Calculating Cooling Loads

Part 3 in a series of articles on sizing heating and air conditioning equipment

By Martin Holladay | May 4, 2012

A few decades ago, residential air conditioning was very rare in colder areas of the U.S., and cooling load calculations were usually unnecessary. These days, however, new U.S. homes routinely include air conditioning equipment, even in Minnesota, so most U.S. builders are faced with the need to calculate cooling loads.

In my last two blogs ("How to Perform a Heat-Loss Calculation," Part 1 and Part 2), I discussed the principles behind heat-loss calculations used to size heating equipment. In this blog, I'll discuss the principles behind cooling-load calculations used to size air-conditioning equipment.

Rule-of-thumb sizing

Although most building codes require load calculations for heating and cooling equipment installed in new homes, the requirement is widely ignored and rarely enforced. Most HVAC contractors never perform cooling load calculations; instead, they size air conditioners by rules of thumb.

The age-old rule of thumb used by most contractors was one ton of cooling equipment for every 400 square feet of conditioned space. In a concession to recent improvements in insulation levels and window specifications, some HVAC contractors have adjusted their rule of thumb, and now size air conditions at one ton per 600 square feet.

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Because these rules of thumb almost always result in gross oversizing of cooling equipment, most energy experts have been battling rule-of-thumb sizing for years. However, rules of thumb have their place. Using a rule of thumb is not really the problem; the problem is that HVAC contractors are using a *bad* rule of thumb.

At least two well-known energy consultants, Michael Blasnik and Allison Bailes, have proposed a new rule of thumb for sizing air conditioners in homes with insulation that meets minimum code requirements: namely, one ton of cooling per 1,000 square feet. According to Blasnik, “Sizing an air conditioner using tons per square foot actually works pretty well, as long as you choose the right rule of thumb.”

A good rule of thumb has many uses; for example, it can be used by builders to get a general idea of

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whether their HVAC contractor's sizing method is in the right ballpark or is totally nuts.

Of course, using a rule of thumb to size an air conditioner is no substitute for performing a room-by-room cooling load calculation. Room-by-room calculations are necessary for many reasons: to properly size ductwork, for example, and to address unusual architectural features like rooms with large west-facing windows. Moreover, as air-conditioning guru John Proctor points out, rule-of-thumb sizing "does not account for orientation of the walls and windows, the difference in surface area between a one-story and a two-story home of the same floor area, the differences in insulation and air leakage between different buildings, the number of occupants, and many other factors."

You know that your air conditioner is sized correctly if it runs for 100% of the time on the hottest afternoon of the year. Since most air conditioners are oversized, however, they tend to short-cycle, even on very hot days.

How buildings gain heat

To understand the theory behind cooling load calculations, it's useful to understand all of the ways that a building gains heat.

Some heat originates from outside the building — these are external loads — while some heat is generated inside the building — these are internal loads.

- Heat is transmitted through the building envelope whenever the outdoor air temperature is higher than the indoor temperature, or whenever solar radiation raises the temperature of the siding or roofing above the indoor temperature.

- Heat enters the building when the sun shines through windows; this is solar heat gain.
- Heat enters the building when warm infiltrating air enters through cracks in the building envelope.
- Heat enters the building when warm exterior air is introduced by the mechanical ventilation system.
- Internal heat gains are generated by pets and people (who emit body heat and moisture), lighting, electrical appliances, and combustion appliances (like kitchen ranges and water heaters) located inside the building's thermal envelope.

Two of these heat sources — air infiltration and internal gains — can lead to both sensible heat gain and latent heat gain. (Latent heat is the heat that needs to be removed from a building in order to dehumidify the air. Since water has a latent heat capacity of about 1,000 BTU per pound, dehumidification is an additional load on an air conditioner. The process of dehumidification adds heat to the air; to put it another way, the phase change from water vapor to liquid water is exothermic.)

As energy rater Allison Bailes explains, "The sensible load is how much cooling you need to do to bring the temperature down, and the latent load is how much cooling you have to do to bring the humidity down." Because of the need to calculate a home's latent load, cooling load calculations (unlike heat-loss calculations) involve psychrometrics.

When outdoor air is hot and humid, the moisture load that accompanies infiltrating air must be removed by the home's air conditioner. Similarly, moisture is generated by building occupants — by people taking showers, cooking pasta, watering plants, or mopping the floor — must also be considered when making cooling load calculations.

A heat gain calculation requires that all of the heat flows into a building — internal and external, sensible and latent — be added up. Because of thermal mass effects and the dynamic nature of heat gain, the cooling load of the air conditioning equipment will usually be less than the building's heat gain. Cooling load calculation methods consider the heat storage capacity of the building shell (a factor that delays heat flow through the building's walls and ceiling) and the heat storage capacity of internal furnishings (a factor that "dampens" the effect of short-term heat gains).

Cooling load assumptions

Cooling-load calculations are made for worst-case conditions. While heat-loss calculations are made for the coldest night of the year, cooling-load calculations assume late-afternoon conditions during the hottest month of the year. The outdoor design temperature is usually less than a location's record hot temperature, however; designing a system for record temperatures results in equipment oversizing. The calculated solar load on the building assumes that the weather is cloudless.

Outdoor design conditions are, of course, location-dependant; different locations have different dry-bulb temperature and humidity conditions.

The usual indoor design conditions for cooling load calculations are a temperature of 75°F and an indoor relative humidity of 50%. Calculation methods assume that a representative number of appliances and lights are on, and that the building is fully occupied.

A surprising number of factors affect cooling load calculations:

- Of course, climate matters.
- Orientation matters. Since windows are not usually evenly distributed on all four orientations, rotating the orientation of a building design by 90 degrees can change the cooling load.
- Latitude matters (because the sun angle changes with latitude).

- The roof overhang width matters, as well as the distance between the top of the window and the soffit.
- The presence or absence of insect screens on windows matter, since they affect solar heat gain. (Since window screens are removable, most calculation methods assume that windows have no insect screens.)
- The presence or absence of curtains or blinds matters.
- The building's air leakage rate matters.
- The mechanical ventilation rate matters. (Software programs usually assume that older leaky homes have no mechanical ventilation system, only infiltration and exfiltration through envelope cracks. For newer homes, most programs require users to input information on the ventilation rate or assume the existence of a mechanical ventilation system that complies with ASHRAE 62.2.)
- The number of occupants matters. (Most calculation methods assume that the number of occupants equals the number of bedrooms plus one.)
- The lighting and appliance specifications matter. (Energy-efficient appliances and lighting produce less waste heat than inefficient appliances and lighting.)

Calculating latent loads

The main sources of latent loads are infiltration, perspiration and exhalation by occupants, cooking, laundry, showering, and bathing.

Although some sources assume that a home's latent load is 30% of the total load, the actual latent load varies widely; it depends on a home's infiltration rate, the climate, and the amount of moisture generated by occupants. For leaky homes in hot, humid states like Louisiana, the latent load can be higher than 30% of the total load. Conversely, homes located in arid states west of the Rocky Mountains usually have latent loads that are much less than 30% of the total load.

The sensible load divided by the total load (including the latent load) is called the sensible heat ratio (SHR) or sensible heat factor (SHF). The cooling load calculation method used by Manual J (the most common calculation method) assumes a default value of 0.75 for the sensible heat ratio; however, software programs allow users to enter a different SHR if they prefer. Most air conditioning equipment is designed to operate at a sensible heat ratio in the range of 0.70 to 0.75.

According to *[no-glossary]ASHRAE[/no-glossary] Fundamentals*, "A latent factor (LF = 1/SHF) of 1.3 or a sensible heat factor (SHF = sensible load/total load) of 0.77 matches the performance of typical residential vapor compression cooling systems. Homes in almost all other regions of North America have cooling loads with an SHF greater than 0.77 and latent factors less than 1.3."

Internal loads

Heat gain in commercial buildings is dominated by internal loads (for example, computers, lighting, and body heat). Compared to commercial buildings, most single-family homes have fewer electrical devices and occupants per square foot, and have a building envelope with a bigger surface area per square foot of conditioned space; as a result, internal loads play less of a factor in homes than in offices or schools.

Nevertheless, internal loads can be significant in homes and must be calculated. The sensible heat gain (body heat) emitted by one occupant is usually assumed to be 230 Btuh (67 watts). The default assumption for a home's appliances is usually 1,600 Btu/h (469 watts); lighting is assumed to add another 1,600 Btu/h (469 watts).

These default assumptions can be adjusted up or down if necessary. If a house has an unusual number of appliances or equipment — for example, a home business that includes a computer server room — internal loads will be higher than these default assumptions.

You should use a computer software program

Cooling load calculations are complicated, and are therefore best performed with computer software. The most commonly used residential cooling-load software programs follow the Manual J method developed by Air Conditioning Contractors of America (ACCA). The Manual J method is itself based on a method developed by ASHRAE, the Cooling Load Temperature Difference (CLTD) method first published in 1977.

HVAC contractors routinely use Manual J software inappropriately; the usual result is an oversized air conditioner. This happens when a contractor first sizes the air conditioner using a rule of thumb — perhaps one ton per 600 square feet. This is a bad rule of thumb, so the air conditioner is oversized; but that's what the contractor wants to install.

If the Manual J software is used correctly, the results will suggest the installation of a much smaller air conditioner; that makes the contractor nervous. So he begins tweaking his input numbers until he gets the result he wants.

There are various ways to do this:

- You can add a few degrees to the outdoor design temperature.
- You can subtract a few degrees from the indoor design temperature.
- You can increase the home's air leakage rate.
- You can reduce the size of the home's roof overhangs.
- You can assume that none of the windows have curtains or blinds.
- You can increase the size of the east-facing and west-facing windows.
- You can increase the number of occupants.
- You can enter a worse SHGC for the windows than the actual specifications show.
- You can reduce the amount of insulation in the attic.
- You can "round up" your inputs or results, or add a "safety factor."

Using some or all of these tricks will guarantee that you'll get the wrong result. Why would a contractor want to do this? There are various reasons; one is simple insecurity. Many contractors are uncertain of their math skills or worried that they are using the program the wrong way. The solution is to tweak and fudge the inputs, "just in case."

Some readers may be shaking their heads, doubting that such errors occur. However, energy raters in the field know that all of the tricks and errors listed above occur every day.

One energy consultant, Brett Dillon of San Antonio, Texas, has written an essay addressing these issues. Like many energy experts, Dillon has found that most residential air conditioners are oversized. "I discovered that the reason the oversized equipment was installed was because the customers had been complaining to the HVAC contractor about being uncomfortable," Dillon wrote. "The assumption on the part of the HVAC contractor was the equipment was too small to handle the load on the home. The reality was that the homeowners were uncomfortable because the distribution system (ductwork) was installed very poorly, resulting in the rooms not getting the airflow needed to condition the space. It wasn't the size of the equipment causing the problem, but the crappy ductwork!"

Allison Bailes once reviewed a Manual J report for a new Energy Star home in Charlotte, North Carolina. The HVAC contractor who performed the Manual J calculation used the report to justify the installation of an air conditioner sized at one ton per 368 square feet of conditioned space. Bailes explained, "When I went into the reports, here are the problems I found that are typical of bad Manual Js:

- They put 6 people in the calculation when this house should have had 4. (It should be the number of bedrooms plus one.)
- The HERS rater calculated that the house had 184 square feet of window area; the Manual J had 383 square feet.
- The HERS rater used a window U-value of 0.32; the Manual J had 0.53. (Lower is better.)"

According to Bailes, the HVAC contractor had one more trick up his sleeve: he adjusted the input for the sensible heat ratio. Bailes wrote, "The crafty calculator who completed this Manual J figured out that by adjusting the SHR, he could get the required capacity to equal what he wanted to install. In this case, he needed [to input] 0.53 SHR to get his 2.5 tons. Can you even get an air conditioner with 0.53 SHR?"

The moral of this story: If you are going to use Manual J, trust your software, and don't fudge your inputs.

How to keep cooling loads low

Playing around with Manual J software can help a designer determine ways to reduce cooling loads. A few points to remember, especially for designers who are more familiar with heating system design than cooling system design:

- Internal loads (appliances and lighting) reduce a home's heating load but increases a home's cooling load.
- Solar heat gain reduces a home's heating load but increases a home's cooling load. Unless they are shaded by a wide porch roof, large west-facing windows can greatly increase a home's cooling load.
- Although thick wall insulation helps reduce heating loads, it has a much smaller impact on cooling loads.
- Attics get hot during the summer, so deep ceiling insulation is an essential feature if you want to keep cooling loads low.
- A tight building envelope with a low air leakage rate helps reduce sensible and latent loads due to infiltration.
- Mechanical ventilation also increases a home's sensible and latent loads, so it's worth experimenting with low ventilation rates if you want to lower your cooling bill.

Summing up

In my last three blogs, I've introduced the principles behind heat-load and cooling-load calculations.

In my next blog (When Do I Need to Perform a Load Calculation?), I'll try to address the following questions:

- Who's the best person to perform these calculations?
- When are room-by-room heat-loss and cooling-load calculations useful, and when are they a waste of time?
- Are there simpler ways to size equipment?

*Last week's blog: **"How to Perform a Heat-Loss Calculation — Part 2."***

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