SIZING HEATING SYSTEMS

by Rick Karg

Simple worksheets and formulas can help you size a heating system and evaluate energy improvements

The average residential heating system in this country is more than twice the size required. For example, if a house requires a system capable of putting out 100,000 Btuh (British thermal units per hour), but has a system capable of 230,000 Btuh, the heating system is oversized by 130%. The oversized system costs more to install and will use fuel less efficiently.

Because oversizing is so common, existing homes should have oil or gas heating systems checked. If the system output is significantly greater than it needs to be, it can be "downsized" or "derated" by an oil or gas technician to make it more efficient.

To avoid these problems in the first place, you should size a new home's heating system using a *design heat load* calculation rather than rules-of-thumb or rough estimates.

Sizing a heating system is a simple process. First, you determine the building's design heat load—also known as the *peak heat load*. This tells you the maximum heat output the system will be expected to supply. You then multiply the design heat load by the appropriate "sizing multiplier" to get the system's *heating output requirement* (HOR) in Btuh.

How to Calculate a Design Heat Load

The design heat load is the amount of thermal energy required to keep a house at 70°F inside when the outdoor temperature drops to the *outside design temperature*. A 97.5% outside design temperature is the temperature below which the winter temperature (December, January, and February) will drop only 2.5% of the time. It obviously varies with locale. Table 1 shows outside design temperatures for selected U.S. cities. You can find outside design temperatures for other cities in either the Air Conditioning Contractors of America's *Manual J* (ACCA, 1513 16th St. NW, Washington, DC 20036; 202/483-9370; $20) or the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) *Handbook of Fundamentals* (ASHRAE Publication Sales, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305; 404/636-8400; $100).

Solar gain and internal gain from people and appliances are not accounted for in the design heat load procedure

Table 1
Design Weather Data for Selected Cities

	Outside Design Temperature (97.5%)	Heating Degree Days
Anchorage, Alaska	-18	10860
Phoenix, Ariz.	34	1680
Little Rock, Ark.	20	3170
San Francisco, Calif.	38	3040
Denver, Colo.	1	6165
Hartford, Conn.	7	6170
Washington, D.C.	17	4240
Miami, Fla.	48	200
Atlanta, Ga.	22	2990
Boise, Idaho	10	5830
Chicago, Ill.	2	6640
Indianapolis, Ind.	2	5630
Cedar Rapids, Iowa	-5	6600
Lexington, Ky.	8	4760
Portland, Maine	-1	7570
Boston, Mass.	9	5630
Grand Rapids, Mich.	5	6890
Minneapolis, Minn.	-12	8250
St. Louis, Mo.	6	4900
Cut Bank, Mont.	-20	9033
Lincoln, Neb.	-2	6050
Reno, Nev.	10	6150
Manchester, N.H.	-3	7100
Atlantic City, N.J.	13	4810
Albuquerque, N.M.	16	4250
Albany, N.Y.	-1	6900
Raleigh, N.C.	20	3440
Fargo, N.D.	-18	9250
Cleveland, Ohio	5	6200
Portland, Ore.	23	4635
Pittsburgh, Pa.	5	5850
Pierre, S.D.	-10	7550
Jackson, Tenn.	16	3350
Houston, Texas	32	1410
Salt Lake City, Utah	8	5990
Burlington, Vt.	-7	8030
Charlottesville, Va.	18	4220
Spokane, Wash.	2	6770
Milwaukee, Wis.	-4	7470
Casper, Wyo.	-5	7510

DESIGN HEAT LOAD WORKSHEET

1. Client name: ______________________________
2. Client address: ______________________________
____
____
3. Client telephone: ______________________________
4. General dwelling description: ______________________________
____
____
5. Outside design temp. (ODT), 97.5%: ______________
6. Volume of dwelling above grade: ______________
7. Average winter air changes per hour (ac/h): ______________
8. Design temp. difference (DTD) = Dwelling temp. – ODT = ______________

Transmission			
Surface	Area (sq. ft.) ÷	R-Value =	Btu/°F hr
		Total	
Infiltration	0.02 x volume x ac/h =		
	0.02 x _______ x _____ =		

Grand total = heat loss coefficient (HLC) [ ]

➨ Design heat load = HLC x DTD = [ ]

Figure 1. *This form gives a relatively quick but accurate method to compute the load a building's heating system will need to meet. Photocopy this or create a similar version for your own calculations.*

DESIGN HEAT LOAD WORKSHEET

1. Client name: ______________________________
2. Client address: ______________________________
____
____
3. Client telephone: ______________________________
4. General dwelling description: ______________________________
____
____
5. Outside design temp. (ODT), 97.5%: ______________
6. Volume of dwelling above grade: ______________
7. Average winter air changers per hour (ac/h): ______________
8. Design temp. difference (DTD) = Dwelling temp. – ODT = ______________

Transmission			
Surface	Area (sq. ft.) ÷	R-Value =	Btu/°F hr
		Total	
Infiltration	0.02 x volume x ac/h =		
	0.02 x _______ x _____ =		

Grand total = heat loss coefficient (HLC) [ ]

➨ Design heat load = HLC x DTD = [ ]

Figure 2. *The heat-load worksheet is filled out for a sample house in Boston, Mass. You need to include all the surface areas that enclose the heated, above-grade portion of the dwelling.*

because they cannot be relied upon to supply heat.

Figure 1 shows a worksheet for calculating a building's design heat load. Finding the design heat load is as easy as filling out that worksheet and performing a few calculations. To fill out the worksheet you'll need to know:

- the outside design temperature
- the heated volume (in cubic feet) of the dwelling above grade
- the average winter infiltration rate (in air changes per hour)
- the surface areas and R-values of all components of the house's insulated shell—floors, walls, windows, doors, ceiling/roofs, etc.

Let's work our way through the worksheet, using a hypothetical house in Boston, Mass. (see Figure 2).

Design temperature, heated volume, and air changes. First, after filling in general information on lines 1 through 4 of the worksheet, we enter the outside design temperature on line 5.

Next we calculate the above-grade heated volume of the dwelling (line 6) by standard geometrical means: For a rectangular area, multiply width x depth x height; for a triangular area (such as the area under the slanted part of a cathedral ceiling), multiply width x depth x 1/2 height. We find our two-story, 1,800-square-foot house holds 14,400 cubic feet of space above grade.

Table 2 will guide us in estimating the number of air changes per hour (line 7). If you have a better means of estimating air changes, such as a blower door, use that instead. Try to estimate as carefully as possible.

Design temperature difference. The design temperature difference (line 8) is the difference between the dwelling temperature (70°F) and the outside design temperature. Simply subtract the outside design temperature from 70. For our house in Boston, the design temperature difference is 61 (70 minus 9).

Surface heat loss. We must next account for heat lost through the surfaces of the building. To do this, we fill out the second section of the Design Heat Load Worksheet. We must enter the areas and R-values for all surfaces separating conditioned and unconditioned spaces—exterior walls, roofs/ceilings, windows, doors, and floors. The first-story ceiling in our two-story house is not included because it does not separate a conditioned and unconditioned space. If some of the double-glazed windows were low-e and some were not, we would need two window listings. Likewise with doors or walls with different R-values.

If you are not familiar with the R-values of the materials of the house, look for a reliable R-value table in a construction or engineering handbook, such as the ASHRAE *Handbook* or ACCA's *Manual J*. Be conscious of the tendency of some manufacturers to exaggerate the R-values of their products.

Once we've entered areas and R-values for all surfaces, we can figure the heat lost by each of these surfaces by dividing the "Area" values by the "R-Value" figures and writing the answers in the "Btu/°F hr" column. Then we add these numbers and enter the result in the "Total" box. In this case the total transmission loss is 296.8 Btu/°F hr. This completes the "Transmission" section of the form.

Infiltration. We must also account for infiltration. To do this we work out the simple formula near the bottom of the form: 0.2 x volume x ach. We've already listed volume (14,400 cubic feet) on line 6 and air changes per hour (.6 ach) on line 7 of the form. Multiplying these figures, we get 172.8 Btu/°F hr of loss.

We add this infiltration value to the transmission value for the "Grand Total." This total is the heat loss coefficient (HLC) of 469.6 Btu/°F hr.

Finally, we find the design heat load by multiplying the heat loss coefficient (HLC) by the design temperature difference from Line 8 (DTD). Record your answer in the bold box at the bottom right corner of the form. We now know the design heat load equals 28,646 Btuh.

Table 2
Infiltration Evaluation

Winter Air Changes Per Hour (ach)

Floor Area	900 or less	900-1500	1500-2100	over 2100
Best	0.4	0.4	0.3	0.3
Average	1.2	1.0	0.8	0.7
Poor	2.2	1.6	1.2	1.0
For each fireplace add:		Best	Average	Poor
		0.1	0.2	0.6

Envelope Evaluation

Best - Continuous infiltration barrier, all cracks and penetrations sealed, tested leakage of windows and doors less then 0.25 CFM per running foot of crack, vents and exhaust fans dampered, recessed ceiling lights gasketed or taped, no combustion air required or combustion air from outdoors, no duct leakage.

Average - Plastic vapor barrier, major cracks and penetrations sealed, tested leakage of windows and doors between 0.25 and 0.50 CFM per running foot of crack, electrical fixtures that penetrate the envelope not taped or gasketed, vents and exhaust fans dampered, combustion air from indoors, intermittent ignition and flue damper, some duct leakage to unconditioned space.

Poor - No infiltration barrier or plastic vapor barrier, no attempt to seal cracks and penetrations, tested leakage of windows and doors greater than 0.50 CFM per running foot of crack, vents and exhaust fans not dampered, combustion air from indoors, standing pilot, no flue damper, considerable duct leakage to unconditioned space.

Fireplace Evaluation

Best - Combustion air from outdoors, tight glass doors and damper.
Average - Combustion air from indoors, tight glass doors or damper.
Poor - Combustion air from indoors, no glass doors or damper.

Note: Allowance for one kitchen and two bathroom exhaust fans, dryer vent, recessed lighting fixtures, pipe and duct penetrations.

Adapted from Manual J: Load Calculation for Residential Winter and Summer Air Conditioning, Seventh Edition, Air Conditioning Contractors of America, 1986, p. 85.

Sizing the System

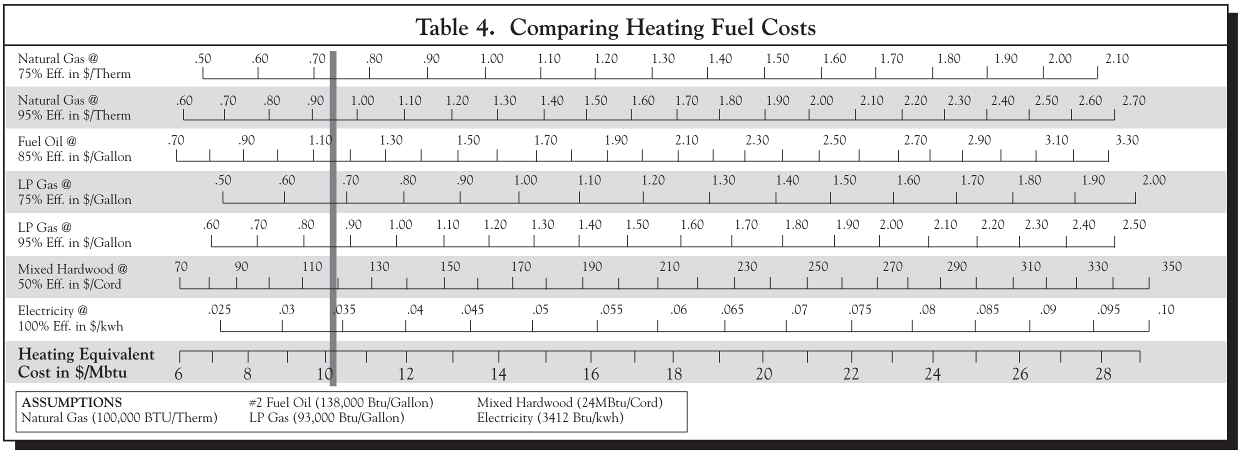
Once you've figured the design heat load, sizing a central heating system is easy. Simply multiply the design heat load by the sizing multiplier for the type of unit you plan to install, as listed in Table 3.

Gas and oil systems. For example, let's say we intend to install a gas-fired boiler in our Boston house. We multiply 28,646 Btuh by 1.1, the sizing multiplier for gas-fired equipment, to yield 31,511 Btuh for the required output (HOR) of the boiler. We need to buy a boiler with a 31,511 Btuh output—or slightly higher, but never lower.

If our favorite manufacturer has no model within a range of 10% higher than the HOR, we should select a different brand rather than buy one that's oversized. The Gas Appliance Manufacturers Association (GAMA) *Consumer's Directory* (GAMA, 1901 N. Moore St., Suite 1100, Arlington, VA 22209; 703/525-9565; $5) lists the output and efficiency ratings for all gas and oil furnaces and boilers on the market.

Table 3
Sizing Multipliers for Heating Systems
(Based on 97.5% Outside Design Temperature)

Heating System Type	Multipliers
Electric Equipment	1.0 x Design Heat Load (DHL)
Oil-Fired Equipment	1.1 to 1.2 x DHL
Gas-Fired Equipment	1.0 to 1.1 x DHL



This chart allows you to quickly compare the costs of different heating options. To find the cost of any option in dollars per million Btus ($/MBtu), find the cost of your fuel on the appropriate horizontal line and read down vertically to the chart's bottom line. For example, the vertical line drawn shows that oil at $1.15 per gallon (at 85% efficiency) costs a little over $10/MBtus. You can also see that electricity would need to sell for less than 3½¢ per kwh to compete with oil at $1.15/gal.

Notice that factoring in the sizing multiplier slightly oversizes oil- and gas-fired systems. This builds in a safety factor in case the design heat load was inaccurately calculated or the system goes out of tune and its output decreases.

Electric systems. Electric heaters and heat pumps are rated in kilowatts (kw), not Btus. But one kilowatt produces 3,412 Btus, so you can derive the required kilowatts from the Btu requirements by dividing the Btus by 3,412. In this case:

28,646 ÷ 3,412 = 8.4. So, if we wish to install a central electric furnace, we need an 8.4 kw model.

If you want to install baseboard electric heaters or electric radiant ceiling units, you must perform a design-heat-load calculation for each room you intend to heat, using the Design Heat Load worksheet. Once you know the design heat load of each room, you simply translate that into kw as just described, then install enough baseboard or radiant ceiling units to meet the required kw load. For example, a load for a 10x12 room in a hypothetical 1950s ranch might be 5,118 Btuh. This translates into 1.5 kw (5,118 divided by 3,412 = 1.5), or 1,500 watts. Most baseboard electric heaters have an output of 250 watts per foot, so such a room would require 6 feet of electric baseboard.

Avoid using antiquated rules-of-thumb for sizing electric baseboard heat. These rules often lead to the installation of over three times the number of feet of electric heat required.

Estimating Annual Fuel Use

Another calculation lets us estimate the annual fuel cost of heating our building. This calculation, while fairly easy, is not the most accurate method, so you shouldn't use it as the basis for any sort of guarantee to your clients. Among other factors, the beneficial effect of solar gain is not included in the equation.

The formula is:

$$\text{Annual Fuel Cost} = \frac{DHL}{DTD} \times HDD \times .000015 \times \$/MBtu$$

where:

DHL = design heat load,
DTD = design temperature difference (see Figure 2, Line 8),
HDD = heating degree days (see Table 1), and
$/MBtu = dollars per one million Btu, as listed on the bottom line of Table 4.

We already know the design heat load and design temperature difference. We can look up the heating degree day figure in Table 1, in ACCA's *Manual J*, or the ASHRAE *Handbook*. The $/MBtu figure is from Table 4—a handy table that lets you compare dollar costs of different methods of heating. The .000015 figure is a correction factor for heating degree days.

Let's run this annual fuel cost equation for our sample house, heated with a "Deep Heat" gas furnace with a seasonal efficiency of 95%, and assuming that gas costs 90¢ per therm. From Table 4, we see that with gas at 90¢ per therm and a 95% efficient burner, the dollar cost per MBtu (bottom line of the table) is about $9.25. We plug that into the annual fuel cost equation:

$$\text{Annual Fuel Cost} = \frac{28{,}646}{61} \times 5{,}630 \times .000015 \times \$9.25 = \$367$$

Keep in mind that this final figure is only an estimate.

Figuring Payback for Energy-Saving Measures

Armed with the calculations above, we can also do a simple payback analysis that will let us see how quick a return any energy-saving investment will have, whether it be a new, more efficient heater, an extra layer of insulation in the attic, or low-e windows.

Let's look at the heating unit first. For the Boston house with the Deep Heat furnace, we figured that the heating bill would be $367 a year. Let's now calculate the fuel bill if the house is served by a "Sunspot" gas furnace with a seasonal efficiency of 75%. We first look up the $/MBtu cost for such a furnace in Table 4, assuming fuel costs of 90¢/therm. We find it's $12. We plug this figure into the annual fuel cost equation:

$$\text{Annual Fuel Cost} = \frac{28{,}646}{61} \times 5{,}630 \times .000015 \times \$12.00 = \$476$$

Now let's say the installed cost of the Deep Heat is $400 more than that of the SunSpot. How long will it take to recover the $400 for the more efficient Deep Heat system?

We already know the Deep Heat furnace saves $109 each year compared to the Sunspot unit. Dividing the cost difference ($400) by the savings per year ($109), we find that we'll recover the extra cost of the better furnace in 3.67 years. This a short payback, after which further savings are money in the bank. It seems the Deep Heat furnace should be installed.

We can use a variation of the same formula to determine the payback time for any energy-saving measure that might be installed in a house. For example, assume that for our Boston house we have the choice of either regular double-glazed windows (R-value 1.8) or low-e, argon-filled, double-glazed windows (R-value 4.0). The low-e windows cost more—assume $1.30 more per square foot—but have a higher insulating value. The house will have 220 square feet of windows and will be heated with electricity at 9¢/kwh. Are the high performance windows worth installing?

To find the answer, first find the projected heat loss per hour through each window type. This calculation is simply the design heat load calculation found in the worksheet in Figure 1, but performed only for the window area. The general equation is: Design heat load = (Area ÷ R-value) x (design temperature difference). Using this equation for the example:

R-1.8 windows = ($220ft^2$ ÷ 1.8) x 61°F = 7,456 Btuh
R-4.0 windows = ($220ft^2$ ÷ 4.0) x 61°F = 3,355 Btuh

The difference between the two answers (7,456 Btuh – 3,355 Btuh = 4,101 Btuh) is the savings in energy for one hour at the outside design temperature in Boston.

Now we figure the annual fuel cost of that difference, using the same equation we used earlier to figure the annual fuel cost for the whole house. Simply plug the difference in Btuh (4,101) into the design heat load (DHL) spot in the annual fuel cost equation.

$$\text{Annual Fuel Cost} = \frac{DHL}{DTD} \times HDD \times .000015 \times \$ \text{ per MBtu}$$

$$\text{Annual Fuel Cost} = \frac{4{,}101}{61} \times 5630 \times .000015 \times \$26.38 = \$149.77$$

This represents the electricity saved in one year if we use the higher R-value windows.

The higher performance windows will cost an additional $286 ($\$1.30/ft^2 \times 220\ ft^2$), yielding a 1.9 year payback (cost difference ÷ savings per year). This short payback makes the high-performance windows a wise choice.

You can use this same method to evaluate insulation levels, window types, and other energy-saving measures in both new construction and remodeling. ■

Rick Karg is an energy management consultant from Topsham, Maine. He often conducts training sessions on the topic of heating system sizing.