Calculating Heating Load or Input Rating

Transmission Heating Load

Transmittance × Area × Temperature difference = Transmissive Load

$$U \frac{\text{BTUs}}{\text{ft}^2 \cdot \text{hr} \cdot °\text{F}} \times A\ \text{ft}^2 \times \Delta T\ °\text{F} = q\ \frac{\text{BTUs}}{\text{hr}}$$

$$0.083 \times 7000 \times 79 = 45{,}899\ \frac{\text{BTUs}}{\text{hr}}$$

Air Exchange Heating Load

Air's heat capacity × Air flow rate × Temperature difference

$$\frac{\text{BTUs}}{\text{ft}^3 \cdot °\text{F}} \times F\ \frac{\text{ft}^3}{\text{hr.}} \times \Delta T\ °\text{F} = q\ \frac{\text{BTUs}}{\text{hr}}$$

$$0.018 \times 4500 \times 79 = 6399\ \frac{\text{BTUs}}{\text{hr}}$$

This simplified heat load (q) calculation assumes that a home in Madison, Wisconsin has a surface area of 7000 square feet, an average R-value of 12 (U=0.083), air leakage of 4500 cubic feet per hour (0.50 air change per hour). Madison's design temperature is -9°F, 79°F temperature difference (ΔT) from the 70° desired indoor temperature. Real heat load calculations employ separate calculations for walls, windows, ceilings, and floors with their different U-factors.

Calculating Heater Output and Input

$$q_{\text{(transmis.)}} + q_{\text{(air)}} = \text{Output Rating}$$

$$45{,}899\ \frac{\text{BTUs}}{\text{hr}} + 6399\ \frac{\text{BTUs}}{\text{hr}} = 52{,}298\ \frac{\text{BTUs}}{\text{hr}}$$

$$\frac{\text{Output Rating}}{\text{Heating Efficiency}} = \text{Input Rating}$$

$$\frac{52{,}298\ \frac{\text{BTUs}}{\text{hr}}}{.80} = 65{,}373\ \frac{\text{BTUs}}{\text{hr}}$$

The difference between input and output is the heat wasted up the chimney and through the heater's cabinet. The heater's input rating is usually increased by 10% or more as a safety factor to insure customer satisfaction during the coldest weather.

Heating and Cooling Design Loads

When working with heating and cooling loads, don't confuse *design* loads with *seasonal* or *annual* loads. The design load, expressed in BTUH (BTUs per hour), is the predicted *rate* at which heat must be added or removed from a building at near-peak conditions, while the seasonal or annual load, expressed in MMBTU (millions of BTUs), is the amount of heat added or removed over the course of a season or a year.

Heating and cooling design loads provide a basis for sizing space conditioning equipment. Complete procedures for calculating heating and cooling loads are found in the ASHRAE *Handbook of Fundamentals* as well as *Manual J*, published by ACCA. ASHRAE is the American Society of Heating, Refrigerating, and Air Conditioning Engineers and ACCA is the Air Conditioning Contractors of America.

Ideally, equipment capacity should closely match a building's load at the design conditions. Design conditions include outdoor temperature, solar radiation, wind, indoor temperature, and relative humidity. Note that design conditions aren't the same as worst-case conditions. You don't need to size equipment based on worst-case climate extremes, and it isn't advisable.

ASHRAE maintains a climatic database for over 1,500 locations in the United States and Canada, last updated in 2009. This database includes statistical temperatures and other weather data. The 99th and 1st percentile temperatures are commonly used for sizing heating and cooling equipment.

The outdoor design temperatures for Baltimore are 17°F and 91°F. Over a period of decades in Baltimore, the temperature was at or below 17° for one percent of the hours, while exceeding 91° for one percent of the hours.

ACCA and Energy Star have adopted the 99%–1% outside design temperatures. This means that space-conditioning (heating and cooling) systems are designed to operate continuously at these two design temperatures. Due to the buffering effect of a building's mass, the indoor temperature is unlikely to deviate more than a couple of degrees from the thermostat setpoint when design temperatures are exceeded (low or high).

Indoor design temperatures for new homes are typically 70°F for heating and 75°F for cooling. In existing homes, consider the occupants' temperature preferences instead of these default temperatures. Indoor humidity is assumed to be 50% in most climate zones. Cooling system sizing is affected by both the sensible (dry bulb) and latent (wet bulb) design temperatures, while the heating system is only affected by the dry bulb temperature.

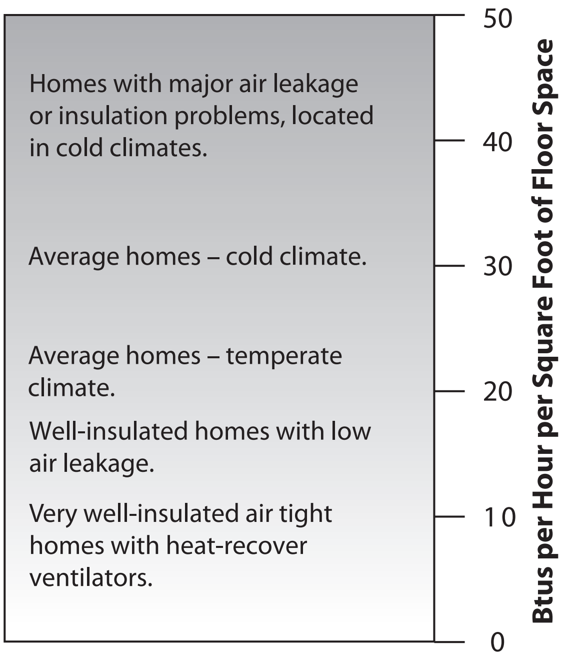
For definitions of wet-bulb and dry-bulb temperatures, see "Glossary" on page 257.

Benefits of right-sizing — Contractors and homeowners both should understand the importance of proper sizing, especially for air conditioners. Oversized HVAC equipment has the following disadvantages.

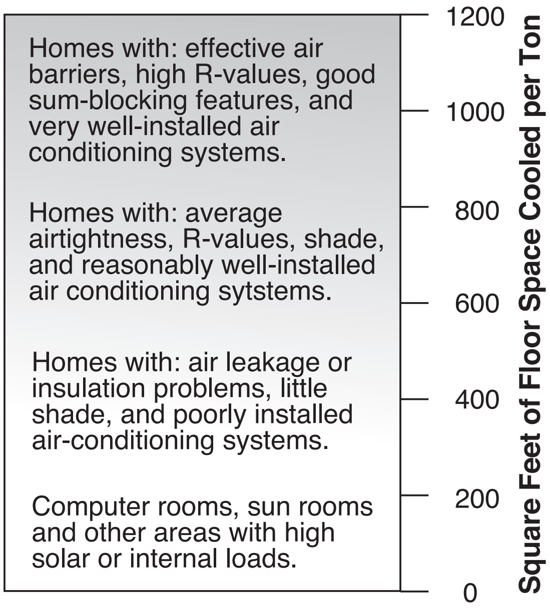
- Oversized equipment costs more and requires larger electrical circuits.
- Oversized compressors have a shorter life expectancy due to short cycling.
- Excess capacity results in comfort issues due to larger temperature variations.
- Oversized air conditioners remove less moisture, an issue in humid climates.
- Excess capacity compromises indoor air quality (less run time = less filtration).
- Excess cooling capacity increases potential for structural damage from moisture.
- Oversized equipment costs more to operate due to inefficient short cycling.

See "Sizing and Selecting Air Conditioners" on page 215.

Variation in Heating and Cooling Loads



The number of BTUH heating capacity needed by a building depends on climate, insulation levels, air leakage, and heating installation's quality.



The number of square feet of floor space that can be cooled by a ton of air-conditioning capacity depends on climate, shade, insulation levels, internal heat gains and air leakage.

Heating and cooling equipment efficiency — Heating and cooling system efficiency is the output capacity divided by the equipment's instantaneous energy consumption (input). Efficiency losses include both energy waste and energy conversion losses, which are reflected in the equipment's rated output capacity. Therefore, equipment efficiency isn't necessary for the load calculation procedure. Rather, efficiency ratings play an important role in equipment selection.

See "Types of Efficiency" on page 148 and "Air-conditioner Efficiency" on page 214.

Heating and cooling distribution losses — Duct efficiency losses include both heat transmission and air leakage. Heat transmission through the duct walls depends on the temperature difference, surface area, insulation R-value, and the amount of air flowing through the duct.

For practical reasons, duct-efficiency losses are considered part of the building load. ASHRAE establishes procedures and equations for estimating duct efficiency losses, which then become part of the building load.

Duct air leakage is difficult to estimate without measurement using a duct blower. The impact of duct leakage depends on the amount of leakage and where the leaks are located. Leakage on the return side can increase or decrease the load, depending on the ambient temperature and humidity of the air entering the return ducts. Leakage on the supply side, when located outside the thermal boundary, always increases the load since the heating or cooling system must condition more air to make up for the conditioned air that escapes.

See "Duct Air Leakage" on page 89.

Air-handler cabinets also transmit heat and leak air. These heat losses and heat gains don't figure into equipment efficiency ratings because the cabinet is assumed to be located inside the thermal boundary. When an air handler is located outside the thermal boundary, you should include cabinet heat flows for the load calculations.

Penetrations for refrigerant lines and condensation drains are often serious air leaks. When you conduct a duct leakage test, the cabinet is part of the tested duct system so any leaks are included in your duct-leakage measurement.

Whenever possible, mechanical equipment and duct systems should be located inside the thermal boundary. Efficiency losses associated with interior ducts are generally ignored when calculating heating and cooling loads. However, these losses affect the performance of the air distribution system and should ideally be reduced by air sealing and insulation.

Annual heating and cooling loads — The primary purpose of calculating annual heating and cooling loads is to predict savings from energy-efficiency improvements. Calculating these annual loads before and after an improvement estimates the savings provided by that improvement.

The heat loss (Q) in BTUs over any time period (usually a season or a year) can be calculated by multiplying the total heat transmittance (U), area in square feet (A), temperature difference in °F (ΔT), and time period in hours (t). This formula is as follows:

$$Q\,(BTU) = U \times A \times \Delta T \times t$$

Degree-days combine ΔT and t in the above formula. Heating degree-days (HDDs) and cooling degree-days (CDDs) are typically based on a balance-point temperature of 65°F. The balance point, also called the base, is the outdoor temperature at which no heating or cooling is required. The degree-day base is typically set lower than the heating and cooling design indoor temperatures due to the effects of solar gain.

Heating degree-days are calculated by subtracting the average daily temperature from the base, while cooling degree-days are calculated by subtracting the base from the average daily temperature. (Ignore negative numbers because no space conditioning is required if degree days are zero or negative.) For example, if the high temperature on a particular day is 45°F and the low temperature is 15°F, then the average temperature is 30°F. In this case, 35 heating degree-days would accumulate for that day. Use the formulas below to calculate HDDs and CDDs.

$$\mathbf{HDDs = 65 - 1/2(T_{high} + T_{low})}$$

$$\mathbf{CDDs = 1/2(T_{high} + T_{low}) - 65}$$

The annual heating and cooling degree-days are the total degree-day values for an entire year. The average HDDs and CDDs for a location are based on historical climate records. For example, Caribou, Maine, experiences an average of 9767 HDD, while Wilmington, North Carolina, experiences 2347 HDD.

While degree-day calculations provide a rough estimate of annual heating or cooling loads, an energy-modeling program is an essential tool for making accurate and repeatable calculations. When analyzing existing homes, some energy-modeling programs can refine their predictions using historical energy usage from utility bills, which greatly improves accuracy. Some energy modeling programs prioritize suggested energy improvements based on their cost-effectiveness.

Seasonal Heat Load: Effect of Insulation

$$\overset{\text{Transmittance}}{U\ \frac{\text{BTUs}}{\text{ft}^2\text{•hr•°F}}} \times \overset{\text{Area}}{A\ \text{ft}^2} \times \overset{\text{Heating degree-days}}{\Delta T\ \frac{\text{HDDs}}{\text{year}}} \times \overset{\text{Change days to hours}}{24\ \frac{\text{hrs.}}{\text{day}}} = \overset{\text{Annual heat loss}}{Q\ \text{Therms or Decatherms per year}}$$

Before insulation

$$0.29 \times 100 \times 5864 \times 24 = \begin{matrix} 40.8 \\ 4.08 \end{matrix}\ \begin{matrix}\text{Therms} \\ \text{or} \\ \text{Decatherms} \\ \text{per year}\end{matrix}$$

After insulation

$$0.069 \times 100 \times 5864 \times 24 = \begin{matrix} 9.71 \\ .971 \end{matrix}\ \begin{matrix}\text{Therms} \\ \text{or} \\ \text{Decatherms} \\ \text{per year}\end{matrix}$$

Calculation of Savings

$$40.8\ \frac{\text{Therms}}{\text{year}} - 9.71\ \frac{\text{Therms}}{\text{year}} = 31.1\ \frac{\text{Therms}}{\text{year}}$$

$$31.1\ \frac{\text{Therms}}{\text{year}} \times 0.805\ \frac{\$}{\text{Therm}} = 25\ \frac{\$}{\text{year}}$$

Savings

Cost of Wall Insulation

$$0.75\ \frac{\$}{\text{ft}^2} \times 100\ \text{ft}^2 = \$75$$

Cost

Payback and Annual Return

$$\text{Payback} = \frac{\text{Cost}}{\text{Savings}} = \frac{\$75}{25\ \frac{\$}{\text{year}}} = 3\ \text{years}$$

$$\text{Annual Return} = \frac{\text{Savings}}{\text{Cost}} = \frac{25\ \frac{\$}{\text{year}}}{\$75} = \frac{33\%}{\text{year}}$$

These calculations outline an economic analysis of installing R-11 insulation in an uninsulated wall. We first calculate savings in therms, then convert therms to dollars.

Manual J Computer Calculation of Room Heat Flows and Air-Handler Airflows

Room	Area (ft^2)	Heating load (BTUH)	Heating Airflow (cfm)	Cooling load (BTUH)	Cooling Airflow (cfm)
Living room	255	4670	188	4568	221
Dining room	224	4219	195	2271	188
Kitchen	144	3201	91	2456	119
Bedroom 1	158	4410	142	1799	98
Bedroom 2	106	1730	53	771	41
Bedroom 3	99	3941	151	2492	136
Bathroom 1	80	1532	65	1206	78
Bathroom 2	60	771	29	521	39
Totals	**1126**	**24,474**	**914**	**16,084**	**920**

Calculating Loads With Computer Programs

Many energy auditors and HVAC contractors use computer programs to make heat-load calculations easy. The programs perform only as well as the person who enters the data.

Utility and government conservation programs prefer computer programs because they standardize decision-making procedures and help maximize energy savings per dollar invested.

Computer programs designed to calculate heating and cooling load can do one or more of the following.

- Calculate heating and cooling loads by room, as in the table above.
- Calculate airflow or water flow needed to heat and cool the building at design conditions.
- Calculate duct sizes or pipe sizes for the heating and cooling delivery system.

Computer programs designed to calculate seasonal energy loads can do one or more of the following.

- Calculate heat loss and heat gain before and after a retrofit to estimate the cost-effectiveness of energy retrofits.
- Predict energy usage to compare with actual energy use. This comparison helps evaluate the calculation's accuracy and indicates whether the building has significant hidden problems.
- Simulate variable building operations to see how energy consumption changes. These programs are especially useful for analyzing large, complicated buildings.
- Manage and keep records of decision-making for weatherization and home-performance jobs.

See "Analyzing Annual Energy Costs" on page 277.