9 The Chimney

Modern, efficient appliances need modern, efficient chimneys. The selection, location and installation of the chimney are as important as the type of wood-burning appliance you choose. A properly designed and installed chimney will provide many years of reliable service and allow your appliance to perform correctly.

How Chimneys Work

An effective chimney is an important part of any successful wood-burning system. Many of the reported problems with the performance of wood-burning appliances can be traced to the chimney. Knowing how chimneys work is not only necessary in selecting the correct type and designing the installation, but also useful in operating your wood-burning system from day to day.

MINIMUM CHIMNEY HEIGHT ABOVE THE ROOF – The top of a chimney should be high enough to be above the air turbulence caused when wind blows against the house and its roof. The chimney must extend at least 1 m (3 ft.) above the highest point of contact with the roof, and at least 60 cm (2 ft.) higher than any roof line or obstacle within a horizontal distance of 3 m (10 ft.).

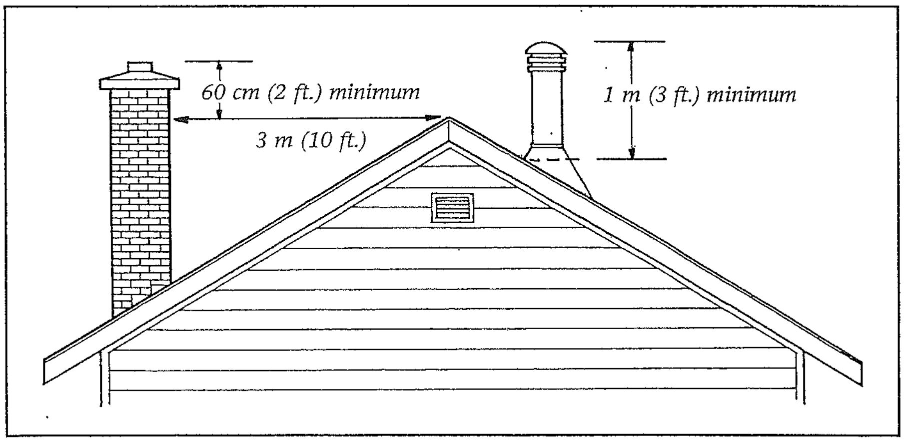
Chimneys operate on the principle that hot air rises above cold air – thus, the hot gas in a chimney rises because it is less dense than the air outside the house. The rising gas creates a pressure difference called draft, which draws combustion air into the appliance and expels the exhaust gas outside through the chimney. The hotter the gas compared with the air outside, the stronger the draft. In this chapter, you will also learn that a chimney should produce a small amount of draft even when no fire is burning. In fact, some of the most serious flaws in chimney performance are revealed when the appliance is not being used.

The chimney's function is to produce the draft that draws combustion air into the appliance and safely exhaust the gases from combustion to the outside. To fulfil this role, the chimney must do the following:

- isolate nearby combustible materials from flue gas heat;
- tolerate the high gas temperatures caused by overfiring and chimney fires;
- * conserve flue gas heat to produce a strong and consistent draft;
- resist corrosion and weather effects; and
- be well sealed to prevent leakage.

Guidelines for Installing Chimneys

1) Install the chimney within the house envelope, rather than up an outside wall. Chimneys along an outside wall are exposed to wind and low temperatures; this chilling effect can reduce the available draft to the appliance and cause condensation. Outside chimneys also tend to create a cold backdraft when no fire is burning. This allows cold air and odours to enter the house and makes it hard to light a fire without getting smoke in the house. On the other hand, chimneys that run up inside the house benefit from being enclosed within a warm environment. Inside chimneys produce stronger draft and accumulate less creosote when a fire is burning. They usually produce a small amount of draft, even when there is no fire.
2) Building codes require that the top of the chimney extends at least 1 m (3 ft.) above the point where it exits the roof. It should also be at



least 60 cm (2 ft.) higher than any roof, building or other obstacle within a horizontal distance of 3 m (10 ft.). These rules are intended to place the top of the chimney higher than any areas of air turbulence caused by wind. In practice, chimneys must sometimes be raised even higher than these minimums in order to avoid air turbulence caused by nearby obstacles, such as trees or other houses.

3) The most important factor in chimney draft is temperature difference. If you experience draft problems, increase flue gas temperature by doing one or more of the following:
   - burn smaller, hotter fires to avoid smouldering;
   - keep the flue pipe assembly as short and straight as possible (try not to use right angles);
   - use a sealed double-wall flue pipe;
   - re-line a masonry chimney;
   - re-install the chimney inside the house; or
   - construct an enclosure or chase around an outside chimney.

4) The chimney flue should be the same size as the appliance flue collar. In the past, many chimneys were too large for the appliance they served. But bigger is not better when it comes to chimney size. Flue gas flows faster and has less time to lose heat in a smaller chimney flue. In planning wood-heating systems, some experienced installers even choose a chimney that has a smaller inside diameter than the appliance flue collar. They usually do this when the chimney runs inside the house and is fairly tall. Chimneys taller than 8 m (about 26 ft.) sometimes produce more draft than the appliance needs, so a smaller-diameter chimney doesn't reduce performance. Only an experienced technician should decide whether the flue should be smaller than the appliance flue collar.

5) Taller chimneys produce stronger draft. A rule of thumb is that the entire system (from the floor on which the appliance is mounted to the top of the chimney) must be at least 4.6 m (15 ft.) high. Most installations are taller than this, but those in cottages with shallow-pitch roofs or in single-storey buildings with flat roofs may not. If you experience draft problems with a short system, consider adding to the chimney's height. However, if your chimney runs up the outside wall of the house, making it taller may not improve draft, because the extra heat loss cancels out any benefit.

Suitable Chimney Options

Two general categories of chimneys are approved for use with wood-burning appliances: the 650°C factory-built chimney and the masonry chimney.

The 650°C Factory-Built Chimney

> *This type of chimney was developed to withstand the high temperatures produced by a chimney fire. It features better insulation than other factory-built chimneys to isolate nearby combustible material from the high gas temperatures in the flue when a fire is burning. At the same time, this increased insulation keeps flue gases and inner flue surfaces warmer. As a result, less creosote forms in the chimney, reducing the risk of chimney fire significantly.*

Specific types of factory-built metal chimneys can be used with wood-burning appliances. Wood stoves, wood-burning central heating furnaces and some factory-built fireplaces must use the 650°C metal chimney, approved to Underwriters' Laboratories of Canada (ULC) standard S629. The 650°C refers to the continuous gas temperature for which it is designed; it is higher than for chimneys intended for other fuels. Most, but not all, 650°C chimneys have 5 cm (2 in.) of insulation between the inner liner and outer shell.

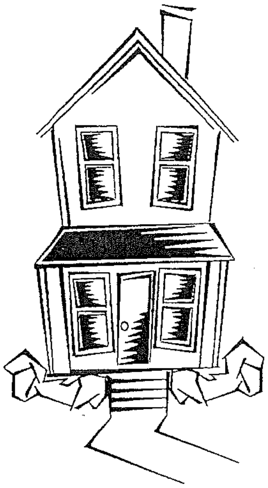
The 650°C chimneys were developed in the early 1980s because earlier chimney designs couldn't withstand the heat from a

Wood Stove Draft Requirements What is Draft?

Simply - it's hot air rising.

Definitions

Draft: The pressure difference that is available to drive the flow of air and/or smoke through an appliance and its venting system.



Natural Draft: The pressure difference created in a venting system by the temperature difference between the air and/or smoke in the venting system and the outdoor air.

Therefore: The temperature difference between the air/gases in the chimney and the air outside the chimney will determine the strength of the draft.

The greater the temperature difference the stronger the draft!

There are many variables that will affect the temperature difference thereby affecting the strength of the "draft".

A. Outdoor temperatures - *the colder the better.*

B. The temperature of the smoke/gases - *the hotter the better.*

C. Chimney construction - the ability of the chimney to sustain heat will help to maintain a greater temperature differential supporting a stronger draft. That is why interior chimneys generally have a better draft than colder exterior chimneys.

D. Resistance - resistance is the friction created when the traveling air is forced to change its flow. i.e. turns (elbows), rough edges of a chimney flue. Resistance is exactly what its name suggests - resistance weakens the force of the draft.

E. Flue size - each stove is designed with a particular flue collar/smoke outlet, which allows for the proper flow of gases to be released from the stove.

This flue collar/smoke outlet diameter dictates the required size of the chimney flue in order to maintain the proper flow of the gases.

Too small a flue will create a bottleneck and create excessive resistance, restricting draft, while a flue that is too large will allow the smoke to expand to the full area of the flue, losing heat and slowing the draft. Both situations mean less draft and more creosote accumulation.

F. Wind - The effects of wind can be both positive and negative on draft, BUT always unreliable because of its variation. (Mother Nature is not to be questioned).

Chimney caps are recommended in all installations, however they are not a guaranteed fix to a chimney suffering from draft problems, wind related or not.

*SO HOW DO YOU KNOW IF THERE'S ENOUGH DRAFT?*MEASURE IT!!!

IT'S THAT SIMPLE!

Most stoves require a minimum draft of 0.05 to 0.10 inches of water column. "Inches of water column" is a unit of measure describing suction, otherwise known as "draft". (A magnahelic, or draft gauge, measures inches of water column).

Draft Measuring Procedure

1. With a cold stove, drill a hole in the stovepipe as close to the stove as possible.
2. Insert the metal tube of the draft gauge into the stovepipe. Be sure the metal tube is perpendicular to the stovepipe.
3. Close all the doors to the stove and close the primary air control. If the stove has a damper, be sure the damper is open.
4. Calibrate the draft gauge to zero.
5. Now, light a fire in the stove, leaving the gauge in place.
6. Take a reading on the draft gauge once a fire is established. Again, most stoves require a minimum of 0.05 to 0.10 in. wc.
7. Remove the tube from the stovepipe and fill with a screw or self-tapping bolt.

Chimney Safety

Proper chimney draft is one of the most important safety considerations in the operation of a combustion appliance. Flue draft is fragile, and we must understand all factors that affect it or suffer the consequences.

We used to think that the creosote smell from the family room fireplace was a normal occurrence. While at one time this might have been considered acceptable, it no longer is today. We now know that the smell is a mix of toxic compounds. Worse, the presence of this smell usually indicates a more serious problem.

Changes in construction practices have meant that our homes operate differently than in the past. In our quest for improved comfort and economy, we build better, more draft-proof homes. Sheet materials - like dry wall, plywood and OSB, gasketed electrical boxes and better sealing around wiring and plumbing penetrations are common. We try for better air sealing between the house and an attached garage to keep carbon monoxide (CO) from infiltrating the living space.

Especially in apartments, upgraded draft proofing not only improves each unit's fire and smoke protection from neighbours, it is one of the main ways to isolate the dwelling from street noise and airborne noise from next-door.

Sealing exterior wall plates can eliminate black perimeter carpet "ghosting". Draft-proofing the attic floor will stop flies from entering the house through the square holes cut for round plumbing stacks.

All these improvements lead to more airtight buildings. This can make chimneys more vulnerable to the influences of large downdraft kitchen exhaust fans, bathroom fans, and dryers as well as to the imbalances created by poorly designed or installed forced air heating systems.

To be successful today, we must not only learn about the equipment we put into houses, but also how it affects and is affected by the home into which we install it. After all, a sick or dead client is not a good referral!

A recent case of combustion gas spillage in South Eastern BC shows how easily spillage of combustion gases into a house can occur. Lethal concentrations of carbon monoxide were detected. Fortunately, the homeowner survived because the amount of spillage was mitigated by the way the house was operated, and the toxic condition was identified in time. Unfortunately, all systems in the house were code compliant, and the incident went unreported.

It is important to recognize that, while codes deal with fundamental safety issues, code compliant mechanical systems can still be unsafe for the occupant. This happens because, despite the best intentions, no code can take into account all possible design configurations of a house, or predict the way in which a home will be operated.

This all becomes clearer when we consider how a house functions, and remember that a house is a system.

Unless the venting of all combustion appliances is sealed, chimney draft will be affected by the pressure imbalances in a house.

Forced warm air systems work because the furnace fan pressurizes the ducts to push the warm air to its intended location. Air is sucked back through the return, because any pressure differential will try to equalize. Improperly sized systems and duct leakage can create regions of higher or lower pressure.

Carpet ghosting is a visual indicator that pressure differences between rooms or between indoors and outdoors exist. More importantly, pressure differences can affect flue drafts in naturally aspirating combustion appliances.

A home's design, its height, the number, type and location of exhaust fans and the heating system, especially if forced air, will affect a chimney's draft and hence a home's safety. When chimney flues are designed, their height, cross section area, straightness, insulation and operating temperature

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when chimney flues are designed, their height, cross section area, straightness, insulation and operating temperature are considered. . . it is important to recognize that the draft in a flue is affected by the chimney's location in the house - whether it is inside or outside the heated envelope

Chimney draft = chimney height x temperature difference between outside and inside, - minus house pressure, - minus resistance of chimney and fittings

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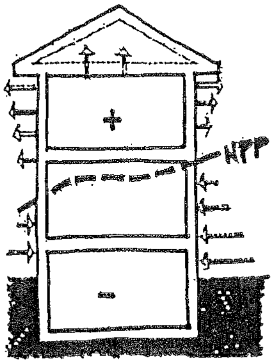
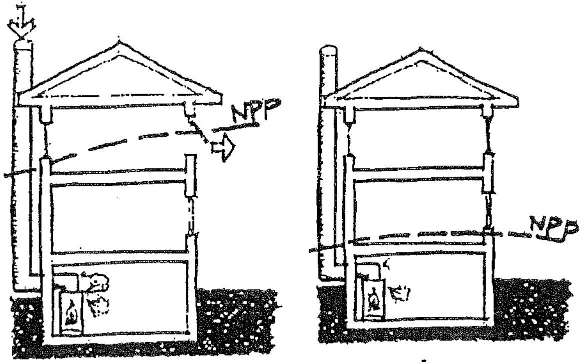
Neutral Pressure Plane



The *neutral pressure plane* (NPP) is a real but invisible plane cutting across a house. Theoretically, one could cut an opening for a pet at the neutral pressure plane and not have to install a door to keep the heat in. The NPP can be thought of as a scarf blowing in the wind, its location where it cuts through the house depends on wind strength, direction, and the temperature difference between inside and outside. Below it, infiltration occurs; above it exfiltration. The NPP will be affected by and move with wind, open windows, and the use of exhaust fans.

Neutral pressure plane is affected by wind strength and temperature difference between inside and outside.



The location of the neutral pressure plane can vary. Depending on building airtightness and dynamic effects of equipment in the house, it can be low or high in the house.
Openings in the upper part of the house (air leakage from the house to the attice, open windows, exhaust fans) will tend to raise the NPP, while a tighter upper portion of the house (closed upper floor windows) tend to lower NPP.

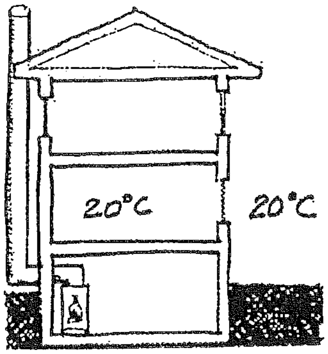
are considered. However, it is especially important to recognize that the draft in a flue is affected by whether it is inside or outside the heated envelope of the house.

A flue on an outside wall, even when it is boxed in and insulated, should for all practical purposes be considered an exterior flue.

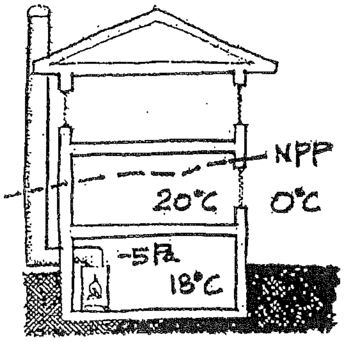
Every house is affected by stack action. The higher the house, and the bigger the temperature difference between inside and outside, the more pronounced the stack effect. Stack action can have a significant impact on the operation of a flu

Chimneys

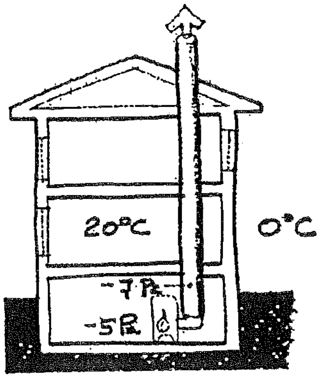
A chimney is a hole in the building's envelope into which we install a duct. If the duct penetrates



Cold chimney. In summer, there is no temperature difference and no pressure difference between inside and outside, so no draft will be generated until a temperature difference develops (i.e. when the furnace or water tank starts).



Cold Chimney. Typical basement may be at -5 Pa relative to the outdoors. The chimney will be at a positive pressure compared to the basement room housing the appliance, and outside air will try to enter the house. Proper draft can't be established until full length of flue is heated to at least the interior house temperature.



In a warm chimney, the air will be at least at house temperature, warmer than outdoor air and buoyant, so will tend to rise. The lower pressure at the draft collar will enhance the draft up the flue.

the ceiling, we call it a warm chimney. If the duct goes out through a lower part of the house, we call it a cold chimney. Both warm and cold chimneys are identical until winter when the heat is turned on. As the outdoor temperature falls, the indoor air being heated will become lighter and begin to drift upwards and leak out through holes in the upper part of the house. The strength of this draft (stack action) increases as winter sets in. A hole penetrating the wall at a low or even mid-height location, regardless of whether it is a chimney or not, will become a make-up air source. It replaces the air that the warm chimney and/or other higher levels holes vent out.

Unfortunately, the safety of an appliance at start-up and tail-out when connected to a side wall chimney penetrating at low to mid wall location is determined more by the distribution of air leakage holes than by any other factor. The location and size and total area of the leakage holes determines the location of the neutral pressure plane. If most of the holes are low, safety is increased. If they are high, safety is decreased. The use of exhaust fans only makes what is inherently poor even less safe.

Return Air Leakage

Forced air heating systems in compartmentalized two- or three-storey houses (i.e. houses divided into rooms) increase the risks. Normally, we assume that a furnace will heat the whole house without considering the home's compartmentalization. In the past we have incorrectly assumed that the furnace delivers as much air to each room as it withdraws. However, because of its relatively large fan capacity, even a small mismatch between delivered and returned volumes to/from each room will cause one room to become pressurized and its neighbour to become the opposite. These pressure imbalances are made worse by leaky ducts. Further, poorly placed exhaust fans, such as clothes dryers placed next to the furnace and hot water tank can also cause problems.

These mechanically induced pressure differences can easily dwarf building stack action and almost as easily challenge the gravity forces of a fully pre-warmed chimney. This explains why a forced air heating system, adding to the home's air leakage, is often credited with providing occupant ventilation, and also explains why the use of forced air heating can easily increase operating costs.

We will likely never be able to fully protect ourselves (without using absolutely sealed, direct vent appliances) against the negative pressures induced by customer selected large kitchen exhaust appliances. But we cannot install and service fuel burning appliances in isolation. We will always be vulnerable to start-up and tail-out spillage problems if we connect combustion appliances to cold chimneys.

We will likely never be able to protect ourselves against these same problems when furnace duct systems are undersized and poorly sealed/installed. It is important to try and foresee these problems in advance. That is what design is all about. That is also a reason why the R-2000 Standard now requires heating systems be designed and installed correctly, based on a room-by-room calculation. ☼

Best practices for wood burning fireplace installation

- ☞ *Ensure that the manufacturer's installation instructions are followed*
- ☞ *Ensure that local codes are complied with*
- ☞ *Make sure of good workmanship by installers*
- ☞ *Install fireplaces and chimneys inside the building envelope*
- ☞ *Penetrate the building envelope at or near its highest level*
- ☞ *Avoid large, uncompensated exhausts*
- ☞ *Avoid very short chimney systems*
- ☞ *Use straight chimney systems*
- ☞ *Provide glass doors*

Static Pressure

- the air pressure that air exerts trying to get into or leave a duct or a house or any closed compartment
- building envelope pressure can be +, - and neutral and is caused by
  a) trying to confine warm air in a house during winter
  b) trying to prevent wind from entering the house
- duct pressure can be + or - and is caused by a fan blowing into or sucking from an air duct
- chimney draft; if the vent pressure is not negative, you get smoked out

CHAPTER 6

CHIMNEYS

Chimneys are just as important as heaters for successful heating with solid fuels. If a heater lets smoke into the room, an inadequate chimney is the most likely reason. If you are not getting enough heat from a stove, the problem could be inadequate draft from the chimney. Creosote problems are not exclusively related to chimney design but can be lessened by good chimneys. Heating efficiency is affected by chimney location and type. A large fraction of house fires associated with wood heating is due to unsafe chimney installations. The practicality and installation cost of solid fuel heating is significantly affected by whether or not an existing chimney can be used; new chimneys can cost as much as new stoves. For all these reasons and more, the chimney is a critical part of any solid fuel heating system.

DRAFT FUNDAMENTALS

A chimney carries the undesirable combustion products (smoke, and so on) out of the house and supplies the draft necessary to feed air to the fire. The force necessary for both functions comes from the tendency of hot air to rise, an effect called *buoyancy*. The flow up a chimney is restrained by resistance from chimney walls, bends, dampers, and the appliance itself. It is the balancing of buoyancy and flow resistance that determines the smoke velocity in a chimney.

Because of the buoyant effect of the hot stack gases, air pressure outside the stove is greater than air pressure inside the stove. If the air inlets of a stove are open, or if there are any cracks or holes in the stove, air will be pushed (or drawn) in. The term used to describe and quantify this effect is *draft*.

Draft is a measure of the force making gases flow. At a place where the draft is high, air will be drawn hard into any opening, but if the opening is small, not much air will get in. Thus, draft and actual air or flue-gas flow are not the same.

Measuring Draft

A common device used to measure draft is a transparent U-shaped tube partly filled with water (Figure 6–1). One end is left open and "senses" the pressure of the atmosphere outside the chimney or stove. The other end is connected to a metal tube that is inserted into the chimney or stove perpendicular to the flow; it senses the pressure inside the chimney. If there is some draft, the pressures are unequal, as indicated by a difference in level of water on the 2 sides of the U-tube. In America, the common unit used to measure draft is "inches of water," referring directly to this height difference. Drafts in residential chimneys are usually between .01 and .15 inches. Because this difference in water level is too small to be seen easily in a U-tube, many draft gauges use different geometries to amplify the visual effect or use different principles entirely.

The draft is zero at the top of the chimney; the

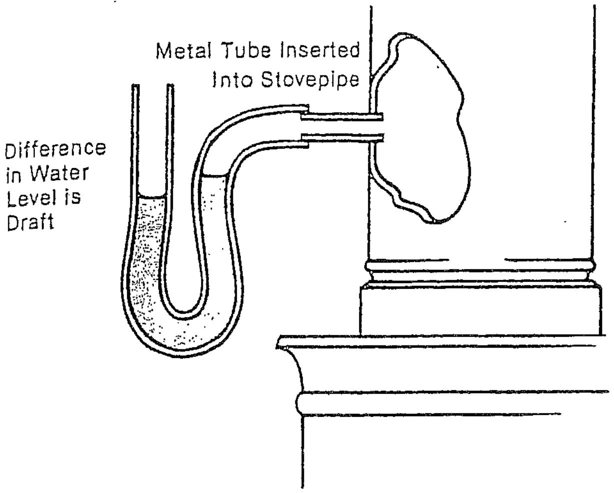


Figure 6-1. Use of a flexible, transparent tube to measure draft, or chimney suction. Practical draft gauges are often built quite differently.

pressure of the flue gases as they emerge essentially equals that of the surrounding air. The draft is usually highest at the bottom of the chimney or in the stovepipe connector. If there is some draft (suction) everywhere in the system, no smoke can leak into the house even if there are cracks; air will be pulled into the cracks rather than smoke pushed out. This is usually the case in solid fuel heating systems.

Chimney Flow Capacity

The ultimately critical question about chimneys is not draft, but flow. Draft is the cause—force or push—behind the flow. The flow is the net effect—the number of pounds or cubic feet of flue gases that pass up the chimney in a given time. If a chimney has an inadequate flow capacity for a particular stove, the stove will not be able to operate at its maximum heat output rate. Even with its air-inlet damper wide open, the suction of the chimney will not draw combustion air into the stove at a high enough rate.

An inadequate chimney may cause smoke to leak out of cracks in the heater and/or stovepipe when the air-inlet damper is opened beyond a certain point or when the heater door is open.

Chimney capacity has 2 approximately equivalent definitions: the maximum flue-gas flow (in units such as pounds per hour or standard cubic feet per minute) under given typical flue-gas temperature conditions,[1] or the largest normal type of heating appliance that can be safely vented through the chimney. For this purpose, appliance size is usually rated in terms of fuel consumption in units such as Btu. per hour.

Flow in a venting system is constrained by friction between the moving flue gases and their surroundings. Stovepipe elbows, chimney rain caps, stove air-inlet dampers, stovepipe dampers, and even straight sections of pipe or chimney all offer resistance to the flowing gases. (Gases here means air or smoke or the combination.) If a chimney could be made hot suddenly, the initially stationary gases would start rising and increase

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[1] The theoretical expression for flue-gas mass flow, M, is $M = (A/k)\sqrt{2ghd_f(d_a - d_f)}$

where A = flue cross-sectional area
k = system resistance coefficient
g = gravitational acceleration
h = chimney height
d_f = density of flue gas
d_a = density of outdoor air

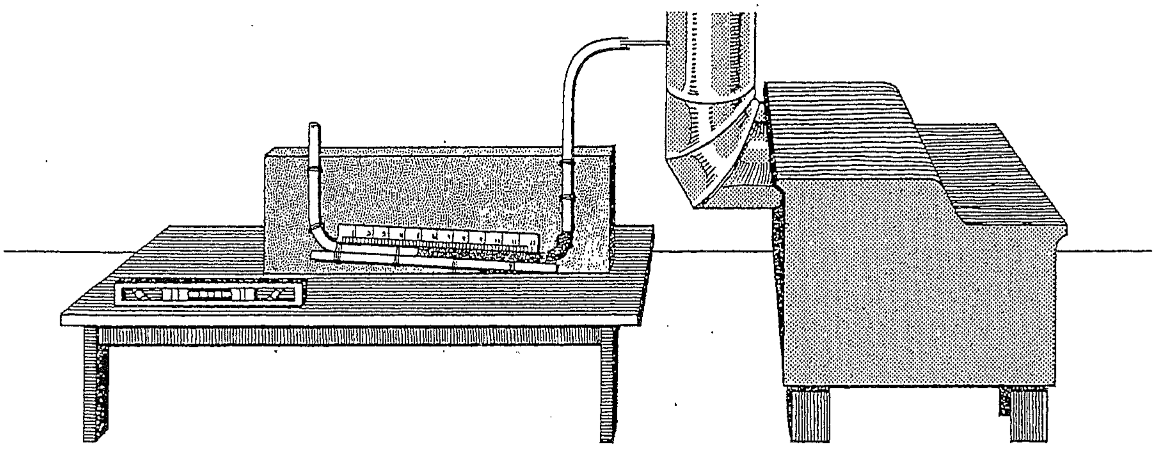

Figure 6-2. A schematic drawing of a homemade, slanted draft gauge.

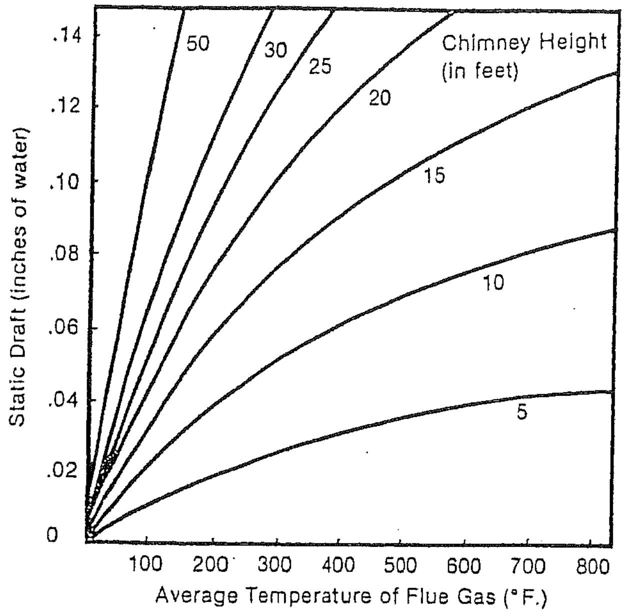

Figure 6–3. Static (theoretical) draft as a function of chimney height and average flue gas temperatures, assuming an outdoor temperature of 40°F. Actual drafts are usually less due to flow resistance. Height is measured from the draft-measurement location to the top of the chimney, and the flue gas temperature is an average over that portion of the chimney.

Static draft has dimensions of pressure and is expressed by $gh\,(d_a - d_f)$*, where:* g *= gravitational acceleration;* h *= chimney height above the location where draft is being calculated;* d_a *= density of the outdoor air; and* d_f *= density of the flue gas.*

in speed until the frictional resistance just balanced the buoyance effects.

In practice, the flow of gases through a chimney is determined by 4 factors.

- The temperature difference between the flue gases and the outdoor air.
- Chimney height.
- Chimney diameter.
- The whole-system resistance coefficient.

Flue-Gas Temperature

Conventional wisdom says the hotter the chimney, the better it draws. For practical purposes, this is true. But as indicated in Table 6–1, sometimes chimney performance may run counter to this traditional wisdom.

A chimney need not be very hot to perform at a substantial portion of its maximum possible capacity. Even when it is a warm 70° F. outside, a chimney is at 45 percent of its maximum capacity when the flue-gas temperature is only 100° F.; at 200° F., the capacity is already 80 percent of maximum. (These flue-gas temperatures are averages over the entire vertical extent of the venting system).

Some Technical Notes on Draft

The draft at any point is the pressure difference between the point of interest inside the chimney, stovepipe, or stove, and the air just outside at the same elevation.

A distinction is sometimes made between "static" and "total" pressure inside chimneys and ducts; total pressure includes the "velocity pressure," which is what your hand would feel facing into the flow when you stick it out the window of a moving car. It is the static pressure which is meant in the context of draft. This is the pressure sensed by a straight, open tube oriented perpendicular to the flow direction.

In this book, normal draft (lower pressure inside a chimney than outside) is treated as a positive number. This convention is consistent with the intuitive notion that increased draft means more suction and hence more air flow. In many technical discussions the signs are reversed—suction in a chimney would indicate a negative draft. In nontechnical discussions this can lead to unnecessary confusion as to whether the draft is increased or decreased when it becomes more negative.

TABLE 6–1
INFLUENCE OF TEMPERATURE ON CHIMNEY CAPACITY

Average Temperature of Flue Gases (°F.)	*Relative Chimney Capacity Ratings*
70	0
75	19
80	27
100	45
200	80
400	97
600	100
800	99
1,000	96

The influence of flue-gas temperature on chimney capacity. The capacity at 600° F. is arbitrarily given a rating of 100. The flue-gas temperature is the average over the height of the chimney from the flue collar to the top of the chimney. An outdoor temperature of 70° F. is assumed.

In many systems, an average flue-gas temperature as low as 100° F. provides adequate draft. This tends to be true of closed solid fuel burners (not fireplaces or fireplace stoves) because their chimneys tend to be oversized. But a serious disadvantage of such low flue-gas temperatures usually is considerable creosote accumulation.

By and large, a chimney should be moderately well insulated and be located as much as possible in heated interior parts of the building to keep flue-gas temperatures reasonably high.

Chimney capacity actually decreases for temperatures higher than about 600° F. Although buoyance, the driving force, is always greater for higher temperatures, the resistance to flow increases even faster. This is because hot gases are less dense and so must have a larger velocity for the same mass flow. However, the effect is very small; practically speaking, the capacity of any given chimney is essentially the same for any average flue-gas temperature over about 300° F.

Chimney Height

To estimate drafts and capacities of venting systems, chimney heights are measured from the flue collar on the appliance to the chimney top. Vertical sections of stovepipe connector contain buoyant gases just as does the chimney; so they also contribute to chimney capacity.

Increasing chimney height improves flow capacity, but not in direct proportion to the change in height. If all other things remained unchanged, a doubling of chimney height would result in a 41 percent increase in capacity; a 10 percent height increase would improve performance by 5 percent. (Chimney flow is proportional to the square root of its height, other things being equal. See footnote 1.)

Other variables do change with height alterations. The higher the chimney, the more the flue gases cool before emerging from the top, which has a negative effect on chimney capacity. There is always an improvement in chimney capacity with increased height, but the amount of improvement is diminished if heat is conducted out through the chimney walls. Insulated chimneys benefit the most from height increases. Table 6-2 illustrates the average *net* effect of height on chimney capacity.

In practice, height is determined by the need to end the chimney above wind-pressure influences and by architectural considerations. In mobile homes and other flat-roofed, single-story structures, chimney heights are often only 10 feet (measured from the stovepipe collar to the chimney top), and they usually work well. For such short chimneys, adding 2 or 3 feet to the height can make a noticeable improvement. But for more typical installations, where the venting system height is 15-30 feet, adding a few more feet is not likely to solve calm-weather draft problems.

TABLE 6-2
INFLUENCE OF HEIGHT ON CHIMNEY CAPACITY

Chimney Height (feet)	*Relative Chimney Capacity Ratings*
6	60
8	69
10	76
15	88
20	100
30	115
50	135

The influence of height on chimney capacity. Capacities are relative to a 20-foot-high chimney, which is arbitrarily given a capacity rating of 100. Heat loss effects are included. The numbers are approximately valid for any type of, and any diameter, chimney, but are specifically for a masonry chimney with an internal area of 38–50 square inches (6–7-inch diameter, if round). Data is adapted from Table 17 in Chapter 26 of The ASHRAE Handbook and Product Directory, 1975 Equipment Volume *(New York: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1975).*

Chimney Diameter

Chimney diameter affects the flow capacity more than chimney height. Assuming the whole venting system (chimney and chimney connector) is of the same diameter, the capacity of the system is approximately proportional to its cross-sectional area. (The proportionality is not exact since heat loss through chimney walls and the resistance to flow also are affected by chimney diameter.)

Table 6-3 illustrates the relationship between chimney diameter and capacity. An 8-inch chimney has about 90 percent more capacity than a 6-inch chimney, and a 6-inch system has about 55 percent more capacity than a 5-inch system. In other words, diameter is *critical*.

In practice, it is usually safe to take the recommendations made by the appliance manufacturer concerning minimum chimney diameter. Lacking

TABLE 6-3
INFLUENCE OF DIAMETER ON CHIMNEY CAPACITY

Chimney Diameter (inches)	*Relative Chimney Capacity Ratings*
3	20
4	38
5	64
6	100
7	139
8	192
10	330
12	506

The influence of diameter on chimney capacity. Capacities are relative to a 6-inch-diameter chimney, which is arbitrarily given a capacity rating of 100. The numbers are approximately valid for any type of, and any height, chimney. Data is adapted from Tables 13 and 14 in chapter 26 of The ASHRAE Handbook and Product Directory, 1975 Equipment Volume *(New York: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1975).*

explicit instructions, a chimney of the same size as the flue collar on the appliance is usually adequate. Substantially larger flues are *not* desirable.

Flow Resistance

Do the number of elbows and the length of stovepipe affect chimney performance? Yes.

Building codes usually require appliances to be located close to their chimneys. Some codes specify no more than two 90-degree elbows in the connector. Some metal fireplace manufacturers specify no more than four 30-degree elbows. But, in practice, many stoves have been used successfully with very long stovepipe connectors (50 feet or more) and more than two 90-degree elbows. This was common a century ago in churches and schoolhouses in New England.

Such long and complex additions to normal venting systems are not recommended, but they will work – if the original system had sufficient excess capacity. This is usually the case with closed burners, such as stoves, furnaces, and boilers; it is usually *not* the case with open burners, such as fireplaces and fireplace stoves. The air inlet on closed burners offers so much more resistance to flow than does any other part of the system that a few more stovepipe lengths or elbows are just not very important to the performance of the whole system. On the other hand, in open burners most of the resistance to flow is due to the venting system itself – since the appliance is open, it offers little flow resistance. In this case, extra elbows, extra lengths of horizontal stovepipe or, in some cases, even a chimney cap can be disastrous – smoke will spill out of the appliance into the house because it does not all get out through the stovepipe and chimney.

Long lengths of stovepipe inside a building increase the heating efficiency of the system; but on balance, they are not recommended. Although stovepipe is not inherently unsafe, the sloppy way in which it often is installed and maintained results in a serious hazard. In addition, such installations usually result in very high rates of creosote accumulation.

Excess Capacity

Too large a flue results in excess capacity, which means less draft and more creosote. The larger the flue, the more chimney surface area there is through which the flue gases will lose heat, and the slower the flue gases will rise, allowing more time for heat to be lost. Cooler temperatures mean less draft and more creosote accumulation.

Excess capacity occurs most often when a large fireplace flue is used for an insert or a stove. If the chimney runs up the outside of the house, the cooling of the smoke is even greater. In extreme cases, cold outdoor air can descend down the chimney from the top at the same time smoke is rising. Recommendations for installing inserts and stoves in fireplaces are given in chapter 12.

To avoid the problems of excess capacity, do not use a chimney flue with a cross-sectional area greater than twice the area of the flue collar on the appliance. See Table 6-4.

House-Chimney Interactions

Many draft and smoking problems are not due to inadequate chimneys. Tight houses can restrict the air supply to the appliance, other appliances can depressurize the house, and the "stack effect" of the house itself can compete with the draft of the chimney.

What happens if a house is *too* tight? The effects depend on the type of appliance. For a closed heater, such as a stove, furnace, or boiler, the consequences may be annoying but are rarely dangerous. When less air enters a stove, the fire is less intense, and so the heat output is less. But smoke may spill out of an open burner, such as a fireplace or fireplace-stove. A minimum flow of

TABLE 6-4
CHIMNEY SIZES

Appliance Type	*Collar Size (inches)*	*Suggested Inside Diameter for Round Chimneys or Flue Liners (inches)*	*Suggested Rectangular Flue Dimensions (nominal exterior (inches)*
Small stoves	4	4-6	4×8
	5	5-7	8×8
Medium and large stoves	6	6-8	8×8
	7	7-8	8×8
Fireplace stoves,* small fireplace inserts,* furnaces, boilers	8	8-10	8×12
	9	10	8×12
Medium fireplaces*		10-12	12×12
Large fireplaces*	12	12	12×16
	14	14	16×16

* A common rule of thumb for fireplaces and fireplace-stove chimneys is that the cross-sectional area of the flue should be about ⅒ (⅛ for chimneys less than 15 feet tall) of the area of the fireplace opening.

Here are the suggested chimney sizes for residential solid fuel heating equipment lacking manufacturer's instructions. Bigger is not always better. Oversized flues tend to create less draft and accumulate more creosote or soot. Adapted from Table 5-4 in J. W. Shelton, Wood Heat Safety *(Charlotte, Vt.: Garden Way Publishing, 1979).*

air, about 0.8 foot per second averaged over the opening, is needed to keep the smoke eddies inside the combustion chamber. Typical air consumption rates of various wood burning appliances are indicated in Table 6-5.

All houses have some air leakage both into and out of the structure, even with all doors and windows closed. Much of this occurs around doors and windows. A certain amount of this *air exchange*, or infiltration plus "exfiltration," is necessary to keep the humidity from getting too high. Typical air exchange rates are from ½ to 2 air changes per hour, although in extremely tight houses the rate can be as low as ¼ change per hour.

In homes with typical natural air leakage, only open appliances are likely to run short of air. Typically, *closed* burners need roughly 10 percent of the air that is naturally entering and leaving the house anyway; but *fireplaces* may need more air than the house can provide.

This air shortage is most likely to occur in electrically heated houses, energy conservative houses, mobile homes, and earth-sheltered (partly underground) houses. Opening a window, decreasing the area of the fireplace opening, and ducting outdoor air to the fireplace (see chapter 9) may make it possible to use open burners in houses that are too tight. In very tight houses, or even in closed rooms, even closed burners may perform better with outside air.

Another reason for poor draft can be the slight depressurization of a house caused by other appliances. Kitchen and bathroom exhaust fans are common culprits. Perhaps more important in practice are other vented fuel-burning appliances, such as central heaters and other solid fuel heaters. For instance, in many houses with more than 1 fireplace, only 1 can be used at a time. Even then, air is pulled down the unused flue, bringing with it creosote odors and sometimes even smoke from the other fireplace flue. A strong draft in 1 large chimney literally sucks on the house, making it harder for any other chimney to operate properly. The suction can be enough to pull outdoor air down any unused (cool) flue, to cause smoke to spill into the house from operating open appliances, to result in sluggish operation of closed burners, and to cause poor combustion and fume spillage in gas-burning and oil-burning equipment. The only practical solution is to supply outside air to one or more of the larger appliances.

Sometimes the house itself acts somewhat like a chimney. On a cold day, the warm air inside the house is relatively buoyant. The warm air pushes

TABLE 6-5
CONSUMPTION AND AIR EXCHANGE RATES

	Air Consumption	
Appliances and Houses	*Cubic Feet per Minute (at 70° F.)*	*Grams per Second*
Small stoves	10-50	5-25
Large stoves, furnaces, and boilers	20-100	10-50
Fireplace stoves with doors open		
Small fireplaces without doors	100-300	50-150
Medium and large fireplaces (without doors)	200-1,000	100-500
House air exchange rate	100-600	50-300

Typical air consumption of solid fuel heaters and air exchange rate for houses. For open burners the flow is roughly 50 cubic feet per minute for every square foot of the opening (for example, the fireplace face).

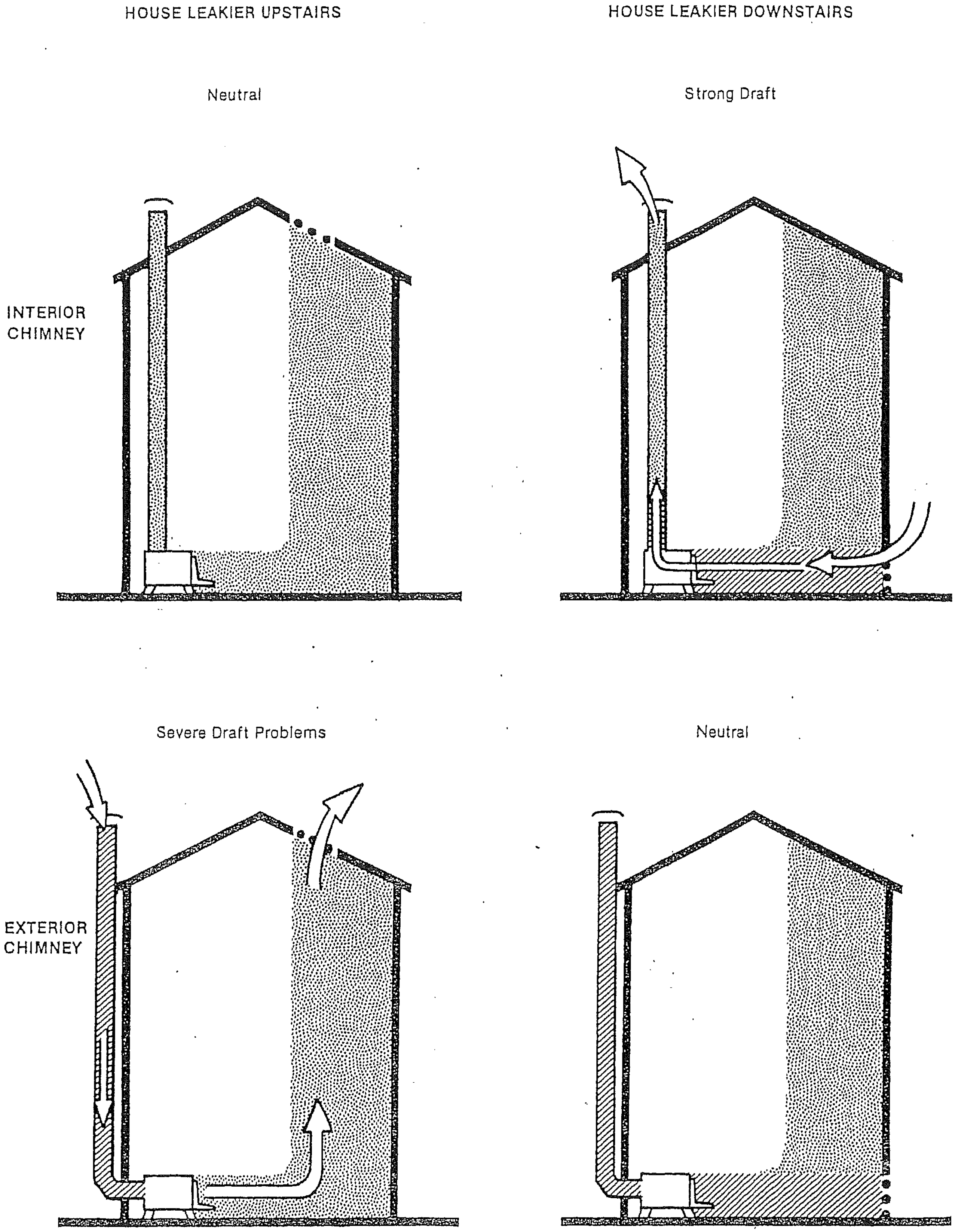

Figure 6–4. House-chimney draft interaction on a cold, calm day.

out any available cracks in the upper portions of the building, and cold outdoor air is sucked in through openings in the lower portions of the building. In very tall buildings, the resulting wind coming into open street-level doors can be very fierce unless special countermeasures are taken.

But the more important effect on chimney performance is the slight changes in house pressure caused by this buoyant house air. If the house has more cracks in its upper portions than near ground level, warm air can get out more easily than cold air can get in, and the result is a slight depressurization of the whole house. Lower pressures inside the house mean less tendency for air and smoke to go up the chimney. In essence the house itself is acting like a competitive chimney (Figure 6-4). In fact, building engineers call this pressure effect in buildings the *stack effect*. In a 2-story or 3-story house, the effect can be as large as 0.03 inches of water.

At the opposite extreme is a house that is predominantly leaky in its lower portions—as would be the case with a ground-level door open. Since cold air can then move in more easily than the warm air can get out, pressure at the bottom of the house tends to equalize with the outdoor pressure at ground level. This pressurization encourages the flow of smoke up the chimney.

When the stack effect of the building is working against the chimney's own draft, not only is the chimney's draft generally decreased, but the flow in the chimney can even reverse! This is most likely with an exterior chimney starting on the ground floor of a multistory house. Exterior chimneys run cooler, so the smoke is less buoyant. A multistory house has a stronger stack effect. If the average temperature of the smoke in the chimney is less than the average temperature of the air in the house, the flow is likely to reverse. Cold air descends down the chimney, feeds the fire, and all the smoke comes into the house through the air inlet of the appliance (Figure 6-5).

Since a contributing cause of flow reversal is cool smoke in the chimney, chimneys with high heat loss contribute to the problem, as does operating the appliance at a low firing rate (often done overnight with stoves). Also colder outdoor temperatures make reversal more likely.

Correcting reverse flow in a chimney can be difficult. The first thing to do *any* time smoke is spilling into the house from a wood burner is to open a door or window on the ground floor and on

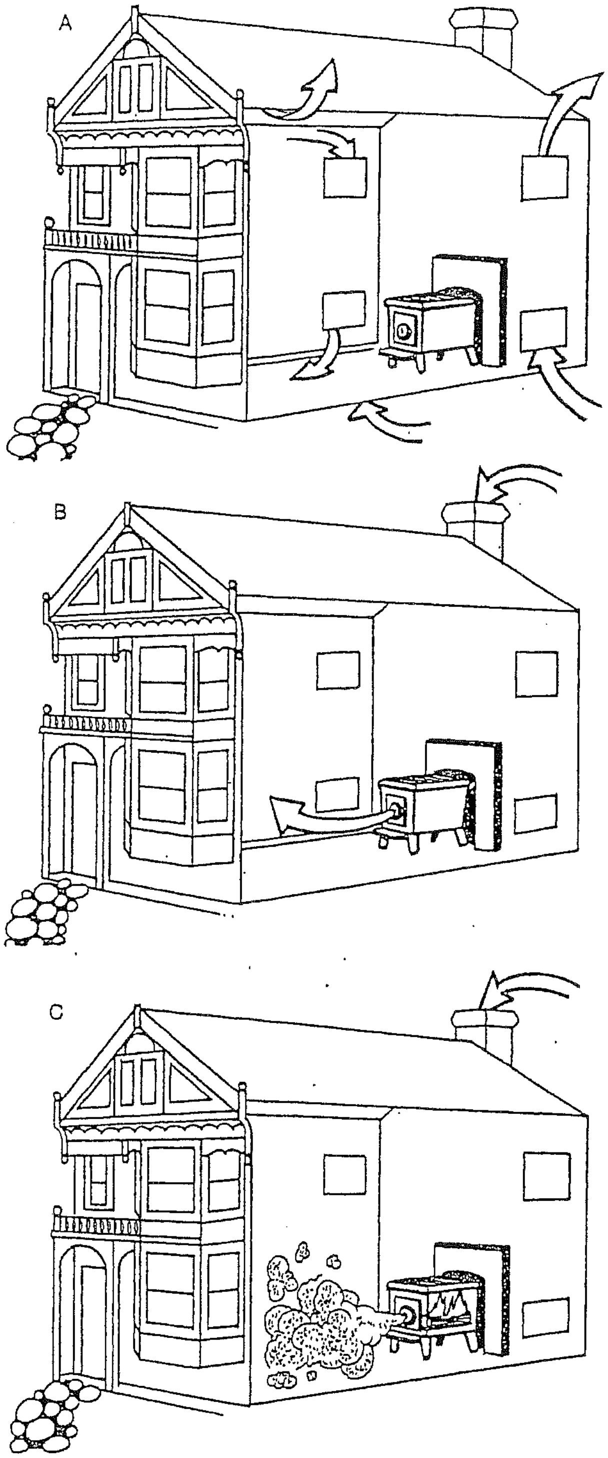

Figure 6-5. Exterior chimneys in multistory houses often have poor draft. A: The normal air flow into and out of a house on a calm winter day. The air tends to be drawn into the house on the ground floor. B: As a result, many exterior chimneys are non-self-starting; air flows down the chimney when it is cold. C: Even when the chimney is in use, smoke can become sufficiently cool that flow reversal occurs.

the upwind side of the house if it is windy, and *close* all other openings. This maximizes the pressure in the house, which may by itself correct the situation. If a window fan is available, use it to force outside air into the room; close all other windows and all doors, both exterior and interior. The resulting pressurization of the room will almost certainly correct the chimney's reverse flow. Directing a strong portable fan at the air inlet or into the open combustion chamber is *not likely* to help and can cause sparks to be blown into the room. In chimneys with easily accessible cleanout doors or unused breachings, it sometimes helps to insert some newspaper inside the chimney and light it; the additional warmth increases the buoyance enough to get the chimney operating properly.

Interior chimneys are rarely susceptible to flow reversal because their warmer environment keeps the smoke at least as warm as the house air temperature.

You can test a chimney for its flow-reversing tendency before actually using it. On a very cold, calm day when the chimney has not been in use for a day or two, susceptible chimneys are likely to have cold outdoor air descending and entering the house. If the air flow is not obvious by its force, temperature, or its chimney odor, you can use cigarette or incense smoke, or tissue paper, or tinsel to see which way the air is moving. Chimneys that run backwards when cold are called *non-self-starting.* The non-self-starting problem itself is traditionally solved by lighting newspaper stuck up into the chimney.

Non-self-starting is only an annoyance. But flow reversal is dangerous because it can lead to asphyxiation. It is best not to use such chimneys, especially for airtight stoves and inserts. If such chimneys are used, smoke detectors in the house are essential.

Weather and Altitude

Windy weather can affect chimney performance adversely by reducing or even reversing the flue-gas flow—making the fireplace or stove smoke. Properly locating the chimney top relative to the roof can alleviate some of the problem, and chimney caps can be very effective.

There are 3 kinds of wind effects. If the wind direction is into an opening through which smoke is trying to come out, the smoke flow is impeded. For example, a low, open (uncapped) chimney at certain locations downwind of a building may not perform well if the wind blows too hard (Figure 6-6). This first effect is caused by what is called the "velocity pressure" of the wind.

There are 2 ways to alleviate this problem. If the chimney extends high enough, the wind generally will blow across it, not into it. This is 1 reason why it is usually recommended that the chimney top be 2 feet higher than any portion of the roof within 10 feet of it and 3 feet higher than the roof area through which it penetrates (Figure 6-7). (The other reason is to prevent hot flue gases or sparks from igniting the roof.)

Installing a chimney cap is the other way to alleviate this wind back-pressure effect. Wind caps make the calm-weather smoke discharge omnidirectional. Then, with wind blowing from any direction, some smoke can still always get out on the other side. A flat plate on posts is a common and simple wind cap for masonry chimneys. Many kinds of metal caps are used, especially on metal chimneys (Figure 6-8). Chimney caps that rotate or have moving parts are sometimes unsatisfactory for use with wood fuel; creosote deposits can foul up the caps to the point where they become stuck.

A second wind effect always helps chimney performance. Air exerts what is called *static pressure*, which, in still air, is the same as atmospheric pressure. But in moving air, the static pressure is less.[2] In principle, a barometer in moving air would read a lower pressure than in nearby still air. Thus, if a chimney top is in a region of strong winds, the general (static) pressure level all around it is reduced. This effectively applies suction on the gases in the chimney, and so it draws better—the wind aspirates smoke from the chimney. The stronger the wind, the larger is the effect. This effect is in addition to the velocity pressure effect previously discussed.

A third effect, related to the viscosity of the air and its turbulent motion, is the creation of a large low pressure eddy region on the downwind side of a house (and a much smaller high pressure region on the upwind side). A chimney terminating in this low pressure region performs better, since the low air pressure tends to suck the smoke out.

When all the effects are combined, and if the

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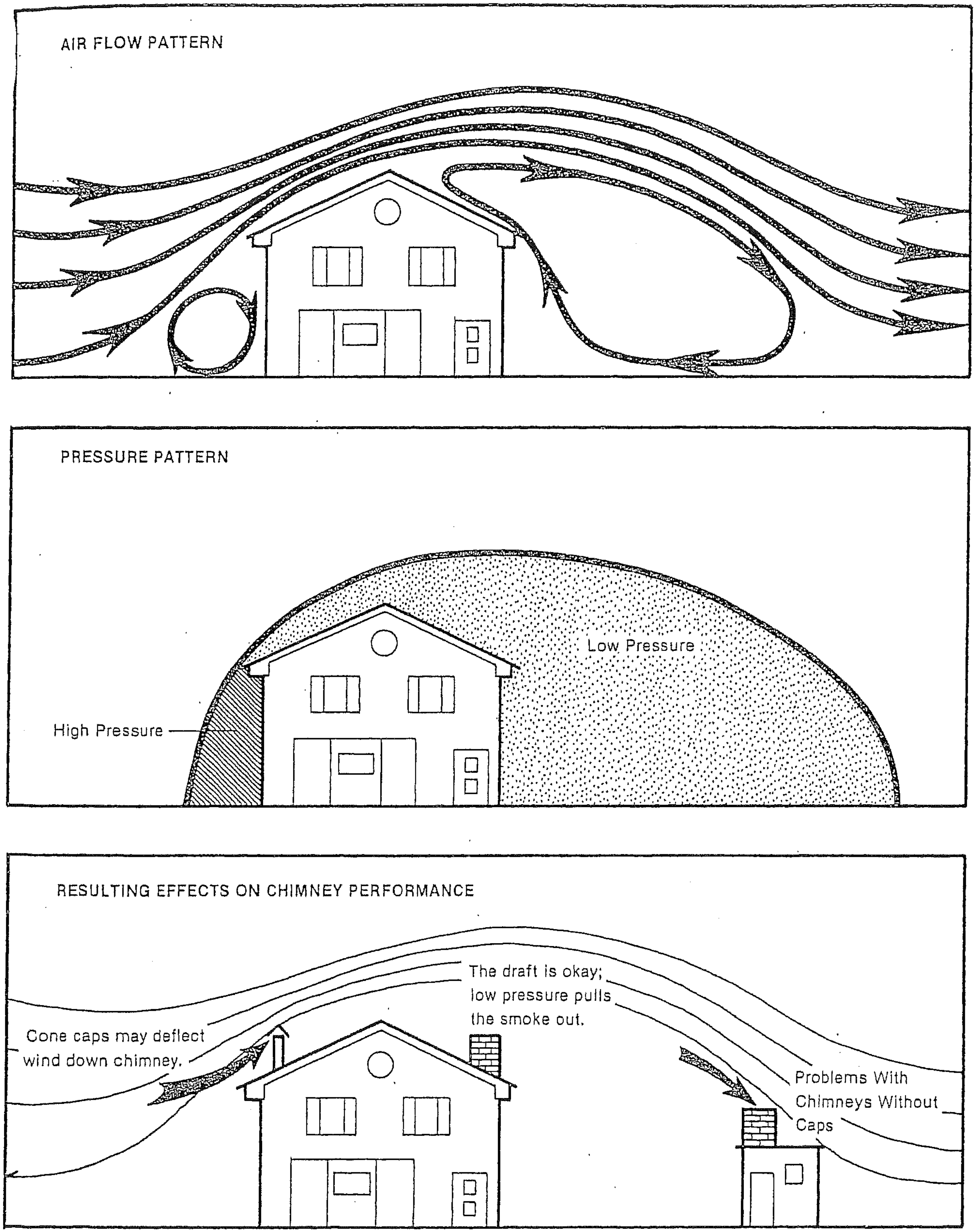
[2] This is approximately described by Bernoulli's equation. Specifically, the pressure decrease in moving air compared to still air is $\frac{1}{2} dv^2$, where d is the mass density of the air, and v is its speed.



AIR FLOW PATTERN

PRESSURE PATTERN

RESULTING EFFECTS ON CHIMNEY PERFORMANCE

Cone caps may deflect wind down chimney.

The draft is okay; low pressure pulls the smoke out.

Problems With Chimneys Without Caps

Figure 6–6. Typical wind effects around a building. Similar patterns are caused by trees and hills.

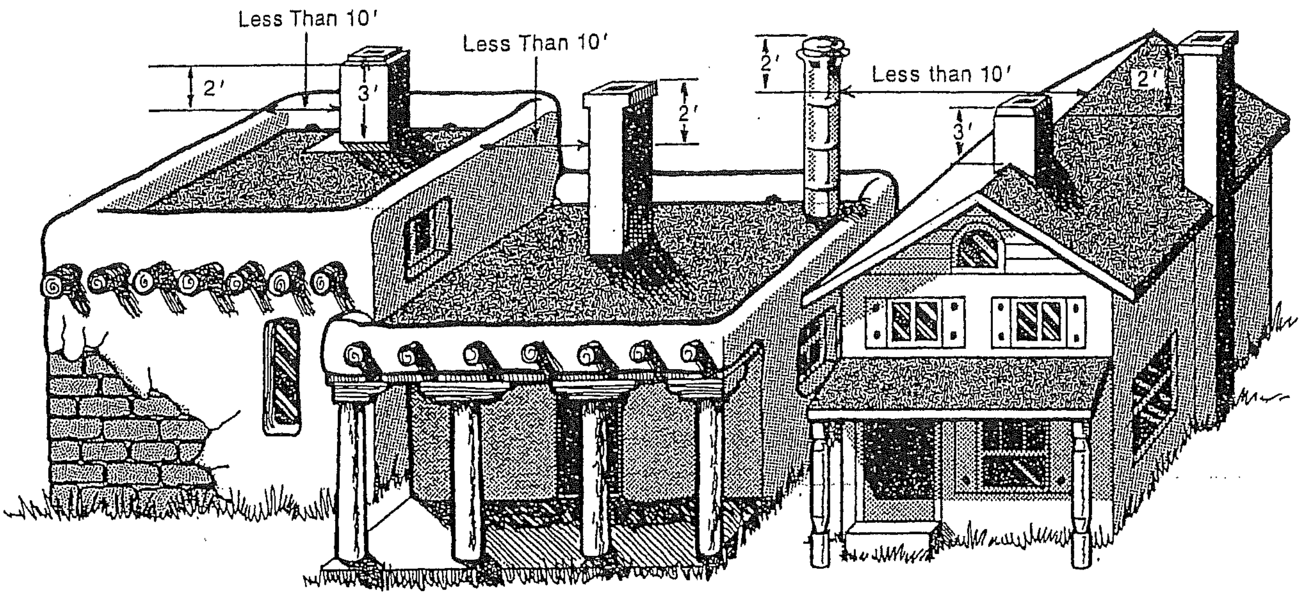


Figure 6-7. Minimum chimney height recommendations according to NFPA and most building codes.

chimney has a good cap, winds usually do not cause serious problems. For wind velocities up to the flue-gas velocity, there is very little effect. (Typical stove flue-gas velocities are 1-6 miles per hour.) For wind speeds 1-3 times the flue-gas velocity, there is a slight reduction in chimney flow. At wind speeds greater than about 3 times the flue-gas velocity, chimney performance is better than in still air. With an effective chimney cap, wind speeds between roughly 5 miles and 20 miles per hour may cause a slight decrease in chimney capacity, slower winds will have little effect, and faster winds often will improve performance.[3]

Gusty winds can cause slight smoke spillage into a house with any kind of chimney and cap, but less with taller chimneys. The currently recommended chimney heights, illustrated in Figure 6-7, are shorter than the chimneys on most eigh-

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[3] These quantitative estimates are from R. L. Stone, "The Role of Chimneys on Heat Losses from Buildings" (Paper delivered at the Annual Meeting of ASHRAE, Boston, Mass., June, 1975).

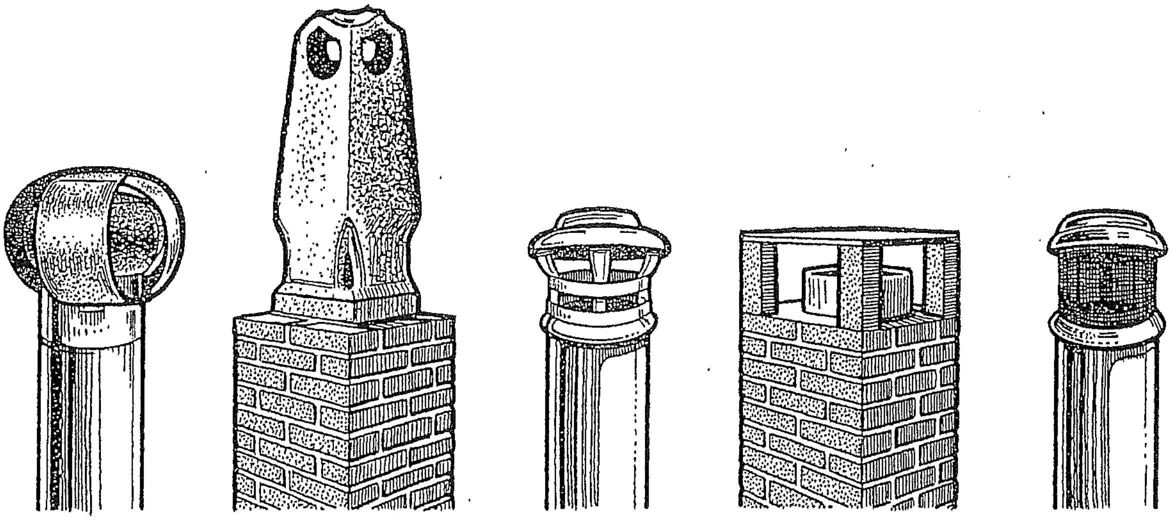

Figure 6-8. Chimney cap designs.

teenth and nineteenth century houses in New England. Taller chimneys are recommended as long as there is still good access for chimney cleaning.

Wind can change the pressure inside a house, which then affects chimney performance. If the house has some open windows or doors on the side facing into the wind, the house pressure increases, which helps the chimney; openings on the downwind side decrease the pressure inside the house, hurting chimney performance. A temporary solution to a badly smoking stove or fireplace on a windy day is to open a downstairs window or two on the upwind side of the house.

Outdoor temperature can affect chimney performance because the draft depends on the difference between the flue-gas temperature and outdoor temperature. The colder the weather, the better the draft in interior chimneys. As the temperature drops from 50° F. to 0° F., chimney capacity can double. Exterior chimneys also perform better in cold weather if their insulating value is high enough and if the flue-gas temperature and flow rate is high enough to prevent excessive cooling of the smoke.

Barometric pressure also has a small effect on chimney capacity. When the pressure is high, the combustion air and the flue gases are a little denser; more smoke can get through a chimney. An increase in pressure of 1 inch of mercury increases chimney capacity by about 4 percent.[4] Typical variations in barometric pressure span no more than 2 inches of mercury, which causes an 8 percent change in chimney capacity.

It is unlikely that humidity in the air has an effect on stove performance. Even when the relative humidity is 100 percent, water vapor can never constitute more than 1.5 percent of air by weight (at 68° F. or less); so changes in humidity can affect the composition of air by only this small amount. The maximum effect of humidity on the oxygen content, density, thermal conductivity, and specific heat in air is less than 1.5 percent, which is negligible.

None of these weather effects is very big by itself, but they frequently act together. When barometric pressure is high in the winter, the weather is often cold and calm; when the pressure drops, the weather is often windy and not as cold. Adding all the effects together suggests that weather can affect chimney capacity by as much as 20 percent, the higher capacity often coinciding with high barometric pressure, making it easier to have hotter fires.

Weather effects will be most noticeable in systems that are marginal to begin with. In many cases, there is enough excess chimney capacity that these weather effects will never be noticed.

Altitude also affects chimney performance. The thinner air at high altitudes decreases chimney capacity just as does low barometric pressure. For every 1,000 feet of elevation above sea level, chimney capacity is decreased by about 4 percent relative to the same chimney at sea level.[5] At 5,000 feet, a chimney would have to be designed with 20 percent extra capacity compared to a chimney at sea level serving the same appliance. At 10,000 feet, the effect is about 40–45 percent.

Although elevation effect is much larger than the barometric pressure effect, it is usually of little practical consequence for solid fuel heaters because chimneys usually have generous excess capacity. Also, the thinner air at high altitudes can mean that less oxygen gets to the fire; if the fire is not as intense, the chimney need not have as much capacity.

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[4] *ASHRAE Handbook and Product Directory, 1975 Equipment Volume*, (New York: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1975) p. 26. 13.