TROUBLE-FREE Forced-Air Heat

Tips for selecting, sizing, ducting, and venting oil and gas furnaces

by Gary Bailey

Some builders try to save money by installing their own warm-air furnaces, and some do a decent job. But more often than not, I end up talking to their frustrated customers a couple years later, when they're ready to rip out a practically new furnace. Whether you're replacing a worn-out furnace or just need to add a few duct runs for an addition, if your clients can't sit in the new family room without freezing, or can't pay the heat bill, they're not going to be happy with you.

Scope Out the Job

Before you can recommend a specific furnace, you have to know what will and won't work with the job conditions at hand. When I survey a job, I'm trying to find out three things:

1. Which fuel to use — natural gas, LP, or oil — and how to vent the flue gas
2. How much heat the house is losing so I can size the new furnace
3. Whether the ductwork is adequate

Figure 1. This standard-efficiency furnace (left) vents into an unprotected chimney on an outside wall. The poor draft has resulted in excessive flue gas condensation, which has corroded the galvanized flue pipe. Instead of repairing a damaged chimney, it is often less expensive to install a PVC-vented high-efficiency furnace (right).

When I have my answers, selecting the right furnace is a piece of cake. The only decisions left are what features the customers want and how much they want to invest.

Fuel Choices

What's the best fuel — oil, natural gas, or LP? The answer depends on which is most commonly installed in your area and its local cost. In our area, natural gas is available in most towns at the relatively low cost of $1/Therm (1 Therm = 100,000 Btu) or less. Add the convenience of never having to schedule a fuel delivery, and natural gas is the smart choice. In rural areas, however, it's usually a toss-up between oil and LP gas. Oil is generally cheaper ($.80/Therm vs. $1.25/Therm for LP), but oil doesn't burn as cleanly as gas so the furnace will require more maintenance. Oil also produces a foul odor, and an oil furnace can't offer the efficiency or features of the best gas units. In my opinion, these drawbacks of burning oil outweigh the lower fuel costs. Unless I can drop in an oil furnace without having to repair the chimney or replace the oil tank, I often suggest that rural customers switch to a high-efficiency LP gas furnace.

Venting Options

An improperly vented warm-air furnace will result in constant callbacks and nuisance no-heat calls — and that's the good news. In the worst case, it will do irreparable damage to your client's home or produce life-threatening carbon monoxide gas.

Oil venting. Oil furnaces require either stainless steel "all-fuel" chimneys or well-built masonry chimneys with masonry or stainless steel liners. (Aluminum liners will quickly corrode.) Some inspectors allow sidewall power-vent kits to be installed on oil equipment, but don't be tempted. These units can cause overdraft, producing excess soot and reducing efficiency. The few hundred dollars you save by not building a chimney will be burned up in higher fuel costs and endless maintenance.

Mid-efficiency gas venting. Builders often confuse mid-efficiency (80% AFUE, or Annual Fuel Utilization Efficiency) furnaces with true "condensing" (above 90% AFUE) furnaces because they look mechanically similar. Beware: Most mid-efficiency furnaces on the market are not approved for sidewall venting and require a properly sized and lined masonry chimney or a B-rated metal chimney system. The combustion products from a gas furnace are as acidic as the mixture used to clean mortar off brick, and will quickly destroy an unlined masonry chimney by reacting with the Portland cement in blocks and mortar. I've seen chimneys actually collapse after only a few years. Masonry chimneys on cold outside walls are the worst offenders, because the flue gases will cool and condense very quickly (see Figure 1).

You can't tell if a chimney is lined just by looking at the top of it. The only way to know for sure is to look in through the thimble with a flashlight and mirror. If the chimney is questionable, a flexible, one-piece aluminum liner, such as the Flexi-Liner (Flex-L International, P.O. Box 29140, Columbus,

Figure 2. Because it was oversized, this 90,000 Btu furnace had to be replaced. The four 7-inch-diameter ducts carried only half the hot air the furnace was capable of producing, causing the heat exchanger to overheat and crack.

OH 43229; 800/561-1980), can be installed.

High-efficiency gas venting. If the chimney is beyond repair or if your customer just wants higher efficiency, you can opt for a condensing gas furnace, which vents through a PVC pipe directly out the sidewall or up (one story) through the roof. These furnaces must be vented exactly as the manufacturer requires, which often limits the length and position of the vent pipe.

Many condensing gas furnaces are available as "sealed combustion" units, which bring combustion air to the firebox in one pipe, and send exhaust back out another. There are many advantages to sealed combustion — no backdrafting of other nearby appliances, and cleaner, drier air for combustion, which means longer component life. There are also pitfalls, the most common being "recirculation lock-out," where the unit sucks moisture-laden exhaust back through the inlet. The best defense is to follow the manufacturer's installation instructions exactly, use the approved two-pipe termination method, and keep pipe lengths as short as possible.

Sizing the Furnace

Many customers who are tired of being cold will want a furnace that is the same size or larger than the one I'm taking out. I have to educate them that with warm-air furnaces, oversizing is the equivalent of stuffing a 747 engine into a Volkswagen. Instead of providing steady, even heat, an oversized furnace will quickly come up to temperature internally and shut down. This "short cycling" will make rooms close to the furnace too hot, and rooms at the end of the line too cold, because the blower never operates long enough to fully mix and circulate the air in the house. People can feel temperature differences as small as a couple of degrees, but if the furnace is oversized, it's not uncommon to experience swings of 10°F or more.

Equipment life. Short-cycling also wears out furnace components, including the blower motor and the heat exchanger, three to four times faster than if the furnace were running normally. I've seen high-quality furnaces that should have lasted for 20 years or more fail completely in three or four years as a result (Figure 2).

Condensation and soot. Burning fossil fuel produces moisture, and like a car that only gets driven around the block, an oversized furnace will never dry itself out or warm up enough to keep a clean flue. Like a car tailpipe, the result is extra soot, scale, and rust — all enemies of metal parts.

Noise. Heating technicians will often jack up the blower speed in an attempt to move the heat off the oversized furnace as quickly as possible. While this may protect the furnace from damage due to overheating, it often causes a sound like a jet plane taking off every time the furnace comes on.

Figuring Heat Loss

When my grandfather started what is now my company, he probably ballparked furnace sizes based on the volume of the house or some other rule of thumb. Today, furnaces are more sophisticated, and the only right way to size one is with a heating load calculation, which tells you how much heat the house is losing. You don't have to be an Einstein to produce a usable load calculation; basically, you are figuring out the area of any surface exposed to cold, then plugging in numbers off a chart.

Future additions. If an addition is part of the project, you'll need to calculate it right along with the existing house and size the new furnace accordingly. Sometimes, however, people want to know if the furnace I'm proposing will be big enough to handle an addition "in the future." I'm reluctant to size a furnace for something that might never happen, especially when doing so will cost the homeowner extra heating dollars year after year. The better solution is to wait until the addition is actually planned and address the heating at that time with a separate system or zone.

Basic Heat Load Calculation

To size a furnace, you have to know how much heat the house is likely to lose in the worst case scenario, which would be on the coldest winter night (no sun gain) with a brisk wind. The difference between room temperature and maximum lowest outdoor temperature is called the "Delta T." Delta (Δ) is a Greek letter used to mean "change." In our area of New York State, we use the design numbers of 70˚F indoor temperature, -10˚F outdoor temperature, or a ΔT (Delta T) of 80˚F. Figure 3 is a chart giving heat loss for common building assemblies at ΔTs ranging from 40˚F to 100˚F. Use the values from the column that best represents your area. If you're not sure what design temperatures apply to your area, any good hvac contractor should be able to tell you. These numbers have been adjusted for average air infiltration.

To calculate heat loss for assemblies not listed, use the formula

$$\frac{\Delta T \text{ x SF}}{\text{R-Value}}$$

where SF is the total square footage of the assembly, ΔT is the commonly used number for your area, and the R-value is the sum of all the R-values in your assembly.

You might want to add 15% for average air infiltration, 30% if the house is known to be very drafty, or nothing for a new tight house. A small mistake probably won't affect your totals, but use common sense and adjust the figures accordingly.

Figure 4 is the worksheet our company uses to perform heat load calcs (we also use it for cooling loads). In the top portion, we sketch the walls of the house, including doors, windows, and other relevant information. Each square of the graph paper represents a 5-foot square. For complex houses, we'll use more than one sheet, dividing the house up as necessary. The sample house is a simple single-story ranch with an uninsulated concrete foundation.

Here's how to use the worksheet:

1. Gross Wall Area: Unless the entire house is the same construction above grade, you must calculate each wall type separately. First measure the outside perimeter of the house. Our sample house has an uninsulated concrete foundation, with 16 inches exposed above grade, and insulated 2x4 exterior walls. Multiply the total length of each type of exposed wall by its height. Include the rim joist area in the stud wall.

Masonry Wall: 140 ft. x 16 in. (1.34 ft.) = 188 SF

Frame Wall w/ Rim Joist : 140 feet x 9 feet = 1260 SF wall (Gross)

2. Windows And Doors: Measure all the windows and doors; round to even feet. A standard entry door is 3x7, or 21 SF, for example. List each by type of glazing — single pane, single pane with storms, and double pane. We don't consider the improvement low-e or other "high performance" films might add because while they improve the daytime performance of the window, they do little for the R-value once the sun goes down. As a fudge factor, we instruct our estimators to use only two values for windows in existing construction:

Window/Door Heat Loss Worksheet

Quantity	Type	Size	Total SF	Btu	Total (round up to 100)
Glazing					
2	Insulated Stl. Entry Door	3 x 7	42	100/SF	4,200
1	Picture Window, Single-Glazed	10 x 5	50	110/SF	5,500
6	Double-Hung Thermal Pane	3 x 4	72	75/SF	5,400
Total Btu Loss Windows/Doors					**15,100**

110 Btu/SF for single pane, 75 Btu/SF if the window has a good storm or is thermal pane. We use the 65 Btu/SF value only in new construction where we can verify how the window was installed. Experience has taught us that new windows are often poorly sealed and insulated around the perimeter.

3. Net Wall Heat Loss: Subtract the window/door area from the gross wall area above grade:

1260 SF wall area – 164 SF window/door area = 1096 Net Wall Area x 6 Btu/SF (from the table) = 6600 Btu/Hr (rounded up)

Calculate exposed basement wall:

140 ft. x 16 in. = 188 SF X 36 Btu/SF (from the table) = 6800 Btu/hr (round up). Note that if there were basement windows, they would be calculated the same as windows in the above grade framed walls.

4. Cold Ceiling: Calculate the exposed ceiling area:

30 ft. x 40 ft. = 1200 SF x 3 Btu/SF = 3600 Btu/hr.

If there are areas of the house insulated differently, they must be measured and calculated separately. If there is no batt or fill insulation above the ceiling or you can't confirm the amount, assume the plaster and wood has at least minor R-value. Rarely will you find a totally uninsulated ceiling except in an unfinished structure like a garage or warehouse.

5. Cold Floors: You either pretend the house is on stilts with the main floor exposed to cold, or you calculate the basement slab and walls, but not both. In this case we are including the basement in the calculation, so the first floor is neutral to heat loss, and we figure the concrete basement slab instead. Surprisingly, the result will be very close either way, once you correct the total for basement area loss (step 7, below). Rounded up, the area is the same as that of the ceiling:

30 ft. x 40 ft. = 1200 SF x 2 Btu/SF = 2400 Btu/Hr.

Other examples of cold floors might be the floors of living spaces above garages, enclosed porches, cantilevered areas on raised ranches, or upstairs rooms above open porches.

6. Add Up the Losses: You're almost done. Once you've calculated the losses through windows/doors, walls, ceilings, and floors, add up the result, rounding up as necessary.

Windows/Doors	15,100
Walls/Masonry	6,800
Frame	6,600
Ceiling	3,600
Floors	2,400
Total Net Loss	**34,500 Btu/Hr**

7. Basement Factor: Take 20% of the Total Net Loss to account for basement area heat loss and air infiltration at the sill. This is a factor we calculated based on information from more than 1,000 jobs. It works well to account for heat loss through below-grade basement walls, and saves us from having

Heat Loss of Building Assemblies (Btu/hr)

Assembly	Approx. R-value of assembly	ΔT 40°F	60°F	80°F	100°F
Windows		Values are per sq. ft.			
Single pane	NA	55	85	110	140
Single pane w/ storm	NA	38	60	75	94
Thermal pane	NA	33	50	65	82
Doors					
Wood, no storm	NA	125	188	250	313
Wood, w/ storm	NA	75	113	150	188
Steel insulated	NA	50	75	100	125
Garage, weatherstripped	NA	75	113	150	188
Walls					
Above-grade masonry - uninsulated	R-2	18	27	36	45
Above-grade masonry w/ 2" EPS	R-12	4	6	8	10
Uninsulated wood, 0" insulation	R-3	11	17	22	28
Insulated wood, 1 1/2-2" insulation	R-5	6	9	12	15
Insulated wood, 3-4" insulation	R-13	3	4	6	8
Insulated wood, 5-6" insulation	R-19	2	3	4	5
Ceiling					
Open, no insulation	R-1.5	23	34	45	56
1 1/2 - 2" insulation, plaster or sheetrock	R-5	6	9	12	15
3-4" insulation, plaster or sheetrock	R-12	3	4	6	8
5-6" insulation, plaster or sheetrock	R-20	2	3	4	5
8-9" insulation, plaster or sheetrock	R-30	2	2	3	4
11-12" insulation, plaster or sheetrock	R-38	1	2	2	3
Floors		Values are per linear foot			
Radiant slab edge, no insulation		125/LF	188/LF	250/LF	313/LF
Slab edge, no insulation		75/LF	113/LF	150/LF	190/LF
Slab edge, 1" EPS insulation		45/LF	68/LF	90/LF	113/LF
Radiant slab edge, 1" EPS insulation		75/LF	113/LF	150/LF	190/LF
		Values are per square foot			
Basement slab, below grade	NA	1	2	2	3
Wood floor, uninsulated, 0"	NA	11	17	22	28
Insulated wood floor, 1 1/2-2" insulation	R-5	6	9	12	15
Insulated wood floor, 3-4" insulation	R-12	3	4	6	8
Insulated wood floor, 5-6" insulation	R-20	2	3	4	5
Insulated wood floor, 8-9" insulation	R-30	2	2	3	4
Insulated wood floor, 11-12" insulation	R-38	1	2	2	3

For building assemblies not listed here, calculate the heat loss in Btu/hr with the formula $\frac{\Delta T \times SF}{\text{R-Value}}$

Add 10-30% for air infiltration losses.

Figure 3. Use this chart to find the heat loss in Btu/hr of various building assemblies. Use the ΔT that applies to your region. This is a design temperature that represents the difference between the coldest night of the year and a 70°F indoor temperature.

System Design and Analysis Worksheet

Customer: RICK + YVONNE SMITH

Phone 1: 555-3121

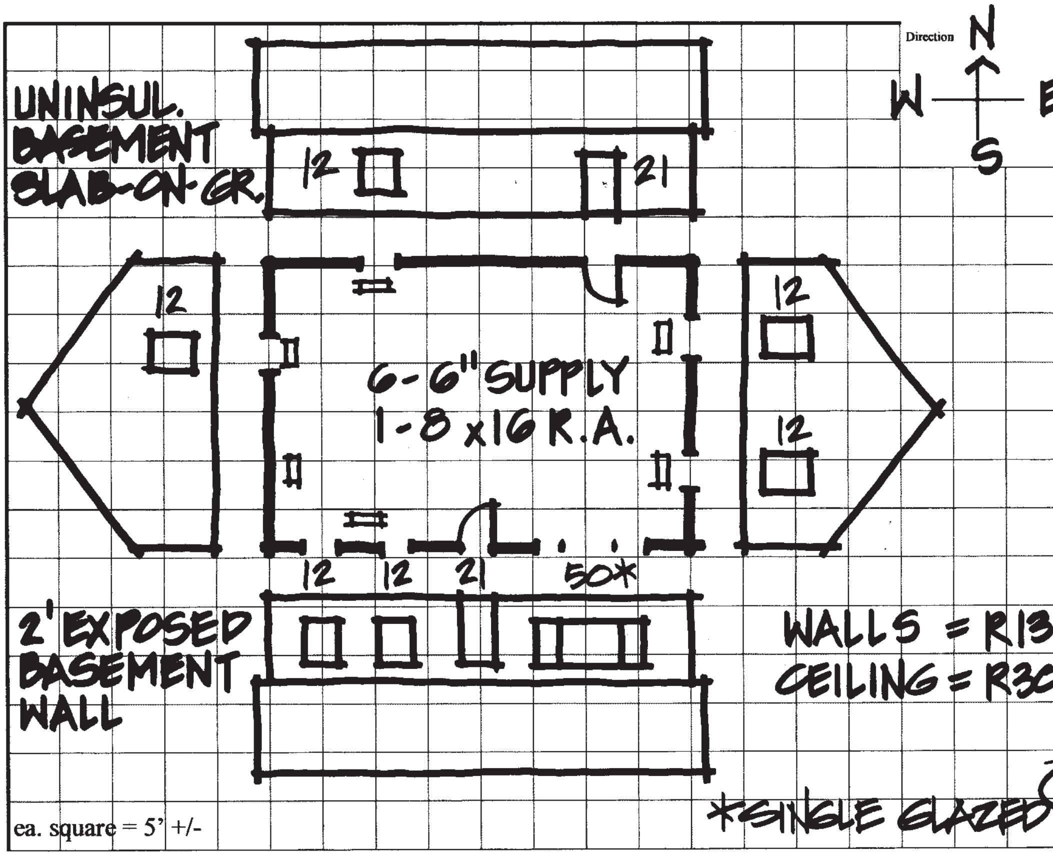
Phone 2:

Address: 2134 RIVER ROAD
EAST DOVER

Notes: VACATION HOME

Calculation is For:
- [x] FA Furnace
- [ ] HW Boiler
- [ ] Steam Boiler
- [ ] Earth Energy
- [ ] Ht.Pmp - air
- [ ] Space Heat
- [ ] A/C
- [ ] CompleteHeat
- [ ] Other

- [ ] Electric
- [x] Nat.G
- [ ] LPG
- [ ] Oil
- [ ] Other



Delivery System:

RA: 1-8x16

TOTAL CFM: 660

SUPPLY: 6-6"
8x16

TOTAL CFM: 600

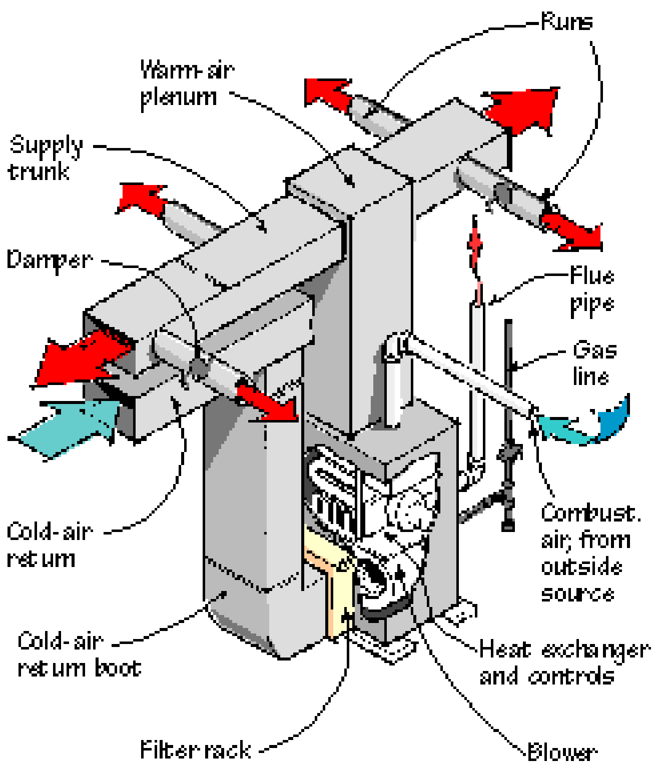
600 = OK

	Windows	Doors	Tot.SF	x_Btu	Total Btu
North	12 [12]	21		N.A.	
East-West	3@12 [36]				
South	50(110) 2@12 [24]	21			
	Total SF for Heat.: ~~72~~ 50	42		Total Cooling	
	_x_BtuH: ~~15~~ 110	100			
	Totals: ~~5400~~ 5500	4200	⇨	Total Heating 15,100	

Wall	Heating		Cooling
Gross SF 1260			NOT USED
SF Glazing 164		15,100	
Net Wall 1096	6	6,600	
Ceiling 1200	3	3,600	
Floor ~~1200~~ 188	~~2~~ 36	~~2400~~ 6800	
Net	34,500		appliance + 2400
Adj (b'mt, attic) 1.20	41,500		+400* ___ = ___
Input 80+	52,000		Adj* ___ = ___
Input 90+	46,100		Total Cooling

Figure 4. The author's company uses this worksheet to perform building heat loss calculations. In the sample calculations shown here, the heat loss for building assemblies is based on a design ΔT of 80°F.

Typical High-Efficiency Furnace



Notes for Chart
The CFM and Btu capacities in this chart are based on a maximum distance of 60 feet from the furnace to the supply register. To use this chart, first select a furnace whose output matches the heat loss for the building. Size individual room ducts based on a room-by-room heat loss calculation. Size the trunk line to carry the total CFM of all the branch ducts. Step down the trunk line to maintain air velocity, making sure that each new trunk section has the capacity to carry all the branch lines coming off from that point to the end of the trunk.

Figure 5. Use this chart to assess existing ductwork or plan for additional runs. The total Btu capacity of the ductwork (both supply and return) must match the Btu output of the furnace.

Sizing Ducts for Forced-Air Heat

Round Pipe (in.)	Square Duct (in.)	CFM	Heating Btu
4		32	2,400
5		60	4,400
6	3 1/4 x 10	100	7,400
	3 1/4 x 12	120	8,900
7	3 1/4 x 14	145	10,700
	8 x 6	180	13,300
8		210	15,600
	8 x 8	270	20,000
9		290	21,500
	8 x 10	370	27,400
10		390	28,900
	8 x 12	460	34,000
11		500	37,000
	8 x 14	560	41,500
12		620	45,900
	8 x 16	660	48,900
13		770	57,000
	8 x 18	800	59,300
	8 x 20	900	66,700
14		930	68,900
	8 x 22	1,000	74,100
	8 x 24	1,100	81,500
15		1,140	84,400
	8 x 26	1,200	88,900
16	8 x 28	1,300	96,300
	8 x 30	1,400	103,700
17	10 x 24	1,500	111,100
	10 x 26	1,700	125,900
18		1,800	133,300
	10 x 28	1,900	140,700
	10 x 30	2,000	148,100

to do a full analysis on each basement surface for every house. We use this factor only for uninsulated, unfinished basements; if the basement is insulated or finished, calculate it the long way.

34,500 x .20 = 7000 (rounded up)

8. Output Required: Add the Total Net Loss to the basement factor (if any). The result is the output needed from the furnace. The furnace output is often listed on the rating label.

34,500 + 7000 = 41,500 Btu/Hr output required

9. Furnace Input Required: Furnaces are generally sold by the input rating of the burner, not by the output. Input required is dependent on efficiency. To find it, divide the output by the AFUE rating on the furnace label or literature. To keep things simple, we typically use 80% for a mid-efficiency furnace and 90% for high-efficiency units. (For ultra-high efficiency units — 95% AFUE, for example, I would use the actual rating.)

41,500/.80 = 52,000 Btu/Hr Input at 80% AFUE (rounded up)

41,500/.90 = 46,100 Btu/Hr Input at 90% AFUE (rounded)

Obviously, furnaces are not sold in oddball sizes, so in this example, a furnace with input of 60,000 would be required for mid-efficiency, but one with input of 50,000 would do the job at high efficiency. It's not uncommon for us to see an oversized 80,000- to 100,000-Btu furnace installed in a house like this one.

Moving Hot Air

Like the furnace, the ductwork must be properly sized; otherwise, a bottleneck in the duct system will have the same effect as a furnace that is too big — short cycling and uneven heat distribution. If you're dealing with new work, my best advice is to have the whole system professionally designed by someone willing to guarantee performance. But if you're putting on a small addition or adding a couple of extra heat runs, that responsibility will probably be yours.

Overall system capacity. Fortunately, checking existing ductwork is not much more complicated than figuring heat loss: A tape measure, an airflow chart like the one in Figure 5 and some basic knowledge are all you need.

The bigger the ducts, the more air and heat they can carry into the building. In the sample heat load calculation, the house is losing 42,000 Btu per hour. A 6-inch round duct, common in forced air systems, can deliver approximately 100 cfm (cubic feet per minute) of air, which in turn can carry about 7,000 Btu. It will take 600 cfm of air to deliver the entire 42,000 Btu (6 x 7,000), so the plenum, trunk lines, cold air returns, and the sum of all individual heat runs must be able to deliver that much air at a minimum. The chart in Figure 5 shows that the trunk lines would have to be at least 8x16 inches (660 cfm), with at least six 6-inch heat runs (6x100 = 600 cfm).

Cold air returns. Watch out for choked-off cold-air-returns, which are common in older homes: The total return capacity should be the same or greater than the supply air. Ideally, each room should have its own return; at a minimum, there should be one return for each major section of the house. The shorter the path from a supply register to a return, the less drafty the house will feel.

Unlike supply runs, which must be in ductwork, it's perfectly acceptable to "pan" joist bays and stud cavities — enclose them with sheet metal or drywall — to carry return air back to the furnace. Always measure the actual size of the cavities used to make sure there is enough total volume.

Not enough or undersized runs. Instead of the typical 6- or 7-inch-diameter runs, some older systems designed to work at much higher pressures and faster air speeds than modern furnaces used runs as small as 4 inches. Again referring to the chart, dropping duct diameter from 6 to 5 inches reduces air flow from 100 cfm to 60 cfm at the same pressure, or "static." If the sum of all runs doesn't equal the total required airflow, you'll have to increase duct size or add more ductwork.

Bad System Design

Think of the duct system as a big drinking straw with holes punched in the sides and your finger on the end. When you blow in the straw, the pressure from your finger makes the air go out the side holes in a controlled way. This delicate balance can, however, be easily upset. If your clients are complaining that some rooms are colder than others and everything else measures up, be on the lookout for the following trouble spots:

Runs bunched on one end of a long trunk or taken directly off the end have the same effect as taking your finger off the end of the straw: All of the air rushes out the end, so very little enters the smaller branch runs.

Trunks that are not "stepped down" properly slow the air velocity and result in poor delivery. To keep air speed constant along their entire length, supply trunks often have to be reduced in size as they travel away from the furnace (Figure 6). Each section of trunk must be big enough to support all the branch runs farther down the line. It does little good to carefully step an 8x20-inch trunk down to 8x8 inches if all the runs are jammed at one end.

Missing branch run dampers make it difficult to balance a poorly designed system. A damper is nothing more than a flapper that can be adjusted to direct air into or away from a branch run. If the dampers are missing, be sure to add them whenever possible. Don't count on adjustable registers in the rooms to do the same job: The dampers need to be close to where each branch run leaves the trunk.

Choosing a Furnace

Once you've sized up the job, you can start exploring equipment options. I like to present a good-better-best scenario to clients (Figure 7), then let them decide what features and costs work best for them.

What's the efficiency? Manufacturers often use misleading terminology when describing their products — for example, calling an 80% efficient furnace "high efficiency." This can lead to confusion or even legal problems for builders and homeowners. To keep it simple, I consider "mid-efficiency" to be furnaces in the 80% AFUE range, and "high-efficiency" anything 90% AFUE and up.

Figure 6. Trunk lines commonly step down to maintain air velocity. The capacity of the trunk at each step-down point must equal the capacity of all the branch runs that come after it.

Selecting the Right Furnace

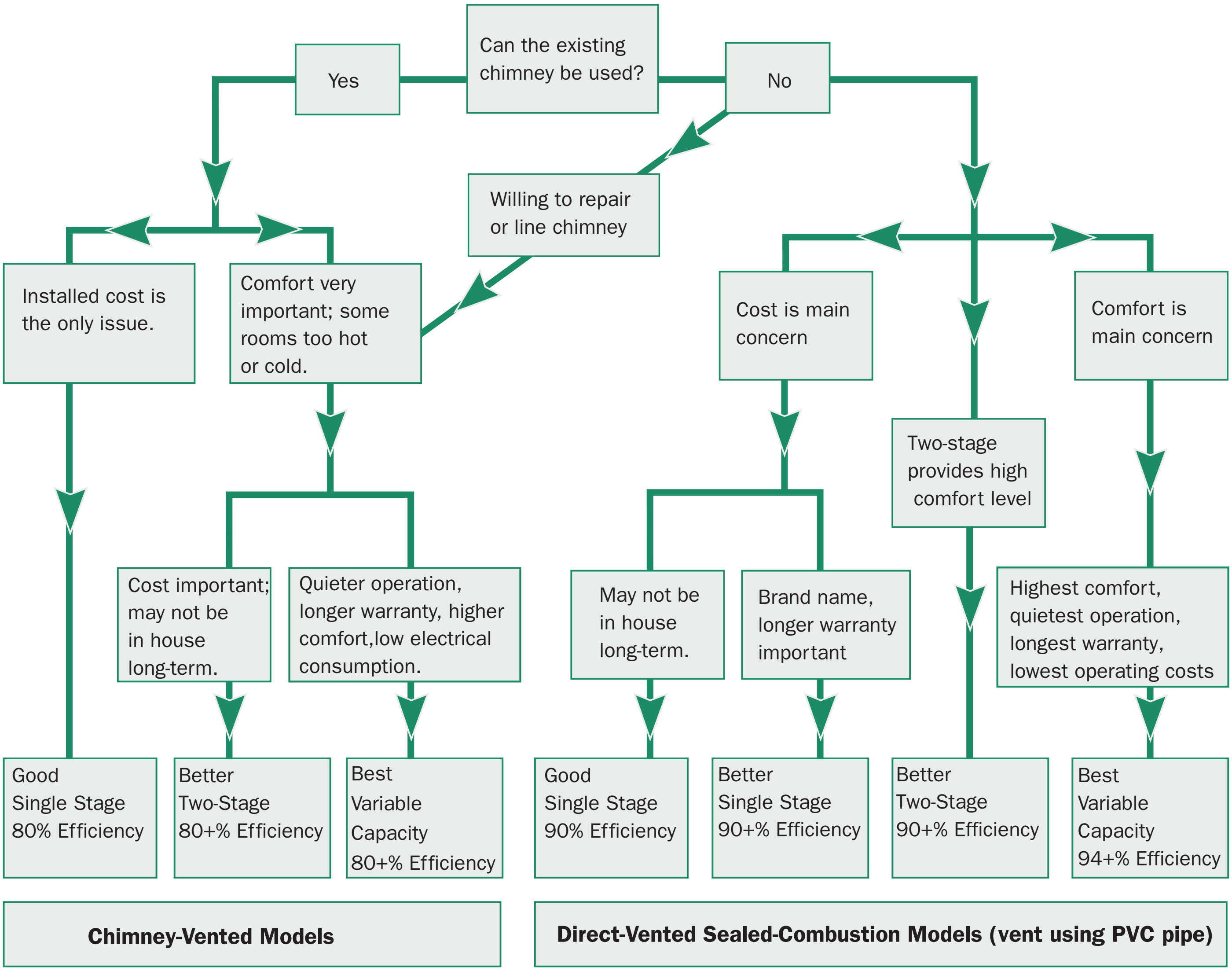


Figure 7. The author uses a flow chart like this one to help customers select the right furnace for the job.

Single- vs. dual-stage. Single-stage means the furnace has only one burner setting — high. By comparison, two-stage units operate most of the time on a lower burner setting, idling along until they need the extra punch of full capacity. Two-stage furnaces are quieter during low-stage operation, and provide more even heat because they run longer on a lower setting and are arguably more efficient. I don't have hard data to back it up, but many customers report lower heating bills with a mid-efficiency two-stage furnace than comparable houses with single-stage condensing units. This makes sense, because we size furnaces for the worst-case scenario, which only occurs 10% of the time in our area of central New York. Two-stage furnaces are also ideal for zoned forced air applications, where often only half the heating capacity is required at any one time.

Variable speed. Some manufacturers have added variable-speed blower motors and even infinite capacity burners to their top-of-the-line models. Instead of distinct high-low operation, these furnaces can be wired to "ramp up" slowly in response to heating requirements. The result is quiet, even heat that can rival the comfort of hot water heating systems. Variable-speed blowers (also called ICM or ECM) cost a fraction of a conventional furnace motor to operate, saving as much as $150 annually in electrical costs alone. Many top-of-the-line models also have auxiliary terminals for hooking up electronic air cleaners, humidifiers, and multi-stage air conditioning without having to add separate controls.

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