BY CLAYTON DEKORNE

Heat Transfer Through Buildings

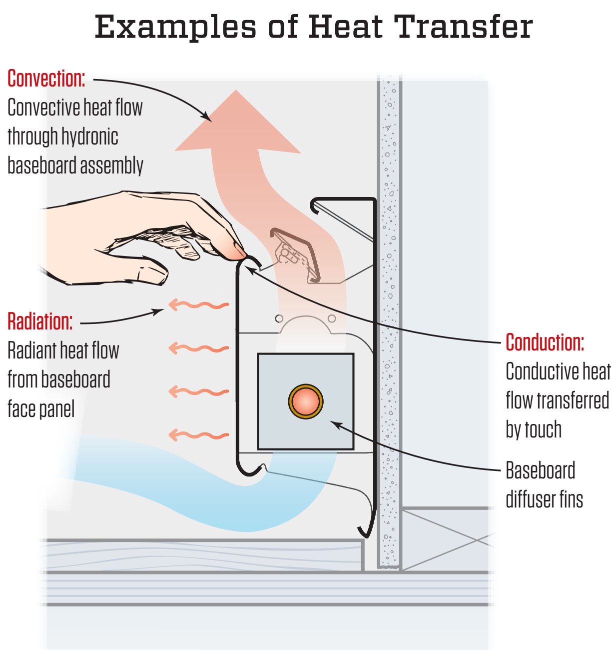
On average, more than half of the total annual energy used by households goes to space heating and air conditioning. About 27% goes to water heating, lighting, and refrigeration combined and the remaining 21% to everything else—from washers and dryers to cellphone chargers, computers, and all the other devices we use in a home.

The amount of energy that's consumed for heating and cooling homes varies significantly by geographic location, house size, construction type, and the equipment and fuels used. But the majority percentage of household energy that is used on heating and cooling speaks loud and clear to the importance of understanding how heat moves through buildings. The mechanisms of heat flow not only influence the heating and cooling systems we install but also inform how we build the "thermal separation" between indoors and outdoors.

ESSENTIAL CONCEPTS

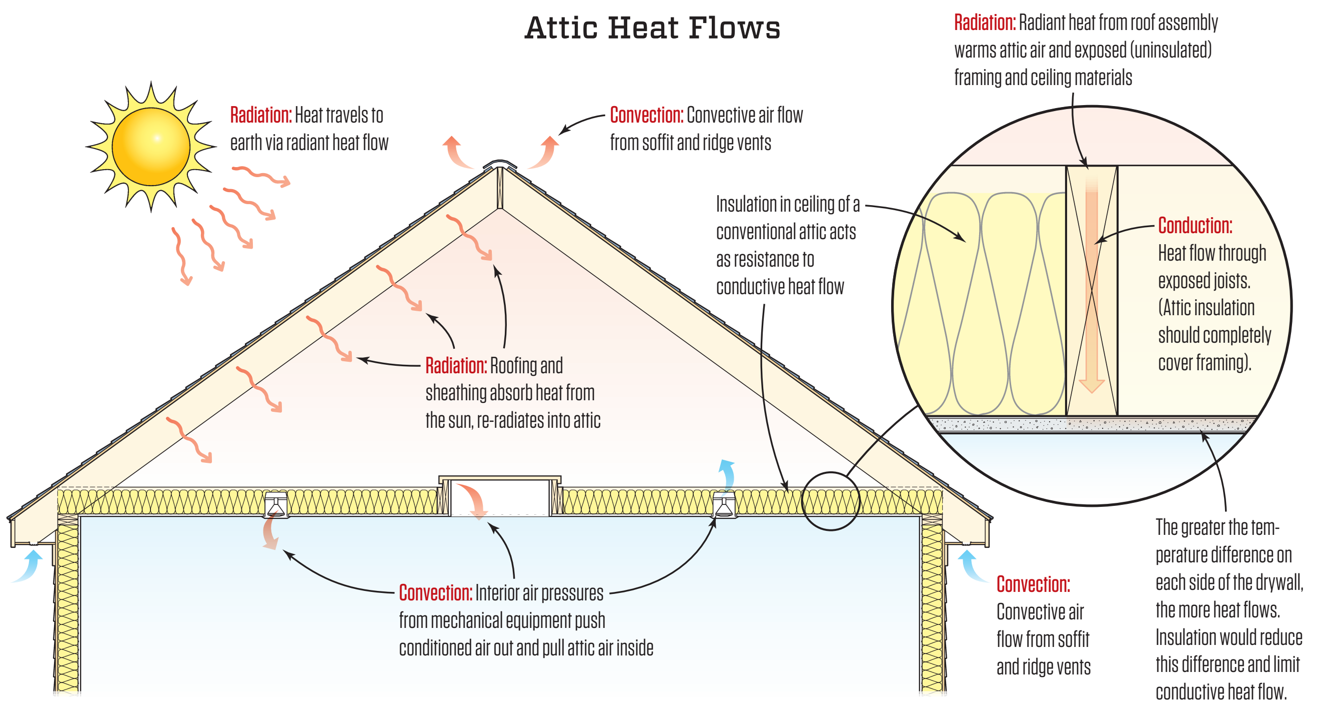
Regardless of the climate or the home, heat always behaves in predictable ways, and these are useful for understanding how heat moves through structures. When evaluating the energy efficiency of any structure, keep the following essential concepts in mind:

- Heat always moves from warmer areas to colder areas. In winter, we heat the interior of a home, so the direction of heat flow is from inside to outside. In summer when it's hotter outdoors, the direction is reversed.
- The greater the temperature difference, the faster heat



Heat flows from warm to cold. In a framed wall assembly, cavity insulation limits conductive heat flow, but the studs themselves can also transfer heat through the assembly unless continuous insulation, such as rigid foam, is installed (above left). A fin-tube radiator (above right) transfers little heat by radiation. It mostly moves heat by convection (air flowing through the diffuser fins) and by conduction (heat moving across the pipe wall and into the aluminum fins).

Photo by Ted Cushman; illustrations by Tim Healey



All three heat transfer methods are illustrated in this attic section. Roofing materials absorb radiant energy from the sun. As those materials heat up, they re-radiate heat into the attic, warming the attic air and exposed framing. Insulation limits heat flow by conduction across the ceiling; the more insulation, the more resistance to conductive heat flow. Convection helps cool the attic by moving air through soffit and ridge vents, while interior air pressures move air through holes in the ceiling.

flows. If it's 70°F inside and 75°F outside, there's not much energy moving through the enclosure, and the difference is not very noticeable. But, if it's 70°F inside and 0°F outside, there is a lot of heat flow, and the difference is immediately noticeable. (Note: Heat flow has a big impact on comfort; that is, how we feel about the heat or the lack of it.)

- Air contains moisture vapor. The warmer the air is, the more moisture it can hold. If the air cools sufficiently to cause the moisture in the air to condense on a surface in the home, it can have a huge impact on building durability. (The mechanics of moisture flow is a whole series of lessons in itself. Stay tuned.)

HEAT VS. TEMPERATURE

Heat is not the same as temperature. Heat is kinetic energy; temperature is a measurement of how intense that kinetic energy is. To illustrate this, think of two containers of water—one containing 10 gallons and one containing 1 gallon. The water in both containers is 50°F. Although they are the same temperature, the larger container holds 10 times more heat than the smaller one. The larger container has more thermal mass and therefore has more heat capacity.

HEAT TRANSFER

Heat moves through building assemblies primarily in three ways: by conduction, by convection, and by radiation.

Conduction is the movement of heat energy directly through solid materials from molecule to molecule. The movement of the material plays no role in the transfer of heat.

Building materials conduct energy at different rates. Metals, such as copper and steel, for example, have high conductivity, meaning heat energy moves through them at a very efficient rate. Fiberglass batts and rigid foam, on the other hand, have low conductivity. Materials that are poor conductors serve as insulators when they are placed between more-conductive materials in an assembly such as a wall or a roof. The flow of heat through an assembly of materials is slowed down appreciably by insulating materials. Wood is somewhere in the middle for conductivity. It's not a good insulator unless it is shredded and has lots of air pockets between the wood fibers. (The secret behind most insulation is air

TABLE R402.1.2
WALL INSULATION REQUIREMENTS

CLIMATE ZONE	WOOD FRAME WALL R-VALUE
1	13
2	13
3	20 or 13+5
4 except Marine	20 or 13+5
5 and Marine 4	20 or 13+5
6	20+5 or 13+5
7 and 8	20+5 or 13+5

In this selection from the energy code, we can think of different climate zones as representing varying temperature differences. In colder climates (zones 4 and above), the temperature differences in winter between indoors and outdoors are greater, so conductive heat flows at a greater rate through building assemblies. To limit this heat flow, more insulation is needed. Note that the "+5" R-values indicate continuous insulation that insulates against heat flowing across wall studs, while the other numbers indicate cavity-insulation R-values.

pockets that disrupt the conductive heat flow through a material.)

The rate of conductive heat flow is measured as U-value, and resistance to heat flow is measured by its reciprocal, R-value.

U-value = rate of heat transfer

R-value = resistance to heat transfer

The lower a given material's U-value, the less conductive it is. The higher the U-value of a material, the more conductive it is.

Convection is the flow of heat within a fluid, with warmer fluids rising and colder fluids falling. In homes, this fluid is air; in the ocean or a boiler, it's water.

In air, convection is often called the "stack effect." As air warms, the molecules move farther apart, and the air becomes more buoyant, floating upwards. As that air rises, cold air is pulled from below to replace it (for more, see "Air Barrier Basics," Jan/19). In a boiler or heat pump, warmed water circulates in a similar way, and piping systems can be designed to use this "thermosiphon" to circulate water.

When we account for convective air flows in buildings, we look at the following variables:

- Difference in temperature (ΔT): As with all methods of heat transfer, a difference in temperature from one area to the other is a necessary condition for heat to flow.
- Time (t): Length of time the air movement occurs.
- Volume of air (V): The volume of air within a home can be measured by multiplying the length, width, and height of interior space. The volume of air in a home remains constant, although the air itself changes.
- Air changes per hour (AC/hr): The rate of air movement is measured as air changes. The "change" is the movement into and out of a defined space, such as the volume of air in a room (the amount used to balance air flow in an HVAC system), or in a whole house (the amount used to measure house leakage).

Radiation is the movement of heat through space (not air) as electromagnetic waves. The sun's energy reaches earth by radiation. Radiation is not affected by the air. The sun and a campfire both emit radiant heat, even when the wind is blowing. Radiant heat moves at the speed of light without heating the space between the radiant source (often called a "radiant body," be it the sun, or a heated slab, or a thick mass of asphaltic roofing and wood sheathing) and the surface of another object.

To be warmed by a radiant heat source, the surface needs to be in the line of sight of the heat source. This is why shading works. We can put an overhang or an awning between the sun and a window to reduce radiant heat flow. In that case, the sun warms the overhang or the awning when the energy is absorbed into those materials.

Instead of being absorbed into materials, radiant heat can reflect off white or shiny surfaces. During the summer, heat absorbed through roofs and through windows are the two main sources of heat gain in homes. To control this heat gain, many windows include a very thin metal coating on one surface to reflect radiant heat. And on roofs, we can use light-colored roofing to reflect heat, or we can install a radiant barrier—a layer of foil on the sheathing facing into the attic.

Radiant energy is a principal heat source in hydronic heating systems. Both hot-water and steam systems depend on "heat emitters." Though more commonly known as radiators, most do not transfer heat by radiation alone. The majority of heat produced by a finned-tube baseboard is convective heat flow: Cooler air enters the bottom of the baseboard enclosure and is warmed as the air moves through the fins, and then warmer air rises out the top. By contrast, most of the heat produced by radiant floors and the heavy cast-iron Euro-style radiant baseboard is radiant heat, though some convection currents are also created as the air around them is heated and rises.

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For a more detailed discussion of these building-science principles, go to **jlconline.com/training-the-trades/heat-transfer-through-buildings**.