Errata to
Fundamentals of Heating Systems, I-P
December 15, 2011

Figures 3-1, 3-2, 3-3, 3-5, 6-3, 6-9, and 7-4 (pages 3:5, 3:9, 3:13, 3:21, 6:7, 6:13, and 7:13, respectively) are illegible or difficult to read. The attacheded pages replace these with improved versions.

The hours of occupancy will indicate whether automatic setback control options would be economical. Buildings occupied only during normal business hours from 8:00 am to 5:00 pm are unoccupied nearly 75% of the time, and so present opportunities for heating energy conservation during those unoccupied periods. The use of automatic setback controls impacts the required system capacity as well as the overall system control characteristics. Thermostat setback produces a lower temperature difference between indoors and outdoors, resulting in proportionately less heating requirements during the setback period.

Figure 3-1 illustrates how the mean space temperature may vary during the setback period and the following recovery period. Obviously, the indoor air temperature does not immediately drop down at the time of setback, as shown in *Figure 3-1*. However, the actual transient cool down and the transient recovery portions of the indoor temperature curve would somewhat cancel each other out, yielding approximately a rectangular temperature response curve as representative of the overall process. The time it takes for the space temperature to drop down to the setback temperature will depend on the outdoor conditions as well as the thermal capacitance of the structure. During mild weather, the space temperature may never reach the setback temperature and the heating system will not need to operate at all.

An important consideration when using setback is the length of time needed for recovery. The system should be set to begin the recovery process at an appropriate time in advance of building occupancy. Some energy management systems can perform this setback function according to preselected schedules, and can even adjust the recovery schedule based on

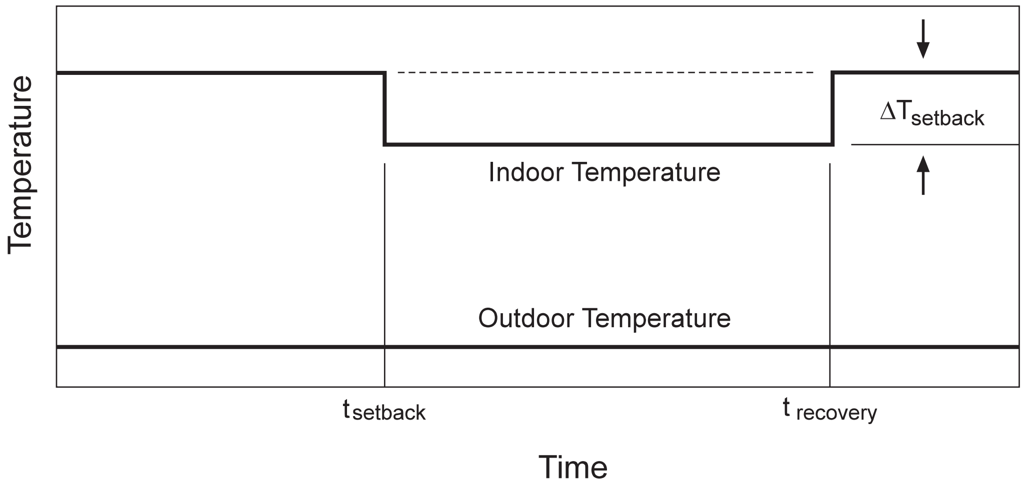

Figure 3-1. Thermostat Setback for Heating Energy Savings

where the temperatures are expressed in °F. While clothing and metabolic levels are beyond the control of the heating system design engineer, they should be considered in the design process in those cases where one or both may be atypical.

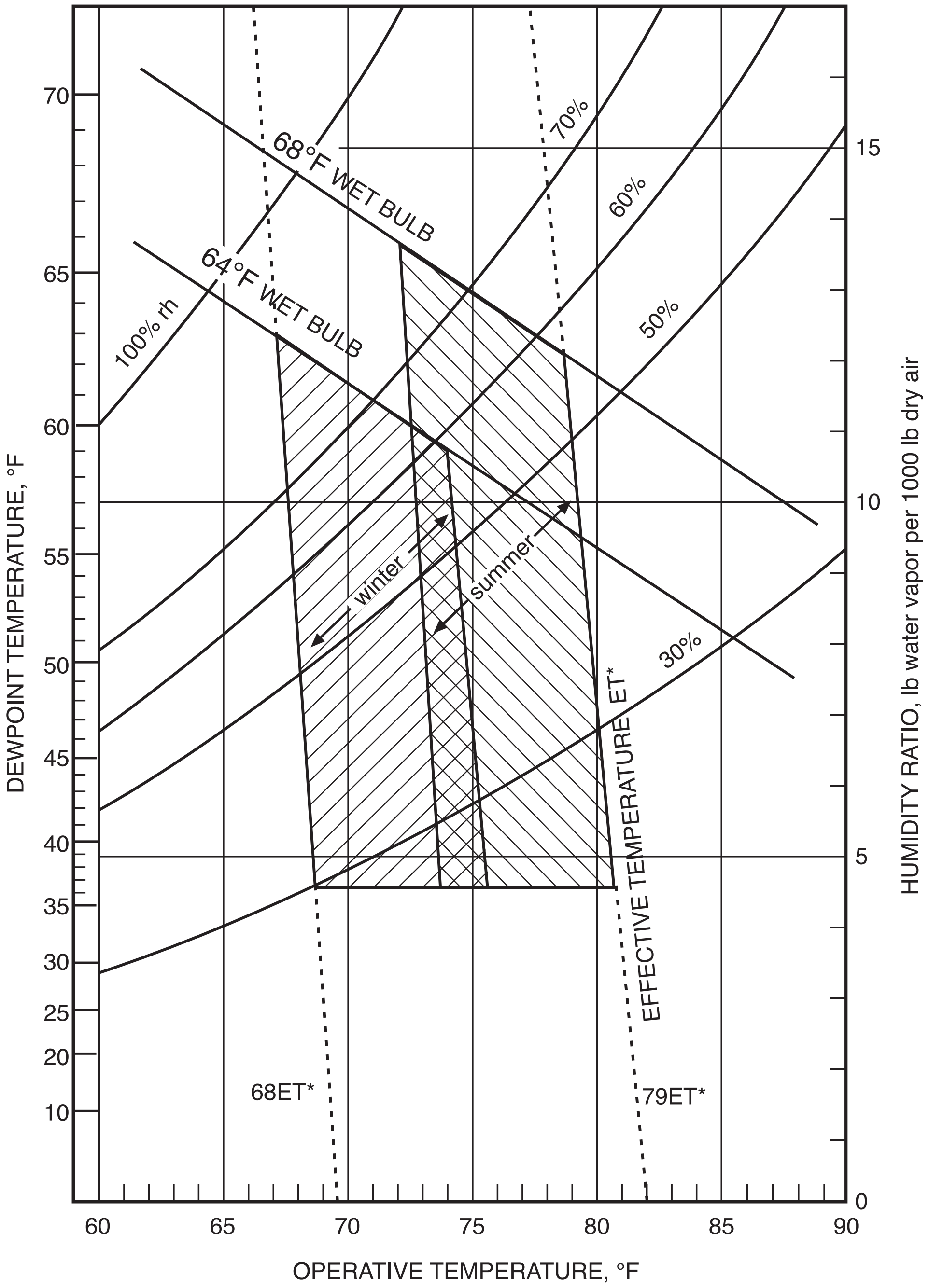

Figure 3-2. Acceptable Comfort Conditions

From an energy conservation perspective, the first issue to address is the building envelope. The building should be relatively airtight and adequately insulated. What are considered appropriate insulation levels depend on the building design and its use, as well as the local climate. Buildings with low occupant densities (such as houses, with as much as 1,000 ft^2 per person) will need high insulation levels to prevent excessive heat losses. Buildings with high occupant densities and lighting loads may require less insulation, particularly in milder climates, because they will likely be cooling dominated from their internal heat gains. Building envelope heat losses may actually reduce total annual energy consumption of such buildings because they reduce the amount of air-conditioning that is required to remove the internal heat that is generated in mild weather.

The average heat loss characteristics of a building due to thermal envelope effects are shown in *Figure 3-3*. The straight line heat load curve essentially averages out the variations in air infiltration rate, solar radiation and wind effects over the heating season. The load curves are usually generated by simply drawing a straight line between the design load point and the point at which the heating load diminishes to zero. *Figure 3-3* shows two curves to illustrate the effect of internal heat gains from occupants, lighting and appliances. The benefit of estimating the building heat losses at off-design conditions usually comes into play when estimating seasonal or annual energy usage. If the output and efficiency of the heating

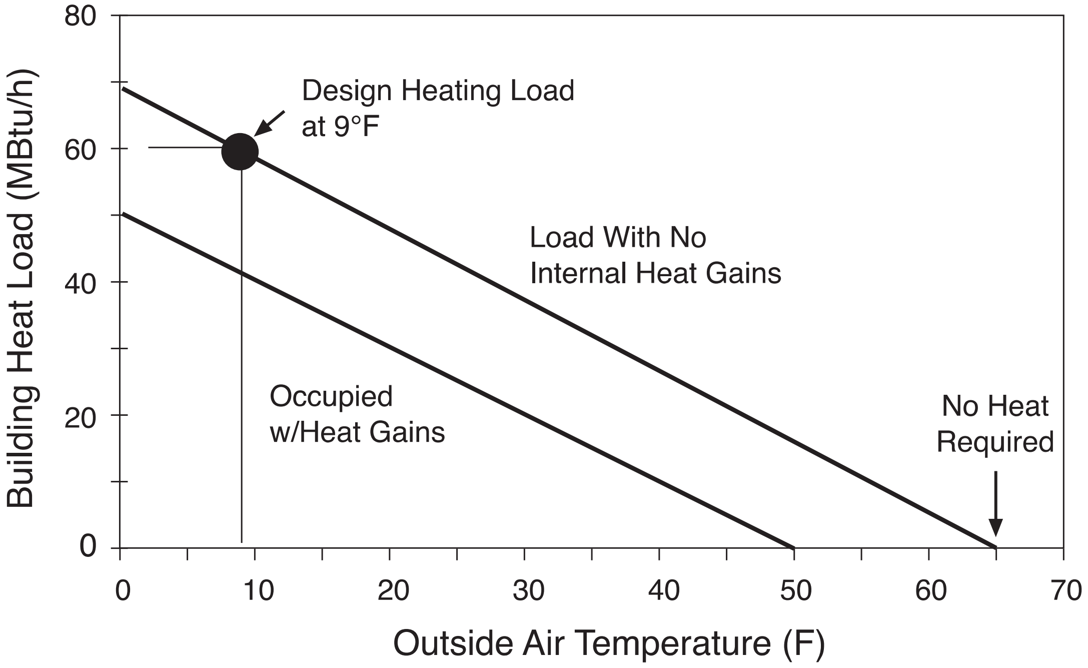

Figure 3-3. Typical Building Load Characteristic Heating Curves

plies. Where electric prices have increased dramatically since the 1970s, these resistance heating systems have been replaced by heat pump systems or possibly gas furnaces if natural gas later became available.

Many new commercial buildings still use electric boilers for their heat source, despite the apparent fuel cost advantage of natural gas. Electric utilities often have a reduced all-electric rate that, when applied to the lighting, air handlers and other electrical loads in the building, negates the savings from using natural gas for the small heating load of a cooling-dominated building.

The most dramatic switch in fuel preference in the United States has occurred since the mid-1980s. Natural gas was a government regulated fuel for many years until it was deregulated in the early 1980s. Prior to deregulation, the artificially low price imposed by the federal government limited the suppliers' profit margins. With little financial incentive to risk the large amounts of capital needed to discover new supplies and lay major pipelines to growing markets, the available supply of natural gas to customers was reduced. Many gas supply companies imposed moratoriums on new installations in the 1970s and early 1980s. Once natural gas was deregulated, the supply greatly increased, new pipelines have been laid, and prices have been quite stable. The result of the greater fuel availability is clearly shown in *Figure 3-5* where natural gas and electricity have switched places since 1985 as the dominant fuel in new home construction in the United States.

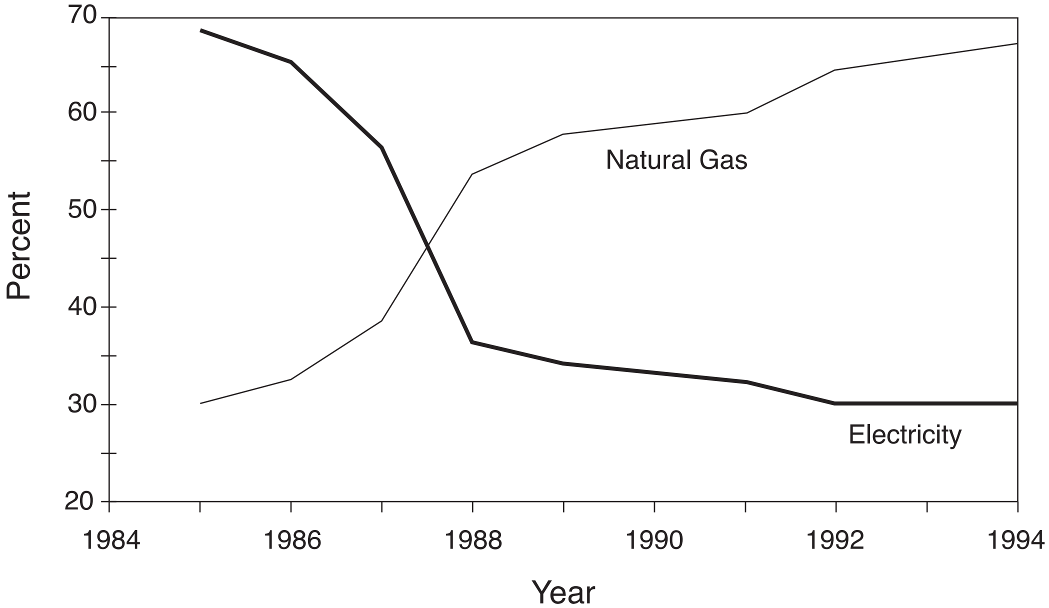

Figure 3-5. Primary Heating Fuels Used in US New Home Construction, 1985-1994

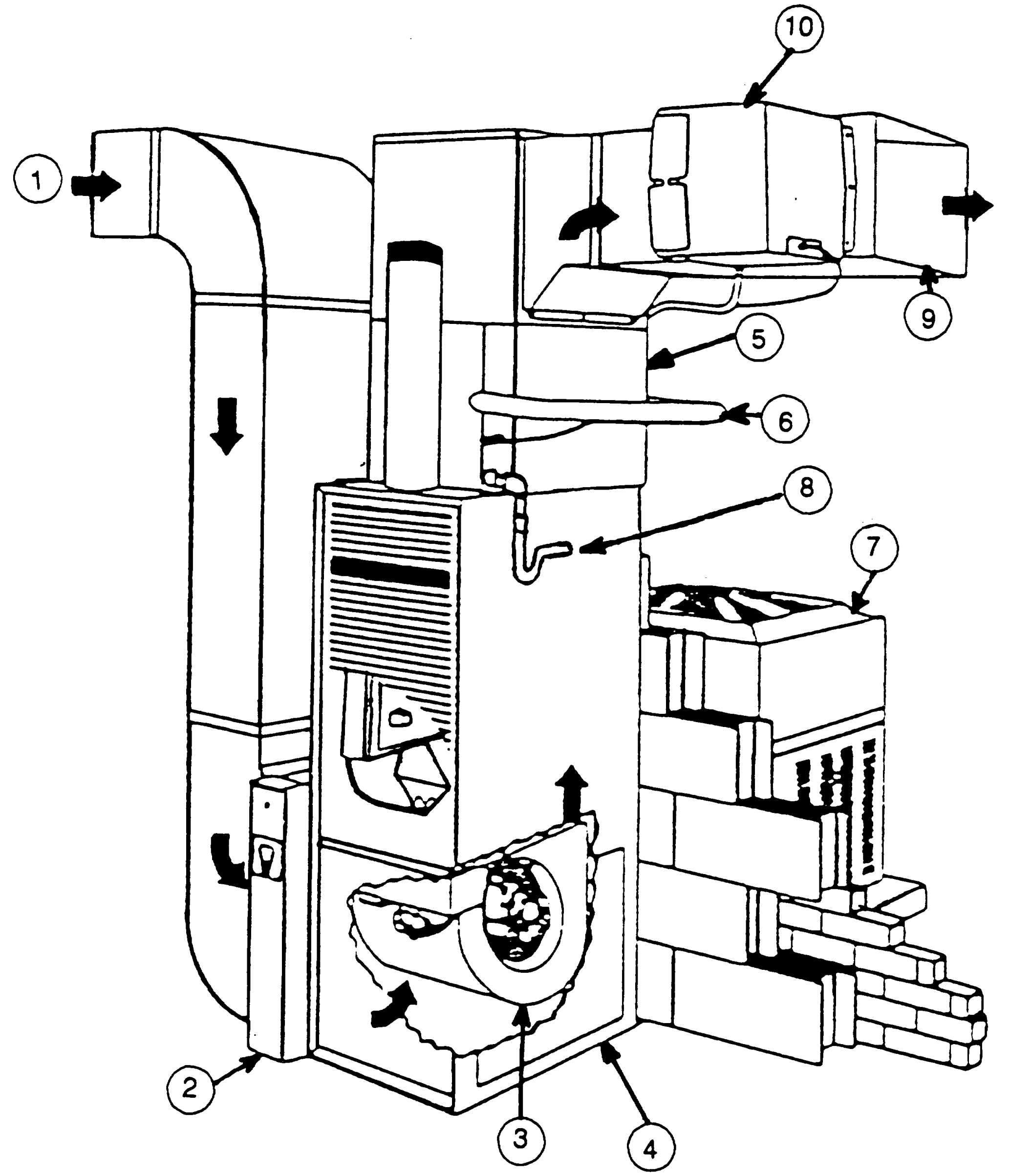

Figure 6-3. Typical Residential Central Gas Furnace/Air-Conditioner System

In 1995, 67% of new houses used a warm air furnace (natural gas, propane or oil), 25% used a heat pump, and 5% used hydronic heating systems.[4] Of these new homes, 80% had central cooling systems. Natural gas or propane were the heating fuels in 67% of the new homes, electricity in 28%, and oil in only 4%. Natural gas and propane furnaces are practically identical in design and operation, and so will not be treated separately in this chapter.

The most common type of electric warm air heating unit is the heat pump system, with a typical split-system air source heat pump configuration shown in *Figure 6-9*. Other than the basic differences between a heat pump and a cooling-only air conditioner, this arrangement is very similar to the furnace/air conditioner arrangement without the furnace. The same coil that provides cooling in summer provides heating in winter. Heat pumps will usually need auxiliary resistance heaters (5) for severe heating conditions when the reduced capacity of the heat pump cannot meet the increased heating requirements of the space (refer to *Figure 4-51* for an illustration of heat pump performance characteristics). The same resistance heaters can be used for emergency heat in the event of a major failure with the heat pump system.

The NAECA minimum efficiency for heat pumps is a cooling seasonal energy efficiency ratio (SEER) of 10.0 Btu/W⇒h and heating seasonal performance factor (HSPF) of 6.8 Btu/W⇒h. The Energy Star efficiency level is a SEER of 12.0 and an HSPF of 7.0 Btu/W⇒h.

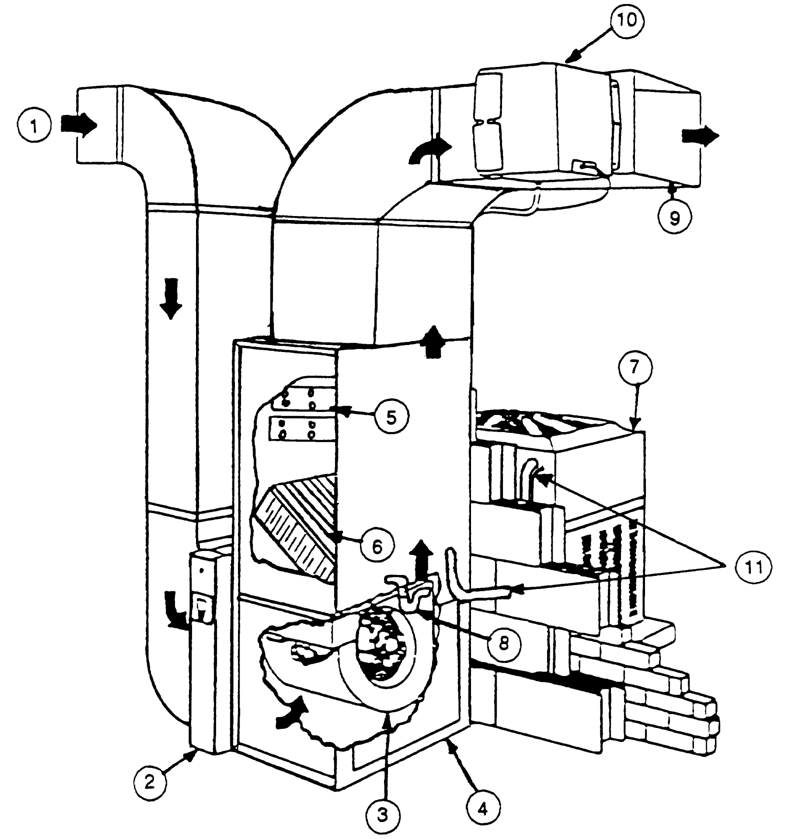

Figure 6-9. Residential Central Heat Pump System

Proper sizing of the heat pump and the resistance heaters is critical for year-round comfort and low operating costs, and is usually based on the cooling requirements of the structure. ASHRAE and ACCA recommend that the heat pump sensible cooling capacity at the design cooling condition not exceed the design sensible cooling requirements by 25% to ensure adequate run-times needed for proper cooling dehumidification. Humidity is not controlled directly in cooling mode, so during low sensible load con-

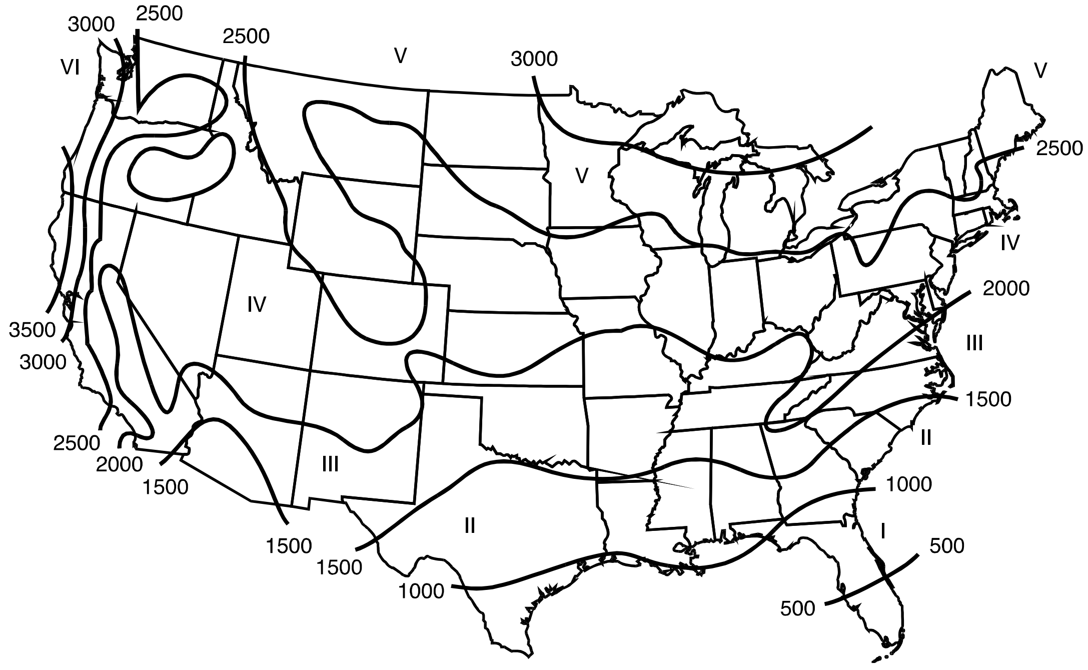

Figure 7-4. Full-Load Hours for Heating Systems[7]

(Courtesy of the Gas Research Institute)

consumption rate to estimate annual fuel consumption. Costs are obtained by multiplying the annual fuel consumption by the cost per unit of fuel. The assumption implicit in this method is that the heating system is perfectly matched to the design load of the building. If the heating unit was significantly oversized (as is typically the case for combustion furnaces) or undersized (as is normally the case for heat pumps), the heating system would not operate for the number of hours given by the heating load hours.

Combustion furnace or boiler systems are assumed to be oversized by 70% in the DOE test procedure that applies to such small heating systems. This oversizing factor permits reasonable recovery after setback, as well as providing adequate capacity for infrequent severe conditions. Such oversizing is not overly detrimental to the efficient operation of these systems. This method uses the national average rated fuel energy use in MMBtu/year from DOE ratings or the *GAMA Directory*[8] for a particular system. An adjustment factor (essentially the ratio of the local heating load hours to the national average value) is used to correct the directory value of annual energy usage to local weather conditions. One advantage of this method is that the directory values also include rated auxiliary electrical energy inputs, so the electrical energy costs can also be estimated for combustion appliances. The electrical energy will be a significant cost factor for high efficiency forced air furnaces, and is not accounted for in the AFUE rating.