this distance should be at least 15 feet.

A rule of thumb suggests that the minimum system height (from hearth to chimney top) should exceed 15 feet in order for it to provide adequate draft. A system installed in a bungalow with a shallow-pitch roof can be less than this height. When diagnosing venting problems, consider total system height as a possible factor.

In practice, increasing the height of an existing chimney may not result in increased draft because the extra length tends to result in greater heat loss. Taller chimneys only produce more draft if temperature difference remains nearly constant.

The reliability of venting through a chimney operating on natural draft is mainly dependent on the temperature difference between the gases in the flue and the outdoor air. There are several other factors that influence chimney venting, but keep in mind that the ability of a chimney to maintain temperature difference establishes its tolerance to the potentially adverse effects of the other factors.

PRESSURE MEASUREMENT IN PASCALS

Pascal (Pa) is the metric unit of measurement for pressures. One Pa equals 0.004 inches of water column (wc). We will use pascals in our discussion of pressures. A single pascal is a very small amount of pressure; a single sheet of paper exerts a pressure of about one pascal on a surface. A good way to learn about the pascal pressure measurement is to relate it to the strength of chimney draft, as follows:

5 Pa equals 0.02"wc
This is lousy draft for a wood fire. At 5 Pa of draft, a wood fire will be almost impossible to kindle and a stove or fireplace will spill smoke when you open the door. On the other hand, this is about the right amount of draft for a gas or oil flame; draft hoods and draft regulators are used to maintain this level.

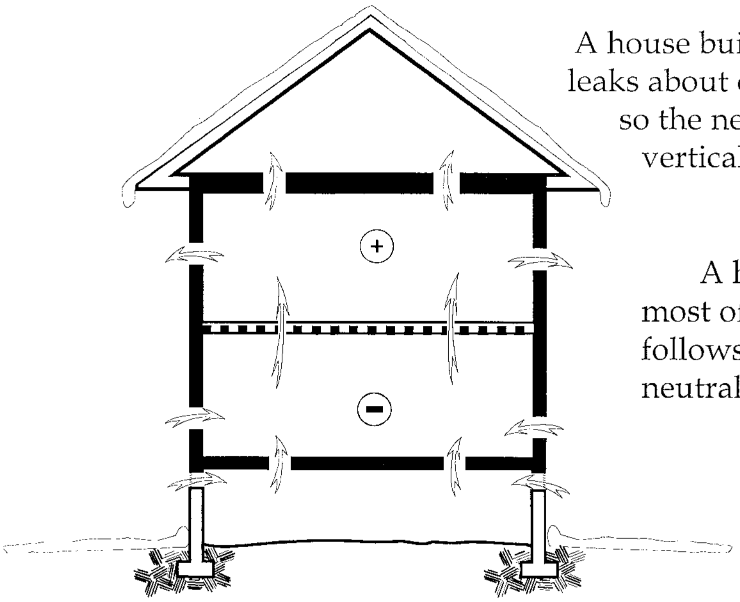
12 Pa equals 0.05"wc
This is minimum draft for reasonable operation. A wood stove or fireplace operating on a draft of 12 Pa will probably spill smoke when the door is opened, but it will burn reasonably well when the door is closed.

25 Pa equals 0.1"wc
This is good draft. A wood stove or fireplace operating on 25 Pa draft will produce a bright hot fire and will probably not spill smoke when the door is opened if the appliance is of good design.

__Stack effect__ is the pressure difference created in a building by the temperature difference between the air inside and the outdoor air.

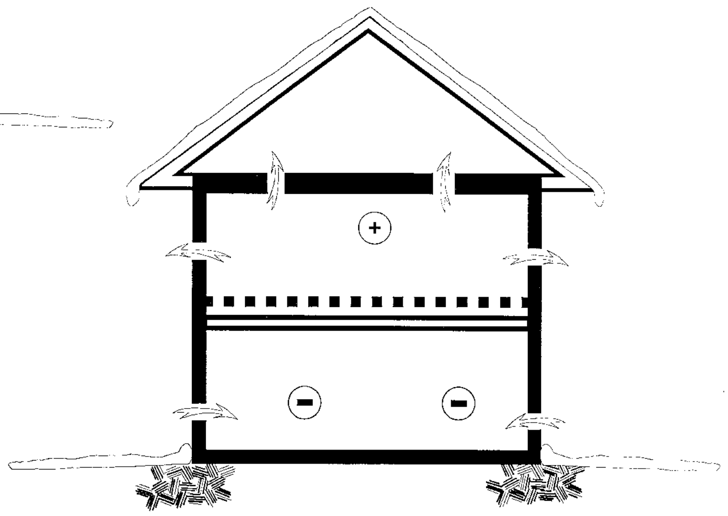
Stack effect creates a pressure greater than atmospheric pressure at high levels of the house and a pressure lower than atmospheric pressure at low levels of the house. As is the case with draft in chimneys, the greater the temperature difference, the more stack effect is produced; the taller the building, the more powerful is the stack effect. If the leaks in the building envelope were evenly distributed, the neutral pressure plane would be at the vertical midpoint of the building.

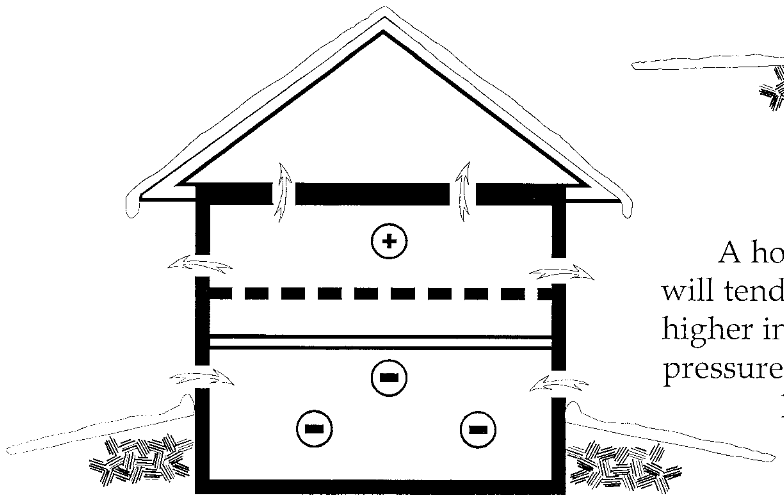
***The neutral pressure plane (NPP)** is the level between the high pressure zone at upper levels and the low pressure at lower levels in a house at which the pressure is equal to atmospheric pressure.*



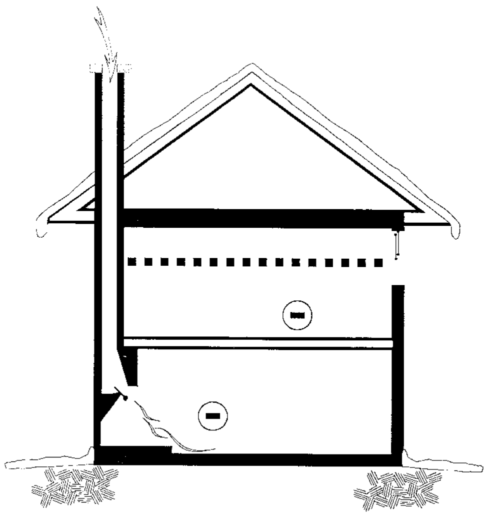
A house built over a vented crawl space may have leaks about evenly distributed around the envelope, so the neutral pressure plane can be at about the vertical midpoint, like the one to the left.

A house built on a concrete slab will have most of its leaks higher, and, because the NPP follows the leaks, will tend to have a higher neutral pressure plane, like the one below.





A house built with a basement below grade will tend to have most of its leaks concentrated higher in the heated space and so its neutral pressure plane will usually be significantly higher than the vertical midpoint, as in the example to the left.



An open window is like a very large leak, and since the NPP follows the leaks, it will move to its level. In some cases an open upstairs window can change the house pressure enough to backdraft a fireplace located low in the house.

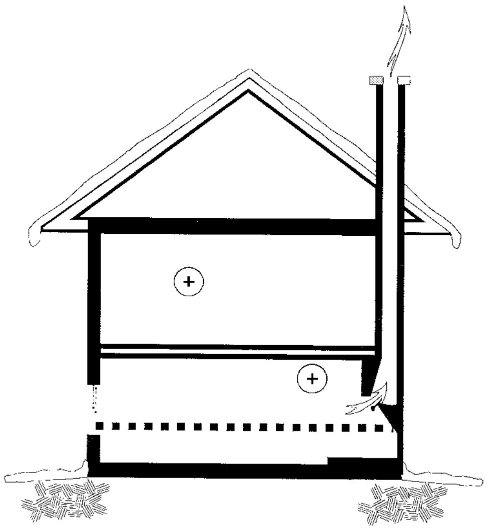
In practice, the majority of leaks in most houses are above the vertical midpoint. Since the neutral pressure plane follows the leaks, it is normally higher in the building than the midpoint.

The fact that the neutral pressure plane follows the leaks is significant. When an upstairs window is opened (in effect, a very large leak), it causes the NPP to rise to its level. This creates a greater level of negative pressure low in the house, and in extreme cases, can cause spillage or backdrafting in a basement fireplace.

When a basement window is opened, the NPP goes down to its level, reducing the negative pressure there. The lowering of the NPP is the reason that the flow in backdrafting chimney serving a fireplace located low in the house can be corrected by opening the nearest window.

Stack effect is produced by temperature difference and is not significantly influenced by the leakiness of the house envelope. At a given outdoor temperature in winter, a pressure difference is created from bottom to top of all houses, but a greater volume of air flows into and out of a leaky house than a tight house.

Weatherizing older houses by installing new windows and caulking leaks often has the effect of raising the neutral pressure plane. This occurs because the most noticeable leaks are those low in the building where cold air leaks in. These leaks are considered the highest priority for weatherizing because they directly affect comfort. Leaks high in the house where air flows out are not noticed by the householder and so they tend to be dealt with last. Since the NPP follows the leaks, it rises toward the majority of the leaks high in the house when lower leaks are sealed. This explains why weatherizing procedures can lead to venting failure, particularly of appliances located low in the house.



When a fireplace is cold backdrafting the flow direction can be reversed by opening a nearby window, thus neutralizing the normally negative pressure low in the house.

Temperature difference, stack height and pressure difference

Table 1 below shows how temperature difference and stack height affect pressure. The numbers in the middle are the pascals of pressure difference created by various stack heights at various temperature differences. Using the table, if difference between the average flue gas temperature and the outdoor temperature is 400°F in a 25 foot chimney, the draft would be 44 Pa. Or, if the outdoor temperature is 20°F (producing a 50°F temperature difference), the stack effect in a house with a total envelope height of 20 feet would be 7 Pa.

Pressure in pascales for various stack heights and temperature differences

Average temperature difference °F (°C) \ Height of stack in feet (metres)	10 (3)	15 (4.6)	20 (6.2)	25 (7.7)	30 (9.2)	35 (10.8)	40 (12.3)
1000 (555)	26	39	52	65	78	92	105
800 (444)	24	36	48	60	73	85	97
600 (333)	21	32	43	54	64	75	86
400 (222)	18	26	35	44	52	61	70
200 (111)	11	17	23	28	34	39	45
100 (56)	7	10	13	16	20	23	26
50 (28)	4	5	7	9	11	13	14
20 (11)	2	2	3	4	5	5	6

Note: this is the average temperature between the gas in the stack and the outside air; it is not a conversion.

The figures in the table are calculated projections of total draft. If you were to measure the temperature in a chimney of known height, then measure the draft using a manometer, you would see a pressure considerably lower than the figure in the table. There are at least three reasons for this. First and most important, the temperature difference figures on the vertical axis of the table are based on the average temperature in the stack, less the outdoor temperature. Your thermometer is measuring the gas temperature at the base of the chimney, which can be hundreds of degrees higher than the exit temperature at the top of the chimney, particularly if the chimney is air-cooled and/or runs outside the building envelope. The second reason for a lower measured pressure is that this table does not account for friction losses in a chimney. And thirdly, your manometer probe is measuring only static pressure. Without more equipment, the manometer will not read the velocity pressure in the stack, a factor which is added to static pressure.

The table is presented as an aid to visualizing the relationships involved in chimney draft and stack effect in buildings. You can consider the lower part of the table as referring to stack effect in houses or the draft developed in a chimney at standby. In fact, you might find that the lower part of the table more closely matches actual measurements of stack effect because the indoor temperature will be consistent throughout the house.

Summary

- natural chimney draft and stack effect in houses are both caused by temperature difference
- the greater the temperature difference, the stronger the draft or stack effect
- the taller the house, the more stack effect is produced; the taller the chimney, the more draft is produced, subject to heat loss from the outdoor portion of the chimney
- the neutral pressure plane follows the leaks
- stack effect is not significantly affected by the leakiness of the building envelope
- the greater the stack effect, the greater the air flow through leaks in the building envelope
- weatherizing of houses can affect chimney venting by causing the neutral pressure plane to rise
- temperature difference is the key factor in successful venting by natural chimney draft

The cold hearth syndrome

A common complaint of fireplace owners is that cold air and odors leak from the fireplace when it is not in use, a problem referred to here as the cold hearth syndrome. The causes of this problem and its solutions reveal some of the basic physics of chimneys.

A chimney is a vertical shaft enclosing at least one flue for conducting air and/or flue gases to the outdoors. When it is operating, the chimney flue contains air or gas that is warmer than the outdoor air. Because of its buoyancy, the warm air or gas rises, creating the desired upward flow in the chimney. This describes the proper function of a chimney.

There are cases in which the house performs better as a chimney than the chimney. The main evidence of this condition occurs when there is no fire in the appliance (standby mode) and cold air flows down the chimney, into the appliance and onto the hearth. There are two distinct causes of this problem.

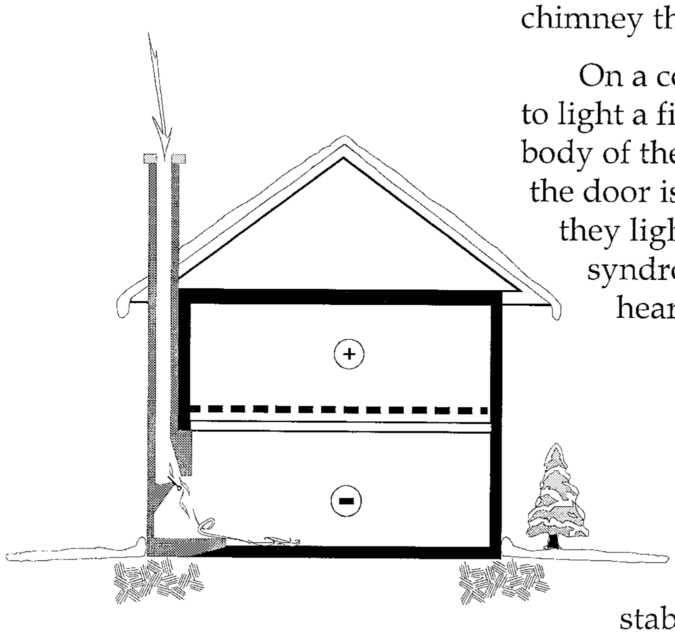
Cause #1: outside chimney and appliance low in the house

The first and most common cause of the cold hearth syndrome occurs when the appliance is located below the neutral pressure plane of the house AND is served by a chimney that runs up outside the house envelope.

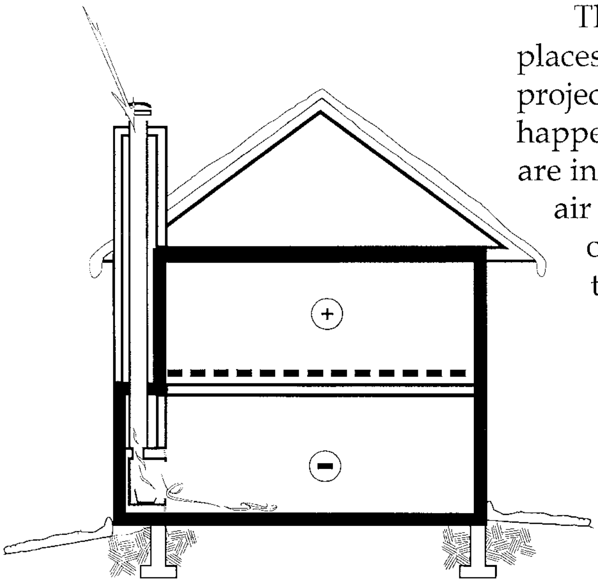
On a cold day when the homeowner goes downstairs to light a fire, he or she might notice that the door and body of the fireplace or stove are cold to the touch. When the door is opened to light a fire, cold air flows out. If they light a fire, the smoke flows into the room. The syndrome also reveals itself by the presence of stale hearth odors in the room.

Here's what is happening: When an outside chimney is at standby, the air inside can easily cool to below room temperature. Since draft is dependent on a temperature difference, less draft is produced.

The house, on the other hand, is at a stable temperature from top to bottom. Because the appliance is located below the neutral pressure plane of the house, it is exposed to slight negative pressure, enough to pull the cold air down the chimney. This is a classic example of the house being a better chimney than the chimney.



Note that the back of the fireplace and its chimney project out beyond the building envelope. When it is cold outside and there is no fire in the fireplace, negative pressure low in the house can draw air down the chimney and onto the hearth



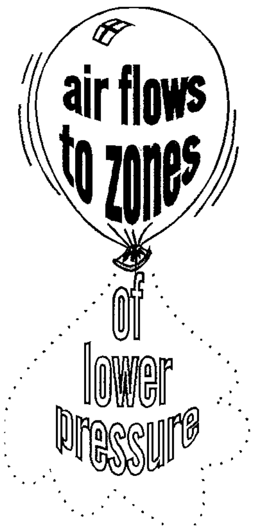
The cross-section above shows that only the lower part of the chase is insulated and sealed. The upper part of the chase is just a framed and sheathed shell. During cold weather, the average temperature in the chimney at standby can easily be at a lower temperature than the house.

The cold hearth syndrome occurs with masonry fireplaces and chimneys that share and outside wall or project out beyond an outside wall (previous page) It also happens to a factory-built fireplace and its chimney that are installed in an external chase (left). In both cases, the air in the chimney is inadequately isolated from the outside cold and its average temperature falls below that of the house.

External chases are usually insulated only at the back and sides of the fireplace, extending to ceiling level of the room in which the fireplace is located. It is also common for these chases to be fairly leaky. This combination of low insulation over much of its height, combined with the leakage of cold outside air into the chase, allows the average temperature of the air in the chimney to fall below that of the air in the house. If the appliance is also located below the neutral pressure plane, the cold hearth syndrome will occur.

Falling Air?

It is often said that cold air leaks from a fireplace simply because cold air is heavy and falls down the chimney. But, this is a misinterpretation of the physics at work in chimneys. While is true that cold air is heavier than warm air, it is does not fall down the chimney. Instead, it is drawn down the chimney towards the zone of lower pressure low in the house. Air flows down the chimney because air always flows to zones of lower pressure, not because cold air is heavy.



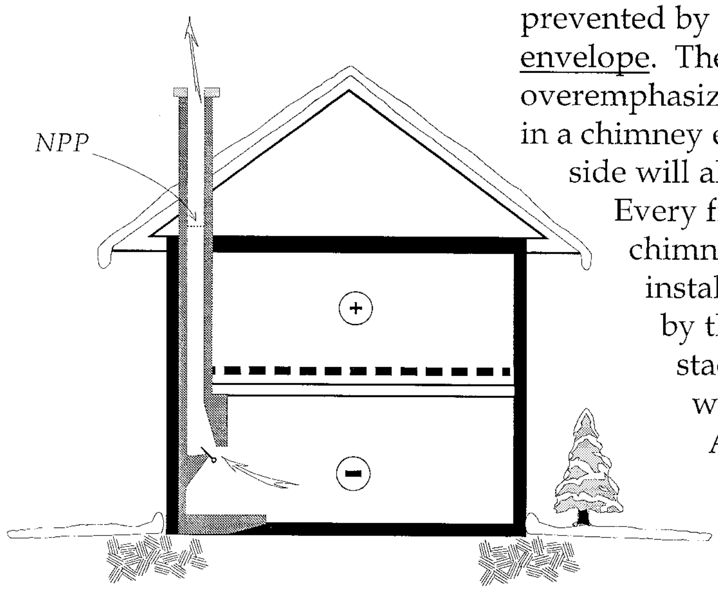
Backdraft: when the upward flow in a chimney fully reverses and 100% of the combustion gases from the appliance (if it is firing) and air in the chimney flow into the building.

(combustion) Spillage: when some of the products of combustion are released into the building.

The cold hearth syndrome also occurs in furnaces and water heaters located in basement utility rooms and served by outside chimneys, although it would properly be referred to as a *cold backdraft at standby*. This backdraft produces cold air spillage from gas appliance draft hoods or oil appliance barometric draft controls. The resulting pooling of cold air on the basement floor is often mistakenly attributed to a leaky building envelope.

Once the backdraft starts, it becomes stable and is difficult to reverse because the chimney is further cooled by the outdoor air flowing down through it. The stability of the cold backdraft is the reason it is so difficult to light a fire in a fireplace suffering the cold hearth syndrome without smoke spillage into the room. Vertically vented gas-fired appliances that have draft hoods are often unable to overcome the backdraft when they fire and may spill their exhaust into the house for the entire combustion cycle.

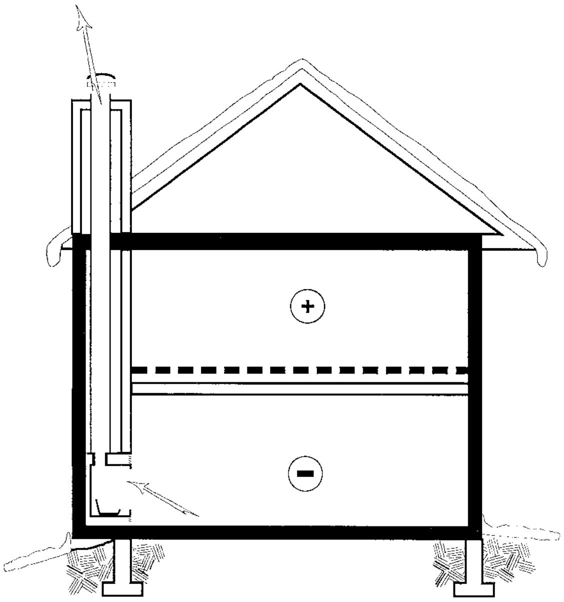
Solution #1: inside chimney



Note that the fireplace and chimney are enclosed within the house and that the chimney has a higher NPP. A chimney that is inside the building envelope will always vent more reliably than an outside chimney because, even at standby, there is always enough temperature difference to create upward flow.

The first cause of the cold hearth syndrome can be prevented by installing chimneys only within the building envelope. The importance of this principle cannot be overemphasized. The chilling of the air and/or flue gases in a chimney exposed over much of its length to the outside will almost certainly inhibit its performance. Every fireplace or stove will benefit from having its chimney within the house envelope. A chimney installed inside the house envelope is not affected by the negative pressure low in the house due to stack effect because an inside chimney is always at or above the house temperature. Also, since the neutral pressure plane follows the leaks, the large opening at the chimney top means that the chimney has a neutral pressure plane that is higher than the one in the house. The result is a consistent upward flow of air through an inside chimney at standby. An inside chimney is always a better chimney than the house, subject to cause #2.

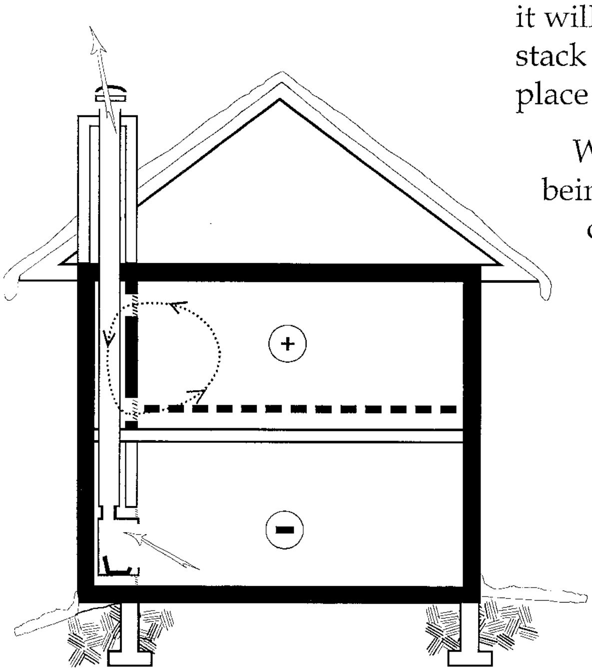
If a factory-built fireplace must be installed in an external chase, the chase must be sealed and insulated at least to the top of the building envelope and there must be no insulation between the chase area and the house. In order for chimney draft to compete with stack effect, the average temperature in the chimney must be the same as the temperature in the house.



Note that the chase is sealed and insulated right to the top of the building envelope and there is no insulation between the chase and the room. These characteristics will help to keep the air in the chimney at the same temperature as the house.

If a chimney is kept warm by being inside the house, it will always make more draft than the house makes stack effect. The resulting low pressure zone at the fireplace opening will suck air up and out of the house.

Where a factory-built fireplace in an external chase is being retrofitted to an existing house, or to correct a cold backdraft in an existing system of this type, provision must be made to keep the fireplace and chimney at the same temperature as the house. One possible strategy is to vent the chase into the room so that warm room air can circulate within the chase (left). This strategy is only practical and viable if the chase is well sealed and insulated so that cold drafts are minimized. Note that if the system passes through two levels of the house, each level would need to be vented separately so that building code firestopping requirements would not be violated.



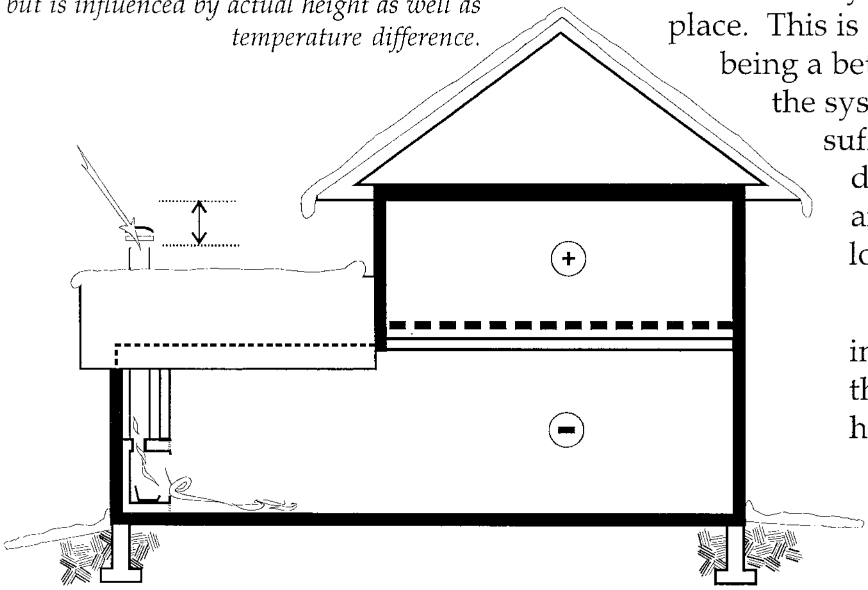
In a retrofit situation, the chase may need to be vented in to the room so that air circulation can keep the chimney warm.

Cause #2: heated space higher than chimney top

Effective stack (height): refers to the relative performance of the stack (house or chimney), normally in standby mode, rather than specifically to its linear height, but is influenced by actual height as well as temperature difference.

In the illustration, notice that the top of the chimney is lower than the upper part of the house envelope. In standby mode (no fire) the house is a taller effective stack than the chimney. If the ceiling of the second floor of this house has leaks such as poorly sealed attic hatch and electrical penetrations, the house can be a better chimney than the chimney when no fire burns in the fireplace. This is another example of the house being a better chimney than the chimney; the system would almost certainly suffer from the cold hearth syndrome, depending on the location and extent of leaks in the envelope.

The illustration shows an inside chimney installation, but if the chimney ran up outside the house envelope, the problem would be far more severe.



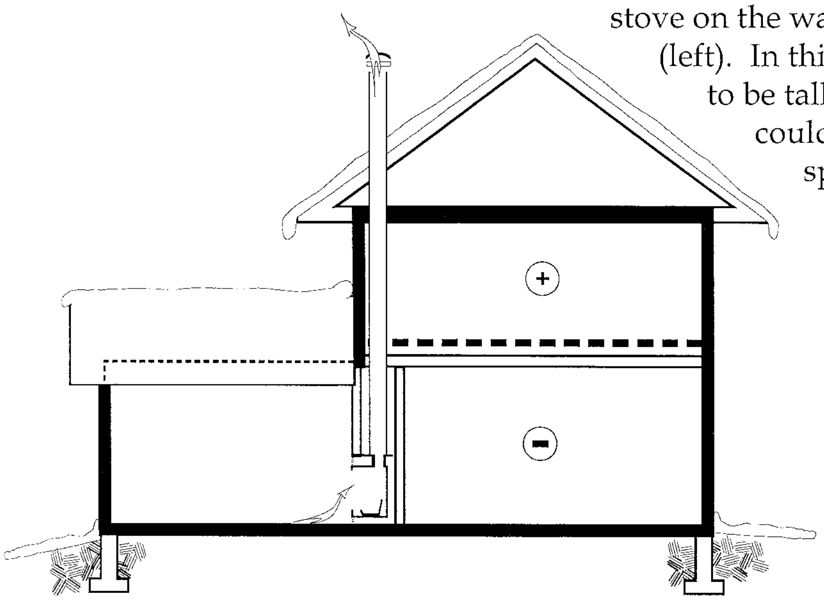
The appliance and chimney should be located on the wall next to the two storey section of the house. In this way, the chimney could be installed to run inside the envelope and penetrate the highest part of the envelope.

Solution #2: chimney top must always be higher than the highest part of the house envelope

To avoid the cold hearth syndrome, it is essential that the top of the chimney be higher than the highest section of the house envelope.

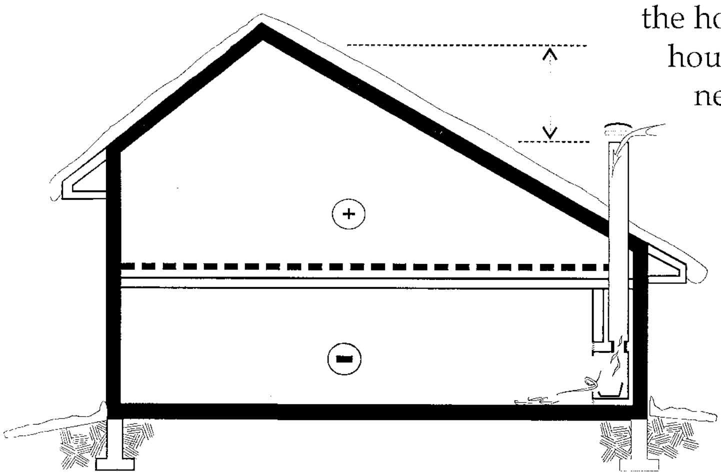
The problem is created early in the design phase of the original house or of the addition to an existing house. The fireplace retailer, installer or builder, faces obstacles to improving the design because the client, whether it be the home builder or homeowner, has already made a commitment to the design before selecting and arranging for the installation of the hearth appliance. Adjusting the design to prevent the cold hearth syndrome may not be as simple as adding height to the chimney. First, raising the height of the chimney enough to exceed the height of the building envelope can make it look unacceptably tall and unsightly, or even create stability problems. Second, the extended chimney will be outside the building envelope for much of its length. With so much of its length exposed to outside, the additional height may be offset by excessive cooling and the problem may not be resolved.

It would be preferable to locate the fireplace or stove on the wall next to the two-storey section (left). In this location the chimney would have to be taller than the house envelope and could be installed up through the warm space.



The chimney should penetrate the building envelope at its highest point.

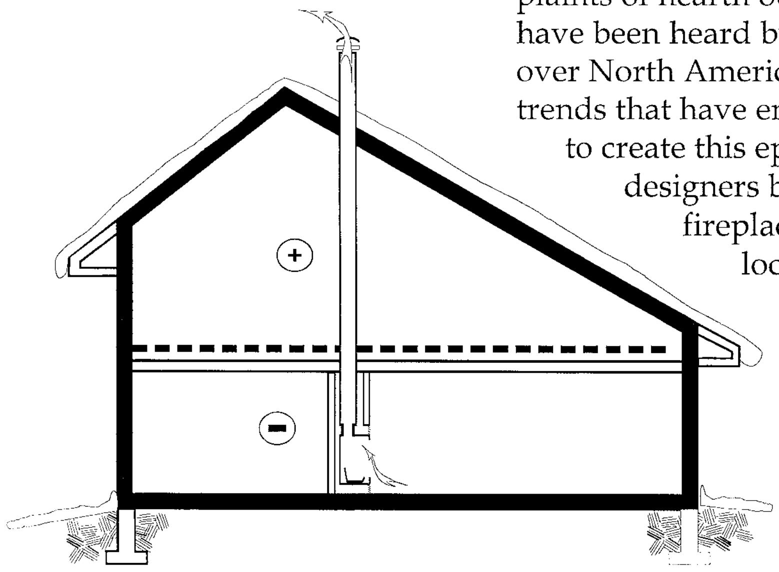
Houses with cathedral or vaulted ceilings sometimes pose severe problems for chimney venting because the house envelope extends to the roof peak. Ensuring that the chimney is always a higher effective stack than the house limits the range of locations within the house that the combustion appliance and chimney can be placed.



In the illustration to the left, it is apparent that for the chimney to be a higher effective stack than the house and to be visually acceptable, it would have to exit the roof far closer to the peak than it does now. Unfortunately, from a design perspective, it is often desirable for the fireplace to be located in the house at the lowest part of the eaves. Nevertheless, it is essential to deal with the issue because this configuration often produces chronic and severe cold backdrafting and hearth odors, particularly if the fireplace is installed in an external chase.

Houses with cathedral ceilings present particular problems because the heated space extends to the peak of the roof. Ideally, the chimney in such houses should penetrate the cathedral ceiling close to the peak.

The cold hearth syndrome has become the most widespread problem with fireplaces in modern homes. Complaints of hearth odors and cold drafts from the hearth have been heard by builders and fireplace specialists all over North America. It appears that several housing trends that have emerged since the 1950s have combined to create this epidemic of cold hearths. First, house designers began to favor external chimneys and fireplaces in external chases whereas centrally located chimneys and fireplaces were previously the norm. Second, cathedral or vaulted ceilings have become far more common during the same period. And third, inexpensive, lightweight manufactured fireplaces with air-cooled chimneys have become more popular than masonry fireplaces in the past twenty years. If these air-cooled chimneys are not kept warm, a reverse flow will be induced by the slightest negative pressure in the house. The problem of the cold hearth is often mistakenly blamed on the fireplace's inability to "get enough air" through the tightly sealed envelope of modern houses. Certainly, negative pressure in the house resulting from the operation of exhaust fans can induce flow reversal in the chimney (and we will cover that issue later), but the majority of cold hearths can be traced to outside chimneys or chimneys that do not have adequate effective stack height.



Ideally, the chimney should penetrate the envelope near the peak of a cathedral roof.

Why the cold hearth syndrome is more than just a nuisance

Since air is not a pollutant, a fair question to ask is: What's the problem if cold air comes down the chimney, aside from affecting comfort? The problem is that the cold hearth is merely a symptom of an underlying system design flaw.

The chimney's function is to flow air and/or exhaust gases up and out of the house. When a backdraft occurs, the event must always be considered a failure of the chimney to do its job. Considering the chimney's role, a backdraft is a very serious and unacceptable event, rather like the wings falling off an airplane. It should not be permitted to occur.

Looked at another way, cold air comes down a chimney that is backdrafting, whether or not the connected appliance is firing. A chimney that is capable of backdrafting because it runs outside the house envelope or because its top is lower than the house envelope may either continue to backdraft when the appliance fires, or may go into backdraft while the appliance is still producing pollutants.

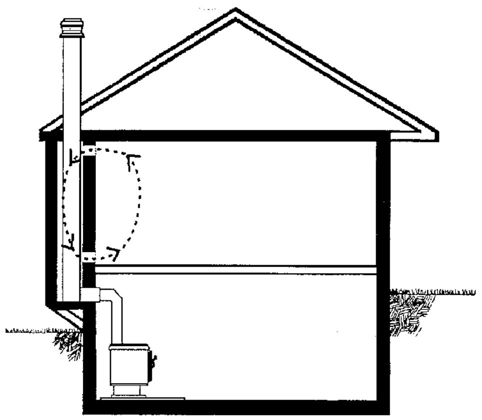
A chimney that is capable of backdrafting because of its relationship with the house envelope is an inherently unstable venting system that should not be trusted.

Never minimize the significance of backdrafting in a chimney. A backdraft in standby mode is always a problem, one that should be corrected if possible. Air pollutants, dust, odors and cold accompany the air that flows down a chimney, so both health and comfort can be effected.

Retrofit solutions for a cold hearth

If you are involved in the design of a new house or a renovation, always be aware of the potential for creating the conditions that produce backdrafting at standby: outside chimneys and chimneys that do not exceed the height of the building envelope.

Resolving a cold hearth problem in an existing building is extremely difficult since the root cause is the relationship between the building envelope and the venting system. The only sure solution is to change the relationship so that the chimney is enclosed within the envelope and penetrates the envelope at its highest point. This is often impossible, and even where it is possible, the cost may be prohibitive. Unfortunately, therefore, the solutions offered here are either complicated, expensive, or only partly effective.



In a retrofit situation, vent the insulated and sealed chase into the warm space of the building.

Enclose in a sealed, insulated chase

An outside factory-built chimney could be enclosed within a sealed, insulated chase. However, unless special care is taken in the design and construction of the chase, this strategy may not be successful. To be effective, the chase must be well sealed and insulated so that it resists air leakage and heat conduction. Also, to ensure that the air in the chimney during standby conditions is at or near the indoor temperature, the chase cavity would probably need to be vented into the house. Since this strategy effectively makes the chase part of the envelope, a firestop would have to be installed at each ceiling level, so the chase must be vented into the house separately for each storey of the house. This venting could be accomplished by installing passive grilles between the house and the chase at floor and ceiling level of each storey. During standby conditions, the chase would gain heat from the house, effectively increasing the house's heat load. When the appliance is operating, the house would gain some of the heat lost by the outer shell of the chimney. This type of chase installation means that the chimney components for inside installation would be installed, including firestops and attic shield. The entire installation should be checked for safe clearances to combustible material.

Masonry chimney retrofits

A masonry chimney can be relined in a variety of ways in order to reduce heat loss through the masonry. Relining can be the least expensive retrofit for a chimney suffering from cold backdraft. By providing a degree of isolation for the exhaust gases or air in the flue from outside cold, relining can help to resist the fall in temperature. Of course, at standby it is quite possible that the average temperature in the chimney would eventually fall below that of the house and a cold backdraft would start. A lining system that includes insulation would help to slow the drop in temperature during standby and would likely improve the performance of the chimney over all. Although relining is an effective method for re-sizing and insulating the flue in a masonry chimney, and some performance improvement is almost certain, relining may not be an entirely successful solution to the cold hearth syndrome, particularly in cases of powerful backdrafts.

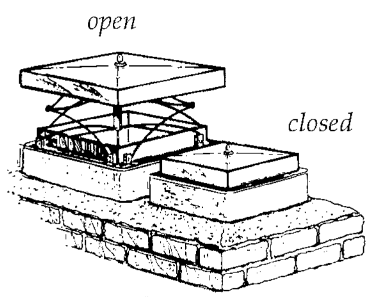
The fact that reliable remedial measures for the cold hearth syndrome are so complex and costly reinforces the importance of avoiding the problem at the design stage.

Theoretically, a masonry chimney could be enclosed in a sealed and insulated chase to make it function like an inside chimney, as was discussed for factory-built chimneys. But, there are practical considerations that could render this strategy unworkable. Primary among these is the fact that inside masonry chimneys require larger clearances to combustible materials than do outside chimneys. If a chase were built around a masonry chimney, the clearances would have to conform to the building code rules for a chimney built inside the envelope. Also, there are no recognized guidelines for terminating a combustible chase at the top of a masonry chimney.

Install a sealing cap on the chimney

The flow of air down an inoperative chimney can be reduced or eliminated by installing a specialized chimney cap that has a sealing damper. The damper in these caps is usually operated by a cable or chain that extends down into the fireplace. When the damper is closed, cold air cannot flow down the chimney.

Be aware, however, that although air cannot flow down from the chimney top, a convection current caused by the cold chimney liner surface can bring odors into the room. A set of tightly-fitting glass doors on the fireplace may be a necessary additional step.



The use of a chimney cap/damper can be effective in blocking the backdraft in a chimney in standby mode.

Two important cautions apply to the use of top sealing dampers:

1. These damper/caps cannot be used with gas or oil fired appliances that operate on thermostats.
2. These dampers are mainly intended for masonry chimneys and fireplaces and their use on factory-built metal chimneys may be prohibited by the chimney manufacturer—check before installing one.

To conclude, the available strategies for resolving the cold hearth syndrome in an existing system are of two types: the first, like relining, chimney top dampers and fireplace door assemblies may not eliminate the problem, and the second, like sealed, insulated chases, tend to be expensive because they entail structural changes to the building. The cold hearth syndrome can be avoided at the design stage and this is certainly the time to address the issue so that remedial measures are unnecessary.

Summary

- chimneys must be located within the building envelope to avoid the cold hearth syndrome
- the chimney should penetrate the building envelope at or near its highest point
- insulated chimney relines, tight-fitting fireplace doors and top sealing dampers can help to minimize the symptoms
- to be effective, external chases must be constructed to be within the building envelope, all the way to the top of the building envelope.
- backdrafting is a serious failure of the chimney to do its job, whether or not combustion gases are spilled
- the cold hearth syndrome is extremely difficult to correct so it must be dealt with at the design stage

Driving pressure: A pressure that produces flow in the desired direction.

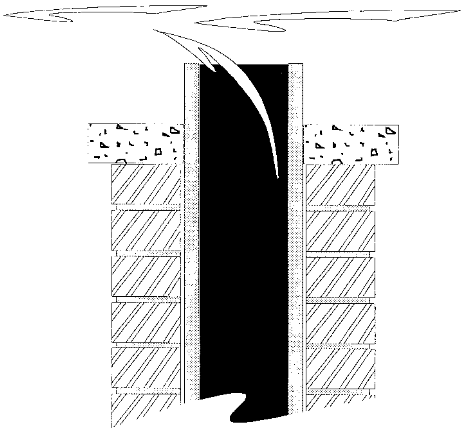
Adverse pressure: A pressure that inhibits flow in the desired direction.

Air is a fluid that has weight, so when it gets moving it exerts pressure on anything that gets in its way. If you have experienced a fifty mile per hour wind, you know all about it. Just like water, air flows in eddies and currents when it gets turbulent, as it does flowing around obstacles. The fact that air is invisible makes diagnosing wind-induced venting failure mostly guesswork, but there is some science that provides guidance.

The effects of wind on chimney performance

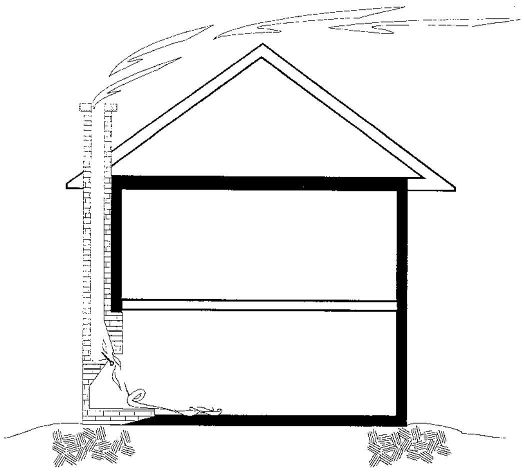
The higher the velocity of a stream of air, the lower is the pressure that it exerts on the surface it is flowing over. It is this principle that gives an airplane wing its lift. For the same reason, wind flowing over the top of a chimney can increase draft by producing a driving pressure that assists in pulling exhaust gases from the chimney.

Despite the fact that wind flowing over a chimney produces a driving pressure, it cannot be depended upon for appliance performance because it is highly variable and unpredictable. The only dependable driving pressure in a chimney operating on natural draft is produced by temperature difference.



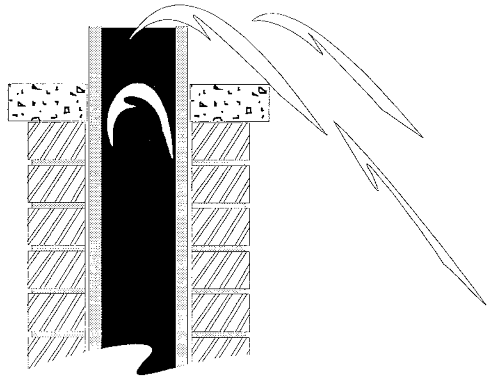
Wind flowing over a chimney assists natural draft by sucking out the gases.

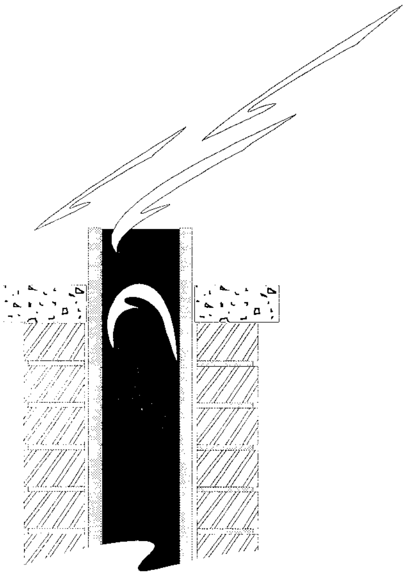
For example, wind can often flow down towards the top of a chimney after passing over an obstacle like a roof, adjacent building or trees. Wind may also approach the top of a chimney from below after flowing up a roofline to a chimney penetrating the peak. Wind tunnel testing has demonstrated that wind flows from either above or below the chimney top can be adverse to upward flow.



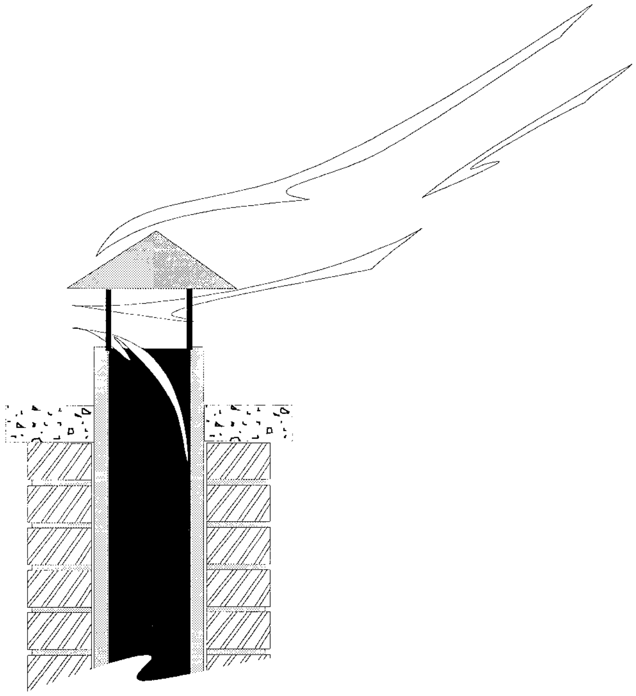
Winds can flow in a direction adverse to draft in an open chimney after flowing over a taller obstacle.

A chimney with no cap is the most vulnerable to the adverse effects of wind. A cap, particularly one that has baffles to prevent direct line of sight access to the opening (as opposed to a simple flat rain cap) provides significant protection from the adverse effects of wind. In fact, research has shown that caps with baffles (of the sort common on factory-built chimneys) can actually enhance draft regardless of wind direction.



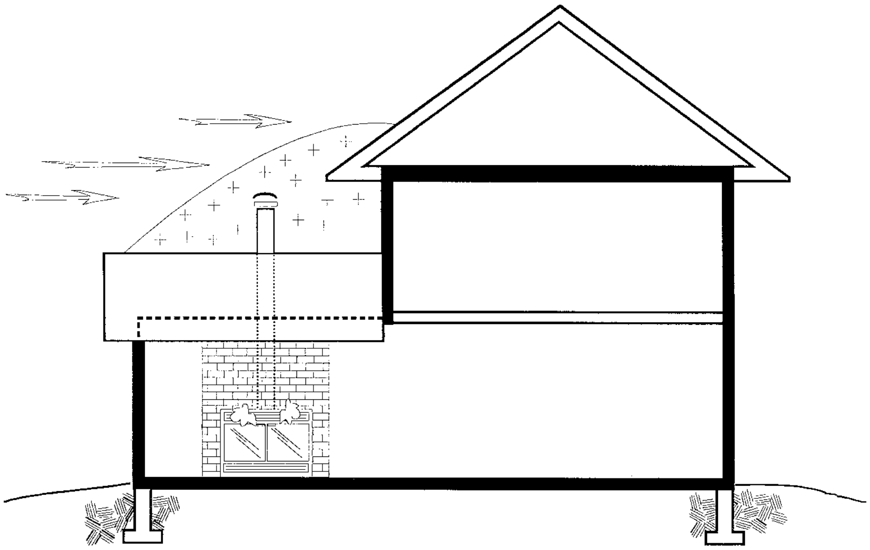


Wind flowing from above or below an open chimney top can have an adverse effect on upward flow by creating turbulence and/or positive pressure at the opening.



Chimney caps help to resist adverse pressures caused by wind. A simple cap like this one is somewhat effective, but caps with baffles are better.

Adverse pressure can also occur when the top of the chimney is in a positive pressure zone caused by the velocity pressure of the wind as it flows against a raised part of the building behind the chimney (below). This is one case in which adding to the height of the chimney may help to resolve a wind-related venting problem.



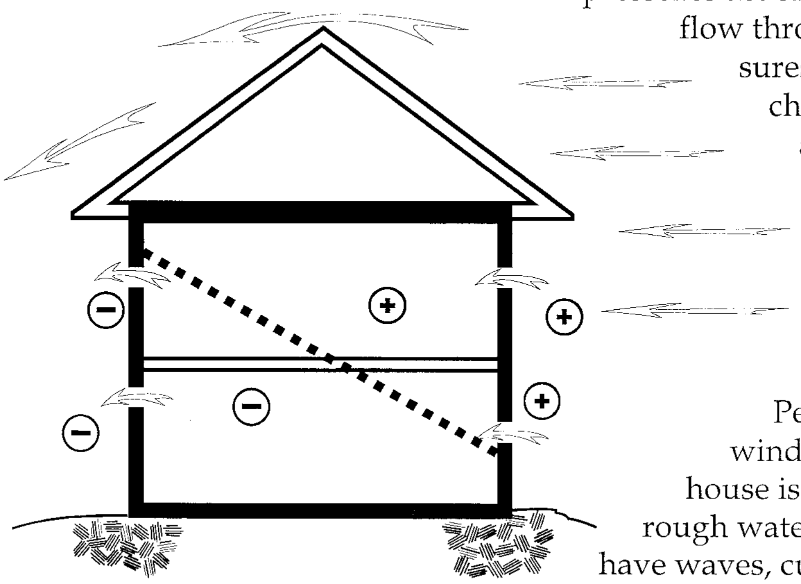
The velocity pressure of wind flowing against a raised part of a building behind the chimney can produce an adverse effect on draft. Note that this system would already have a problem because the top of the chimney is lower than the upper part of the building envelope. This is a good example of how adverse characteristics can combine to create serious venting problems.

Some caution is warranted when diagnosing what may appear to be wind-induced venting failure, particularly when the chimney already has a suitable cap. For example, a householder might report the intermittent puffing of smoke from the appliance that occurs only on windy days. The pulsing effect of wind gusts clearly plays a role in this type of smoke puffing, but is it the only cause? Other contributing factors could be low flue gas temperature due to fire smoldering, an outside chimney, or a chimney that is shorter that the building envelope as in the illustration above.

Often, wind gusts simply cause a vulnerable system that verges on failure to spill the distinctive puff of smoke that implies wind-induced downdraft. At one time or other, most chimney sweeps and technicians have recommended the installation of a specialized "anti-downdraft" chimney cap only to find that it did not cure the problem. Adverse pressure caused by wind acting on the chimney top is rarely the only cause of a venting problem. Nevertheless, chimneys in locations such as the one above may be susceptible to wind-induced failure, partly because they were failure-prone to begin with.

The effects of wind on the house envelope

The force of wind blowing around a house produces a positive pressure zone on the windward side and a negative pressure zone on the downwind side. These pressures act on the leaks in the envelope, causing air flow through them and changing the pressures within the house. These pressure changes are best illustrated by looking at their effect on the position of the neutral pressure plane. The NPP can tilt away from the horizontal (left), but no illustration can properly convey the ragged, messy shape that the zone of neutral pressure can be distorted into by wind effects.

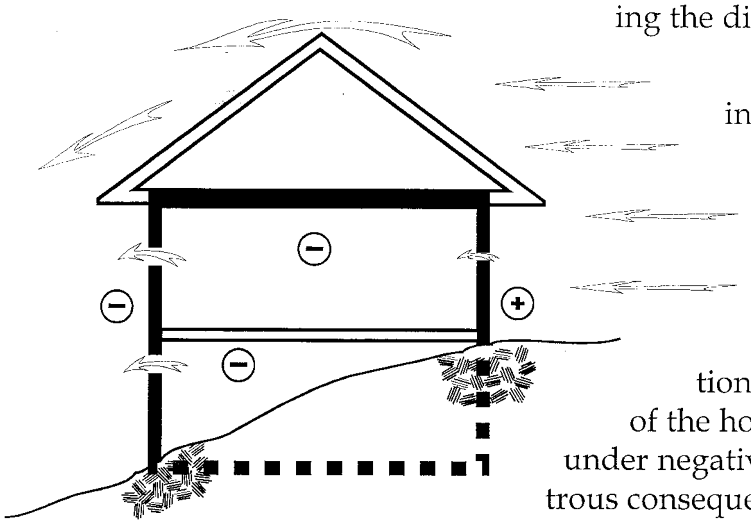


Wind can cause dramatic pressure fluctuations inside the building and can cause the neutral pressure plane to tilt, and cause the position and strength of positive and negative zones to vary wildly.

Perhaps the best way to visualize the wind-induced pressure variations in a house is to compare the NPP to the surface of rough water. The plane of neutral pressure will have waves, curves, peaks and valleys responding to the aerodynamic influences around the building envelope. This understanding renders inherently inaccurate any simple attempt to define and illustrate the position of the NPP under windy conditions.

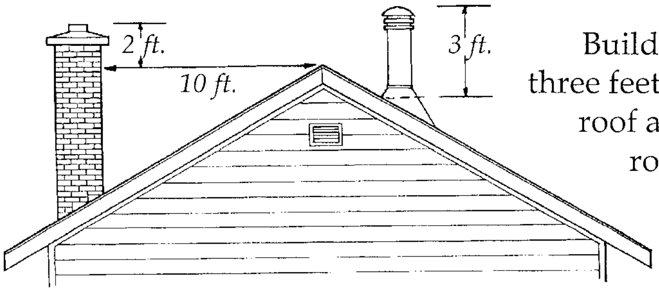
In strong winds, the pressures experienced by the building envelope can be very powerful—several times the normal pressures produced in chimneys through natural draft. In gusting winds, the pressures and position of the NPP are in constant change, further complicating the diagnostic process.

The design and setting of a house can influence the pressure environment inside during high winds. Imagine that the house on the left backs onto an attractive ravine and that the architect located most of the windows to take advantage of the view. The majority of leaks in the envelope could be on the exposed two-storey section. When a strong wind blows from the front of the house, the entire interior could be placed under negative pressure. This effect could have disastrous consequences for a hearth system installed inside.



This whole house could be depressurized by wind because of the location of the majority of leaks .

The effect of wind on the pressures around and inside a building are complex and unpredictable. In general, however, the leakier the building, the more pronounced and immediate is the effect on pressures inside. The unpredictable effects of wind pressure is one reason why the installation of a specialized chimney cap may not cure a venting problem. The pressure changes inside the house may be either driving or adverse to the desired flow of exhaust gases up the chimney.



Building codes call for the chimney project at least three feet above the highest point at which it touches the roof and that its top must be two feet higher than any roofline or obstacle within a horizontal distance of ten feet. Like all building code provisions, these are the minimums allowable and may need to be exceeded in order to meet performance objectives.

Although the effects of wind are unpredictable, one thing is abundantly clear: fireplace and chimney systems of good design are highly resistant to wind-induced venting failure. A chimney that is installed inside the envelope, that penetrates the roof near the peak and that has a baffled cap is unlikely to be negatively affected by wind.

Summary

- wind flowing over the top of a chimney can produce a driving pressure, increasing draft
- wind may also create adverse pressures at the top of a chimney because of its direction of flow or turbulence created as it flows over nearby obstacles, or when the top of the chimney is in a positive pressure zone
- wind pressure induces air flow through leaks in the building envelope
- wind causes pressure changes inside a building which in turn changes the position of the neutral pressure plane
- wind is an unreliable source of draft because it is highly variable and may be driving or adverse to chimney venting
- every chimney should have a cap, preferably one that is baffled, to minimize the potentially adverse effects of wind
- specialized chimney caps may reduce the effects of adverse winds, but are sometimes used in error as a cure-all for troubled venting systems
- the best defence against wind-induced venting failure is good system design

The effects of powered exhausts

The pressure inside a building is affected when inside air is exhausted to outside. The amount of pressure change is influenced by:

- the volume of the air flow – the more air is exhausted, the more negative the pressure inside will become, and;
- the tightness of the building envelope – the tighter the building envelope, the more negative the pressure will become for a given volume of air flow.

Excessive depressurization of a house caused by exhaust flows can overcome chimney draft and result in venting failure. There are at least three housing trends that contribute to the increased frequency of house depressurization leading to venting failure. First, builders are giving more attention to air sealing of their houses for energy conservation and comfort reasons, so leakage rates are lower. Second, building materials are evolving; for example, standard doors and windows are more commonly gasketed and have effective latches that pull them tightly closed, also reducing leakage. And finally, modern clothes dryers and kitchen exhausts, usually the largest exhaust devices in a house, are more powerful than older models. In other words, houses are getting tighter and exhaust fans are getting more powerful. The result is more frequent and more severe depressurization of houses.

The tighter the house envelope, the more the pressure inside is affected by exhaust flows. The leaky house (above right) is only slightly affected by the exhaust flow. The tight house (right) is significantly depressurized by the same volume flow.

Intermittent exhaust devices

The most common mechanical exhaust ventilators are the kitchen range exhaust, clothes dryer, central vacuum and bathroom fan. The operation of these devices, independently or in combination, causes house depressurization. None of these devices is designed to run continuously so they are referred to collectively as intermittent exhaust devices.

Chimney vented fireplaces function as exhaust devices when they take air for combustion from the house and expel it outside. The exception would be fireplaces that get their combustion air from outside, but as we will see, outdoor air supplies have their own special problems. Because the air flow through open woodburning fireplaces (no doors) is uncontrolled, they can act as powerful exhausts, so powerful they have been sarcastically referred to by some housing specialists as wood-fired exhaust ventilators. In general, however, hearth appliances with doors, and particularly those with gasketed doors, draw comparatively little air from the house. Table 2 below shows the average air flows of common intermittent exhaust devices and combustion equipment.

Manufacturers of exhaust devices such as bathroom fans, kitchen range exhausts, clothes dryers and central vacuums generally publish higher air flow capacities than those shown in Table 2. This is because the manufacturer's ratings are performed under more ideal conditions than commonly occur in the field. Every additional elbow and length of duct contributes to the restrictions that reduce the net flow. Field tests have shown that actual flows are often about 40 per cent less than manufacturer's ratings.

Table 2.
ESTIMATED AIR FLOWS OF TYPICAL INTERMITTENT EXHAUST DEVICES

	L/s*	cfm*
bathroom fan	15 - 30	30 - 60
standard kitchen range hood	40 - 60	80 - 120
downdraft bbq range exhaust	100 -300	200 - 600
clothes dryer	40 - 75	80 - 150
central vacuum	25 - 50	50 - 100

AVERAGE AIR FLOWS OF CHIMNEY VENTED COMBUSTION SYSTEMS

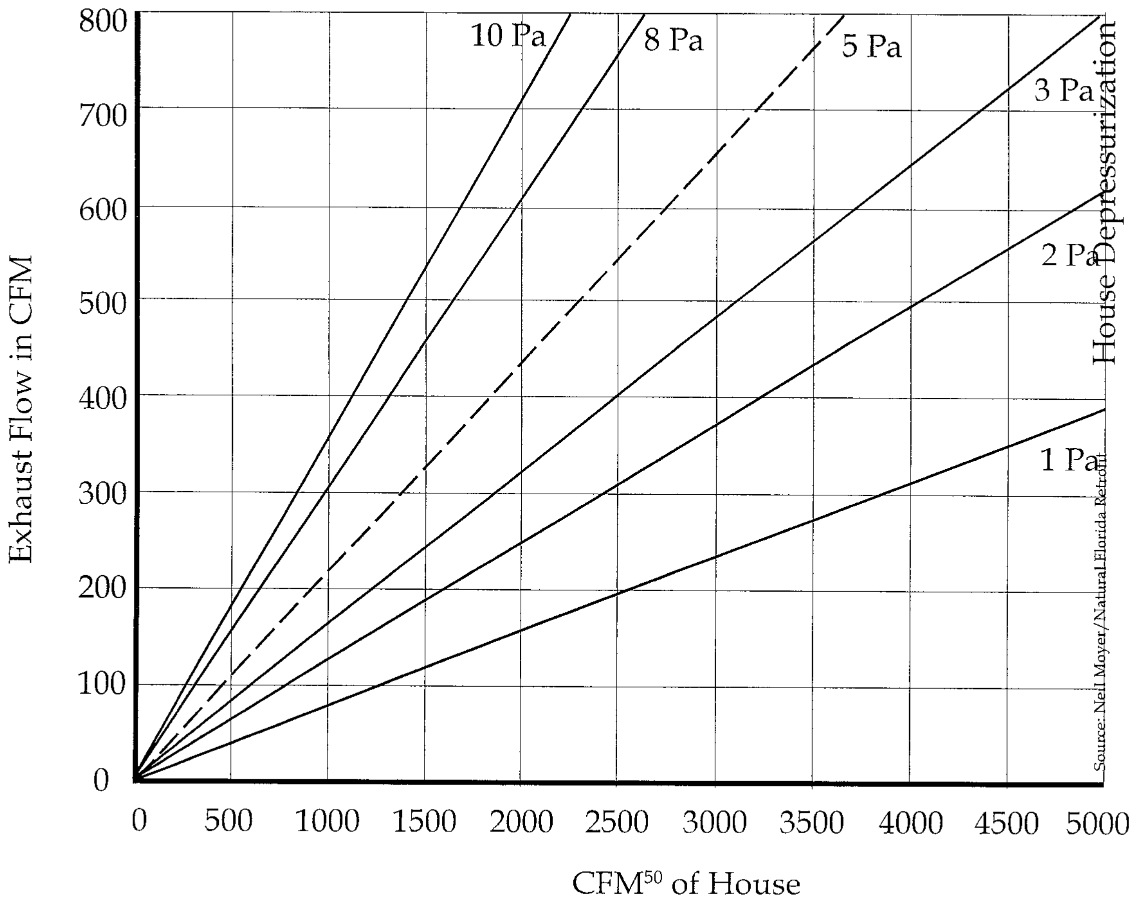
	L/s*	cfm*
chimney vented oil furnace	40 - 75	80 - 150
B-vented gas furnace	40 - 60	80 - 120
B-vented gas fireplace	30 - 50	60 - 100
open wood/gas fireplace	80 - 300	160 - 600
wood fireplace with doors	30 - 50	60 - 100
controlled combustion woodburning appliance	5 - 15	10 - 30
masonry heater, burning wood	20 - 30	40 - 60

**L/s is litres per second; cfm is cubic feet per minute. The figures in the table have been rounded off.*

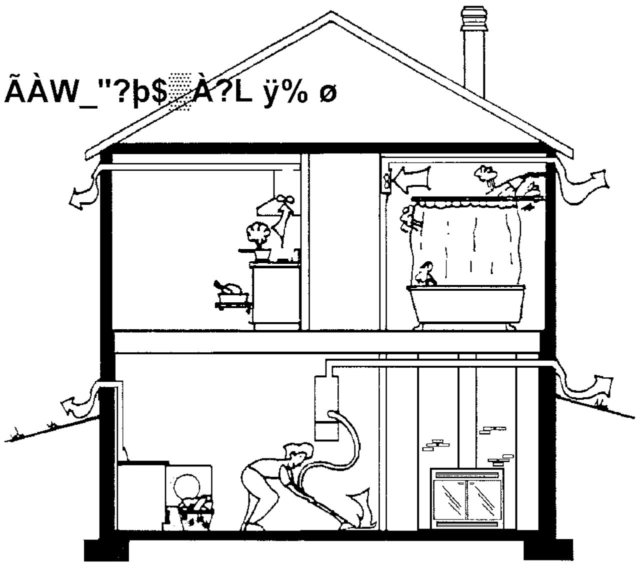
Table 3 (next page) shows the effect of various exhaust flows on the pressure in buildings with envelopes of various degrees of leakiness. The figures on the vertical axis are the combined exhaust capacity of devices of concern, usually the clothes dryer and kitchen exhaust. The horizontal axis is the range of house leakiness expressed as cfm^{50} which is the number of cubic feet of air that would be exhausted each minute by a fan that depressurizes the building to 50 Pa. The diagonal lines show the resulting house depressurization at intersecting points of cfm^{50} and exhaust flow. The dotted diagonal line is the -5 Pa level at which the most sensitive chimney vented systems may begin to experience problems.

According to the chart, a kitchen range fan that exhausts 300 cfm in a house with a leakage rate of 1500 cfm^{50} would depressurize the house between 4 and 5 Pa. To put the cfm^{50} figures into context, well built houses in northern United States and southern Canada would have leakage rates between 1000 and 1500 cfm^{50}. A large house of complex design would have a higher leakage rate; a small house of simple design could be tighter. Houses built in milder climates where cold weather comfort and heating fuel economy are not high priorities will tend to have greater leakage. Old houses have far higher leakage

Table 3. House Depressurization Chart



CFM^{50} is the volume flow of air out of a house through a fan that depressurizes the house by 50 pascales



Although a house may be severely depressurized if all its exhaust devices operate at the same time, worst-case is usually considered to be achieved when the two largest exhausts are running. In this case the two largest would be the kitchen exhaust and the clothes dryer.

rates than these. Looked at another way, a house with a leakage of 1500 cfm^{50} would have an equivalent leakage area (if the total of all leaks were expressed as the diameter of a hole) of roughly 16 inches.

While the table is a useful tool for gaining insights into the relationships involved, the figures cannot be relied upon for predicting the behavior of a particular house. The house pressure test outlined later in this manual is the correct approach to predicting reliable venting.

Once draft is established by the presence of hot combustion gases in the chimney, a fireplace with doors is relatively tolerant of house depressurization caused by all but the most powerful exhaust ventilators. However, at start-up before draft is established and during the tail-out or coal bed phase of a wood fire as draft declines, chimney vented systems are vulnerable to spillage or backdrafting caused by house depressurization. While chimney vented systems burning gas or oil are also vulnerable to backdrafting at shut down, the impact is less serious because fewer air pollutants are produced after the burner shuts off.

> Venting systems of good design are most tolerant of fan-induced depressurization. Conversely, troubled systems, such as those that are leaky, short or subject to excessive cooling, are extremely vulnerable to failure due to house depressurization.

Continuous exhaust devices

Continuous exhaust devices must be treated differently than intermittent devices because of the potentially greater impact they can have on fireplace performance.

The exhaust devices listed in Table 2 are all defined as intermittent in that they operate only for a period of time and then shut off. The only real example of a continuous exhaust device is an exhaust-only house ventilation system. Such ventilation systems can be as simple as a duct running from inside the house to an attic ventilator at the roof peak. Others use a fan exhausting through a wall or roof vent. More elaborate designs can have ducts connected so that stale, moist air is picked up from the kitchen and bathroom areas and forced out of the house with a fan.

As house envelopes are built tighter to increase comfort and reduce energy consumption, a point is reached at which an active ventilation system is required to provide fresh air for healthy living and to remove pollutants and excess moisture from the house environment. The most obvious evidence of the need for ventilation in tight houses in cold weather is the condensation of water vapor on windows.

Because the operation of continuous exhaust devices spans the start-up and tail-out periods during which a fireplace is most vulnerable to house depressurization, they are more likely to cause venting failure than intermittent devices. In fact, they are almost certain to present problems, particularly when the fireplace and chimney are in standby mode (no fire). Unfortunately, exhaust-only ventilation systems are becoming more popular because they are the least expensive way to ventilate tight houses.

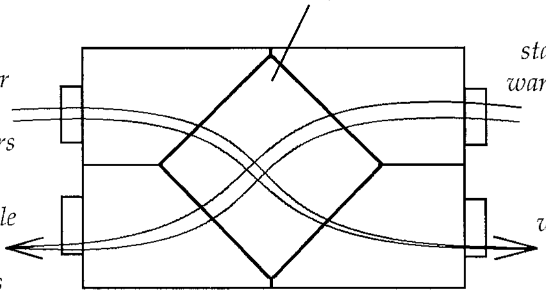
With exhaust-only ventilation systems, air to replace that which is exhausted is expected to enter through leaks in the building envelope, whether random leaks or planned leaks such as those built into window frames. The tighter the house, the greater is the level of depressurization needed to induce the required replacement air flow.

Given some time to adjust, the building industry will likely come to realize that exhaust-only systems are an inappropriate way to ventilate modern houses with natural draft fireplaces. In the mean time, however, exhaust-only ventilators will cause chimney venting problems.

Balanced ventilation systems

Ideally, tight houses with fireplaces should have balanced ventilation systems, in which replacement air from outdoors is forced into the house in the same volume as the stale air is exhausted. The additional cost of balanced ventilation is relatively minor, but the benefits go beyond providing a safer environment for chimney venting, and include more effectiveness and comfort, and lower energy consumption for the homeowner.

The most common form of balanced ventilation system is the heat recovery ventilator, or HRV, which has become popular in regions with cold winters. During cold weather the heat recovery feature of these units both saves energy and moderates the temperature of the in-



Inside a heat recovery ventilator (HRV), stale air from the house passes through a heat exchanger in close proximity to a stream of cold outdoor air, giving up some of its heat to the cold air and moderating its temperature.

coming air so that it does not create discomfort. Balanced ventilation systems are available without heat recovery at lower cost than HRVs.

Successful chimney venting is assisted by balanced ventilation. In other words, the absence of balanced ventilation is an adverse house feature and its presence is a driving feature. This factor has important implications for architects, builders and hearth specialists. You can help to ensure successful venting through your recommendations to the homeowner.

- If you are designing a house that contains a wood-burning fireplace or stove, or any fuel-burning appliance operating on natural draft, specify a balanced ventilation system.
- If you are building a house using materials and techniques that will reduce leakage, inform the client about the need for a ventilation system and strongly recommend a balanced one.
- If you are designing the hearth system for a new house that you expect to be tight, recommend that balanced ventilation be installed.
- If you are diagnosing a chimney venting problem and notice that water vapor is condensing on the windows or that the indoor air is stale or stuffy, you should recommend that a balanced ventilation system be installed.

A heat recovery ventilator must not be used to supply combustion air or air to compensate for that exhausted by other appliances. In cold weather, if more air is brought into the house through the HRV than is exhausted, the moisture in the exhaust air will freeze in the heat exchanger core, blocking air flow. In order for the HRV to function properly, the fresh air and exhaust air flows must be balanced.

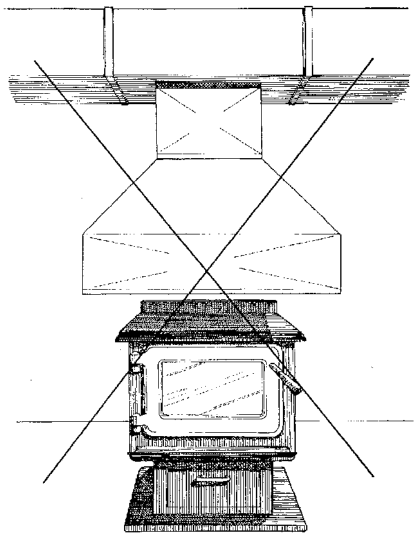
Certain types of HRV can become fairly powerful exhaust ventilators when they are in defrost mode. This "damper-type" defrost system makes an HRV an exhaust-only device intermittently during very cold weather. This feature must be taken into account when assessing the installed exhaust capacity in a house.

The furnace fan as a room exhaust

The air distribution ductwork serving a forced-air furnace can be designed and installed in such a way as to cause zone depressurization in a building. This phenomenon is often linked to the enclosure of joist spaces in a basement to form part of the cold air return duct system. This common design feature, referred to as joist lining or panning, involves nailing sheet metal across joist spaces to form a duct, the sides of which are the joists, the bottom of which is the sheet metal and the top of which is the floor above. Installers rarely seal the space properly to prevent air leakage.

When the furnace fan starts, the cold air return ductwork is put under negative pressure. Air flowing through leaks in the joist panned ducts has the effect of depressurizing the basement. In fact, with leaky return air ducts, an operating furnace fan effectively pumps air from the basement to the higher levels of the house. This imbalance of the duct system and resulting zone depressurization can cause venting problems for chimney vented combustion equipment in the basement.

Zone depressurization can also be caused by a lack of free air circulation between rooms. For example, if the installation of wall-to-wall carpeting reduces the gap under the doors to bedrooms and other rooms, the operation of the furnace fan can cause depressurization of the zone in which the cold air returns are located, typically the central area made up of livingroom, dining room and kitchen. In this case, the air forced into the rooms with doors closed cannot easily flow back to the cold air return registers, resulting in zone pressure differentials. This phenomenon appears most commonly in houses outfitted with central air conditioning systems which move a high volume of air.

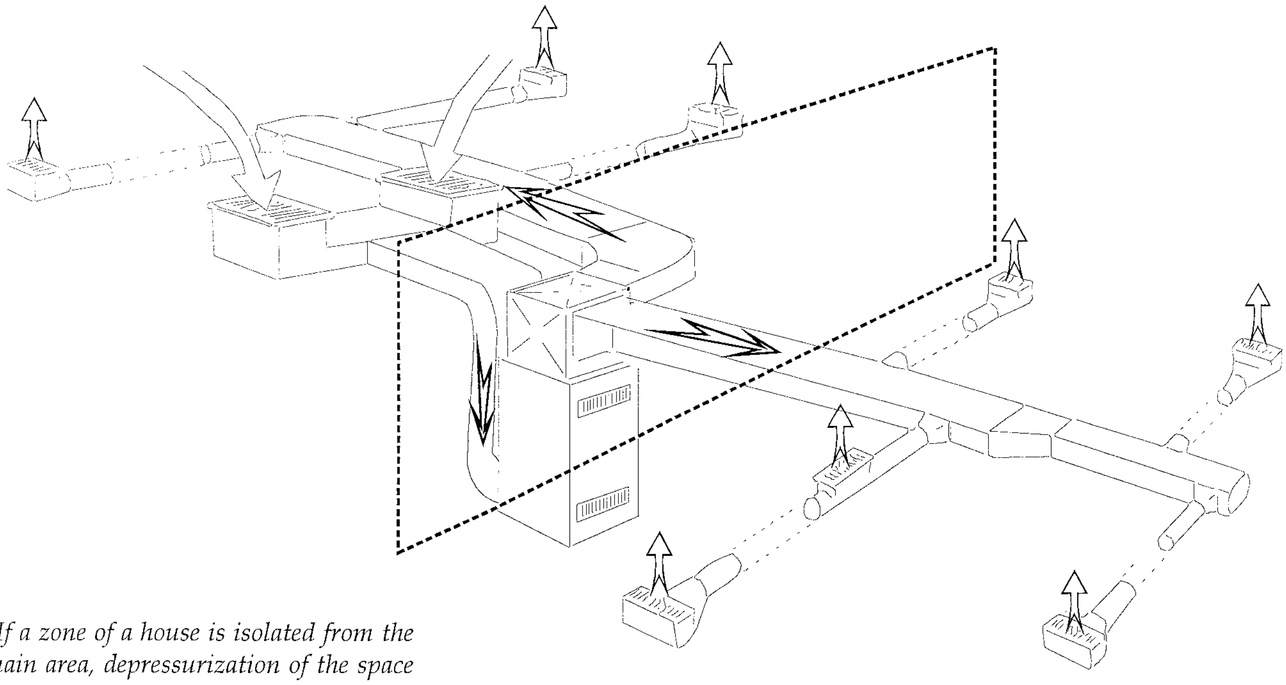


Some resourceful homeowners increase the cold air return capacity in the room containing a space heater as a strategy for distributing its heat to other areas of the home. Some even construct a hood to capture heat rising from their space heater and connect it to a cold air return duct. The room depressurization that occurs when the furnace fan comes on can cause severe backdrafting.

Some homeowners install additional cold air return grilles at ceiling level near their basement wood stoves, or even install hoods over their wood heaters and connect the hood to a cold air duct in an effort to distribute its heat to other areas of the house. These practices are dangerous because, with the furnace fan on, more air is removed from the room than is supplied, and depressurization results. The potential danger of this type of installation should be made clear to the owner. Other causes of air distribution system imbalance include loose blower doors and leaking blower and filter compartments.

Problems with the original system design can also cause imbalance. For example, systems designed with two or more zones controlled by thermostats in various locations of the house can cause zone depressurization because it is common to zone control only the supply side of the distribution system. Those areas of the house that are not being heated receive no supply air but return air is removed, potentially causing depressurization.

Forced-air distribution systems should be balanced so their operation does not influence the pressure of any room in the house. Using the house pressure test outlined later in this manual, you can measure the effect of the furnace fan on room pressure. If the effect is significant, remedial measures should be recommended. In some cases it may be advisable to call in a central heating system contractor to conduct thorough testing and make the necessary alterations to resolve the problem of system imbalance. Such remedial measures can help to correct combustion venting problems.



If a zone of a house is isolated from the main area, depressurization of the space containing the cold air return grilles can occur when the furnace fan comes on.

Summary

- the greater the volume of air that is exhausted from a building, the more negative the pressure inside will become
- the tighter the building envelope, the more negative the pressure inside will become for a given volume of air exhausted
- chimney vented combustion systems act as exhausts, but, aside from open fireplaces, their flow rates are relatively low
- chimney vented systems are vulnerable to backdrafting and spillage due to house depressurization during start-up and tail-out, but are relatively tolerant of depressurization once draft is established
- exhaust-only house ventilation systems cause serious problems for chimney vented combustion systems because their operation spans the vulnerable start-up and tail-out periods
- balanced ventilation systems are needed in tight houses with chimney vented combustion systems
- leaking ducts and/or design problems with a central heating system can cause zone depressurization which can affect safe combustion venting
- the practice of increasing cold air return capacity to the room containing a space heater should be discouraged because it causes zone depressurization

A few years ago, building scientists and hearth specialists were convinced that bringing combustion air from outdoors to the appliance was the answer to venting failure problems. Now we know better.

Ideally, a fireplace operating on natural draft takes its combustion air from a neutral pressure environment so that the air supply is steady and consistent. Perfection would be an air supply provided at neutral pressure and with no resistance to flow. Fireplaces are designed to consume combustion air in response to the amount of chimney draft produced by the waste heat of their own flue gases. A stove or fireplace will be fussy to start and likely to spill when it tries to get its combustion air from a seriously depressurized building. The extent of building depressurization is deducted from potential chimney draft, like this:

theoretical draft - depressurization = net draft

Building depressurization competes directly with chimney draft. If the chimney wins the competition, the flow direction is up (successful venting); if the fan causing the depressurization wins, the flow is down (spillage or backdrafting).

Several years ago, when large exhaust systems—like downdraft kitchen range exhausts—began to cause spillage from fireplaces in reasonably tight houses, a consensus briefly formed around the idea of bringing combustion air from outdoors. The theory was that the flow of air from outdoors would be free of influence from building pressure, allowing the combustion appliance to get the air it needed. In the late 1980s such certainty existed among technologists and regulatory authorities on the issue of outdoor combustion air that it was made mandatory in some building codes. Unfortunately, the decision to enforce mandatory outdoor air requirements was made before research was done to investigate how these air supplies actually work.

The idea that spillage from combustion systems can be reduced or eliminated by providing a supply of outdoor air to the appliance is not supported by research results. Laboratory and field reports have revealed that providing outdoor air is not a simple or effective cure for spillage, and that some designs could create a fire hazard. Two forms of outdoor air supply have been used: passive make-up type air supplies and direct-to-combustion chamber air supplies.

Passive make-up air supplies

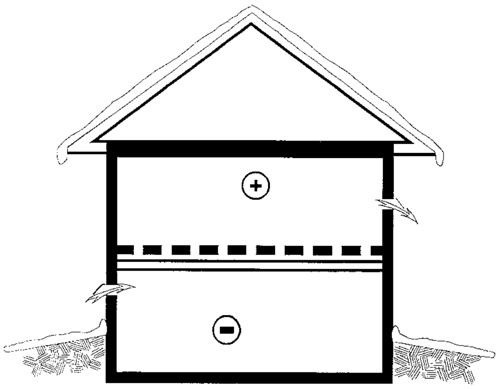
Passive make-up air supply: *Air from outdoors supplied indirectly in the form of a duct terminating either in proximity to the combustion appliance or connected to the appliance air circulation chamber; this is the 'hole in the wall' approach to air supply.*

A passive make-up type air supply is one that is not connected directly to the fireplace combustion chamber. Since it is connected only to the house environment and not to the appliance, it flows air into a house only when the pressure inside is lower than the pressure outdoors at the duct weatherhood. Table 4 shows that the standard 4 inch diameter air supply connected to the air circulation chamber of a factory-built fireplace would be able to flow only about 10 CFM at -5 Pa room pressure, the allowable depressurization for such fireplaces. Since this type of fireplace consumes between 40 and 60 CFM of air while operating, a 4 inch air supply is far too small. Enough air for a combustion appliance could only flow through the duct if the house were severely depressurized, but that level would cause the appliance to backdraft. A passive make-up air supply of reasonable size would only be able to moderately reduce the effects of powerful exhausts on room depressurization, it would not neutralize them. At normal house pressures and in reasonable diameters, this type of air supply is insufficient to provide the air requirements of most fireplaces. For example, to provide all the air requirements for a factory-built fireplace with bi-fold doors at -5 Pa room pressure would require a flex duct with a diameter in the range of 8 to 9 inches (see Table 4). Such a large air supply duct would be difficult to install properly and is probably impractical.

Table 4
Air flows through passive supplies of various diameters at -5 Pa room pressure

Air Flow L/s	Air Flow CFM	Duct Diameter in inches
5	(10)	4
10	(21)	5
15	(31)	6
20	(42)	6
25	(53)	7
30	(64)	7
35	(74)	7
40	(85)	8
50	(106)	8
60	(127)	9
70	(148)	9
80	(170)	10
90	(191)	10
100	(212)	10
120	(254)	12
140	(297)	12

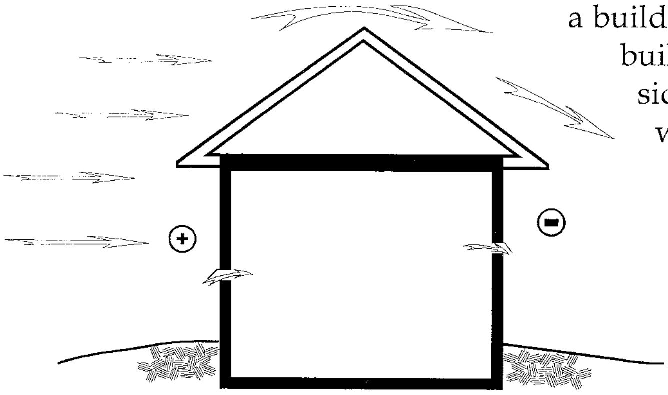
Note: this table assumes an air supply consisting of a screened weatherhood, three elbows and a total length of 10 feet in rigid duct. If flex pipe is used, add one inch of duct diameter. Wind effects around the house would alter the flows significantly.



Air will flow OUT through a passive inlet located above the neutral pressure plane and IN through a 'hole in the wall' located below the NPP.

More importantly, it is misleading to think of the *hole in the wall* approach as supplying combustion air. In fact, passive air supplies provide air only in response to pressure differences. In cold weather, if a passive make-up air supply is located below the neutral pressure plane of the house (and there is no wind effect and no exhaust systems are operating), air will flow into the house. If, on the other hand, the passive inlet is located above the house neutral pressure plane, *air will flow out*. It is useful to keep in mind a key physical principle: AIR FLOWS TO ZONES OF LOWER PRESSURE through any available opening.

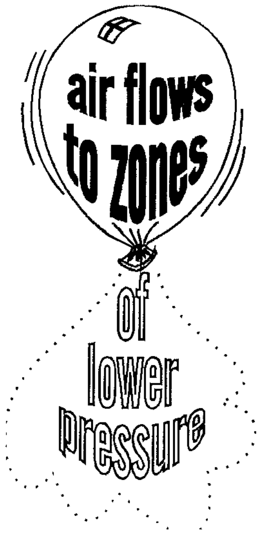
Wind effects around the house also affect the direction and volume of flow through a passive inlet. If the weatherhood of a passive inlet is on the windward side of a building, wind pressure is likely to force air into the building; if the weatherhood is on the downwind side, the negative pressure zone created by the wind is likely to draw air out of the house, possibly depressurizing it.



Wind effects can cause air to flow into or out of the house through a passive air supply, depending on the location of the opening in relation to wind direction.

Another drawback of passive supplies is that they are often plugged by householders because in cold weather they can lead to uncomfortable cold air pooling at floor level.

The real problem with the passive make-up air strategy is that it does not reliably supply combustion air, nor does it reliably reduce combustion spillage. Under favorable conditions it may tip the balance of driving and adverse pressures in favor of successful venting. This is why some fireplace specialists have reported performance improvements after the installation of a passive supply. However, it is also possible for a passive supply to cause spillage if air is drawn out of the house into a low pressure zone caused by wind effects. A remedial strategy that only works sometimes, and that may make the problem worse, is not a good strategy. A passive make-up air supply is really nothing more than another uncontrolled leak in the house envelope. A leaky house envelope is no guarantee of successful venting.



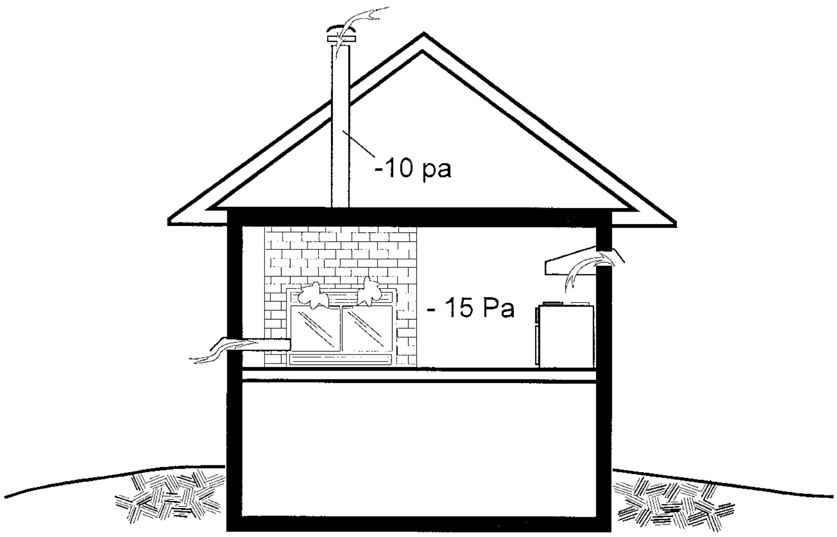
Direct combustion air supplies

Direct combustion air supply: Air from outdoors supplied directly through a duct to the appliance combustion chamber.

Research has shown that properly sized air supplies routed from outside directly to a fireplace or stove combustion chamber can supply the total combustion air requirements after the system has reached operating temperature, provided the firebox is sealed tightly from the room with gasketed glass doors.

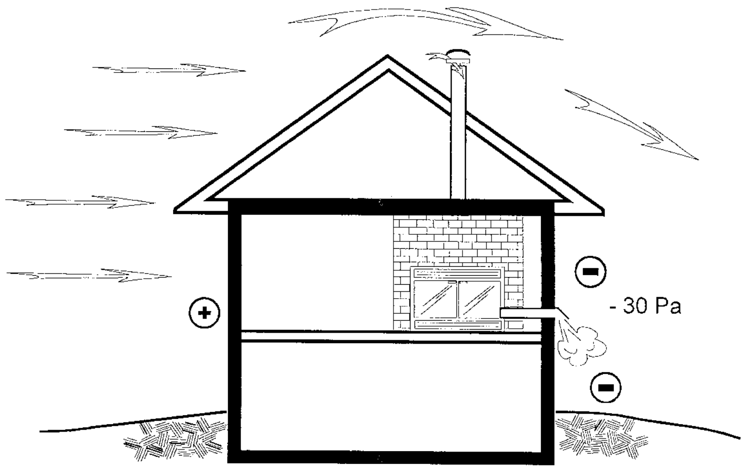
However, two key findings from the research serve as cautions against the widespread use of direct combustion air supplies.

1. Smoke leakage can occur, even when the appliance has tightly sealed doors. If a powerful exhaust ventilator depressurizes the room to a level greater than the draft produced in the chimney, combustion gases will leak from any available opening, such as gaps in gaskets and the joints between factory-built chimney sections. Because air flows to zones of lower pressure, a tightly sealed combustion/venting system will spill a smaller volume of combustion gas into the room than a leakier system, but it will still leak unless it is perfectly sealed. Perfect sealing would be difficult to achieve at the time of construction or installation and is unlikely to be permanent.



When outdoor air is supplied directly to the combustion chamber, exhaust gases will spill into the room if the room pressure is lower than the draft pressure created in the chimney.

2. Direct air supplies can reverse flow direction if the weatherhood is exposed to a negative pressure in excess of chimney draft. Hot exhaust gas passing through a combustion air duct constitutes a potential fire hazard. The pressure effects of wind force around buildings can be far more powerful than the pressures produced by chimney draft. Chimney draft ranges from zero to about 50 Pa in normal residential installations, whereas high wind effects can produce pressures around houses up to 100 Pa.



When a strong wind creates a negative pressure zone around a combustion air supply inlet, it may overcome chimney draft and cause a reversal of gas flow.

Evidence of wind-induced reversals in combustion air ducts is becoming more common now that so many systems have been installed. When diagnosing venting problems in systems with direct outdoor combustion air ducts, look for soot or staining inside the duct. If there is any evidence of reversal, disconnect the duct and plug the hole in the house envelope.

It has been suggested that a direct combustion air supply to a woodburning appliance would eliminate its air consumption impact on other chimney vented combustion equipment in the building. However, when their doors are closed, most woodburning appliances exhaust comparatively little air from the dwelling (see Table 2), so the risk of reversal of a ducted combustion air supply usually outweighs any advantage gained by bringing air from outdoors.

An open fireplace, in contrast, can exhaust such a large volume of air that it could affect the operation of, for example, a conventional gas-fired furnace or water heater. But direct combustion air supplies cannot effectively be connected to a fireplace without doors because insufficient pressure difference is created to drive the flow. Other strategies are required to deal with the impact of open fireplaces on the operation of spillage-susceptible chimney vented equipment in the building. (See Spillage from open fireplaces.)

There may be circumstances in which a direct outdoor air supply is considered necessary. If it is decided to supply combustion air directly to a firebox, it should be done with full awareness that spillage is still likely if the room becomes seriously depressurized and, for safety reasons, steps should be taken to control temperatures on combustibles adjacent to the air supply duct in case wind effects lead to a flow reversal.

Despite the fact that it is enshrined in some building codes and its adherents are often vocally forceful, there is no scientific evidence to suggest that outdoor air supplies, either direct to the combustion chamber or indirect supplies to the living space, are reliable and effective remedial measures for combustion spillage from the appliance for which the supply is intended.

The house as a combustion air supply chamber

A fireplace vented by natural draft needs a reliable and unrestricted supply of combustion air. Since passive outdoor air supplies in reasonable sizes are ineffective and since direct combustion air supplies are unreliable and potentially dangerous, other options must be considered. The most obvious alternative to outdoor air is to take combustion air from inside the building.

The advantage of taking combustion air directly from the room in which the fireplace is installed is that the building envelope moderates the effect of wind on the air supply by damping out wind-induced pressure fluctuations. The pressure inside the house will still be affected by wind to some extent, but the flow resistance offered by the envelope tends to remove the peaks and valleys of high and low pressure caused by wind gusts.

The main disadvantage of taking air from inside the house is that the pressure environment can be adversely affected by powered exhausts. However, depressurization caused by powered exhaust flows is predictable and manageable, unlike the more random and unpredictable effects of wind on outdoor air supplies. The worst-case indoor air pressure environment can be measured using the house pressure test described later, and can be controlled either by limiting exhaust flows or by installing a powered make-up air system.

In general, therefore, fireplaces that are vented by natural chimney draft should draw the air for combustion from the room in which they are located. Where necessary the indoor air pressure should be controlled to minimize depressurization.

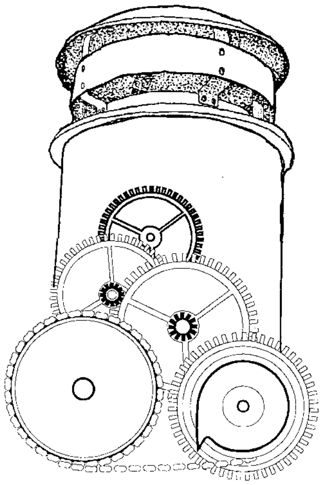
Summary

- passive air supplies do not supply combustion air, but only flow air in response to the pressure in the house compared to outside
- passive air supplies of reasonable size are able to provide only a portion of the air requirements of most fireplaces at house pressures normally encountered
- directly-ducted combustion air supplies may supply all the air requirements, but spillage will still occur if the room is depressurized to a level of pressure greater than that produced in the chimney
- directly-ducted combustion air supplies can reverse flow direction when wind effects create a zone of negative pressure at the outdoor weatherhood
- air flows to zones of lower pressure
- appliances that are vented by natural chimney draft should draw the air required for combustion from the room in which they are located

Susceptibility to combustion spillage can be affected by the design of the venting system. The system is made up of the chimney and, in the case of stoves, the flue pipe assembly. Fireplace owners commonly blame smoking and other malfunctions on the fireplace itself. But in in the majority of cases, it is the design and location of the venting system that is the source of problems. Here is a review of the characteristics of the venting system that can affect fireplace performance.

Flue insulation

As you have learned, the temperature difference between the air and/or combustion gas in the venting system and the outdoor air produces the key driving pressure in natural draft systems. Therefore, chimneys that minimize heat loss tend to perform better because they maintain a higher average flue gas temperature and produce more draft.



The chimney is the "engine" that drives the fireplace system.

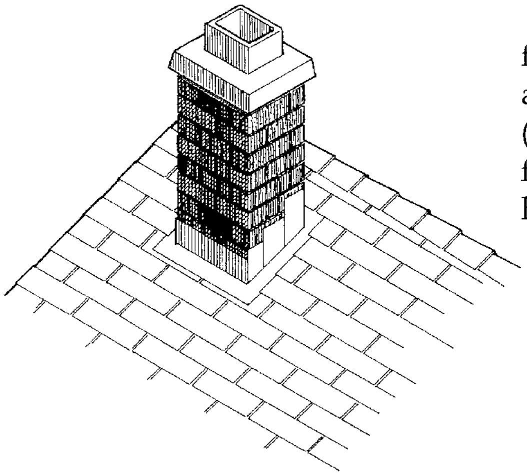
A useful analogy when considering the functional characteristics of chimneys is to view the chimney as the engine that drives the system. Think of heat as the fuel for the engine and think of draft as its power output. The more heat (fuel) that is delivered to the engine, the more draft (power) it will produce. Any loss of heat from the engine itself is wasted fuel that detracts from its potential power output.

Theoretically therefore, the best chimney is one that insulates the flue gas passage perfectly, losing no heat to the outside. Such a chimney would maintain the highest possible average gas temperature from bottom to top. In practical terms, however, a perfect chimney might require the use of exotic materials and could be very expensive. So, given the commercial and practical limitations, how do modern chimneys stack up against perfection?

The vast majority of modern chimneys fall into three categories: masonry chimneys, solid-pack insulated metal chimneys, and double- or triple-wall, air-cooled metal chimneys.

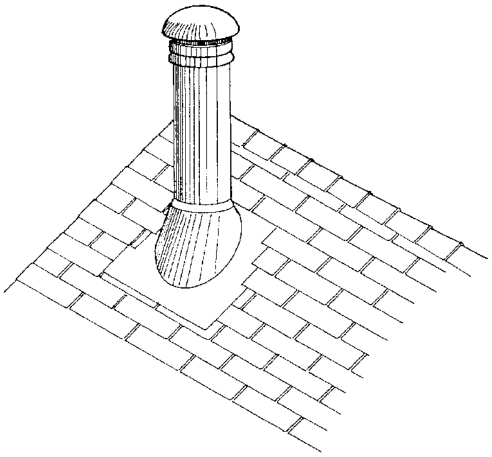
Conventional masonry chimneys

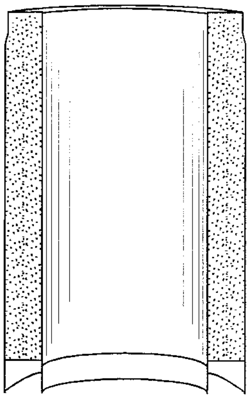
Conventional masonry chimneys consist of a clay tile flue liner surrounded by an outer shell of brick, block or stone. The flue liner is not insulated and the masonry materials themselves are not particularly good insulators. The massive construction and lack of insulation means it is slow to develop draft as the initial flue gas heat is absorbed into the masonry. On the other hand, when the



fire recedes to a coal bed, draft declines relatively slowly as the stored heat is released back into the flue passage (see Energy momentum). During tail-out phase of the fire, the surface temperature of the flue liner can be higher than the flue gas temperature.

Solid-pack insulated metal chimneys

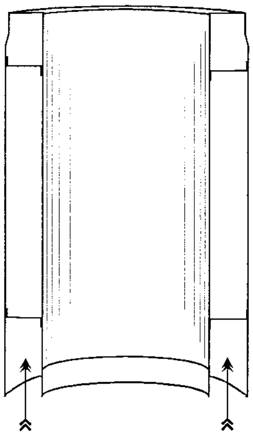




Solid-pack insulated metal chimney

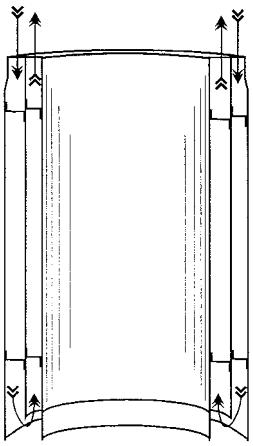
Solid-pack insulated metal chimneys consist of a stainless steel flue liner surrounded by a fibrous insulation and a metal outer casing. A solid-pack chimney develops draft very quickly at start-up because the thin liner has little mass and heat transfer to outside is resisted by the insulation. However, the insulation in some models of solid-pack chimney is not particularly effective because part of its function is to draw heat away from the flue liner to prevent it from overheating during extreme high firing or a chimney fire. The solid-pack material acts as a "heat sink" or mass, which explains why a section of solid-pack chimney is relatively heavy considering its small size. This characteristic may help to maintain some draft as the fire recedes because the mass in the chimney gives up stored heat to the flue gases.

Air-cooled, air insulated and hybrid chimneys

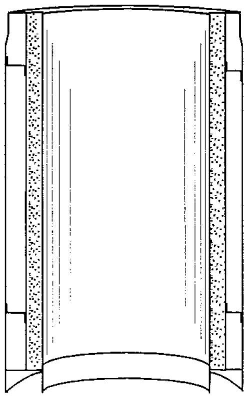


Double-wall, air-cooled metal chimney

Air space is used either alone or in combination with fiber insulation in a number of chimney designs. Double-wall air-cooled chimneys consist of a stainless steel flue liner, an air space and a metal outer casing. There are openings at the base of the chimney for the entry of cooling air which flows between the liner and casing of each section before being expelled at the top of the chimney under the rain cap. Triple-wall air-cooled chimneys draw cooling air from one part of the special top termination where it flows down to the base of the chimney, around the inner wall and back up the inner passage to exit from another section of the complex chimney cap. Air-cooled chimneys allow flue gas heat to be released faster than masonry or solid-pack metal. The very low mass of an



Triple-wall, air-cooled metal chimney



Hybrid air-insulated, solid-pack metal chimney

While it may be tempting to blame the apparent increase in venting failures on houses that are "too airtight", such a view misses other influences, such as chimney design and location, which can be more significant than airtight housing. Besides, resisting the movement towards energy conservation is not likely to be productive or successful in the long run.

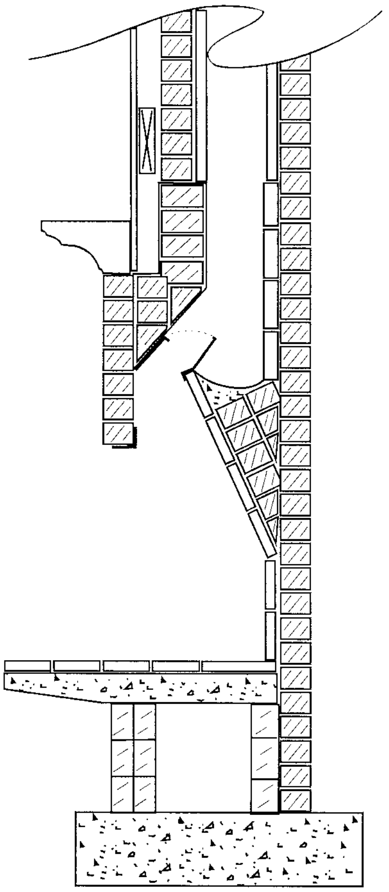
air-cooled chimney means it heats up and develops draft quickly, but it also cools down very quickly. Unlike a masonry or solid-pack chimney, the flue liner in an air-cooled chimney is virtually never at a higher temperature than the flue gases. In general, air-cooled chimneys are used for fireplaces that do not control the rate of combustion to a significant degree. The high flow rates and temperatures characteristic of such fireplaces tend to suit the behavior of air-cooled chimneys.

One serious drawback of air-cooled chimneys is related to the problem of the cold hearth syndrome. Since cold outdoor air circulates through some of these designs, there can be cases in which the air in the chimney is cooled below room temperature, even if the chimney is installed within the building envelope. When this occurs, of course, a cold backdraft is the likely result if the fireplace is installed below the building's neutral pressure plane.

Two hybrid designs use both fiber and air insulation. In one case, a relatively thin layer of fibrous insulation is used around the flue liner and is surrounded by an air space, and in the other case, a thin, sealed air space is maintained between the flue liner and insulation. These types of chimney probably have functional characteristics between that of the solid-pack and air-cooled types.

Going back to our analogy of the chimney as an engine, it is apparent that most modern chimneys do not compare well to perfection. Chimney technology is one aspect of energy use that has not benefited from twenty years of activity in the field of energy conservation. Dramatic reductions in energy consumption have been achieved in virtually every other area: in housing, transportation, industrial process and so on. Efficiency improvements in furnaces, stoves and many fireplaces mean that more of the fuel's heat energy is delivered to the house, resulting in lower flue gas temperatures entering the base of chimneys. Yet the majority of our chimneys continue to waste this precious heat at about the same rate as chimneys did fifty years ago. The relative absence of serious efforts to conserve energy through improved chimney technology, while houses and combustion appliances have changed dramatically, is part of the explanation for the serious venting failures that seem more common today than in the past.

Flow resistance



The damper area of a conventional open masonry fireplace is often the point of greatest flow resistance because of its shape and size.

Another main design feature of a venting system that can affect spillage is the resistance to flow that the system presents to the stream of exhaust gases. The most common restrictions are elbows and key dampers in flue pipe assemblies, flue dampers in masonry fireplaces, baffles in stoves, and offsets, creosote deposits and undersized flues in chimneys. Flow resistance in the venting system is most likely to be a factor when the appliance loading door is opened for fuelling. Open door smoke spillage is linked to venting system restrictions because of the higher volume of gas and air that must be vented. When an appliance is operating normally with its door closed, the volume of flow and speed of the flue gases is relatively low, around 3 ft per second (1 m/s). Elbows, offsets or a small flue offer little resistance at this low flow rate. When the door is opened for loading, however, the flow rate typically doubles as dilution air is drawn through the opening, and the restrictions begin to have a far greater effect. If the venting system restricts its free flow, a portion of the exhaust gas may spill into the room. The lower the resistance to gas flow, the less likely is the spillage of combustion gases when the loading door is opened.

Air leakage

The amount of air permitted to leak into the venting system affects its performance. There are two ways in which air leakage inhibits performance: first, the leaks bleed off pressure, making less draft available at the appliance; and second, cold air leaking into the flue cools the flue gases, reducing temperature difference and therefore draft.

Flue sizing

A chimney with a flue area that is too small for the volume of gas that must be vented acts as a restriction to flow. Inadequate flue size is a problem only for open fireplaces and for other fireplaces and heaters when their doors are opened for loading. In fact, if it weren't for the need to open doors for loading, fireplaces and heaters could get by with much smaller chimneys than are normally used because of the low gas flow rates involved.

A chimney with a flue area that is larger than necessary also inhibits venting performance, but in a different way. A given volume of flue gas flows slower through a large flue than through a small one, allowing more time for heat to transfer from the gases to the liner. And the larger the flue area, the greater is the flue liner surface area for each unit of length. Therefore, an oversized chimney flue leads to excessive flue gas heat loss, particularly in a chimney with little or no liner insulation. Ideally, flue gases move as quickly as possible through the venting system to minimize the time available for heat transfer to the liner. Flue pipes and chimneys should be sized to match the area of the appliance flue collar if there is one, or, in the case of masonry fireplaces, to the correct ratio between flue area and fireplace opening area.

Combining deficiencies

Venting system design deficiencies can combine to produce extremely poor performance. A common example of this combination of deficiencies is an oversized, outside masonry chimney. In this example:

- the chimney runs up the outside of the house envelope, so it is exposed to outside cold,
- the flue liner in standard masonry construction is not insulated, so there is little resistance to heat loss, and
- a nominal 8" x 12" flue liner is considerably larger in area than the perhaps 6" flue collar of the modern efficient appliance it serves, so heat loss is excessive

In this simple, yet common example, three serious deficiencies are combined in a single system. Note also that the flue gas flows through two 90 degree changes of direction – one in the flue pipe and one in the base of the chimney – that add turbulence and further cooling. This chimney would certainly contribute to poor performance of the combustion/venting system.

Where the venting system includes a flue pipe assembly (chimney connector) it should have the following features:

- it is short
- it has no elbows or only one elbow
- it has no key damper or barometric damper
- its joints fit tightly to reduce leaks
- if excessive heat loss is a concern, sealed double-wall flue pipe can be used

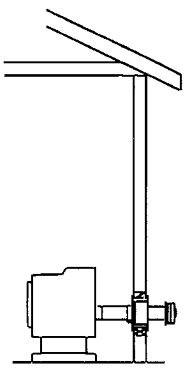
To perform well, the chimney should have the following characteristics:

Hint: this is the BIG list for good chimney performance!

- it is installed inside the building envelope
- it exits the building envelope at or near its highest point
- insulation surrounds the flue liner
- it has no offset or only slight (15°) offset
- it has no significant leaks
- its top is not exposed to adverse wind pressures
- it exceeds 15 ft. (4.6 m) in height
- the flue area matches the appliance flue collar area

Pellet appliance venting

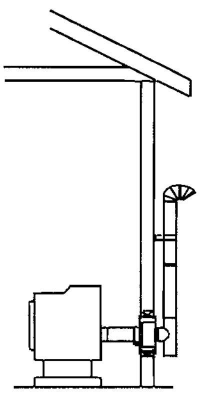
Pellet appliances have an internal fan that draws air through the combustion chamber and forces the exhaust into the venting system. These automatic feed appliances do not strictly rely on natural draft for successful operation, but some natural draft can help to avoid smoke spillage under some conditions.



Horizontal pellet vent installation.

Pellet stoves are not required to vent through a chimney. Instead, a special double wall pipe is used, similar to the B-vent used for gas appliances except that it uses a stainless steel liner. There is no insulation between the two walls of the pipe.

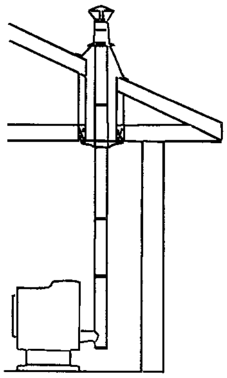
Since they have a powered exhaust system, it was first thought that pellet stoves could just be vented horizontally through the wall. This design works well unless an electrical power failure stops the exhaust fan. Then, the smoke from the small amount of burning fuel seeps out of the stove into the room. This problem has prompted some angry calls from pellet stove owners to the stores that sold them. Now, a new battery backup accessory is available that keeps the fan running for a few minutes, thereby preventing the seeping smoke.



Horizontal pellet vent with natural draft assist.

As an alternative to battery backup, some amount of natural draft can be provided so that any remaining combustion products will be vented in case of a power failure. To do this, a few feet of rise was added to the horizontal vent. The idea is that the hot gas in the vertical portion of the vent will create some draft for long enough to burn the remaining fuel in the chamber and vent it outside. This proved to be a successful strategy for most situations.

Some locations, however, do not favor horizontal venting of pellet stoves. Experience has shown that



Vertical pellet vent installation.

houses located on the ocean or other high wind locations, particularly when the vent termination faces into the wind, can suffer from venting failure. When wind creates a high pressure zone on the same wall as the vent termination, the vent pressure from the exhaust fan can be overcome. In moderate cases the result is erratic, dirty combustion, and in severe cases, full backdrafts of exhaust into the home.

The only certain way to deal with the problem of wind is to run the vent up through the roof. The vent termination will still experience wind, but will not experience the velocity pressure produced when wind strikes the wall of a house. The vertical pellet vent installation is the most consistently reliable way to vent a pellet appliance, but it is rarely used because of the additional cost involved.

Summary

- insulated chimneys produce stronger and more reliable draft than uninsulated chimneys
- flow resistance in a venting system increases the likelihood of open door spillage
- air leakage into the venting system should be minimized
- chimney venting systems should exceed 15 ft. (4.6 m) in height
- the chimney flue should be matched in size to the requirements of the appliance it serves
- most chimneys currently available to the public do not posses the characteristics needed for reliable venting
- pellet vents should have some rise to provide natural draft assist to the draft fan; in windy locations pellet appliances should be vented vertically through the roof

Appliance design influences

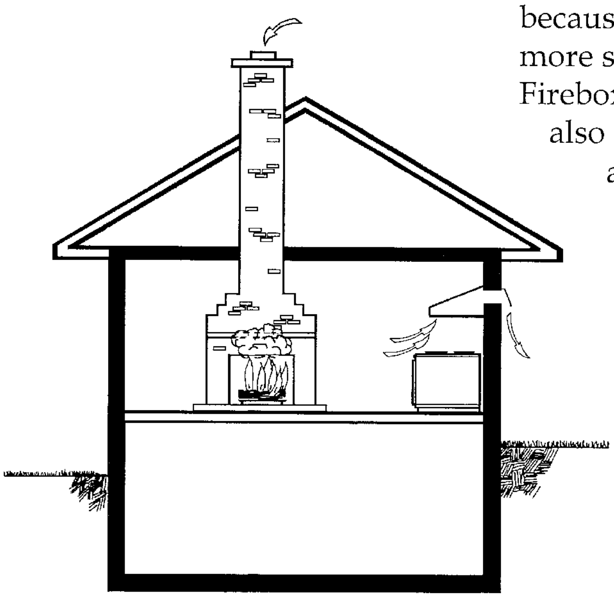
The design of the fireplace or stove can contribute to either spillage resistance or the likelihood of the system to spill. Although there are several appliance characteristics that affect spillage performance, one characteristic tends to dominate all others: the demand for combustion and dilution air. Generally, the less air an appliance needs for proper operation, the more resistant to spillage it will be. The following list of chimney vented hearth categories is presented in approximate order of the least to the most spillage resistant:

- open fireplaces (wood or gas log)
- gas appliances with draft hoods (space heaters, inserts, fireplaces)
- conventional masonry or factory-built fireplaces with doors but no gaskets
- controlled combustion woodburning appliances
- EPA certified woodburning appliances

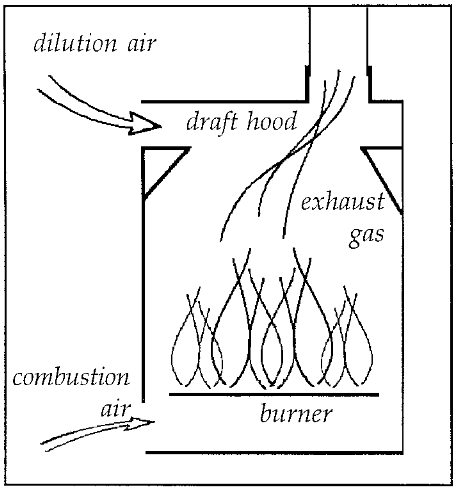
Note that some other characteristics of an appliance within a category may effect its spillage resistance and change its ranking.

The presence of a solid barrier between the room and the combustion chamber increases spillage resistance dramatically. This effect is not simply because doors keep the smoke inside by providing fewer leakage sites. In fact, it has more to do with higher gas temperatures and stronger draft because less dilution air is admitted.

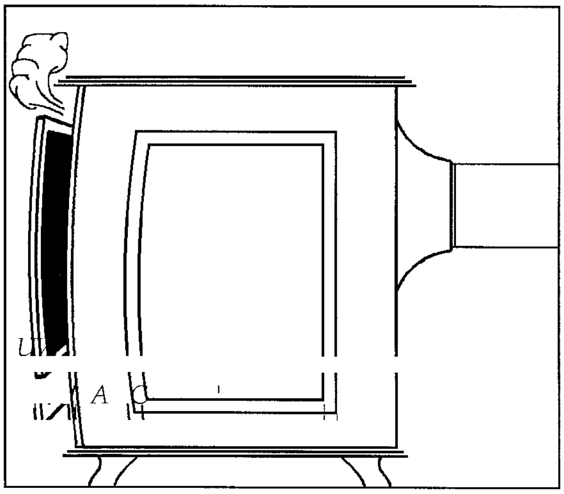
EPA certified appliances tend to be more spillage resistant than other appliances having similar tightness because their sophisticated combustion systems provide more stable combustion and so are less likely to smolder. Firebox insulation and a more complex internal structure also gives EPA certified stoves and fireplace more mass and therefore more energy momentum than conventional equipment.



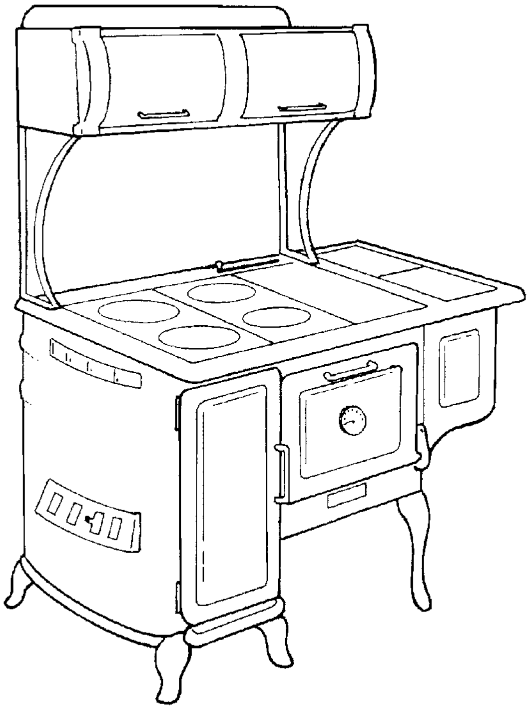
- *An open fireplace without doors has almost no spillage resistance during a significant part of the burn cycle because there is no barrier provided between the combustion process and the room.*



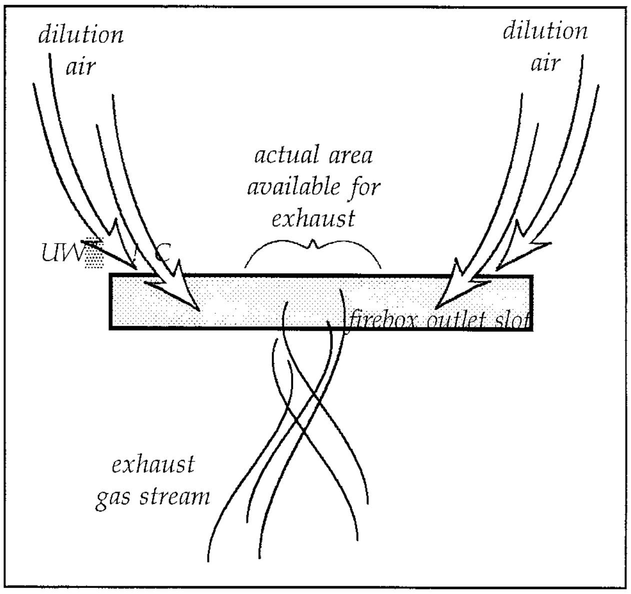
- *Gas and propane appliances with draft hoods are considered to be "open" in the same way we refer to fireplaces without doors as being open, in that there is no boundary separating the flue gas passage from the room. As a result, they are about as susceptible to spillage as open fireplaces.*



- *An appliance with a firebox exhaust exit that is lower than the top of the door opening is more susceptible to open door spillage.*



- *An appliance that has leaky joints is more susceptible to spillage. Cook stoves commonly spill combustion gases from their leaky cooking surfaces, either when the door is opened for fuelling, or when the door is closed if draft falls to very low levels.*



- *An appliance in which the firebox outlet is in the shape of a narrow slot is more susceptible to spillage when the loading door is opened than one with a round outlet because the flow of dilution air tends to block much of the exhaust opening. Examples of such appliances are conventional masonry fireplaces and wood stoves with horizontal baffles.*

What you can do about appliance design

Aside from replacing gaskets and cementing cast iron joints in order to reduce leakage, you may be unable to modify the appliance to make it more spillage-resistant. However, in diagnosing spillage problems, you should recognize the characteristic of an appliance that may make it spillage-susceptible and try to overcome it by improving the venting system.

Also, when considering a suitable appliance for a particular situation, you can take account of an appliance's adverse characteristic by ensuring that the rest of the installation has the necessary driving characteristics to compensate.

Here are some other appliance characteristics that can affect spillage performance:

- *Appliances with large door openings relative to their smallest internal flue passage will spill smoke more readily when their loading door is opened for fuelling.*

- *An appliance with flue passages that are lower than the top of the combustion chamber may be more susceptible to closed door spillage. Examples include many cooking ranges, and wood stoves with side or downdraft combustion design.*

- *If fireplaces without doors are spillage susceptible, then fireplaces with two openings are* extremely *spillage susceptible. If smoke in a house is not an acceptable result of appliance selection, never select a so-called "see-through" fireplace – it will smoke.*

Hearth Appliance Options

If you are looking for spillage resistance, pick these | not these

	FIREPLACES		FIREPLACE INSERTS	FREESTANDING STOVES
	MASONRY	FACTORY-BUILT		
WOODBURNING	• conventional or Rumford style, open or with loose doors	• conventional with loose doors, i.e. builder's box • freestanding	• retro-fit fireplace/smoke chamber liner assemblies	• conventional, "non-airtight" cook stoves, Franklin fireplace/stoves antiques, etc.
	• masonry heater with heat transfer to massive structure	• ideally EPA/B415 emissions certified; if not, at least cont-rolled combustion	• ideally EPA/B415 emissions certified mandatory in U.S. and other jurisdictions	• ideally EPA/B415 emissions certified mandatory in U.S. and other jurisdictions
PELLET BURNING	N/A	• vented horizontally	• vented horizontally	• vented horizontally
	N/A	• vented vertically	• verted vertically	• vented vertically
PIPED GAS OR PROPANE	• gas logs	• B-vented (vertical)	• B-vented (vertical)	• B-vented (vertical)
	• gas-fired masonry heater	• sealed direct vent (horizontal)	• sealed direct vent (vertical or horizontal)	• sealed direct vent (usually horizontal)

Summary

- in general, the less air an appliance needs for proper operation, the more spillage resistant it will be
- open appliances, such as fireplaces without doors or gas appliances with draft hoods, have little resist-ance to spillage
- appliances with large door openings relative to their flue size are susceptible to open door spillage
- appliances with firebox outlets in the shape of a narrow slot are susceptible to open door spillage
- appliances with flue outlets below the top of the loading door are susceptible to open door spillage
- appliances with flue outlets or internal passages that route flue gases downward are susceptible to closed door spillage
- appliances with leaky joints are susceptible to both open and closed door spillage
- in many cases the spillage susceptible characteris-tics of appliances can be overcome by good venting system design

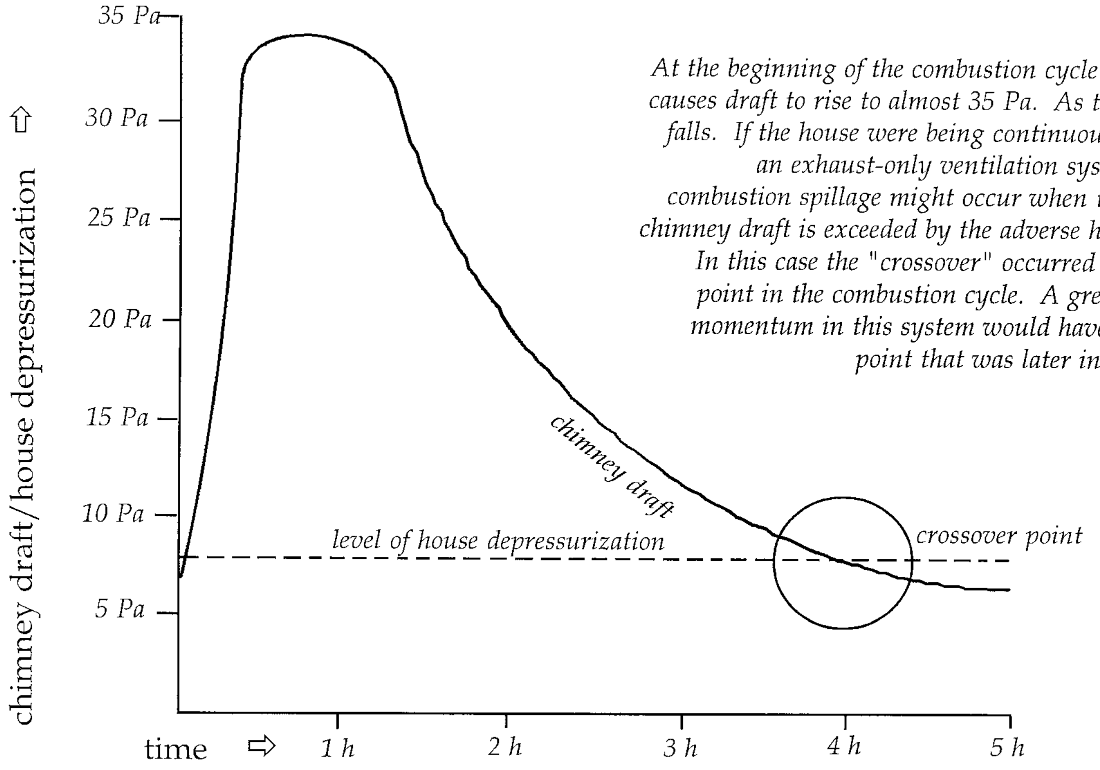
Combustion appliances operating on natural draft are most susceptible to spillage when system temperatures are low. Low temperatures occur at the beginning and end of the combustion cycle.

As a combustion cycle begins, hot gas rises through the system, producing draft and reducing the susceptibility to combustion spillage. Some of the heat produced at the beginning of the combustion cycle is absorbed by the materials of the appliance and venting system.

As a wood fire recedes into the coal bed phase, the heat output and gas flow rates decline until combustion ceases completely. During this tail-out phase of the fire, the system becomes increasingly susceptible to combustion spillage if the room is depressurized.

***Energy momentum** is the tendency of some combustion/venting systems to continue to produce draft after combustion has stopped as the heat energy stored in the materials of the system is released into the flue.*

Part of the heat output of an appliance is stored in the materials of the appliance and venting system. When the fire recedes or cycles off, this stored heat energy is released and continues to produce draft in the system after combustion has ceased. The energy momentum created by the stored heat in the combustion appliance and chimney makes the system less susceptible to spillage during tail-out.



At the beginning of the combustion cycle the heat in the system causes draft to rise to almost 35 Pa. As the fire 'tails out' draft falls. If the house were being continuously depressurized – by an exhaust-only ventilation system in this example – combustion spillage might occur when the driving pressure of chimney draft is exceeded by the adverse house depressurization. In this case the "crossover" occurred at about the four hour point in the combustion cycle. A greater amount of energy momentum in this system would have produced a crossover point that was later in the combustion cycle.

The value of energy momentum "invested" in the system during a combustion cycle is dependent mostly on the mass or weight of the materials it is made of. The more massive the appliance and chimney, the more energy momentum the system will have.

A masonry heater is an example of a system with very high energy momentum. The heat stored in the mass of the structure continues to produce strong draft long after combustion has ceased. This characteristic makes masonry heaters most resistant to spillage during tail-out.

At the other extreme, a lightweight factory-built fireplace vented through an air-cooled chimney is an example of a system possessing very little energy momentum. The air cooling of the chimney liner would chill the flue gases throughout the tail-out period. Such fireplace/chimney systems are highly susceptible to spillage if the room is depressurized during the tail-out phase of the fire.

Appliances certified by EPA as having low emissions fall somewhere between the examples cited above. EPA certified appliances tend to have firebrick lining or other forms of firebox insulation and/or internal structures like catalytic chambers to achieve low emissions. These features tend to create more mass and therefore energy momentum in these products.

There is little you can do about the energy momentum characteristics of the fireplace you select, but knowledge of the concept can be helpful in the diagnosis of spillage problems.

Summary

- energy momentum is created by the mass of the appliance and venting system
- the more energy momentum that is created in a system, the more resistant it will be to spillage during tail-out if the building is depressurized

Unlike automated hearth and heating systems using oil, gas or electricity, woodburning systems require regular input by the user. There is a wide variation in skill and knowledge among operators of woodburning devices. Survey research has shown that a skilled operator could avoid spillage from a fireplace or heater, even if the system had several adverse design characteristics. On the other hand, some users could induce spillage from systems of good design by using inappropriate operating techniques.

Open door spillage

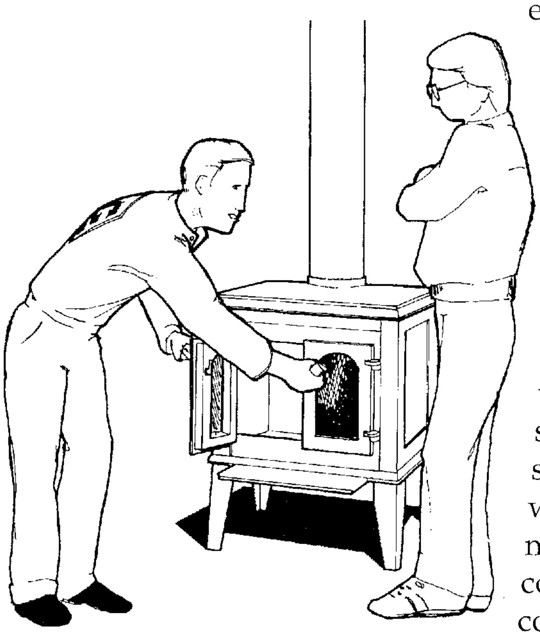
The most common spillage incident occurs when the appliance loading door is opened for stoking, a form of spillage referred to as smoke roll-out. Roll-out can be induced in virtually any woodburning system by opening the loading door quickly, particularly before draft has been fully established or during a low fire. Failure to open a flue pipe key damper or an appliance bypass damper before opening the loading door are also common operating errors leading to smoke roll-out. Although smoke roll-out is common when the appliance door is opened for stoking, it is the least dangerous form of spillage because it occurs when the user is present to take corrective action by closing the door.

Smoke roll-out from an open fireplace is more serious since there are no doors to close in order to stop the spillage. The problem of smoke roll-out from an open masonry fireplace can sometimes be reduced by changing its internal shape (see Combustion spillage from open fireplaces).

Closed door spillage

Closed door spillage is of greater concern because it can occur when there is no one nearby to take remedial action, such as over night when people are sleeping. Spillage or backdrafting induced by severe house depressurization when a large exhaust system is turned on can usually be corrected by turning off the exhaust system. Mind you, a reliable remedial measure that would prevent excessive depressurization is more desirable than depending on the quick thinking of the householder.

Spillage that is not associated with room depressurization but occurs with the appliance door(s) closed is associated with a combination of inadequate temperature difference (low draft), appliance design, and adverse pressures caused by stack effect or wind effects. Although users cannot control these adverse pressures, they can have some control over temperature difference. The following actual cases of closed door spillage illustrate the mechanisms of user input.



The owner of a new side-draft wood stove with an internal bypass damper was unfamiliar with the operation of the combustion air control which included a bimetallic coil to moderate the firing rate. The stove had a rear exit flue collar and a very short flue pipe assembly directly entering the breech of an inside masonry chimney having a nominal 8" x 12" flue tile. The user complained of a slight but chronic smell of wood smoke in the house. Diagnosis revealed that, although the user's firewood was fine and his kindling and stoking techniques were good, he was setting the air control far too close to the closed position in the attempt to achieve an overnight burn. The result was that the fire starved for air and combustion collapsed to a smolder. The chimney was not receiving enough heat to produce reasonable draft, the appliance was acting as its own short stack, and a small amount of smoke leaked steadily from a gasketed section at the top of the stove. The remedial measures were simple: the user was informed about the bimetallic mechanism and its proper use, and the combustion air control was adjusted to make its range of movement more consistent with what the user should expect in terms of firing rate. The spillage was eliminated and the smell of smoke did not return.

In the second example, a 30 year old cooking range was used for both cooking and supplementary heating in a rural home. It had a key damper in the flue pipe leading to an outside masonry chimney with a nominal 8" x 12" flue. The users were long-time woodburners who had experienced brief episodes of spillage of the type that is common with older cook stoves. However, one night the system suffered a full backdraft that filled the house with smoke as the family slept. Although there were no injuries and no damage, the family was frightened by the experience. The users had largely diagnosed the problem by the time professionals became involved. They reported that it had been a particularly cold night, that larger than normal pieces of firewood had been used and that the flue pipe key damper had been closed more than normal in order to achieve an overnight burn. The actual mechanism of the failure was probably as follows: combustion collapsed to a smolder due to the combination of large wood pieces and the low draft caused by the key damper setting. The chimney was not receiving much heat and was being further cooled by cold weather. Smoke began to spill from the leaky cooking surface of the stove, diverting some of the combustion heat to the house rather than to the chimney, and a full backdraft followed shortly thereafter. As a result of this episode, the householders resolved to be more careful in the use of the flue pipe key damper and to use other means for over night heating until they could afford to have a new chimney installed inside the house envelope.

Both of these examples of closed door spillage have four key factors in common. First, in both cases the fire was in an extreme smolder mode, producing a lot of smoke and very little heat. Second, both systems had a damper between the combustion chamber and chimney which was used to route the exhaust through relatively restrictive internal passages. Third, the internal passages routed the exhaust downward before exiting the rear of the appliance. And fourth, user input was a significant factor in the mechanism of spillage in both cases.

In neither case were the effects of adverse wind directly implicated in the spillage, although it is easy to imagine how it could come into play in similar cases.

While the internal characteristics of the two appliances were implicated in these episodes of closed-door spillage, such designs should not necessarily be avoided. A venting system with good (driving) characteristics, combined with an informed user can easily overcome the somewhat adverse characteristics of such appliances.

Influence of operator skill

Since temperature difference is the most important ingredient in successful chimney venting, the practices of the user in building and maintaining wood fires is a critical factor. Users who permit wood combustion to collapse into a smolder are far more likely to experience both open and closed door spillage than those who use appropriate techniques. It has also been shown that users of woodburning appliances that have glass doors with "air-wash" systems learn proper techniques more readily because they can see the effects of their input. Users who are informed that the door glass should stay clear and that if it doesn't, something is wrong, are far more likely to avoid smoldering than users of appliances with solid doors. This visual feedback mechanism is an unexpected but significant benefit of glass air wash systems.

Another beneficial coincidence is that the appliance features and operating procedures that are needed to reduce outdoor air emissions are precisely the same as those that will minimize indoor air pollution resulting from combustion spillage. These include internal characteristics that promote stable combustion, properly seasoned and sized firewood, firing practices that produce quick ignition when a fire is started, and air control settings that will sustain flaming combustion or catalytic combustion, (depending on appliance design) until the coal bed phase.

Tolerance of wood smoke in the house

The amount of wood smoke permitted to spill into a house is governed to some degree by the tolerance of the householders to this form of indoor air pollution. It is apparent that some householders accept the smell of wood smoke as a by-product of using a stove or fireplace, even associating "that nice woodsy smell" with the pleasures of woodburning. Others are intolerant to the slightest evidence of spillage. Part of the solution to the problem of combustion spillage from woodburning systems is to inform users that the smell of wood smoke in the house is not normal and should not be tolerated.

Summary

- users of woodburning equipment may either induce or prevent spillage, depending on their skill level
- the most common form of spillage occurs when the loading doors are open
- the most problematic user influence is to cause the fire to smolder, a condition that can be linked to dangerous closed-door spillage
- the tolerance of householders to the smell of wood smoke can influence the amount of smoke spilled

It could be said that open fireplaces are not compatible with modern housing. To vent successfully in a house with a tight envelope, an open fireplace would have to be of perfect design in all respects and be combined with a sophisticated house pressure management system.

Fireplaces without doors present special problems because they provide no barrier between the combustion chamber and the room. Whether they are woodburning or have a gas log, open fireplaces operate within a narrow band between successful venting and spillage. A small amount of room depressurization, or even the moving air currents produced by someone walking briskly in front of the opening, can be enough to cause spillage. There are several reasons why open fireplaces seem so fussy today despite the fact that they were used as the sole source of heat for many houses as recently as a century ago. Historically, the chimney was contained within the building envelope, the envelope was leaky, the venting system was massive and was kept warm around the clock because the fireplace was the sole source of heat. All of these factors contributed to reliable venting, even with an open fireplace.

Influence of a tight envelope

The most commonly cited reason for spillage is the more airtight house construction that has become increasingly common over the past 20 years. An open fireplace consumes a large volume of room air beyond that required for combustion (referred to as excess air) in order to flow combustion gases up the chimney instead of into the room. Excess air levels are regularly between 10 and 20 times the amount needed for combustion. The envelope of a tightly constructed house resists the infiltration of this much air. The result is that the fireplace can starve for air and some smoke may escape into the room. Although the flow resistance of a tight building envelope is a key factor in many cases of venting failure in open fireplaces, it is by no means the only cause.

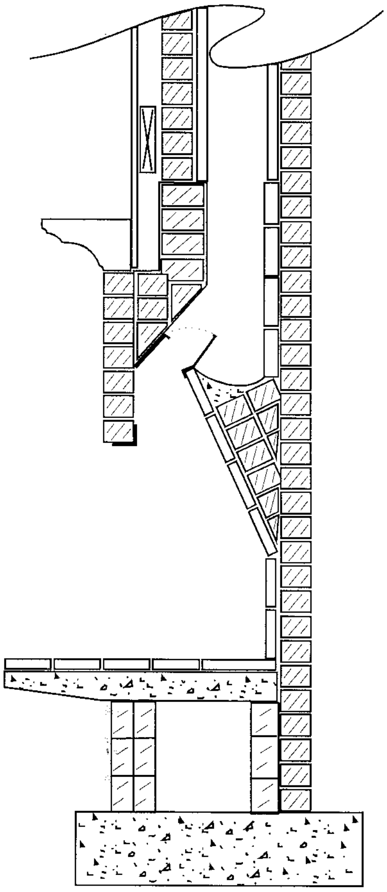
Masonry fireplace design

While some people may contest the point, it is clear that the internal design of the traditional masonry fireplace is based more on speculation than science. For example, the standard rectangular shape of the throat damper opening is adverse to effective venting. The sloping forward of the back of the firebox as it rises to form the smoke shelf forces combustion gases toward the opening, making spillage more likely. And forcing the exhaust gas and dilution air to change direction abruptly around the sharp edges and angles of the smoke shelf and damper causes resistance to flow, again making spillage more likely. The plume of exhaust gas from a fire naturally forms a conical shape as it spirals upward. Any interference with this shape tends to promote spillage.

From an aerodynamic perspective, the traditional fireplace design is all wrong.

Factory-built fireplaces are often more resistant to spillage than masonry versions because of their more appropriate internal shape: a domed firebox ceiling and centrally located round flue. Nevertheless, all open fireplaces, whether factory-built or masonry, are susceptible to spillage, particularly during fire kindling and tail-out periods. The tighter envelopes of modern houses just make matters worse.

Remedial options



The internal design of the traditional masonry fireplace tends to promote spillage.

There is no single best remedial measure for open fireplaces that spill. This is because of the wide range of taste in fireplace design and in the perceived need for a functioning hearth among the homeowners. Although it is conceivable that any fireplace could be made to work in any building, the cost in some cases would surely be prohibitive.

The most obvious, effective and inexpensive remedial measure for a troubled open fireplace is to install a set of glass doors. The presence of this barrier between the firebox and the room makes the fireplace far more resistant to spillage and reduces its excess air consumption. The installation of an EPA certified wood burning fireplace insert is even more effective than glass doors, provided the installation includes stainless steel chimney liner running to the top of the masonry chimney. Another viable option is a direct vent gas insert.

Despite the effectiveness of glass doors and fireplace inserts, they are not acceptable in some situations because the householder demands historical accuracy or simply wants the aesthetics of an open hearth. This discussion of remedial measures assumes that the glass door and fireplace insert options have been offered to the customer and rejected.

Solve the cold backdraft first

If the fireplace is prone to cold backdraft because it is located well below the neutral pressure plane and because the chimney is outside or is effectively shorter than the house envelope, the right strategy is to solve the cold backdraft first. An open fireplace that cold backdrafts in addition to the other inherent problems will be almost impossible to operate without smoke spillage. On the other hand, an open fireplace that vents properly at standby is much more likely to operate successfully, and even if there are spillage problems, corrective measures may be effective.

While other strategies are able to mask the cold backdraft problem, only by enclosing the chimney within the house envelope can the cause of the backdraft be eliminated. If enclosing the chimney within the house envelope is not practical or the expense cannot be justified, a less desirable but potentially effective method that can be called seal at standby/pressurize at start-up could be considered. This option does not require renovations to the house, but does not fully resolve the problem of the cold hearth. It is a two-step strategy:

- install a tight fitting damper at the chimney top, and
- install a powered make-up air system controlled by a switch (possibly with a timer) near the fireplace

In this scenario, the chimney damper prevents a cold backdraft and the make-up air system causes the room to be pressurized while a fire is built and chimney draft is established. If the fireplace is large and the building envelope is tight, the make-up air system may have to operate continuously while the fireplace is used to prevent air starvation. It would certainly need to be used continuously if there were other spillage-susceptible combustion equipment in the house, such as a conventional gas furnace or water heater. Note that the make-up air system would be installed in the basement or in a utility room, but the control switch could be located near the fireplace. It is rarely necessary to "place" the make-up air near the exhausting appliance, although, considering the volume of make-up air required by an open fireplace, the supply outlet should be on the same level of the house and should not be separated from the fireplace by tight fitting interior doors.

Theoretically, once the householders had been trained in the correct use of the system, they could build a fire at any time without fear of smoke spillage, and they would not have to put up with the cold hearth syndrome.

The main disadvantage, and potential danger, of this approach is that the core problem of cold backdraft has not been corrected. The system could revert to cold backdraft during a receding fire if the chimney were being severely chilled. A cold backdraft on an active coal bed can result in the spillage of a significant quantity of carbon monoxide. This is not just a theoretical possibility, but is one of the more common failure modes of severely troubled open systems. Another problem, although less serious, occurs when the fireplace is not being used and the chimney-top damper is closed. By sealing the flue at the top, a top damper stops outdoor air from flowing down the chimney, but permits a convection current of room air to flow within the chimney. This flow of air not only brings cool air into the room, it also brings hearth odors. If glass doors are not an acceptable option, hearth deodorizing chemicals, available from specialty hearth dealers, can help to control odors from unused fireplaces.

The decision as to the viability of this option would be based on the amount of use the fireplace was likely to get and on the severity of the cold backdraft. If the backdraft is chronic and powerful, this option should not be recommended.

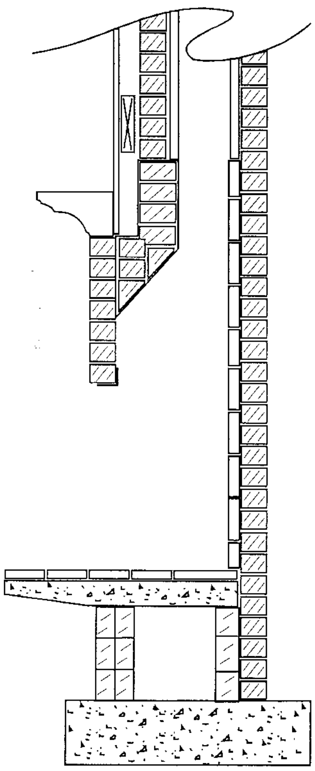
Solving other spillage problems

A couple of remedial strategies are available for a fireplace that does not cold backdraft but from which smoke rolls out during operation.

Note: *any modification of a factory-built fireplace would void its warranty and violate the conditions that building codes impose on its installation; factory-built fireplaces must not be modified. If the design of a factory-built fireplace is determined to be the cause of smoke spillage, it should be replaced with a fireplace of better design.*

If modifications to a masonry fireplace are planned, they must not reduce structural strength or protection for combustible material to less than building codes require.

The performance of a traditional fireplace may be improved by removing the damper and smoke shelf and creating a smoothly tapered, inverted funnel shape. The throat damper is replaced with a chimney top damper operated by a cable from the fireplace. Although this internal reshaping can be the most successful remedial measure for a problem masonry fireplace, the work can be technically challenging and should be carried out only by experienced personnel. A simpler way of achieving the same result is to use a factory-built retrofit fireplace liner consisting of a cast refractory firebox, stainless steel smoke dome and stainless steel liner.



The aerodynamic characteristics of a masonry fireplace may be improved by removing the smoke shelf and damper.

The ratio of the flue area to the area of the fireplace opening is one aspect of masonry fireplace design that is regulated by most building codes. The codes usually provide tables of flue sizes for various opening sizes. The tables in some codes include guidelines for flue size based on a range of chimney height and for chimneys with insulated flues. The basis of the tables, however, is simple ratios of firebox opening area to flue area. These normally range from a ratio of 10:1 for short, uninsulated chimneys to as much as 19:1 for tall chimneys that are insulated. Where the resistance offered by a flue area that is too small for the firebox opening is judged to be the cause of spillage, the standard remedial measure is to make the firebox opening smaller, since it is difficult if not impossible to make an existing chimney larger. In general, however, it is better to correct any internal restrictions, such as the design of the damper and smoke shelf before dealing with what appears to be a flue of inadequate area. Field experience has shown that a fireplace with a smooth, conical dome above the firebox can perform well with a relatively small flue.

Fireplaces with more than one face open to the room are particularly prone to spillage. Open fireplace designs, such as two-sided see-through, three-sided bay or peninsula, or four-sided will only work under perfectly ideal conditions. Just because architects, builders and home buyers like such designs for aesthetic appeal and decorating possibilities, does not mean they are practical or technically feasible in modern housing. When such a fireplace design is proposed, those involved should be warned in clear terms that smoke spillage is extremely likely. Clearly stating this warning is a key responsibility of qualified hearth or housing personnel.

If all other remedial measures fail to control smoke roll-out, the final option is to pressurize the building while the fireplace is operating. This less-than-elegant solution should not be recommended except in cases in which the need to have an functioning open fireplace outweighs the disadvantages. The disadvantages include the cost of additional energy consumed, the challenge of training the householders in the use of the system, and the inherent problems of both fully manual switches and timers.

Conclusion

It could be argued with some validity that open fireplaces are not compatible with modern housing. As building envelopes become more tightly sealed for comfort and energy conservation reasons, the operation of open fireplaces becomes more problematic. An "off the shelf" open fireplace design is almost certain to suffer venting failure in a tight house.

To vent successfully in a house with a tight envelope, an open fireplace would have to be of perfect design in all respects AND be combined with a sophisticated house pressure management system.

Instead of the "prescriptive" approach to fireplace design found in most building codes, open fireplace installations need to be engineered to account for the particular characteristics of the house and the fireplace. A "performance" based requirement for open hearths would put the onus on the designer/installer to prove through testing that the system would function safely in the house environment.

Summary

- open fireplaces are extremely vulnerable to combustion spillage
- the internal design of traditional masonry fireplaces is not conducive to successful venting
- the installation of glass doors is the most effective and least expensive way to increase the spillage resistance of open fireplaces
- the most effective and trouble-free remedial measure for a troubled open fireplace is the installation of an EPA certified woodburning fireplace insert with a full stainless steel liner to the top of the chimney, or a direct vent gas fireplace insert
- the ratio of flue area to hearth opening is a factor in smoke roll-out
- fireplaces with more than one face open to the room are particularly prone to spillage
- to vent properly in a tight house, an open fireplace would need to be of perfect design in all respects and be combined with a sophisticated house pressure management system

The spillage test

Research testing by various organizations has demonstrated the spillage resistance of most combustion appliance types, including fireplaces. Once you know what level of house depressurization a particular fireplace can tolerate without spilling, you can compare this level to the actual pressure environment of a house.

Using the procedure set out here, you can test the house to find out how depressurized it can become when its exhaust ventilators are operating. The test results will tell you if the maximum house depressurization level exceeds the spillage resistance pressure of the fireplace. At that point you can either choose a more spillage resistant fireplace or install devices to maintain the house pressure within safe bounds.

The general procedure* for the pressure test is to close and latch all exterior doors, windows and other openings to simulate the house condition during cold weather. Then, various exhaust ventilators are turned on, the level of depressurization is measured, and is compared to the pressure limit for the appliance in question. The test is designed to reveal the pressure drop caused by exhaust systems only; it does not include a measurement of stack effect. This is because stack effect is entirely dependent on temperature difference. If you want to find out the net influence of exhaust systems and stack effect on chimney performance for the day of the test, measure chimney draft while the exhaust systems are operating. Be aware, however, that the level of chimney draft or stack effect in the house are highly variable, depending on temperature difference and wind effects.

The test may be done at any outdoor temperature, but should only be done when there is little or no breeze; wind speed should not exceed 10 mph so that pressure fluctuations are minimized.

* The procedure outlined here is intended to be used only as a system design and diagnostic tool. It is anticipated that regulatory authorities in some jurisdictions may adopt a standardized approach to house pressure testing in order to ensure safe combustion venting in new buildings. The use of the procedure set out here should be discontinued in favor of a standardized approach when such is available.

Spillage test procedures

1. **Assemble tools and equipment**
    - a digital (preferably), or magnehelic, or inclined-tube pressure gauge (manometer) with a resolution of +/-1 Pa and a range of at least 0 - 60 Pa
    - 30 ft. of plastic tubing to fit pressure gauge taps
    - smoke pencil or other device to illustrate flow direction (a strip of facial tissue works in most cases)
    - electric drill and bit to match flue pipe probe

2. **Put house in heating season condition**
    - close and latch all exterior doors and windows; ensure attic hatches are seated, etc.
    - open all interior doors (testing may be done with certain doors closed later in the procedure)
    - turn off all exhaust fans and combustion equipment; i.e.. turn down thermostats for oil and gas furnaces and water heaters
    - close doors and dampers of woodburning appliances

3. **Set up the pressure gauge**
    - set up the pressure gauge on the same level of the house and, if possible, in the same room as the stove or fireplace is located
    - connect tubing to the reference or high pressure tap of the gauge and pass it through the corner of a door or window so that the tube is not pinched when the door or window is closed and leakage is minimized; seal the joint with masking tape if necessary
    - place the end of the tube about 20 ft. from the building so there is little or no influence from air turbulence around the building
    - if there is an indoor/outdoor temperature difference, the gauge will read stack pressure which is of no interest in this test, so set the gauge reading to zero or deduct average stack effect reading from all subsequent readings; in this way only depressurization caused by exhaust devices will be measured

4. **Test furnace fan effects**
   - turn the furnace air-circulation fan on high speed to determine if the room pressure is affected; close the furnace room door (if applicable) and read the pressure again
   - record both figures
   - if the operation of the fan causes depressurization, apply corrective measures or leave it on throughout the test

5. **Turn on exhaust equipment**
   - turn on equipment that exhausts to outside such as kitchen and bathroom fans, clothes dryer, HRV with damper defrost, central vacuum, workshop exhaust, etc.
   - record the maximum depressurization
   - beginning with the exhaust assumed to be the smallest, turn off the exhausts one at a time and record the pressure changes at each stage
   - operate exhausts in combinations expected to be most common; record the results; worst case is usually considered to be the two largest exhausts and these are usually the clothes dryer and kitchen range exhaust

6. **Check for combustion spillage**
   - while operating exhaust devices in combinations expected to be most common, check the wood stove or fireplace to see if there is a standby backdraft; a cold backdraft does not necessarily mean there is a problem because you may have "bumped" it into backdraft by running all the exhausts at once
   - if the worst case depressurization is less than the allowable pressure for the fireplace, yet the fireplace cold backdrafts, shut off the fans, correct the backdraft (usually by opening a window) and repeat the test by starting only the two largest exhausts; report the findings of this test to the householder

7. **Clean up**
   - return thermostats to previous settings and return the house to its previous condition

Table 5 **Depressurization Limits for Combustion Systems***		continuouse pressure limit (Pa)	inter-mittent pressure limit (Pa)
OPEN: Chimney vented systems with draft hoods, barometric draft controls or other relief air openings	Includes all gas, propane and oil-fired equipment connected to flues that rely on natural draft. Includes most conventional furnaces and water heaters, including low and mid-efficiency gas furnaces, and oil furnaces.	**5**	**5**
CLOSED: Chimney vented systems consisting of a single appliance with no relief air openings	Includes gas, propane and oil-fired equipment connected to a dedicated natural draft flue with no openings through which gases can spill. Include induced draft mid-efficiency gas appliances with no draft hood and high pressure oil burners with sealed flues and no barometric draft control. Include pellet-fired appliances, whether horizontally or vertically vented.	**5**	**10**
SEALED: Direct vent or power vented gas or oil-fired systems with gas-tight vents	Include gas, propane and oil-fired equipment that is vented horizontally through gas-tight vents, uses outdoor air for combustion and fan-forced exhaust.	**10**	**20**
ADVANCED WOOD HEATER: EPA/B415 certified (or equivalent) stoves or fireplaces	Include all low emissions certified appliances meeting EPA/B415 requirements or equivalent. Include masonry heaters in this category.	**5**	**7**
CONVENTIONAL WOOD BURNER: Fireplace, cook stove or furnace	Includes woodburning appliances that are not emissions certified but have doors that close off the combustion chamber.	**5**	**5**
OPEN FIREPLACE: Wood burning or gas log	Includes fireplaces without doors that substantially close off the firebox while in operation.	**<5**	**<5**

****Note:*** *this table is adapted from the Canadian General Standards Board standard CAN/CGSB 51.71 "The Spillage Test". As more research is conducted and various jurisdictions codify the requirements, slightly different pressure limits may be chosen. Therefore, the figures in this table should be used as an interim guideline, not as the final word on the tolerance of various system types to house depressurization.*

Analysing the results from the house pressure test

In most cases the house pressure test is used to confirm an anticipated result and to provide precise figures upon which to base recommendations and remedial measures. When dealing with an existing house, you already know if there is a venting problem, and by assessing the features of the combustion/venting system, you can get a sense of its vulnerability to spillage. A quick inspection of the house will probably indicate its relative airtightness; cues such as its size and design, and the presence of gaskets on doors and windows reveal the potential for tightness.

The results of the pressure test do not necessarily dictate a specific course of action. In fact, for any given situation, there are usually optional strategies that could be followed.

Here is an example to illustrate the process of interpreting test results and developing remedial measures:

The pressure test of a new house that is not yet occupied shows that it can be depressurized 9 Pa when all exhaust systems are operating. The most spillage-susceptible appliance is an EPA certified factory-built fireplace with a straight chimney enclosed within the house envelope. The test is being conducted to determine if a powered make-up air supply is required for safe venting of the fireplace. The testing technician decides that it is extremely unlikely that the kitchen exhaust, two bathroom exhausts, the clothes dryer and central vacuum would all run at the same time. The practical maximum depressurization level is usually considered to be achieved with <u>the two largest exhaust systems operating</u>; in this case, the kitchen exhaust and the clothes dryer. The pressure test revealed that, with the two largest exhausts operating, the depressurization level was 7 Pa. The technician also realizes that this particular fireplace is in the most spillage-resistant category of natural firewood-burning appliances and it is vented through an inside chimney. The figures in Table 5, advanced wood heater category confirm, that this fireplace can tolerate 7 pa of intermittent depressurization. It is decided, therefore, that no make-up air system is necessary. The key point here is that some judgement must be used in the analysis of results. In any case, the technician must be prepared to explain and defend the analytical process underlying the judgement call.

Where the practical maximum depressurization level (ie. the two largest exhausts operating) exceeds the pressure limit for the appliance in question, further investigation is warranted. Although the normal course of action would be to install a powered make-up air supply interlocked to the largest exhaust system(s), other options may be available. For example, if the largest exhaust is a hood-type range exhaust which the homeowner agrees is more powerful than necessary, its flow could be reduced slightly by blocking part of the inlet or outlet. This option would only be useful if the appliance pressure limit is exceeded by one or two Pa. Testing the viability of this option would be as simple as temporarily blocking part of the inlet during the house pressure test and recording the pressure change.

After some experience with the house pressure test you will gain a feel for the cause and effect relationships involved. The test is just one of the tools available to the hearth/housing analyst in designing new systems and diagnosing problems with existing systems.

The two common strategies used in the attempt to ensure safe chimney venting in tight houses—passive make-up and direct-to-combustion chamber air supplies—have been shown to be unreliable. Neither approach can consistently prevent combustion spillage when mechanical exhausts cause excessive depressurization of the building envelope. These findings raise the question: What design or remedial measure can be used in a house that can be depressurized more than the fireplace or stove can tolerate? The answer is to force make-up air into the house at the right time and in the correct volume to bring the pressure back closer to neutral.

Most houses do not need make-up air systems to prevent the failure of chimney vented combustion systems. Assuming a system of good design, reliable chimney venting occurs when:

- the combustion appliance is closed, that is, it has doors and no draft hood
- there are no extremely large mechanical exhaust systems
- the house has a moderate natural air leakage rate
- if the house is mechanically ventilated, the system is balanced

A make-up air system may be required if one or more of the characteristics above are not present, ie. an open appliance and/or a very powerful exhaust ventilator and/or an extremely tight building envelope. The first two characteristics can be observed, but the degree of airtightness of the envelope must be established by testing. When you encounter a house with an exhaust-only ventilation system that is causing venting failure, the only effective strategy is to replace it with a balanced system.

If the house pressure test results show that exhaust ventilators can cause more depressurization than can be tolerated by the fireplace, a powered make-up air system can be installed. Forcing make-up air into the building with a fan is necessary because passive make-up air systems are unreliable and impractical.

A successful make-up air system should have the following features:

- it forces make-up air into the house only on demand and does not leak air when not in use

- if the incoming air is more than 20°F or 10°C below room temperature, it should be tempered by heating or dilution so that it does not create discomfort
- the make-up air supply is electrically interlocked to the largest exhaust ventilator, usually the kitchen exhaust
- it can be adjusted to supply only enough air to bring the house pressure to the depressurization limit of the combustion appliance

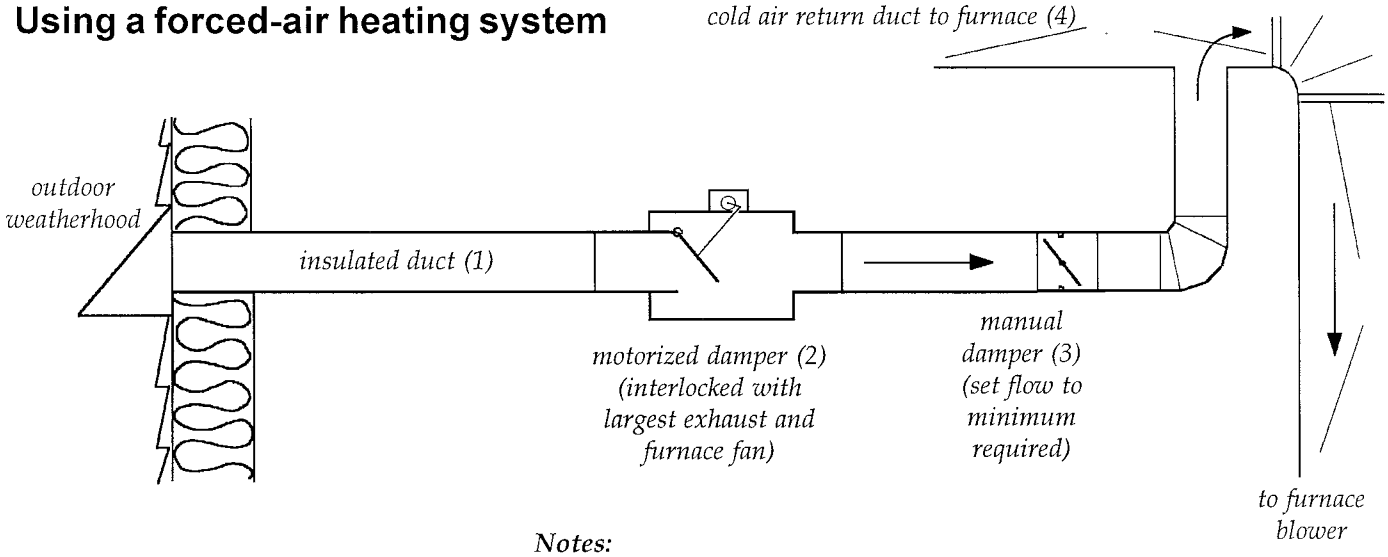
In houses with forced-air heating

In a house with a forced-air heating system, the furnace fan and distribution ductwork can be used to drive the flow of incoming make-up air, temper it and distribute it throughout the house. This approach involves connecting an air supply duct between the outdoors and the main cold air duct upstream of the furnace blower cabinet. A tight fitting, motorized damper in the make-up air duct is interlocked with the switches of the largest exhaust ventilator and the furnace fan. The system is activated when the largest exhaust (usually the kitchen range exhaust) is turned on, which in turn causes the furnace fan to start and the make-up air damper to open. The negative pressure in the return duct causes make-up air to flow through the duct into the return system where it is tempered by mixing with the circulation air and distributed throughout the house. A standard 24 volt AC step-down transformer is needed to convert the line voltage of the kitchen exhaust fan circuit to the low voltage of the make-up air duct damper. This electrical wiring should be subcontracted to a qualified electrician.

The volume of flow through the duct is determined by the extent of negative pressure in the cold air system and the diameter and configuration of the make-up air supply duct. The problem of return air duct system leakage discussed earlier is a key issue to consider when evaluating the installation of this type of make-up air system. If the negative pressure developed in the cold air ducts is low and/or if the operation of the furnace fan depressurizes the basement or utility room, check for leaking joist lined or panned ducts. Sealing the leaks can help to increase the driving pressure in the duct and reduce the fan effect on room pressure.

The illustration at the top of the opposite page shows one example of the necessary components and how they can be arranged.

Using a forced-air heating system



Notes:

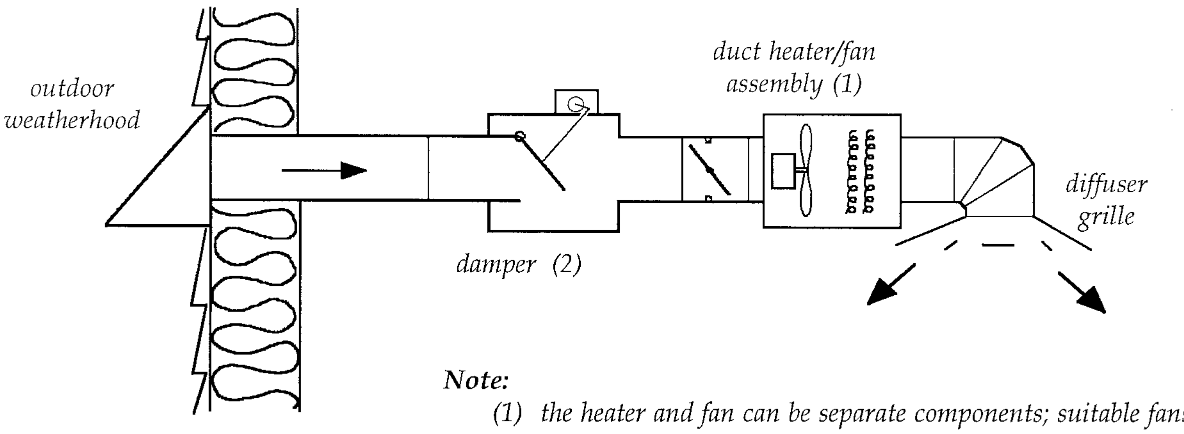
(1) *in cold climate zones the duct must be insulated and covered with a sealed air barrier (usually plastic film) to prevent condensation and freezing of moist house air on the surface of the duct; in severe climate zones and where a high volume of make-up air is required, a supplementary duct heater may be required to temper the incoming air*

(2) *see Appendix C for suppliers of suitable motorized dampers*

(3) *this is a simple duct damper available from HVAC suppliers; when the installation is complete, run the house pressure test again and set the damper to the minimum flow required to bring the house depressurization to an acceptable level*

(4) *the make-up air supply duct should terminate in a sealed connection with the main cold air return duct about 10 ft. and two 90° elbows upstream of the furnace fan to ensure mixing and dilution*

Using a duct heater/fan assembly



Note:

(1) *the heater and fan can be separate components; suitable fans (in-line with plastic housing) and duct heaters are available from most HVAC suppliers*

(2) *the damper can be of the spring-loaded type (rather than the motorized type shown) in system like this with a dedicated supply fan*

* *installation should be subcontracted to a HVAC specialist*

Cold climate caution: The objective in designing a make-up air system coupled to a forced-air heating system, particularly in cold climate zones, is to bring in as little outdoor air as possible. This is because a large volume of cold outdoor air can cause thermal shock to the furnace heat exchanger or condensation of furnace exhaust gases. With this type of system, flows greater than 200 CFM should be avoided, unless a supplementary duct heater is added to the system to temper the cold incoming air. The heater can be controlled by a thermostat so that it is activated only when necessary.

Houses without forced-air heating

In a house without forced-air heating, an electric duct heater with a fan can be used to drive the flow of air and temper it to a comfortable temperature. A diffuser grille located at ceiling level is normally used to disperse the incoming air and to minimize cold air pooling at floor level. This type of installation should be handled by a qualified heating contractor. See the illustration at the bottom of the previous page for its general configuration.

Packaged make-up air systems

At least two companies have developed experimental automatic make-up air systems that sense building pressure and activate the make-up air fan when negative pressure reaches a set-point. Simpler versions designed for interlocking with large exhausts and consisting of a make-up air fan and a mixing and tempering device have also been developed. Such systems will likely become more common in the future. Check with your local HVAC suppliers for availability.

Sizing make-up air systems

The most accurate way to determine how much make-up air is needed to reduce envelope depressurization by a specific amount is to test the house using the fan depressurization method (blower door). This method can yield a measurement of the actual make-up air requirement. However, if this test is not being done on the house for other reasons, the cost is not likely justified. Without such equipment, it is unwise to attempt excessive precision because you could unintentionally create a system that is unable to deliver sufficient make-up air. Ideally, the make-up air system is designed to be slightly larger than necessary so that it can be adjusted downward to provide the correct flow.

The approximate volume of make-up air that must be supplied can be inferred by using Tables 2 and 3 (repeated on the following pages for convenience) in combination with the results of the simplified house pressure test. Table 2 provides the estimated air flow of the exhaust devices that are primarily causing the excess depressurization, Table 3 provides insights into the relationships between flow and pressure in houses with various degrees of leakiness, and the house pressure test tells you exactly how the house pressure is affected by the exhaust flows.

Table 6 on the next page provides the estimated air flows for standard powered make-up air systems of the type illustrated at the top of page 83.

Here is an example of how Tables 2 and 3 and the house pressure test can be used as aids in the design of an effective powered make-up air system.

A house contains a factory-built fireplace that can tolerate a depressurization level of 5 Pa. The house pressure test reveals that the clothes dryer causes a 2 Pa depressurization when operating alone and the house pressure changes to -7 Pa when the kitchen range hood exhaust is turned on. From Table 2 it is determined that the total exhaust from these two devices is in the range of:

clothes dryer	80 to 150 CFM
range hood	80 to 120 CFM
total	160 to 270 CFM

We will use 270 CFM as the worst-case exhaust flow condition. In Table 3, we find that an exhaust flow of 270 CFM produces a 7 Pa depressurization (from the pressure test) in a house with a CFM^{50} of about 950. By looking down to the 5 Pa line on the chart, we determine that an exhaust flow of 200 CFM could be tolerated. The necessary make-up air flow would be:

actual exhaust	270 CFM
safe exhaust	200 CFM
make-up air	70 CFM

To determine the size of make-up air system required, the negative pressure in the cold air return system is measured. In this example, the return pressure is -20 Pa. Using Table 6 on the next page, we find that a 6 inch system of the type illustrated will flow 68 CFM and that a 7 inch system would flow 102 CFM at a 20 Pa driving pressure. The technician carrying out the modifications might decide boost the return air pressure to -25 Pa by sealing leaks and slightly increasing the fan speed. At 25 Pa driving pressure, a 6 inch system will flow 74 CFM. If, on the other hand, the actual design of the make-up air system is more complicated than the one illustrated, or if flex duct is used, it would be wise to go with a 7 inch system. In this example, we used the worst-case estimate of exhaust flow from Table 2 and the safest permissible flow from Table 3, so our make-up air system will be able to flow somewhat more air than we need to maintain the house pressure at or above -5 Pa.

Using the house pressure test to adjust a make-up air system

Following on with our example, when the make-up air system installation is completed, the house pressure test is repeated to confirm that the depressurization level is reduced to a level that can be tolerated by the fireplace. The second house pressure test shows that with its manual damper fully open, the make-up air system reduces the depressurization level to 3 Pa. With more air being delivered than necessary, the manual damper in the make-up air duct is adjusted so that, with the clothes dryer and kitchen range hood exhaust operating, the depressurization is reduced to -5 Pa. This procedure ensures that the house cannot become depressurized to the extent that it compromises the operation of the fireplace, yet only the minimum necessary amount of make-up air is delivered to the house.

Table 6.
Air flows through various diameters of make-up air systems at a range of return duct pressures in L/s (CFM)

Cold air return duct pressure in pascals	Diameter of make-up air assembly*				
	4"	5"	6"	7"	8"
5	6 (13)	9 (19)	16 (34)	20 (42)	34 (72)
10	9 (19)	15 (32)	22 (47)	33 (70)	48 (102)
15	11 (23)	18 (38)	27 (57)	40 (85)	58 (123)
20	13 (28)	21 (45)	32 (68)	48 (102)	68 (144)
25	15 (32)	24 (51)	35 (74)	54 (114)	77 (163)
30	17 (36)	26 (55)	38 (81)	59 (125)	85 (180)
35	18 (38)	28 (59)	42 (89)	64 (136)	91 (193)
40	20 (42)	31 (66)	44 (93)	68 (144)	98 (208)

** This table assumes that the make-up air supply has the following characteristics: (see illustration top of page 68)*
- *10 ft in total length of rigid duct (increase one size for flex duct)*
- *one 90 degree elbow*
- *one key damper and one motorized damper*
- *sealed connection with furnace cold air return duct*

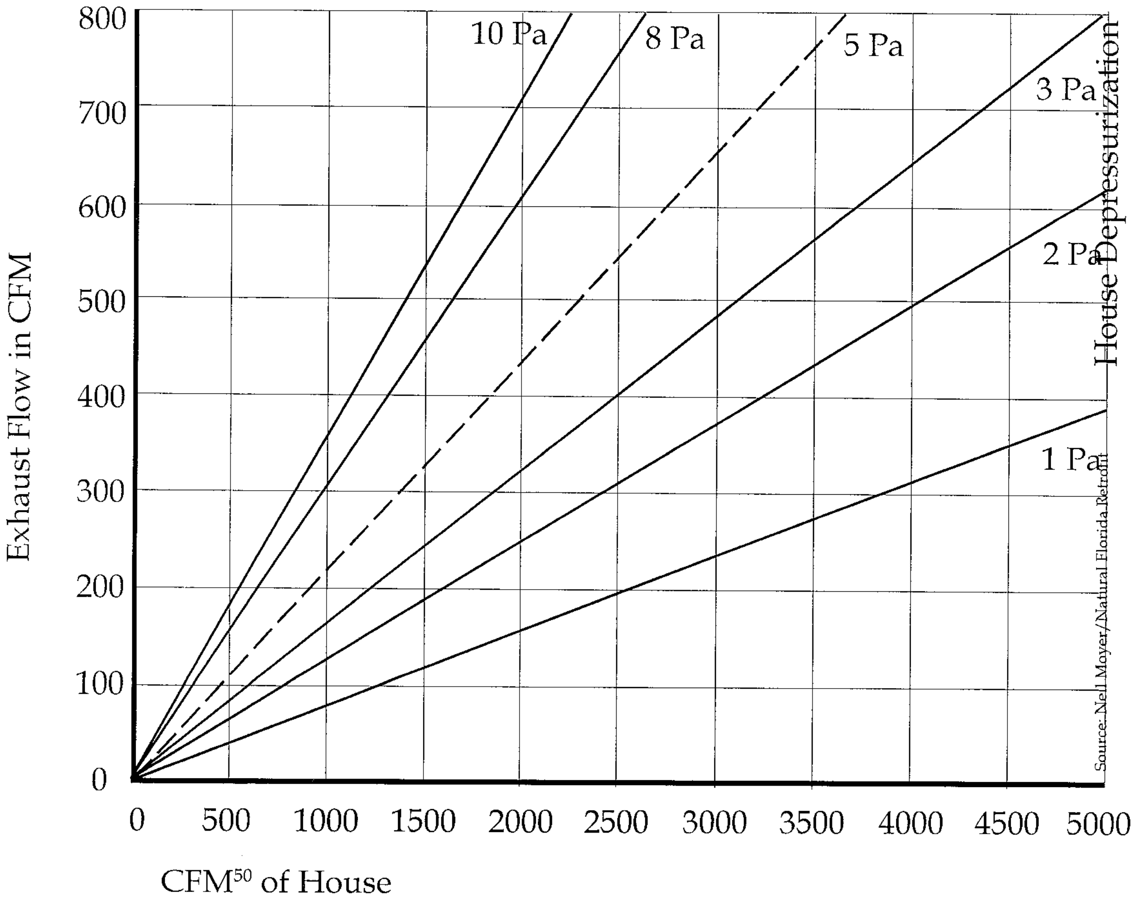
Table 2 from page 34 and Table 3 from page 35 are reproduced here for your convenience.

Table 2. ESTIMATED AIR FLOWS OF TYPICAL INTERMITTENT EXHAUST DEVICES

	L/s*	cfm*
bathroom fan	15 - 30	30 - 60
standard kitchen range hood	40 - 60	80 - 120
downdraft bbq range exhaust	100 -300	200 - 600
clothes dryer	40 - 75	80 - 150
central vacuum	25 - 50	50 - 100
AVERAGE AIR FLOWS OF CHIMNEY VENTED COMBUSTION SYSTEMS		
chimney vented oil furnace	40 - 75	80 - 150
B-vented gas furnace	40 - 60	80 - 120
B-vented gas fireplace	30 - 50	60 - 100
open wood/gas fireplace	80 - 300	160 - 600
wood fireplace with doors	30 - 50	60 - 100
controlled combustion woodburning appliance	5 - 15	10 - 30
masonry heater, burning wood	20 - 30	40 - 60

**L/s is litres per second; cfm is cubic feet per minute. The figures in the table have been rounded off.*

Table 3. House Depressurization Chart



The spillage test is a useful tool, both for predicting the performance of a fireplace in a new home and for diagnosing the cause of venting failure in an existing system.

The spillage test report form sample on the facing page is provided for your convenience, should you wish to make copies of it.

Spillage Test [illegible] port Form

THE HOUSE

Customer name: . . . .

Address: . . . .

Phone: . . . .

House description (total floor area & number of floors): . .. .

. . . .

. . . .

Purpose of test: . . . .

THE TESTER

Name: . . . .

Company: . . . .

Pressure measuring apparatus: . . . .

. . . .

THE CONDITIONS

Approximate outdoor temperature: . . . .

Approximate wind speed: . . . .

EXHAUST APPLIANCES

Clothes dryer ❑

Kitchen exhaust ❑ Hood type ❑ Down draft ❑

Central vacuum ❑

Bathroom fan ❑ Number . . . .

Heat Recovery Ventilator ❑ Damper Defrost ❑

Other exhaust ventilators . . . .

. . . .

COMBUSTION APPLIANCES (from Table 5)

Gas furnace ❑ Depressurization limit . . . .

" water htr ❑ Depressurization limit . . . .

Oil furnace ❑ Depressurization limit . . . .

" water htr ❑ Depressurization limit . . . .

Fireplace ❑ Wood ❑ Gas ❑ Doors: Yes ❑ No ❑

Fireplace depressurization limit . . . .

Wood heater ❑ Depressurization limit . . . .

Comments on condition/design of combustion system . . . .

. . . .

. . . .

. . . .

THE TEST

Furnace fan effects tested Yes ❑ No ❑

Results: . . . .

. . . .

Adjustments made: . . . .

Continuous depressurization test (ie. exhaust-only ventilation)

Depressurization . . . . Pa

Intermittent depressurization (ie. kitchen exhaust, clothes dryer, central vacuum, HRV on defrost, etc.)

Maximum depressurization (all devices on) . . . . Pa

Practical worst case (ie. the two largest) . . . . Pa

Comments: . . . .

. . . .

. . . .

FOLLOW-UP/REMEDIAL RECOMMENDATIONS

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Notes:

. . . .

. . . .

. . . .

Some final thoughts

Why do chimney vented fireplaces spill and backdraft and what is needed to make them function successfully? That seems like such a simple question, but it is not. If you find this subject area complicated, difficult and sometimes confusing, you are not alone. After all, if the question were simple and the answer obvious, solutions would have been found long ago. Although venting failure has been a problem for many years, much of the formal research and analysis needed to reveal the dynamics of chimney venting in houses has been done only in the past two decades. We have just recently begun to understand all the contributing factors and their relative importance.

Incremental changes and the interplay between influences

Chimney venting design and diagnosis is challenging because it is all about increments. That is, when a venting system is in operation or even at standby, an array of influences are simultaneously at work: chimney height, stack temperature, fireplace design, house tightness, wind effects, outdoor temperature and many other factors contribute to the net effect. The interplay between these influences – some driving and some adverse to successful venting – determines the result. An incremental change to one of the influencing factors can change the result. The dilemma that we often face is: Which factor should be changed and by how much to achieve the desired result? Obviously, there is no simple solution that would apply in every case. It is clear, however, that fireplace and chimney systems of good design provide a larger margin of resistance to venting failure and are less affected by external factors such as wind or room depressurization than are systems with design flaws.

What about the exceptions?

This book offers a number of design guidelines that can help to ensure successful venting. In most cases, they are just that, guidelines, not rigid rules, and there will be cases that appear to contradict them. For example, a key suggestion in this manual is that chimneys should be installed within the building envelope, yet there may be systems that seem to function fine when vented through an outside chimney. Such apparent contradictions do not disprove the principle of inside chimneys any more than the old-timer's stove pipe clearance of 6 inches that has been there for 30 years invalidates the 18 inch chimney connector clearance rule in safety codes. We know that at some point the old-timer's flue pipe is likely to ignite the wall, just as we now know that at some point the outside chimney, because it weakens the system's resistance to spillage, is likely to be a factor in venting failure. Professionals and regulatory authorities decided a long time ago not to take chances with safety. Now that we have reliable guidelines for chimney venting of fireplaces, we must decide how rigorously to apply them. The prevention of venting failure requires a new approach, one in which the lessons learned about the causes of venting failure and how to avoid it are applied with more clarity and determination than in the past.

Generalizing about modern housing

The trend towards more tightly sealed housing might lead one to believe that houses will become ever more airtight until there are no uncontrolled leaks. However, as more is learned about the cause and effect relationships involved, it becomes apparent that there are diminishing returns as one approaches total airtightness. Depending on the construction methods and materials used, a point is reached at which the additional costs to achieve tightness are not justified by any significant reduction in energy costs or increases in comfort. For those of us interested in fireplaces, the issue revolves around the point at which a house becomes too tight for a hearth appliance to draw its combustion air from inside the envelope.

Now, with nearly 20 years of experience with tightly sealed houses, thousands of which have been airtightness tested with accurate devices like blower doors, some trends have emerged and some general statements can be made, as follows:

- Except in rare cases, even tightly sealed houses have sufficient natural leakage to supply combustion air to controlled combustion woodburning appliances.

- When a builder uses materials and techniques designed to reduce air leakage, the resulting house can approach the degree of tightness at which the pressure inside is significantly affected by air flows produced by large exhaust devices.

- Because of its greater surface area and greater potential for leaks, a large house of complex design normally has a greater equivalent leakage area than a small house of simple design when similar materials and construction techniques are used. Therefore, a large exhaust ventilator will cause a greater level of depressurization in a small house than in a large house.

- In general, energy efficient houses can accommodate combustion appliances with modest combustion air requirements (supplied from inside the envelope) without requiring a make-up air system, provided large exhaust ventilators are not installed.

- Because energy efficient houses can be so tightly sealed that the pressure inside can be affected by exhaust systems, the only way to be sure that a venting system can perform satisfactorily in such houses is to test them using the simplified house pressure test.

Summary Tools

By applying the lessons learned in this book, you will have more success in specifying or installing a system that does not fail. And, if necessary, you will be able to diagnose problems in existing systems more quickly and accurately. Use the material on the following pages as reminders of the system design strategies presented throughout the book.

Defining Perfection

Very few things in this world are perfect, but it is worth describing perfection so that one can tell just how bad any given thing is. By defining perfection in chimney venting terms, we become less accepting of flawed systems because the flaws tend to stand out more.

When designing or troubleshooting systems, consider the extent to which they stray from perfection. That is, assign a demerit point for each characteristic that does not conform to perfection. Think of each of the following as a 'driving' characteristic and each flaw in a system as an 'adverse' characteristic.

The characteristics of a "perfect" chimney vented fireplace system

1. The system is installed in a house that may be fairly 'tight' but which has a balanced ventilation system.
2. The chimney runs inside the building envelope and has no offsets.
3. The chimney flue is insulated and is the correct size for the appliance.
4. The chimney penetrates the highest part of the house envelope.
5. The chimney is tall enough and is clear of obstacles to wind flow.
6. The flue pipe assembly runs straight up from the appliance flue collar to the base of the chimney.
7. There are no large exhaust ventilators in the house, or if one exists, it is interlocked to a fan-forced make-up air supply.
8. The appliance and venting system are reasonably well-sealed.
9. The appliance is EPA certified or has equivalent characteristics (ie. unlikely to smolder).
10. The appliance is operated by an informed householder.

	RELIABLE VENTING	SPILLAGE PRONE	VENTING FAILURE
Chimney			
	installed inside building envelope	half in/half out	installed outside envelope
	higher than top of envelope	same height as envelope	lower than top of envelope
	sized to match appliance outlet	one size smaller or larger	too big/too small
	high mass	moderate mass	low mass
	well insulated	some insulation	not insulated/air cooled
	straight up	slight offset	severe/multiple offset(s)
	sealed	somewhat leaky	leaky
Flue pipe (if applicable)			
	sized to match appliance outlet	one size larger or smaller	too large/too small
	straight up	one elbow	more than one elbow
	tight joints	loose joints	leaky joints
	no obstructions/major leaks	key damper or barometric draft control	flue pipe heat exchanger
	total length less than 6'	between 6' and 10'	more than 10'
Appliance			
gas/propane appliances	sealed/direct vent	induced draft	draft hood
oil-fired appliances	sealed with induced draft	induced draft	barometric draft control
woodburning appliances	gasketed doors	leaky doors	open — no doors
	adequate internal flow area	somewhat restrictive	very restrictive internal design
	updraft — no internal by-pass	sidedraft/downdraft — internal by-pass damper	
	high mass	moderate mass	low mass
	round firebox outlet	rectangular firebox outlet	slot firebox outlet
	EPA certified (stable combustion)	some combustion design (may smolder)	no combustion system (will smolder)

Building environment

The relative tightness of the building envelope is a key factor in venting performance but a reasonably tight envelope does not necessarily contribute to spillage and a loose envelope does not guarantee reliable venting. The related features are the total mechanical exhaust capacity and whether a powered make-up air system has been installed.

RELIABLE VENTING	SPILLAGE PRONE	VENTING FAILURE
balanced ventilation	no ventilation system	exhaust-only ventilation
no large mechanical exhausts	moderate exhaust capacity	high volume mechanical exhausts

Note: This table is presented as a convenient summary of the lessons learned about reliable chimney venting. Please be aware that this condensed treatment of such complex issues cannot be accurately applied to all circumstances. Use the table as a reminder of the key issues involved. Where details or precision are required, refer to the main text of the manual.

The building envelope

Building envelopes are being constructed more tightly to increase comfort and to reduce energy consumption and exfiltration to structural components. Pressurizing buildings is not considered to be good building science because of the damage that condensed room air can do to building components. There is a wide range in leakage rate among the existing housing stock. The natural leakage rate of tight houses is not sufficient for healthy living, which creates the need for mechanical ventilation systems.

The effects of temperature difference

Natural chimney draft and stack effect in houses are both caused by temperature difference. The greater the temperature difference, the stronger the draft. The taller the chimney, the more draft is produced, subject to heat loss from the outdoor portion of the chimney. Temperature difference is the key factor in successful chimney venting by natural draft.

The colder the outdoor temperature, the stronger is the stack effect in a building. The taller the house, the more stack effect is produced. The neutral pressure plane in a building follows the leaks. Stack effect is not significantly affected by the leakiness of the building envelope. Weatherizing of houses can affect chimney venting by causing the neutral pressure plane to rise.

The cold hearth syndrome

Chimneys must be located within the building envelope to avoid the cold hearth syndrome. The chimney should penetrate the building envelope at or near its highest point. External chases must be constructed to be within the building envelope, all the way to the top of the envelope. Backdrafting is a serious failure of the chimney to do its job, whether or not combustion gases are spilled. External chases must be constructed to be part of the building envelope, all the way to the top of the building envelope. The cold hearth syndrome is extremely difficult to correct, so the potential must be dealt with at the design stage.

The effects of wind

Wind flowing over the top of a chimney can produce a driving pressure, increasing draft. Wind may also create adverse pressures at the top of a chimney because of its direction of flow or turbulence created as it flows over nearby obstacles. Wind is an unreliable source of draft because it is highly variable and may be driving or adverse to chimney venting. Specialized chimney caps may reduce the effects of adverse winds, but are often used in error as a 'cure all' for troubled venting systems. Wind pressure induces air flow through leaks in the building envelope, causing pressure changes inside, which in turn, changes the position of the neutral pressure plane.

The effects of powered exhausts

The more air is exhausted from a building, the more negative the pressure inside will become. The tighter the building envelope, the more negative the pressure inside will become for a given volume of air exhausted. Chimney vented combustion systems act as exhausts, but, aside from open fireplaces, their flow rates are relatively low. Chimney vented systems are vulnerable to backdrafting and spillage due to house depressurization during start-up and tail-out, but are relatively intolerant of depressurization once draft is established. Exhaust-only house ventilation systems cause serious problems for chimney vented combustion systems because their operation spans the vulnerable start-up and tail-out periods. Balanced ventilation systems are needed in tight houses with chimney vented combustion systems. Leaking ductwork or bad design of a central heating system can cause zone depressurization.

Combustion air supplies

Passive air supplies do not supply combustion air, but only flow air in response to the pressure in the house. Passive air supplies of reasonable size are able to provide only a portion of the air requirements of a combustion appliance, depending on the room pressure.

Directly ducted combustion air supplies may supply all the air requirements, but spillage will still occur if the room is depressurized to a level of pressure greater than that produced in the chimney. Directly-ducted combustion air supplies can reverse flow direction when wind effects create a zone of negative pressure at the outdoor weatherhood. Air flows to zones of lower pressure. Appliances that are vented by natural chimney draft should draw the air required for combustion from the room in which they are located.

Venting system design

Insulated chimneys produce stronger and more reliable draft than uninsulated chimneys. Flow resistance in a venting system increases the likelihood of open door spillage. Air leakage into the venting system should be minimized because it lowers draft. Chimney venting systems should exceed 15 ft. (4.6 m) in height. The chimney flue should be matched in size to the requirements of the appliance it serves. Most chimneys currently available to the public do not possess the characteristics needed for successful venting.

Appliance design

Open appliances, such as fireplaces without doors or gas appliances with draft hoods, have little resistance to spillage. Appliances with large door openings relative to their flue size are susceptible to open door spillage. Appliances with firebox exhaust outlets in the shape of a narrow slot are susceptible to open door spillage. Appliances with flue outlets below the top of the loading door are susceptible to open door spillage. Appliances with flue outlets or internal passages that route flue gases downward are susceptible to closed door spillage. Appliances with leaky joints are susceptible to both open and closed door spillage. In many cases, the spillage susceptible characteristics of appliances can be overcome by good venting system design.

Energy momentum

Energy momentum is created by the mass of the appliance and venting system. The more energy momentum is created in a system, the more resistant it will be to spillage during tail-out if the building is depressurized.

The human factor in woodburning

Users of wood burning equipment may either induce or prevent spillage. The most common, but least serious, form of spillage occurs when the loading doors are open. The most problematic user influence is to cause the fire to smolder, a condition that promotes dangerous closed-door spillage. The tolerance of householders to the smell of wood smoke can influence the amount of smoke spilled.

Combustion spillage from open fireplaces

Open fireplaces are extremely vulnerable to combustion spillage. The internal design of traditional masonry fireplaces is not conducive to successful venting. The installation of glass doors is the most effective and least expensive way to increase the spillage resistance of open fireplaces. The ratio of flue area to hearth opening is a factor in smoke roll-out. Fireplaces with more than one face open to the room are particularly prone to spillage. To vent properly in a tight house, an open fireplace would need to be of perfect design in all respects and be combined with a sophisticated house pressure management system.

Summary of definitions

adverse pressure: is a pressure that inhibits flow in the desired direction. The negative pressure in a basement is an adverse pressure because it works against chimney draft.

air changes per hour (ACH): the number of times in an hour that all of the air in a building is replaced with outdoor air.

backdraft: when the upward flow in a chimney fully reverses and 100% of the combustion gases from the appliance (if it is firing) and air in the chimney flow into the building.

building envelope: the surfaces, formed by all components of the building, that enclose the conditioned (heated or cooled) space.

chimney: a primarily vertical shaft enclosing at least one flue for conducting gases to the outdoors

combustion air supply: is air from outdoors supplied directly through a duct to the appliance combustion chamber.

combustion spillage: when some of the products of combustion are released into the building.

draft: the pressure difference which is available to drive the flow of air and/or combustion gases through an appliance and its venting system.

draft, natural: the pressure difference created in a venting system by the temperature difference between the air and/or combustion gases in the venting system and the outdoor air.

driving pressure: is a pressure that produces flow in the desired direction. Heat in a chimney produces draft which is a driving pressure. Wind blowing over the top of a chimney produces a driving pressure that assists in pulling exhaust gases from the chimney.

effective stack (height): refers to the relative performance of the stack (house or chimney), normally in standby mode, rather than specifically to its linear height, but is influenced by actual height as well as temperature difference.

energy momentum: the tendency of a venting system to continue to produce draft after combustion has stopped as the heat energy stored in the materials of the system is released into the flue.

equivalent leakage area (ELA): the size of hole you would get if all the leaks in a house could be gathered together in one place.

neutral pressure plane (NPP): the level between the high pressure zone at upper levels and the low pressure at lower levels in a house at which the pressure is equal to atmospheric pressure.

passive make-up air supply: is air from outdoors supplied indirectly in the form of a duct terminating in proximity to the combustion appliance; this is the 'hole in the wall' approach to air supply.

stack effect: the pressure difference created in a building by the temperature difference between the inside air and outdoor air.

venting: the action of air or gases escaping to the outdoors

The equipment needed to accurately measure the air flow in a duct is too bulky, expensive and fragile to be of real use in day-to-day work in the field. But there are times when it would be nice to know if this supply register was supplying more or less air than that one. Or to see if, despite all the noise, the bathroom fan is moving a reasonable amount of air. Or if the outdoor air duct is supplying enough air to have any effect on appliance operation.

The staff of the research division of Canada Mortgage and Housing Corporation saw the need for a simple, inexpensive device that technicians could use to measure air flows to and from duct registers. So they did the obvious: they calibrated a garbage bag!

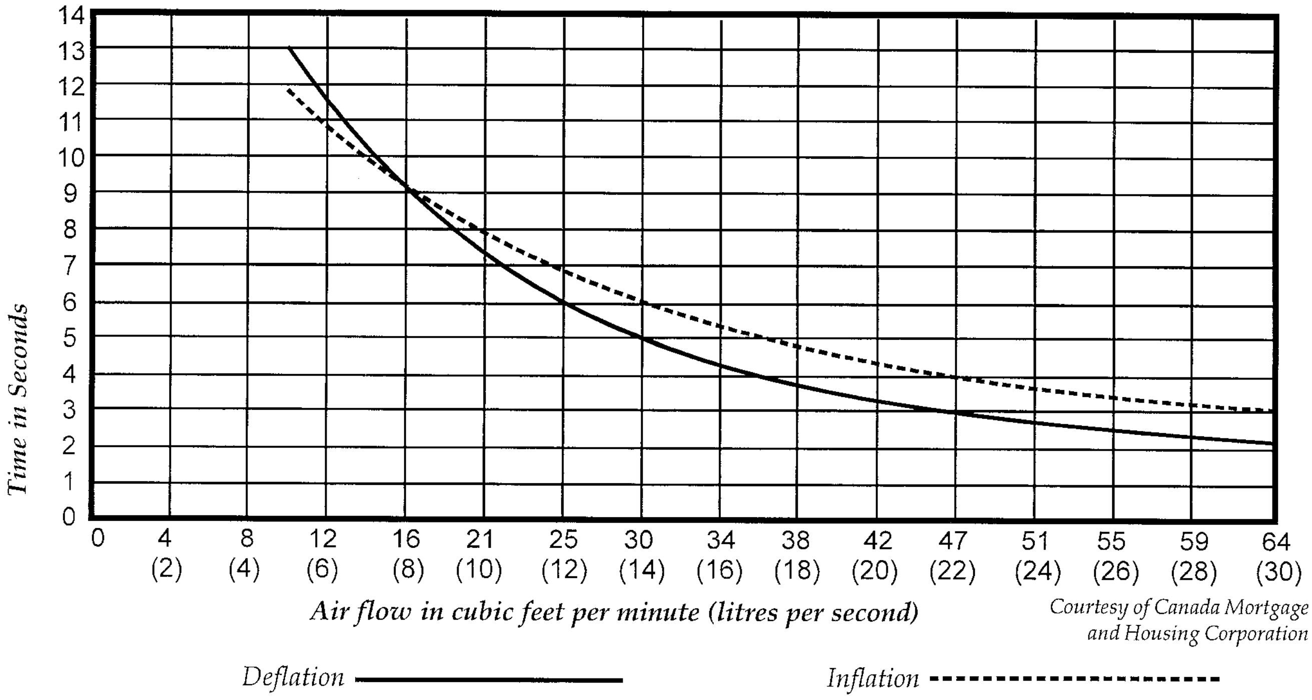
The device is easy to make and easy to use. Open up a wire coat hanger until it forms a rough rectangle. Take a standard household plastic garbage bag (Glad 26"x36" or 66x91 cm) and tape its open end around the coat hanger wire rectangle. The resulting contraption should resemble a big green butterfly net.

Crush the bag gently to deflate it, hold it over a supply register and time how long it takes to inflate it. Don't worry about full inflation; it will still be wrinkly. Since these bags have a fixed volume, the bigger the air flow, the faster it fills up. For example, at 50 CFM (25 L/s) the bag will inflate in about 3 seconds, at 30 CFM (15 L/s) it takes about 5 seconds and at 10 CFM (5 L/s) it takes 12 - 13 seconds (see graph). You can also use the device for exhausts by swinging an inflated bag up to a bathroom exhaust grille or down onto a floor-mounted return air grille and timing how long it takes to almost completely deflate it.

The accuracy of the calibrated garbage bag is not terrific, but it will certainly distinguish a healthy warm air supply duct (40-80 CFM or 20-40 L/s at the register) from one that is not doing the job. You can also check the flow through an open-ended duct by dispensing with the hanger and wrapping the open end of the bag around the end of the duct.

Duct Flow Estimating

Using the CMHC garbage bag method (based on Glad 66x91 cm refuse bag)



Courtesy of Canada Mortgage and Housing Corporation

Research and technical publication references:

Chimney Safety Tests Users' Manual (Second Edition), Canada Mortgage and Housing Corporation (CMHC), 1988, (Scanada-Sheltair Consortium Inc.)

Fireplace Air Requirements, CMHC, 1989, (C.A. McGugan, M.C. Swinton, S. Moffatt)

Indoor Air Quality Device, CMHC, 1989, (Brian McDonald)

That Nice 'Woodsy' Smell; Combustion Spillage From Residential Wood Heating Systems, CMHC, 1991 (J.F. Gulland, C. LeMay)

Air Requirements and Related Parameters for Masonry Heating Systems, CMHC 1994 (Norbert Senf)

CAN/CSA-F326-M91 Residential Mechanical Ventilation Systems, Canadian Standards Association, 1991

CAN/CGSB-51.71-95, The Spillage Test, Canadian General Standards Board, 1995

Residential Mechanical Ventilation Systems, 1993 Edition, Heating, Refrigerating and Air-Conditioning Institute of Canada, 1993

Wood Energy Technical Training reference manual, Wood Energy Technology Transfer Inc., 1987, 1992, 1994

Sources of equipment:

Manometers (pressure gauges)

Dwyer Instruments, Inc., Michigan City, IN 46360: Magnehelic gauge in 0 - 60 Pascal range, accuracy +/- 2 Pa (this gauge is inexpensive and available from most HVAC distributors, but is not considered accurate enough for reference house pressure testing; it can, however, provide useful information on the pressure environment); Dwyer also makes a range of inclined tube manometers with the accuracy needed for house pressure testing.

Energy Conservatory, Minneapolis, MN 55417, (612) 827-1117: Digital Pressure Gauge, Model DG-2 in 0 - 199.9 Pa range at 0.1 Pa resolution with accuracy of +/- 1% of reading, and switchable to 0 - 1999 Pa range at 1 Pa resolution with accuracy of +/- 1% of reading (this instrument is very accurate and easy to use and is recommended for reference pressure testing; it is, however, relatively expensive)

Air Solutions Inc., Cambridge, ON N3C 3Y1, (519) 658-6232: Canadian distributor of Energy Conservatory Digital Pressure Gauge

Motorized Duct Dampers for make-up air supplies

Hoyme Manufacturing Inc., Camrose, Alberta, Canada T4V 4E5 1-800-661-7382 Fax 1-800-661-8065: Model VAC damper with 24 volt operator and integral insulation/air barrier; also Model MOH, as above with integral outdoor weatherhood.