**Conduction Principles**

One of three methods by which heat moves, conduction is the process whereby heat is transferred from a warmer material to a colder material while moving directly through the material itself. When heat is transferred by conduction, it moves from molecule to molecule; no movement of the material plays a role in the transfer.

In order for heat to move by conduction, materials must be in direct contact with each another. An example: When touching a hot pan on a stove, conduction of heat moves from the stove to the pan to your hand. In this case, each material is in direct physical contact with each other.

Different materials all have different conductivity. Copper, for example, has a high conductivity, meaning it passes heat energy at an efficient rate. Cotton, on the other hand, has a low conductivity; it does not pass heat energy very efficiently. Materials that are poor conductors act as insulators when they are placed between highly conductive materials. The flow of heat through the conducting materials is appreciably slowed down by the poorer conducting materials. However, because heat can also move by convection, the insulating characteristics (resistance to heat flow) of any insulation can be reduced if air is allowed to move through it.

**U-Value vs. R-Value**

The rate of 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**

R-value and U-factor are the inverse of one another:

**U = 1/R**

**R = 1/U**

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

The higher the R-value of a material, the better it is at resisting heat loss or heat gain. Materials that are very good at resisting the flow of heat (high R-value, low U-value) can serve as insulation materials.

In a home energy analysis, U-factor equals the number of BTUs of energy passing through a square foot of material in an hour for every degree Fahrenheit difference in temperature across the material:

**U = Btu/ft2hr°F**

To examine this last relationship in detail, you should understand each of the factors that affect heat transfer in general, and conduction, in particular.

**Three Basic Factors Affecting Conduction**

There are three basic factors affecting heat transfer that will help us to understand and evaluate different insulation systems and different energy systems in a building:

1. Temperature difference: More heat is lost when it’s colder outside than when it’s warmer outside.

2. The time over which the transfer occurs: The greater the amount of time, the greater the transfer of heat. For example, if you go outside where it’s 0°F and stay out for one hour, you will feel a lot colder than if you were outside for only fifteen minutes. Similarly, the greater the temperature difference over a longer period, the more energy a house will use.

3. The area over which the transfer occurs: A bigger house takes more energy to heat or cool because there is more surface area that transfers heat. Similarly, the area of heat transfer plays a role in the effectiveness of the condensing coils of air conditioning systems or of radiant heat emitters.

These three variables — temperature difference, area, and time — are the basis for any heat load calculation to measure the heat loss in a home. The temperature difference is often expressed numerically as "ΔT"' (the Greek letter Δ, delta, is used as a symbol to represent change; T represents temperature).

**Evaluating Heat Loss by Conduction**

The relationship of heat loss to time and area is a linear relationship expressed in terms of BTU/hr/sq. ft. For example, if a wall assembly transfers 100 BTUs from inside to outside for one hour, heat loss for the total time period will equal 300 BTUs per hour. Or, if we have 10 BTUs per hour per square foot, then 4 square feet of wall area loses 40 BTUs per hour.

**Using U-value.** Putting all this together, the overall energy performance of the structure can be calculated using the following formula:

**Q = U x A x ΔT x t**

In this formula, Q represents the heat loss of a material; U = U-value expressed as Btu/ft2hr°F; A = area expressed in square feet; ΔT = the change in temperature in degrees Fahrenheit from one side of the wall to the other in a worst-case scenario; and t = time, expressed in hours.

**Q = BTU/ft²hrºF x ft² x °F x hr**

So, to properly size a furnace, for example, the goal is to match the heat loss of a structure to furnace output. Using this formula, a heating contractor would go through the structure, piece by piece, and calculate the heat loss for each assembly, first figuring out how many square feet of exterior walls there were in the house, and then multiplying this by the U-value of each wall assembly.

**Using R-value.** In a typical energy analysis, the U-value of each building assembly is selected from a chart or a menu in a computer program. If the U-value is not listed, then it can be calculated using the formula expressed in terms of R-value:

**Q = A x ΔT x t / R**

or

**Q = ft² x °F x hr/ ft²hr°F/BTU**

where A is the total square footage of the assembly; ΔT is the commonly used number expressing temperature change for the local area; and R is the sum of all the R-values in the building assembly. (Note: t, time, commonly equals 1 hour and can be left out, though it must always be remembered that heat loss is a function of time.)