How to Perform a Heat-Loss Calculation — Part 1

Let's begin by discussing outdoor design temperatures and the many ways that heat can escape from a house.

By Martin Holladay | April 20, 2012

I'm going to devote the next several blogs to a discussion of heat-loss and heat-gain calculations. These calculations are the first step in the design of a home's heating and cooling system.

In order to address this big topic in little bites, I'll start by discussing heat-loss calculations. I'll get around to heat-gain calculations and cooling equipment in a future blog.

Before digging in to the topic, however, it's worth answering the question, "Why do I need to know how to perform these calculations?" If you are a homeowner or carpenter, you may not need to know anything about calculating heating loads. However, if you are a designer, architect, or builder, this knowledge will prove useful — even if you never perform the calculations yourself, but instead depend on computer software or consultants to perform the calculations.

Understanding the principles behind heat-loss calculations will help you understand how buildings work and how heating and cooling systems perform. With this knowledge, the quality of your dialogue with window suppliers, HVAC contractors, and engineers will definitely improve.

Outdoor design temperature

If you're performing a heat-loss calculation to size heating equipment, you need to perform the calculation for the worst-case condition: namely, the coldest night of the year. (Because the coldest condition usually occurs at night, a heat-loss calculation does not consider solar gain through windows.) The temperature on that night is referred to as the outdoor design temperature. (To be precise, the outdoor design temperature is usually defined as the temperature that is equaled or exceeded for 97.5% of the time during the three coldest months of the year. Other sources define the outdoor design temperature as the temperature that is equaled or exceeded for 99% of the year. As it turns out, most homes will remain comfortable even when the thermometer dips below the design temperature 2.5% of the time.)

Design temperatures for many locations around the world can be found in Chapter 24 of [no-glossary]ASHRAE[/no-glossary] Fundamentals. Design temperatures for U.S. locations are posted online by the International Code Council; the design temperatures for ACCA's Manual J are posted here. Fairbanks, Alaska has a winter design temperature of -47°F, while Honolulu has a winter design temperature of 63°F.

The indoor design temperature for heating systems is usually assumed to be 70°F, although a higher design temperature may be chosen if desired. The difference between the outdoor design temperature and the indoor design temperature is the ΔT (delta-T). For example, the winter design temperature in Burlington, Vermont is -7°F, so a heat-loss calculation for Burlington assumes a ΔT of 77 F°.

Obviously, the higher the ΔT, the higher the rate of heat loss. That's why it takes more fuel to stay warm in Fairbanks than it does in Miami.

There are many ways that a house loses heat

Now that we know how warm we want our interior and how cold we anticipate it will get outdoors, we can begin calculating how much heat our home will lose per hour on the coldest night of the year.

To be sure our calculations are accurate, we have to start by listing all the ways that a house loses heat:

- Heat is transmitted to the exterior through a home's floors, walls, ceilings, windows, doors, and penetrations.

- Heat leaves the home when warm indoor air leaks through cracks in the home's envelope.
- Heat leaves the home through air that is deliberately exhausted by bathroom fans, range hoods, and clothes dryers.
- Heat leaves the home when warm water goes down the drain and flows to municipal sewer pipes or a septic tank.
- Heat leaves the home when combustion gases from a furnace, boiler, or water heater exit via a flue.

Some of the heat flows listed above — for example, the heat that leaves through drain pipes — are relatively minor and are therefore ignored by most heat-loss calculation methods. Others — especially heat transmission through the home's envelope and heat lost via air leakage — are so significant that they can't be ignored.

Remember, it's called the "U-factor," not "U-value"

To calculate how fast heat flows through a building assembly like a floor, wall, or ceiling, energy modelers need to know the building assembly's U-factor. (U-factor is the inverse of R-value, so U=1/R and R=1/U.) The lower the U-factor, the lower the rate of heat loss. In the U.S., U-factor is defined as the number of BTUs that flow through one square foot of material in an hour for every degree Fahrenheit difference in temperature across the material (Btu/ft^2 • hr • F°). Thick insulation has a low U-factor, while a single sheet of glass has a relatively high U-factor. Low U-factors are good; high U-factors are bad.

Calculating heat flow through building assemblies gets complicated, because walls don't have a uniform U-factor. In a typical wood-framed building, for example, the insulation between the studs has a certain U-factor, but the U-factor of the studs and plates is usually higher. Furthermore, the window's U-factor differs from the U-factor of the insulation and the framing lumber; in fact, different areas of the window have different U-factors. The center of the glass has one U-factor, while the perimeter of the glass has a higher U-factor. Finally, the window frame has its own U-factor.

Each penetration has its own U-factor. For example, if an insulated ceiling is penetrated by a large brick chimney, the U-factor of the chimney is much higher than the rest of the ceiling.

Most heat-loss calculations methods avoid the hard math by making a few default assumptions: for example, calculation methods usually assign a framing factor to wood-frame walls — for example, 23%. In other words, it's easier to assume that 23% of the wall consists of framing lumber, and 77% of the wall consists of insulation, than it is to try to calculate the actual percentage for every wall of the house.

Needless to say, heat transmission through below-grade walls and floors must be calculated differently from heat transmission through above-grade walls. Heat loss calculations must also take into account the effect of buffer spaces like crawl spaces and attics; during the winter, the temperature of these partially conditioned spaces is usually higher than the outdoor temperature and lower that the indoor temperature.

What about air leakage?

Thirty years ago, heat-loss calculation methods were fairly unsophisticated, especially when it came to air leakage. I first learned how to perform heat-loss calculations in 1975, using a pencil and a paper form called the "I=B=R Calculation Sheet." (This method was promoted by the Institute of Boiler and Radiator Manufacturers, an organization that no longer exists.)

The handbook accompanying the calculation sheet advised that there were three levels of air tightness:

- The tightest homes had "windows and doors weatherstripped or with storm sash."
- Mid-range homes had "windows and doors not weatherstripped and without storm sash."

- The leakiest homes had the following wall construction: “Clapboards or wood siding, studs without insulation, 1/2-inch drywall, no sheathing.”

These days, some heat-loss calculation methods use a similar approach, with default values assigned to various descriptions of leakiness — for example, “quite leaky,” “average,” and “tight.” My 1993 edition of ASHRAE Fundamentals lists three levels of air leakage, and the definitions have been updated from those provided by I=B=R:

- “Tight” homes have “close-fitting doors [and] windows … New homes with full vapor retardant [sic], no fireplace, will-fitted windows, weatherstripped doors, one story, and less than 1,500 square feet of floor area fall into this category.”
- “Medium” homes include “two-story frame houses or one-story houses more than 10 years old with average maintenance, a floor area greater than 1,500 square feet, average fit windows and doors, and a fireplace with damper and glass closure.”
- “Loose” homes are “poorly constructed” residences with “poorly fitted windows and doors.”

Some software modeling programs allow users to input the results of a blower-door test — an approach that (at least in theory) should yield a more accurate result.

However, even when we have blower-door results for the house under consideration, we still don’t have enough information to understand how much air will leak out of the house on a cold night. That’s because when it comes to holes in a building’s thermal envelope, what matters is “location, location, location.” If the holes are evenly divided between ceiling holes and basement holes, the air leakage rate will be high; however, if the holes are mostly located near the neutral pressure plane in the middle of the house, the air leakage rate will be much lower.

The heat-loss calculation methods used by contractors and architects never take account of envelope leak location, even though it matters; instead, default assumptions prevail.

Sharpening our pencils

Now that we’ve discussed how heat leaks out of a house, we’re almost ready to begin making a few calculations. In next week’s blog, I’ll explain how to use the area of a portion of your home’s thermal envelope and its associated U-factor (a value that you can look up in a table, or calculate yourself by adding up the R-values of all the layers in the building assembly) to determine the rate of heat loss (in BTU/hour) at the design temperature for that portion of the envelope. Stay tuned!