The Importance of Residential and Commercial Building Insulation

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If ranking the benefits of various energy projects done to save energy costs in a building, adding insulation is often at the top of the list. The only other projects that usually come close to the benefit versus cost are sealing up very large air gaps in a home. Fortunately, many insulation projects can be done by the homeowner if they can and want to invest some sweat equity. This Fact Sheet discusses some of the basic issues one should investigate when considering an insulation project.

Insulation Basics

The main idea behind using building insulation is easy enough to understand. Anyone who has used a foam plastic picnic cooler knows that ice will stay frozen inside the foam layer much longer than if it were just in a plastic bag. The foam resists the movement of heat from the warm outside of the cooler to the colder interior. Cold is not escaping because there really isn't anything that can be identified as a unit of "cold." There is only heat and heat always travels from locations of more heat to locations of less heat. The ability of foam, or any material, to ***resist*** the movement of heat is described by its coefficient of heat transfer resistance, or "R" value. This is the R-value seen on rolls of insulation at the hardware store. As you can imagine "R" has some strange units: $ft^2 \cdot {}^\circ F \cdot hr/Btu$. Basically you can see that the R-value is examining the rate at which heat is moving through an area like a wall or ceiling. A higher "R" value means *less* heat is passing through the material. A good conducting metal like copper will have a very low R-value and an insulator like plastic foam will have a high R-value.

Some building materials use a "U" value (Heat Conductance) instead of R. This is actually just the inverse of "R"- Value and it shows how easily heat can pass through a surface. Windows are often rated in U-Value instead of R-value, but the concept is the same. R-values are used in this Fact Sheet.

Insulation Thickness

Insulation is usually rated as having a certain R-value per inch or some set thickness such as ¾ inch. The R-value increases in a linear, or constant, rate as the thickness increases. For example if one inch of fiberglass batt insulation has an R-value of 3.2, then two inches of the same fiberglass batt will have an R-value of 6.4 and have twice the insulation ability of the one-inch thickness. Different insulators will have different R-values, and these different resistances can add-up if they are layered together. A typical wall might have a brick facing, vapor retardant, particle board, fiberglass insulation, gypsum board and even a layer of stucco/paint. There would be at least[1] six R-values adding together to calculate the total R-value of this wall (see Figure 1). The insulation ***thickness*** is one of the major factors in the material's ability to resist heat movement.

Insulation Material

The other prime factor of a structure's ability to hold heat in or out is the actual ***material*** of the insulation. Interestingly, there is a parallel between heat conduction and electrical conduction. Metals such as copper are excellent electrical and heat conductors. Most plastics make good electrical and heat insulators. Dead air is a good heat insulator as is a vacuum (thermos bottle). Trapped gases such as air or argon make poor heat conductors (good insulators) and are used in some windows. All building insulation uses this property to some degree. Fiberglass insulation is really all about the air trapped between the fibers. Plastic foams, both open and closed cell, have tiny bubbles or passageways that trap air or gases and

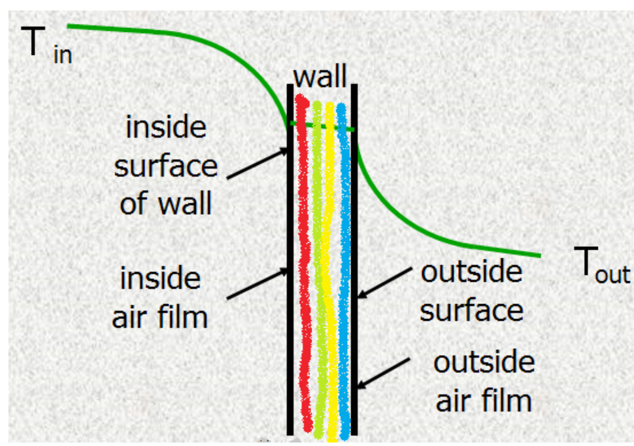

Figure 1. Diagram showing wall insulation sandwich of different materials with temperature inside (Tin) and temperature outside (Tout) on a cold day.

[1] Interestingly, the air films on the surfaces of the walls will also have an R-Value.

Table 1. Insulation properties of different materials (U.S. Dept. of Energy).

Material Type	*R-value*	*Cost per square foot*	*Cost per square foot per R-value*
Fiberglass batt (3.5 to 12 inches thick)	13 30	\$0.20 to \$0.40 \$0.60 to \$1.00	\$0.02 \$0.03
Loose fill such as fiberglass, cellulose, and mineral wool (8 to 23 inches thick)	30 50	\$0.45 to \$1.35 \$0.75 to 2.25	\$0.03
Open cell polyurethane spray foam (3.5 inches thick)	12.6	\$1.70 to \$2.50	\$0.17
Closed cell polyurethane spray foam (1 inch thick)	6.5	\$1.30 to \$2.00	\$0.25
Expanded polystyrene foam board (1 inch thick)	3.8 – 4.4	\$0.20 to \$0.35	\$0.07
Extruded polystyrene foam board (1 inch thick)	5	\$0.40 to \$0.55	\$0.10
Polyisocyanurate foam board (1 inch thick)	6.5	\$0.60 to \$0.70	\$0.10
Cotton	3.5	\$0.12 to \$0.22	\$0.05
Mineral wool, rock wool	4	\$0.18 to \$0.33	\$0.06

this resists heat movement.

Many materials have been studied, and their insulation properties are well known (Table 1). Different materials can have very different insulation properties.

If the R-value is known, the expected temperatures and the area of a wall or ceiling, the amount of heat that will pass through in a certain time can be calculated, using the following equation:

$Q = UA\Delta T$ or $Q = (A\Delta T)/R$, Where: Q=heat movement, A=wall or ceiling area, ΔT=Temperature difference from inside and outside the structure

The current heat movement through a wall is calculated, and the insulation R-value is changed to a higher number (thicker or different material) and recalculated. The difference in heat passing through is the amount of energy saved from a heater or air conditioner maintaining the same temperature. This is basically how energy auditing software predicts the energy and associated cost savings from adding insulation in a building. This is also how a contractor should determine the size of heating and cooling equipment for a building. Let's look at a calculation comparing old, settled insulation versus new fiberglass batts in an attic:

Example: Insulated Ceiling in Unconditioned Attic, 1,500 ft^2, old insulation on ½-inch plywood (R=0.62).

- Initial conditions (Heating Season): Old cellulous insulation settled to R=7, total ceiling R=7.62
- $Q = UA\Delta T$ or $Q = (A\Delta T)/R$ Where: Q=heat movement, A=wall or ceiling area, ΔT=Temperature difference from inside and outside
- 1,500 square foot area of fiberglass batt 1 inch thick, 70F inside and 30F outside (attic space)
- Q = (1,500sqrft x 40F)/7.62 = 7,874 Btu/hour
- Replace with fiberglass batts (R-32), 70F inside and 30F outside
- Qnew = (1,500sqrft x 40F)/(32.62) = 1,839 Btu/hr

Notice the added insulation immediately dropped the heat loss 300 percent (7,874 Btu/hour to 1,839 Btu/hour). If this represented the entire home's construction including walls, the heating bills would effectively drop to one quarter of those previously. This shows the importance of insulation. If the insulation thickness is changed in the above example a point is quickly reached where more and more insulation is not providing such big jumps in energy savings. This means there is some point where buying more insulation does not help, but 90 percent to 95 percent of the benefits have been reached without spending more.

If this example is used for heat gain in the summer with a 120 F attic:

- Qold = 9,842 Btu/hr (heat gain that A/C must fight)
- Qnew = 2,299 Btu/hr
- Q Difference = 7,543 Btu/hr (this is more than half a ton of cooling not needed now)

For a typical Oklahoma heating and cooling season, this is a heating cost savings of about \$130 per year and a cooling savings of about $235 per year[2]. Through a 20-year period, this is a $7,300 savings – just for improving attic insulation. If the homeowner does this project themselves, and materials cost $1,500, the payback would be in about 4 years, which is good for a home improvement project. Make sure insulation in the rest of the home is good (walls, doors, windows) and the savings could be higher.

Water Vapor Movement

In addition to controlling temperature, internal comfort of a structure depends to some degree on the ability to control the movement of moisture and humidity through the structure. Buildings experience internal water loads from showers, cooking, painting and people. This water vapor (along with other vapors and fumes) needs to escape the building at some rate. The outside environment may be higher in water vapor concentration. In this case, the vapor will be trying to move into the building. High humidity in the interior of buildings can lead to comfort and health issues. This can also facilitate the growth of mold in the building interior.

Some of the insulation materials described here can act as vapor barriers that stop the movement of water. Others simply slow down the water movement (semi-permeability)and some allow moisture to pass directly through the insulation. Proper placement of vapor barriers depends on local climates and building interior use. Always consult a professional when installing vapor barriers. It is generally not advisable to install insulation with a vapor barrier in a building that already has a vapor barrier because this can trap moisture between building materials layers, where it can destroy walls and ceilings.

Insulation Types and Costs

There are a variety of insulation materials available to the consumer or contractor. Each has pros and cons. Let's examine a few types of insulation materials.

Fiberglass Batts: This material has been around for some time. It is relatively inexpensive and the homeowners can install this themselves. The problem is that it must be cut into very precise pieces and shapes to cover the area it is trying to insulate. This can become quite a chore for odd shaped spaces and corners around wood beams. The batts must fit tightly into all spaces – no leaks. Installing fiberglass insulation is not difficult, but it can be an itchy, hot job. Over several years, fiberglass can settle and loose its initial R-value of approximately 3.5 per inch of thickness. From Table 1, we see that fiberglass batts are one of the least expensive ways to provide insulation (at first) at about $0.02-$0.05 per R-value.

Cellulous: This material is often just finely shredded newspaper. The material is simply blown loose into the space where it is needed (attic or walls). This is typically not a homeowner project because special equipment is needed to deliver the material through a blower and hoses. The price is on the low side for insulation, depending on the vendor (approximately $0.04 per R-value per square foot installed). One of cellulose's advantages is that the small particles tend to seal up air leaks in oddly shaped areas. Installation time can be within minutes once everything is set up, simply blow the material into the attic to a desired depth. Some of the disadvantages of loose cellulose include: Careless application can have the shredded material covering various needed vents in the attic (soffit, etc.). High winds can move the insulation around and leave large uninsulated ceiling areas (fences around vents solve this). The material is subject to settling. A large part of the R-value of insulation is due to its thickness and the trapped air within. As insulation settles and becomes a thinner layer with time, its R-value drops. Loose cellulose is very susceptible to this settling and needs to be inspected every few years.

Closed Cell Foam: In recent decades, spray-on insulation foam has gained popularity. The foam is sprayed on a surface, expands and hardens, then trimmed and finished with various coverings (or left exposed). If applied well, the foam will completely seal almost any surface and can easily be applied to the undersides of surfaces. The R-value of closed cell foam is quite high per inch of insulation at about 6.5 per inch. These are very attractive benefits as air movement from the outside is effectively stopped. This means humidity, or water vapor, movement into the space is also stopped. Application is fairly quick once setup. The disadvantages include a high initial cost about three times higher than fiberglass insulation (about $0.16-$0.25 per R-value per square foot installed). Some of the more subtle problems include anything underneath the foam is completely encapsulated and stuck together. For example, wiring must be dug out of the foam to be worked on. The foam can also hide water damage from view that might be otherwise spotted[3].

Open Cell Foam: This is very similar to closed cell foam, but differs in that the small bubbles in the foam are open to each other. This reduces the R-value to about 4.2 per inch and allows some moisture to travel through the material. In general, open cell foam costs about half as much as closed cell foam. Application is very similar to closed cell as are some of the advantages and disadvantages. Foams are a good choice if one wants to convert an attic space into living space. The odd shapes of surfaces in the attic are relatively easy to seal with the spray application.

Foam Boards: These premade boards can have high insulation (R) values. They are fairly easy to handle and install, and are certainly worth considering for the homeowner willing to try to install insulation themselves. However, their cost tends to be higher than loose cellulose, fiberglass batts or spray foams.

Polyisocyanurate Board (ISO): This is a premade rigid foam board usually with an aluminum paper backing. The ISO or PIR board has a very high R-value of about 6.2 to 7.2 per inch thickness. The cost is relatively high and in-line with some of the spray foams for dollar per R-value. Some of the advantages of PIR board are that it is relatively compact per amount of insulation. Being ridged, ISO is easy to handle and attach to vertical surfaces. ISO does not give off much dust and installation is fairly clean for such an operation. This material is a good candidate for do-it-yourselfers. On the downside, like fiberglass batts, precise geometric pieces must be cut to fill in voids and make spaces resistant to air flow. If installed correctly ISO material can act as a vapor barrier.

Expanded Polystyrene Board (EPS): This is a rigid foam board but with no backing. This board is often used in

[2] Gas furnace at AFUE=0.8 and $0.7/Decatherm, A/C at COP=3.0 and $0.1/kWh

[3] This is assuming someone would spot the water damage coming through fiberglass – big assumption.

insulated concrete forms. Think of an inexpensive white foam cooler or coffee cup and it is probably EPS. The material has good insulation properties (R-value equals 4 per inch of thickness), however the boards are somewhat expensive. The boards break easily if mishandled. In general, the EPS boards both absorb and allow water vapor to pass through. Therefore, they are not considered as vapor barriers. The EPS boards are the least expensive of the premade foam panel boards.

Extruded Polystyrene Board (XPS): Is stronger than EPS and is also a foam board. This material may or may not have a facing. The R-value of 5 per inch of insulation puts it between EPS and ISO boards in its thermal resistance capability. This material slows down but does not stop water vapor from passing, therefore it is not a vapor barrier, but a vapor retardant. The XPS board also tends to be expensive (about $0.23 per R-value per square foot installed).

Other Insulation Materials: There are a variety of other insulation materials occasionally seen on the market. Cotton, sheep's wool, mineral wool and various plastics can be used as building insulation. These are not common and the homeowner would probably have trouble finding a contractor to install these materials.

Summary

Insulation is a very basic energy efficiency measure. Old homes with little or no insulation can benefit considerably from addition of insulation. Existing homes with fiberglass or loose cellulous that has settled can benefit from adding more insulation to get the thickness (and R-value) back up. Insulation, like excess air infiltration, is a basic energy efficiency/conservation measure that should be addressed first before any other, more interesting and expensive projects are attempted. The payback could be well worth the effort.

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