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Energy Efficiency: Building Insulation - Volume I

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Energy Efficiency: Building Insulation
Volume I – Theory & Materials

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Introduction

The efficiency of a building envelope, which includes anything that encloses a building such as walls, ceilings, windows, foundations, is a key to improving the energy efficiency of structures. Basically, the envelope is anything that separates the inside of a building from the outside environment. A good energy efficiency program begins with having a building envelope that efficiently minimizes heat loss.

Heating and cooling accounts for 50 to 70% of the energy used in an average home. Inadequate insulation and air leakage are leading causes of energy waste in most residential homes. The benefits of a good building envelope include:

- Saves money,
- Makes the home more comfortable by helping to maintain a uniform temperature throughout the house, and
- Makes walls, ceilings, and floors warmer in the winter and cooler in the summer.

The amount of energy efficiency improvements depend on several factors: local climate; the size, shape, and construction of the house; the living habits; the type and efficiency of the heating and cooling systems; and the fuel used.

There are many different types of insulation and this course will explain each of the major types including describing insulating values and advantages and disadvantages. The graph in Figure 1 shows the insulating values of several common insulation types.

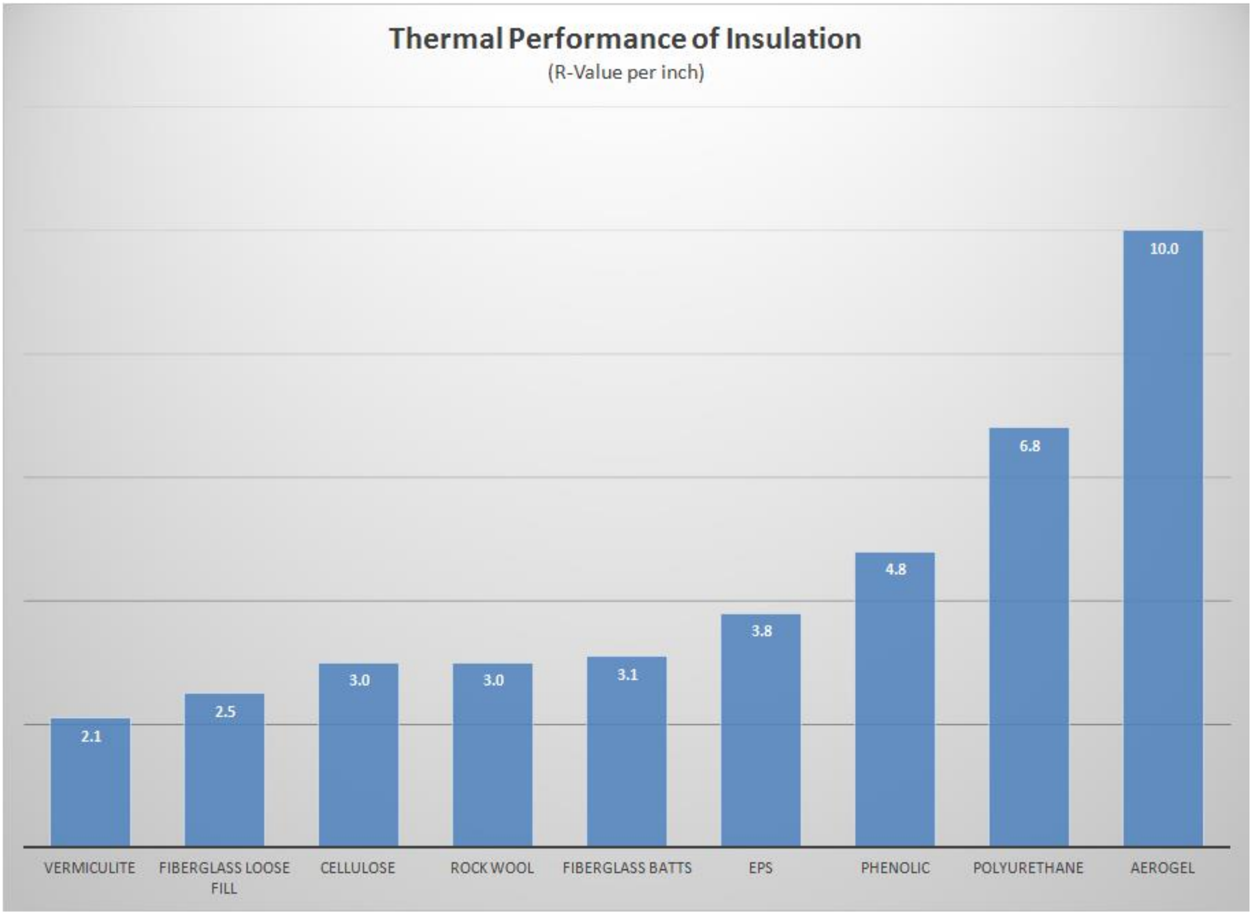

Figure 1

This is the first course in a two-part series. This course will help you to understand how insulation works, what different types of insulation are available, and some of the regulatory and environmental issues with insulation. Part Two of this series delves into the cost issues that influence insulation decisions, how to decide what type of insulation is best for a particular application, and how to control moisture and provide adequate ventilation.

Chapter 1

How Insulation Works

In this chapter we will look at the how insulation works, how it is measured, and factors that define a good building envelope.

Heat flows naturally from a warmer to a cooler space. In winter, the heat moves directly from all heated living spaces to the outdoors and to adjacent unheated attics, garages, and basements - wherever there is a difference in temperature. During the summer, heat moves from outdoors to the house interior. To maintain comfort, the heat lost in winter must be replaced by the heating system and the heat gained in summer must be removed by an air conditioner. Insulating ceilings, walls, and floors decreases the heating or cooling needed by providing an effective resistance to the flow of heat. Batts, blankets, loose fill, and low-density foams all work by limiting air movement. The still air is an effective insulator because it eliminates convection and has low conduction. Some foam, such as polyisocyanurate, polyurethane, and extruded polystyrene, are filled with special gases that provide additional resistance to heat flow.

Basics of Heat Flow

From thermodynamics we know that there are three forms of heat transfer. Heat transfer occurs by conduction, convection, and radiation. We will look at how each of these forms of heat transfer work. See Figure 2.

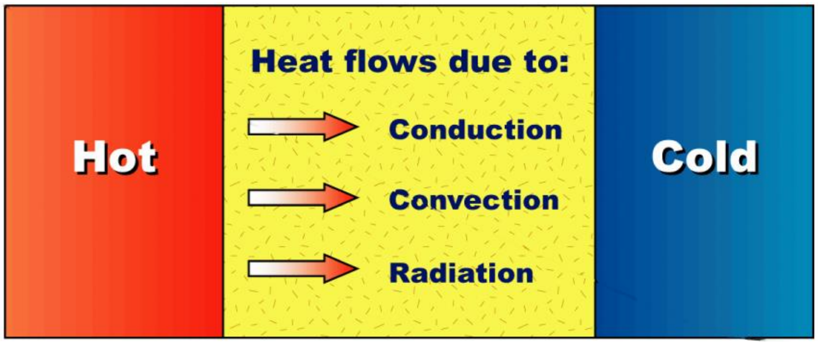

Figure 2

Conduction causes heat to flow by way of collisions between atoms and molecules, which cause a transfer in kinetic energy. Hot atoms move faster than cold atoms and when they come in contact the collisions slow down the "fast" atoms and speed up the "slow" atoms, which cause the transfer of some kinetic energy. Different materials transfer heat at different rates and the transfer capability of a material is known as its thermal conductivity. Some materials, such as steel and iron have high thermal conductivity and hence, transfer heat readily. Other materials, such as wood, and fiberglass are poor thermal conductors. Air is a poor thermal conductor so materials that have dead air space, such as fiberglass insulation and double pane windows are good insulators.

The second form of heat transfer is *convection*. Convection is the flow of heat through the movement of a large mass of matter. Convection is most often associated with the movement of air masses. As an air mass heats up the molecules in the air spread out causing the air mass to be less dense than the surrounding air. Since the air is less dense than the surrounding air it will rise in relation to the surrounding air and force the denser air downward. This is why cooler air is found closer to the floor in buildings and warmer air is found near the ceiling. This same effect is seen in the atmosphere as rising warm air creates low pressure and colder denser air descending creates high pressure. This process creates a “breeze” that attempts to equalize the pressures.

The third form of heat transfer is *radiation*. Radiation is the transfer of energy that does not require the movement of a material from one place to another. In fact, radiation can occur in a vacuum. For instance the heat from sunlight travels through space to reach the earth, which is an example of radiation heating. Of course, sunlight is visible, but not all forms of radiation heating are visible. A microwave oven is another form of radiation heating. One method to control radiation is with a radiant barrier, sometimes called *reflective insulation*. Reflective insulation works by reducing the amount of energy that travels in the form of radiation. Some forms of reflective insulation also divide a space up into small regions to reduce air movement, or convection, but not to the same extent as batts, blankets, loose-fill, and foam.

Infiltration

Heat loss through gaps in the building envelope is called *infiltration* and is a form of convection. The most common energy conservation methods to reduce infiltration are caulking, using expanding foam around window and door frames, sealing electrical outlets, and using whole-house infiltration wraps. Some insulation types, such as cellulose, claim to offer significant reductions in infiltration, and it may be slightly better than fiberglass, but insulation alone is not sufficient to achieve acceptable levels of air infiltration.

Air barriers are intended to block random air movement through building cavities. Air barriers can be made of almost anything. A continuous air barrier is an important feature in energy-efficient design not only for the energy it can save but also because the water vapor carried by the air is the primary way moisture related damage gets started in structural cavities. As the water vapor cools it condenses and so promotes structural damage, rotting wood, other mold growth. Air barriers reduce this problem by stopping much of the air movement but still allowing what water vapor that does get in to diffuse back out again.

Some common materials used for this purpose are: "house wrap," plywood, drywall (gypsum) board and foam board. Many of these materials are also used for insulation, structural purposes, and finished surfaces.

The most common air barrier material is use today is "house wrap” such as Tyvek®. Some wraps have better weathering or water repelling abilities than others. All come in a variety of sizes for different purposes and are made of fibrous spun polyolefin plastic, matted into sheets and rolled up for shipping. Sometimes, they also have other materials woven or bonded to them for tear resistance. House wraps are usually wrapped around the exterior of a house during construction. Sealing all of the joints with tape is a good practice that improves the wrap's performance by about 20%.

An air/vapor retarder attempts to combine water vapor and the air movement control with one material. This method is most appropriate for wet Southern climates where keeping humid outdoor air from entering the building cavities is critical during the cooling season.

An air/vapor retarder is generally placed around the perimeter of the building just under the exterior finish, or it may actually be the exterior finish. In many cases it's constructed of one of the following: polyethylene plastic sheets, builder's foil, foam board insulation, and other exterior sheathings. The key to making this method work effectively is to permanently and carefully seal all of the seams and penetrations, including around windows, doors, electrical outlets, plumbing stacks, and vent fans.

Insulation

Heat loss through the building structure is caused by conduction where heat moves through gypsum board, wood framing, exterior finish, window glass, and doors. Since heat flows naturally from a warmer to a cooler space, the purpose of insulation is to help slow the outflow of heat from the building structure during the winter. In the summer, insulation helps slow the inflow of heat into the building. Insulation is the most significant factor impacting the heat loss through a building envelope.

The purpose of insulation is to slow the flow of heat through a buildings walls, ceilings, and floors. Two important terms in energy efficiency are “BTU’s” and “R-Values”.

- A BTU is an abbreviation for British Thermal Units. A *BTU* is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

- The effectiveness of thermal insulation is determined using “R-Values”. A thermal insulator is any material that resists the conduction of heat energy. The official definition

> of R-Value is complex as you can see here, "*R-Value* is the reciprocal of the BTU's of energy conducted times inches of thickness per hour of time per square foot of area per degree Fahrenheit of temperature difference between the two sides of the material. The unit of R-Value is Hr * Ft^2 * F/BTU."

Insulation is rated in terms of thermal resistance, called R-value, which indicates the resistance to heat flow. The R-value of thermal insulation depends on the type of material, its thickness, and its density. In calculating the R-value of a multi-layered installation, the R-values of the individual layers are added.

The higher the R-value, the greater the insulating effectiveness.

The effectiveness of an insulated ceiling, wall or floor depends on how and where the insulation is installed.

Insulation which is compressed will not yield its full rated R-value. This can happen if denser insulation is added on top of lighter insulation in an attic. It also happens if batts rated for one thickness are placed into a thinner cavity, such as placing R-19 insulation rated for 6 1/4 inches into a 5 1/2 inch wall cavity.

Insulation placed between joists, rafters, and studs does not retard heat flow through those joists or studs. This heat flow is called *thermal bridging*. So, the overall R-value of a wall or ceiling will be somewhat different from the R-value of the insulation itself. That is why it is important that attic insulation cover the tops of the joists and that is also why it is recommended to use insulating sheathing on walls. The short-circuiting through metal framing is much greater than that through wood-framed walls; sometimes the insulated metal wall's overall R-value can be as low as half the insulation's R-value.

What is important to remember about R-Value is that it is a measure of the resistance of a material to heat flow and the higher the number the greater the insulating value. It is also important to remember that R-Values only involve one of the three methods of heat transfer – conduction.

Chapter 2

Types of Insulation

Thermal insulation is used in the construction or retrofit of buildings. The materials are used to reduce heat transfer by conduction, radiation or convection and are employed in varying combinations to achieve better thermal comfort and reduced energy consumption. Insulation is categorized by its,

1. Composition,
2. Form, and
3. Functional mode.

Composition describes the type of material used for insulation such as fiberglass, cellulose, etc. The *form* may be either non-structural or structural forms. Non-structural includes batts, blankets, loose-fill, spray foam, and panels. Structural forms include insulating concrete forms, structured panels, and straw bales. *Function* describes the purpose of the insulation such as whether it is intended to address conduction, radiation, or convection or a combination of all of these. For instance, a thermally reflective surface, such as a radiant barrier, is added to a material to reduce the transfer of heat through radiation as well as conduction.

Following is a table of commonly used materials and their associated R-values per inch of material.

Table 1

R-Values by Insulation Type

(values are "per inch unless otherwise noted)

Material	R-Value (per inch)
Fiberglass	
Fiberglass loose-fill	2.5 - 3.7
Fiberglass rigid panel	2.5
Fiberglass batts	3.1 - 4.3
Fiberglass batts, high density	3.6 - 5.0
Cellulose (Loose-Fill or Wet-Spray)	3.0 - 3.8
Mineral Wool	
Batts	3.0 - 3.8

Loose-fill	2.5 - 3.7
Natural Fiber	
Cotton batts	3.4 - 3.7
Straw bale	2.4
Softwood	1.4
Wood chips	1.0
Wood sheathing	2.5
Hardwood	0.7
Cardboard	3.0 - 4.0
Polyethylene	3.8 – 4.3
Polystyrene	
Molded expanded polystyrene (EPS) low-density	3.85
Molded expanded polystyrene (EPS) high-density	3.8 – 4.4
Extruded expanded polystyrene (XPS) low-density	3.6 - 4.7
Extruded expanded polystyrene (XPS) high-density	5.0 - 5.4
Polystyrene board	5.00
Polyisocyanurate	
Foil-faced polyisocyanurate rigid panel	5.6
Polyisocyanurate spray foam	4.3 - 8.3
Polyurethane	
Open-cell spray foam	3.6
Closed-cell spray foam	3.6
Polyurethane rigid panel	6.8
Aerogel	14.0+
Vermiculite	2.4
Perlite	2.4
Phenolic	
spray foam	4.8 – 7.0

rigid panel	4.0 - 5.0
Urea-Formaldehyde	
Panels	5.0 - 6.0
Spray foam	5.25
Urea-formaldehyde foam	4.0 - 4.6
Cementitious foam	2.0 - 3.9
Other Materials	
Concrete	3.90
Poured concrete	0.08
Air-entrained	3.9
Snow	1.0
Brick	0.8
Glass	0.14
Drywall (1/2”	0.45/panel
Plywood	1.25
Hardwood Floor	0.91
Carpet	2.08/unit
Concrete Block (12”)	1.28/Block
Wood Studs	
2x4 (1 ½” side)	1.88/unit
2x4 (3 ½” side)	4.38/unit
2x6 (5 ½” side)	6.88/unit
Air Film	0.17/unit

We will now look at the characteristics of many of the common insulating materials in use today. The diagram in Figure 3 shows the dominate insulation types. As you can see, fiberglass insulation has the largest market followed by plastic foam and then cellulose which is a distance third to fiberglass and plastic foam.

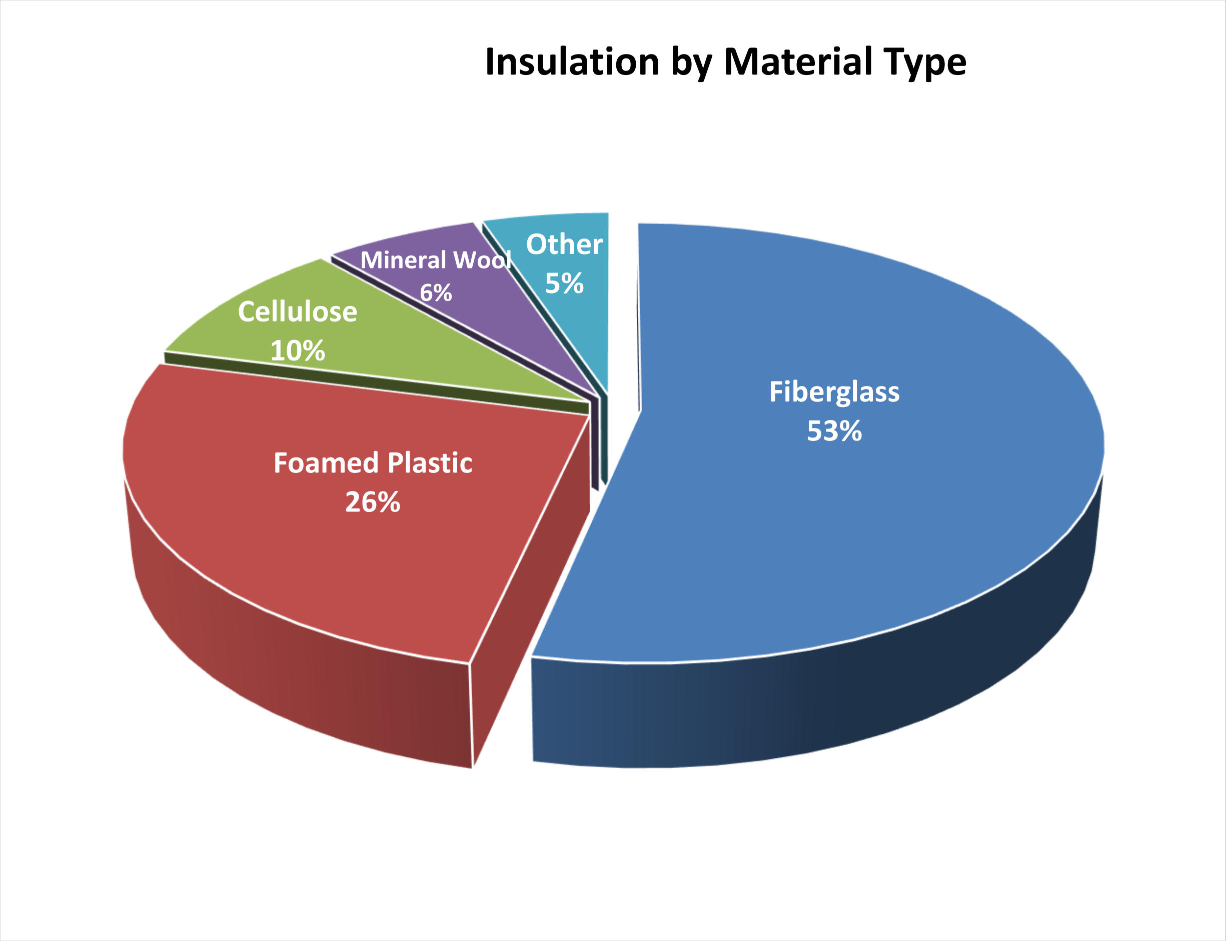

Figure 3

Fiberglass

Fiberglass insulation is made from fiberglass, arranged into a texture similar to wool and is also known as “Glass Wool”. Glass wool is produced in rolls or in slabs, with different thermal and mechanical properties. Fiberglass insulation is an effective resistor to heat flow and is made from molten glass and sand that is spun into fibers. The fiberglass has tiny air pockets that resist the flow of heat and cold making it an extremely effective form of insulation. It consists of intertwined and flexible glass fibers, which causes it to "package" air, resulting in a low density that can be varied through compression and binder content.

Fiberglass can be a loose fill material, blown into attics, or, together with an active binder sprayed on the underside of structures, sheets and panels that can be used to insulate flat surfaces such as cavity wall insulation, ceiling tiles, curtain walls as well as ducting. It is also used to insulate piping and for soundproofing.

Fiberglass insulation is manufactured by fusing a mixture of natural sand and recycled glass at 1,450C, and the resulting glass that is produced is converted into fibers. It is typically produced - similar to candy floss - by being forced through a fine mesh by centrifugal force, cooling on contact with the air. The cohesion and mechanical strength of the product is obtained by the presence of a binder that “cements” the fibers together. Ideally, a drop of bonder is placed at each fiber intersection. This fiber mat is then heated to around 200C to polymerize the resin and is calendared to give it strength and stability. The final stage involves cutting the fiberglass and packing it in rolls or panels under very high pressure before palletizing the finished product in order to facilitate transport and storage. Most manufacturers use 20%–30% recycled glass content.

Fiberglass insulation is manufactured and sold in continuous rolls (called blankets), pre-cut batts, and as loose-fill material that may be sprayed into a cavity. Batts are precut, whereas blankets are available in continuous rolls. Compressing the material reduces its effectiveness. Cutting it to accommodate electrical boxes and other obstructions allows air a free path to cross through the wall cavity. Gaps between batts can become sites of air infiltration or condensation (both of which reduce the effectiveness of the insulation) and requires strict attention during the installation.

One variation of fiberglass loose-fill insulation is the *Blown-In-Blanket* (BIB). The BIB is similar to the more common "wet-spray" cellulose in that the material is mixed with a latex adhesive, misted with water to activate the glue, and blown into wall stud cavities. Tests have shown that walls insulated with a BIB system are significantly better filled than those with other forms of fiberglass insulation, such as batts.

Cellulose insulation

Cellulose insulation is made from ground-up newspapers. Cellulose is gaining favor as an excellent building envelope insulator and may actually provide a slight advantage over tradition fiberglass insulation for air infiltration. It also seems to have superior sound absorbing characteristics.

Cellulose will settle over time, which may leave areas un-insulated. The manufacturers of blown-in cellulose note the *settled R-Value* of their material on the bag labels. Untreated cellulose will burn so it must be treated with a special fire retardant chemical before installation. The fire retardant chemical may be corrosive to some plumbing and wiring so special care is required during installation.

There are four major types of loose-fill cellulose products and they are characterized as,

1. Dry cellulose,
2. Spray applied cellulose,
3. Stabilized cellulose, and
4. Low dust cellulose.

These types are used in different parts of a building and for different reasons.

1. Dry cellulose

This material is used in retrofitting old homes by blowing the cellulose into holes drilled into the tops of the walls. It can also be blown into a new wall construction by using temporary retainers or netting that is clamped in place then removed once the cellulose has reached the appropriate density. This form of application does settle as much as 20% but the stated R-value of the cellulose is accurate after settling occurs. In addition, a dense-pack option can be used to reduce settling and further minimize air gaps. Loose fill in walls is an antiquated technique of using cellulose in wall cavities. The home performance industry and its accrediting bodies support the dense-pack standard of insulating wall cavities, which does not settle. This method stops the stack effect and convective loops in wall cavities.

2. Spray-applied cellulose

Spray-applied cellulose is used for applying cellulose to new wall construction. The differences are the addition of water to the cellulose while spraying as well as adding some kind of moisture retardant such as chlorine to prevent mold cultures. In some cases the insulation might also mix in a very small percentage of adhesive or activate a dry adhesive present in the cellulose. Wet-spray allows application without the need for a temporary retainer. In addition, wet-spray allows for an even better seal of the insulated cavity against air infiltration and eliminates settling problems. Wet-spray installation requires that the wall be allowed to dry for a minimum of 24 hours (or until maximum of 25% moisture is reached) before being covered.

3. Stabilized cellulose

Stabilized cellulose is used most often in attic/roof insulation. It is applied with a very small amount of water to activate an adhesive. This reduces settling and decreases the amount of cellulose needed. This can prove advantageous at reducing the overall weight of the product on the ceiling drywall helping prevent possible sag. This application is ideal for sloped roofs and has been approved for 5:12 slopes.

4. Low Dust Cellulose

Low-dust cellulose is another type of cellulose insulation on the market. Nuisance levels of dust are created during application of most types of dry insulation causing the need for simple dust masks to be worn during installation. This kind of cellulose has a small percentage of oil or similar dust dampener added. This may also be appropriate to homes where people are sensitive to newsprint or paper dust.

Advantages of cellulose insulation

The thermal performance of loose filled cellulose compares favorably to other types of insulation. The thermal conductivity of loose-fill cellulose is approximately R3.0 - R3.8 per inch which is about the same as or slightly better than fiberglass.

Cellulose is very good at fitting around items in walls like pipes and wiring, leaving few air pockets that can reduce the overall efficiency of the wall. Dense pack cellulose can seal walls from air infiltration while providing the density to limit convection, when installed properly. The University of Colorado School of Architecture and Planning did a study that compared two seemingly identical test structures, one with cellulose and the other with fiberglass. The cellulose structure used 26.4% less energy to heat. It also was shown to tighten the structure more than 30%. Subsequent real world surveys have cellulose performing 20-30% better at reducing energy used for heating than fiberglass.

Cellulose aids in noise reduction. Noise reduction is achieved in three ways with cellulose. The first is that cellulose completely fills cavities leaving few air pockets for sound to travel in. The second is the cellulose material's ability to trap air. The significant difference between noise reduction with cellulose and fiberglass is its density. Cellulose is approximately three times denser then fiberglass. This helps deaden the sound through walls and between floor levels.

Several installation options allow walls to have a Sound Transmission Class (STC) of 50 or greater. As a comparison, walls with fiberglass batts have an STC of less than 40, depending on the type of wall construction used.

The borates in cellulose insulation provide superior control against mold. Installations have shown that even several months of water-saturation and improper installation did not result in mold. The borate treatment also gives cellulose the highest (Class I) fire safety rating. Many cellulose companies use a blend of ammonium sulfate and borate. Although ammonium sulfate is normally odorless, unexplained emission of ammonia and a resulting ammonia smell has been found in some cases.

A vapor barrier may not be needed with cellulose insulation. For example, recent studies have shown that air movement is the primary method by which excessive moisture can accumulate in mild marine climate. An insulation that fills the wall cavity completely (such as cellulose or foam) can help prevent moisture problems.

Recommendations against using vapor barriers with cellulose insulation are supported by studies, even though they classify cellulose as vapor permeable. In addition, cellulose acts to distribute moisture throughout the cavity, preventing the buildup of moisture in one area and helping to dry the moisture more quickly. Cellulose manufacturers do not recommend the installation of a vapor barrier with cellulose.

Disadvantages of Cellulose

Cellulose has a few disadvantages. Cellulose is prone to create too much dust that is blown into the house through inadequate seals around fixtures or minute holes. This is mostly found in rooms that are used frequently and can be a health issue.

In some areas it can be difficult to locate installers that are experienced with cellulose. An experienced installer understands how to correctly dense-pack loose fill dry cellulose, how to best apply stabilized (partly wet) cellulose on sloped surfaces, and the proper time required for wet-spray cellulose to dry.

Wet-spray provides the advantage of a better sealing of the insulated cavity and superior rigidity. However, the moisture from wet-spray insulation requires a longer drying time before the drywall/sheet-rock is applied to a newly insulated wall. This drying time is usually reduced by the use of large space heaters that are run for a few days to weeks, depending on ambient humidity.

For a given R-value, loose cellulose weighs roughly three times as much per square foot as loose fiberglass. Ceiling structures should be inspected for signs of weakness before choosing a material for insulating the ceilings of existing structures.

Cellulose is composed of 75-85% recycled paper fiber, usually post-consumer waste newsprint. The other 15% is a fire retardant such as boric acid or ammonium sulphate. Cellulose has the highest recycled content of any insulation available. For example, fiberglass has a maximum amount of 30% recycled content.

Mineral Wool

The term *mineral wool* typically refers to two types of insulation material:

- *Rock wool* - a man-made material consisting of natural minerals like basalt or diabase.
- *Slag wool* - a man-made material from blast furnace slag (the scum that forms on the surface of molten metal).

Mineral wool contains an average of 75% post-industrial recycled content. It doesn't require additional chemicals to make it fire resistant, and it can be used in either blanket (batts and rolls) or loose-fill.

Made from rock (basalt, diabase), iron ore blast furnace slag, or recycled glass. It is nonflammable and is more resistant to airflow than fiberglass. Clumps and loses effectiveness when moist or wet, but does not absorb much moisture, and regains effectiveness once dried. Older mineral wool can contain asbestos, but normally this is in trace amounts.

Natural Fiber

Some natural fibers - including cotton, sheep's wool, straw, hemp, and wood - are used as insulation materials. Natural fiber insulations can be used loose as granules or formed into flexible or semi-rigid panels and rigid panels using a binder (mostly synthetic such as polyester, polyurethane or polyolefin).

Examples of natural fiber insulation include cork, cotton, recycled tissue/clothes, hemp, flax, coco, wool, lightweight wood fiber, cellulose, seaweed, etc. Similarly, many plant-based waste materials can be used as insulation such as nut shells, the cob of corns, most straws including lavender straw, recycled wine bottle corks, etc. They may have a little less thermal performance than industrial products which can regained with a little more thickness. They may or may not require fire retardants or anti-insect/pest treatments. Clay coating is a non toxic additive which often meets these requirements. Traditional clay-impregnated light straw insulation has been used for centuries in the northern climates of Europe.

Cotton insulation consists of 85% recycled cotton and 15% plastic fibers that have been treated with borate—the same flame retardant and insect/rodent repellent as cellulose insulation. One product uses recycled blue jean manufacturing trim waste. Cotton insulation is available in batts with a thermal resistance of R3.4 – R3.7 per inch.

Cotton insulation is increasing in popularity as an environmentally preferable option for insulation. It has a higher R-value than most fiberglass batts. The cotton is primarily recycled industrial scrap, providing a sustainability benefit. The batts do not use the toxic formaldehyde backing found in fiberglass, and the manufacture is nowhere near as energy intensive as the mining and production process required for fiberglass. Boric acid is used as a flame retardant. A small quantity of polyolefin is melted as an adhesive to bind the product together. Installation is similar to fiberglass, without the need for a respirator but requiring some additional time to cut the material. Even with proper installation, batts do not completely seal the cavity against air movement (as with cellulose or expanding foam). Cotton insulation will require a vapor retarder or barrier. It is also difficult to dry if a leak allows excessive moisture into the insulated cavity. Cotton insulation costs about 15 – 20% more than fiberglass insulation.

For use as insulation, sheep's wool is also treated with borate to resist pests, fire, and mold. It can hold large quantities of water, which is an advantage for use in some walls, but repeated wetting and drying can leach out the borate. The thermal resistance or R-value of sheep's wool batts is about R-3.5 per inch, which is similar to other fibrous insulation types.

Straw bale construction – popular over 150 years ago on the Great Plains of the United States - has received renewed interest. Straw yield R-values of R-2.4 to R-3.0 per inch. The R-2.4 per inch value is more representative of typical straw bale construction due to the many gaps between the stacked bales. Straw may also be made into insulating panels.

The process of fusing straw into boards without adhesives was developed in the 1930s. Panels are usually between two and four inches thick and faced with heavyweight Kraft paper on each side. Although manufacturer’s claims vary, R-values realistically range from a low of 1.4 to perhaps 3.0 per inch. The boards also make effective sound-absorbing panels for interior partitions. Some manufacturers have developed structural insulated panels from multiple-layered, compressed-straw panels.

Hemp insulation is relatively unknown and not commonly used in the United States. It offers a similar R-value (about R-3.5 per inch of thickness) as other fibrous insulation types.

Wood fiber insulation is available as loose fill, flexible batts and rigid panels for all thermal and sound insulation uses. It can be used as internal insulation such as between studs, joists or ceiling rafters, under timber floors to reduce sound transmittance, against masonry walls or externally, using a rain screen cladding or roofing, or directly plastered/rendered, over timber rafters or studs or masonry structures as external insulation to reduce thermal bridges.

Manufacturing is a wet process similar to pulp mills in which the fibers are softened and under heat and pressure the lignin in the fibers is used to create boards. The boards are limited to approximately 1-inch thickness. Additives such as latex or bitumen are added to increase water resistance.

Polystyrene

Polystyrene is one form of *Plastic foam insulation* which includes a wide variety of chemical foam insulators. Plastic foam includes extruded polystyrene, expanded polystyrene, polyurethane, and polyisocyanurate. Polystyrene foam is commonly used for "blue board" and "pink board" that covers the outer shell of a typical residential structure. Foam boards—rigid panels of insulation—can be used to insulate almost any part of a home, from the roof down to the foundation. They provide good thermal resistance and often add structural strength to a home. Foam board insulation sheathing reduces heat conduction through structural elements, like wood and steel studs.

Polystyrene is a colorless, transparent thermoplastic and is commonly used to make foam board or beadboard insulation, concrete block insulation, and a type of loose-fill insulation, which consists of small beads of polystyrene. The most common types of polystyrene insulation are molded expanded polystyrene (MEPS) and extruded expanded polystyrene (XPS).

Molded expanded polystyrene (MEPS) is a closed-cell material that can be molded into many everyday items, such as coffee cups and shipping materials, or into large sheets of foam board insulation. MEPS foam board insulation is commonly known as *beadboard.*

To make beadboard, loose, unexpanded polystyrene beads containing liquid pentane are mixed with a blowing agent and poured into an enclosed container. The mixture is heated to expand the beads many times their original size. The beads are then injected into a mold. Under more heat and pressure, they expand to become foam blocks, which are shaped as needed.

The physical properties of MEPS foam board vary with the type of bead used. It's manufactured at various densities, depending on the application. Beadboard for roofing materials has to be dense enough to walk on without damage; wall insulation foam boards are several times less dense than roof boards. R-values range from 3.8 to 4.4 per inch of thickness.

MEPS foam board is available with a variety of facings. Since spaces between the foam beads can absorb water, a vapor diffusion retarder is necessary if water transmission through the insulation might become a problem. MEPS foam board also is often used as the insulation for structural insulated panels (SIPs) and insulating concrete forms (ICFs).

Extruded expanded polystyrene (XEPS) is closed-cell foam insulation similar to MEPS. To make it, the polystyrene pellets are mixed with various chemicals to liquefy them. A blowing agent is then injected into the mixture, forming gas bubbles. The foaming, thick liquid is then forced through a shaping die. When cooled, the panel is cut as required. Foam densities are typically 1.5 pounds per cubic foot.

XEPS is more expensive than MEPS. Like MEPS, the R-value depends upon the density of the material and is generally about R-5 per inch. It's also much more consistent in density and has a higher compressive strength than MEPS, making it better suited for use on roofs or for wall panels. Extruded polystyrene also has excellent resistance to moisture absorption. Like MEPS, XEPS is available with a variety of facings and is also often used as the insulation for SIPs and ICFs.

Polyisocyanurate

Polyisocyanurate or polyiso is a thermosetting type of plastic, closed-cell foam that contains a low-conductivity gas (usually hydro chlorofluorocarbons or HCFC) in its cells. The high thermal resistance of the gas gives polyisocyanurate insulation materials an R-value typically from R-5.6 to R-8 per inch.

Polyisocyanurate insulation is available as a liquid, sprayed foam, and rigid foam board. It can also be made into laminated insulation panels with a variety of facings. Foamed-in-place applications of polyisocyanurate insulation are usually cheaper than installing foam boards. They also usually perform better since the liquid foam molds itself to all of the surfaces.

Over time, the R-value of polyisocyanurate insulation can drop as some of the low-conductivity gas escapes and air replaces it. This phenomenon is known as *thermal drift*. Experimental data indicates that most thermal drift occurs within the first two years after the insulation material is manufactured. The R-value then slowly decreases. For example, if the insulation has an initial R-value of R-9 per inch, it will probably eventually drop to R-7 per inch. The R-value then remains unchanged unless the foam is damaged.

Foil and plastic facings on rigid, polyisocyanurate foam panels can help stabilize the R-value. Testing suggests that the stabilized R-value of rigid foam with metal foil facings remains unchanged after 10 years. Reflective foil, if installed correctly, can also act as a radiant barrier, which adds another R-2 to the overall thermal resistance. Panels with foil facings have stabilized R-values of R-7.1 to R-8.7 per inch.

Polyurethane

Polyurethane is a closed-cell foam insulation material that contains a low-conductivity gas (usually hydro chlorofluorocarbons or HCFC) in its cells.

Polyurethane is chemical foam that must be sprayed into place and offers R-values of between R3.4 and R6.8 per inch. It is more expensive than other forms of insulation and is considered specialty insulation for hard to reach crevices in buildings such as around window and door frames.

Just like polyiso, the R-value of polyurethane insulation can drop as some of the low-conductivity gas escapes and air replaces it. The R-value then slowly decreases. For example, if the insulation has an initial R-value of R-9 per inch, it will probably eventually drop to R-7 per inch. The R-value then remains unchanged unless the foam is damaged.

Polyurethane insulation is available as a liquid sprayed foam and rigid foam board. It can also be made into laminated insulation panels with a variety of facings.

Sprayed-Foamed applications of polyurethane insulation are usually cheaper than installing foam boards. These applications also usually perform better since the liquid foam molds itself to all of the surfaces.

All closed-cell polyurethane foam insulation made today is produced with a non-CFC (chlorofluorocarbon) gas as the foaming agent. Some polyurethane foam combines with a HCFC gas. These types don't insulate as well as insulation made with a CFC gas. However, these foams still have an aged R-6.5 per inch thickness. Their density is generally 2.0 lb/ft^3.

There also are low-density open-cell polyurethane foams (0.5 lb/ft^3). These foams are similar to conventional polyurethane foams, but are more flexible. Some low-density varieties use carbon dioxide (CO_2) as the foaming agent.

Low-density foams are sprayed into open wall cavities and rapidly expand to seal and fill the cavity. One manufacturer offers slow-expanding foam, which is intended for cavities in existing homes. The liquid foam expands very slowly and thus reduces the chance of damaging the wall from overexpansion. The foam is water-vapor permeable, remains flexible, and is resistant to wicking of moisture. It provides good air sealing and yields about R-3.6 per inch of thickness. It is also fire resistant and won't sustain a flame.

Advantages of Polyurethane

- Blocks airflow by expanding and sealing off leaks, gaps and penetrations.

- Can serve as a semi-permeable vapor barrier with a better permeability rating than plastic sheeting vapor barriers and consequently reduce the buildup of moisture, which can cause mold growth.
- Can fill wall cavities in finished walls without tearing the walls apart (as required with batts).
- Works well in tight spaces.
- Provides acoustical insulation.
- Expands while curing, filling bypasses, and providing excellent resistance to air infiltration.
- Increases structural stability.
- Can be used in places where loose-fill cannot, such as between joists and rafters. When used between rafters, the spray foam can cover up the nails protruding from the underside of the sheathing, protecting your head.
- Can be applied in small quantities.
- Cementitious foam is fireproof.

Disadvantages of Polyurethane

- The cost can be high compared to traditional insulation.
- Most of all, with the exception of cementitious foams, release toxic fumes when they burn.
- Most foam products require protection with a thermal barrier such as drywall on the interior of a house. For example a 15-minute fire rating may be required.
- Can shrink slightly while curing if not applied on a substrate heated to manufacturer's recommended temperature.
- Most, such as Polyurethane and Isocyanate insulation, contain hazardous chemicals such as benzene and toluene. These are a potential hazard and environmental concern during raw material production, transport, manufacture, and installation.
- R-value will diminish slightly with age, though the degradation of R-value stops once equilibrium with the environment is reached. Even after this process, the stabilized R-value is very high.
- Most types of foams require protection from sunlight and solvents.
- It is difficult to retrofit some types of foams to an existing building structure because of the chemicals and processes involved.

Polyethylene

Plastic fiber insulation material is primarily made from recycled plastic milk bottles using *polyethylene terephthalate* (PET). The fibers are then formed into batt insulation similar to high-density fiberglass. The insulation is treated with a fire retardant so it doesn't readily burn; however, it does melt when exposed to flame.

The R-values of plastic fiber insulation vary with batt density: R-3.8 per inch at 1.0 lb/ft^3 density to R-4.3 per inch at 3.0 lb/ft^3 density.

Plastic fiber insulation is relatively non-irritating to work with, but the batts reportedly can be difficult to handle and cut with standard tools.

Vermiculite and Perlite

Vermiculite and *Perlite* consist of very small, lightweight pellets, which are made by heating rock pellets until they pop. This creates a type of loose-fill insulation with a thermal resistance of up to R-2.4 per inch. These pellets can be poured into place, used to fill concrete block cores, or mixed with cement to create a lightweight, less heat-conductive concrete.

Vermiculite and perlite insulation materials were commonly used as attic insulation in homes built before 1950. Vermiculite insulation materials aren't widely used anymore because they sometimes contain asbestos. However asbestos is not intrinsic to vermiculite and only a few sources of vermiculite have been found to contain more than tiny trace amounts.

Aerogels

Aerogel is a synthetic porous, very light, material derived from a gel, in which the liquid component of the gel has been replaced with a gas. The result is a solid with extremely low density and low thermal conductivity. Aerogels are produced by extracting the liquid component of a gel through supercritical drying. This allows the liquid to be slowly dried off without causing the solid matrix in the gel to collapse from capillary action, as would happen with conventional evaporation.

Despite their name, aerogels are solid, rigid, and dry materials that do not resemble a gel in their physical properties: The name comes from the fact that they are made from gels. Aerogels are good thermal insulators because they almost nullify two of the three methods of heat transfer (convection, conduction, and radiation). They are good conduction insulators because they are composed almost entirely from a gas, and gases are very poor heat conductors. Silica aerogel is especially good because silica is also a poor conductor of heat. They are good convection inhibitors because air cannot circulate through the lattice. Aerogels are poor radiation insulators because infrared radiation passes right through the aerogel.

Silica aerogel is the most common type of aerogel, and the most extensively studied and used. It is silica-based, derived from silica gel. It has remarkable thermal insulating properties, having an extremely low thermal conductivity: R-values of 14 to 105 in a 3.5 inch thickness.

Skylights, solariums and other special applications may use aerogels, a high-performance, low-density material. Silica aerogel has the lowest thermal conductivity of any known substance (short of a vacuum), and carbon aerogel absorbs infrared radiation while still allowing daylight to enter. The combination of silica and carbon aerogel gives the best insulating properties of any known material, approximately twice the insulating protection of the next best insulating material, closed-cell foam.

Urea-Formaldehyde Foam Insulation Material

Urea-formaldehyde (UF) foam was used in homes during the 1970s and early 1980s. However, after many health-related court cases due to improper installations, UF foam is no longer available for residential use and has been discredited for its formaldehyde emissions and shrinkage. It is now used primarily for masonry walls in commercial and industrial buildings.

UF foam insulation has an R-value of about 5.0 per inch, and uses compressed air as the foaming agent. Nitrogen-based UF foam may take several weeks to cure completely. Unlike polyurethane insulation, UF foam doesn't expand as it cures. Water vapor can easily pass through it, and it breaks down at prolonged temperatures above 88C. UF foam contains no fire retardant.

Cementitious Foam

Cementitious Foam insulation material is a cement-based foam used as sprayed-foam or foamed-in-placed insulation. One type of cementitious spray foam insulation known as air krete® contains magnesium silicate and has an R-value of about 3.9 per inch. With an initial consistency similar to shaving cream, Air Krete® is pumped into closed cavities. Cementitious foam costs about as much as polyurethane foam, is nontoxic and nonflammable, and is made from minerals extracted from seawater.

Phenolic Foam

Phenolic (phenol-formaldehyde) foam was somewhat popular years ago as rigid foam board insulation. It is currently available only as a foamed-in-place insulation.

Phenolic foamed-in-place insulation has an R-4.8 value per inch of thickness and uses air as the foaming agent. One major disadvantage of phenolic foam is that it can shrink up to 2% after curing.

Radiant barriers

An unusual insulation is *reflective insulation*, which is a reflective material such as aluminum foil or a plastic film that reflects the heat waves away from the structure (for cooling) or reflects the heat back into the structure (for heating). Unlike the other forms of insulation mentioned, reflective insulation does not work to restrict conductive heat flow, but instead reflects radiant heat flow that is emitted from a warm source. Generally the material is installed to either reflect heat away or to reflect heat back into the structure, but not both. One use of reflective insulation is to add a layer of aluminum foil finish onto polystyrene board to cover building shells. Another specialized use of reflective insulation is on satellites and spacecraft where the material is used to reflect heat away from the craft. Some manufacturers claim R-values of up to R-8 for reflective insulation, but in most residential and commercial building applications, reflective insulation only provides a marginal contribution to the structure's total R-value.

Reflective insulation and radiant barriers reduce the radiation of heat to or from the surface of a material. Radiant barriers will reflect radiant energy. A radiant barrier by itself will not affect heat conducted through the material by direct contact or heat transferred by moist air rising or convection. For this reason, trying to associate R-values with radiant barriers is difficult and inappropriate. The R-value test measures heat transfer through the material, not to or from its surface. There is no standard test designed to measure the reflection of radiated heat energy alone. Radiated heat is a significant means of heat transfer; the sun's heat arrives by radiating through space and not by conduction or convection. At night the absence of heat (i.e. cold) is the exact same phenomenon, with the heat radiating described mathematically as the linear opposite. Radiant barriers prevent radiant heat transfer equally in both directions. However, heat flow to and from surfaces also occurs via convection, which in some geometries is different in different directions.

Reflective aluminum foil is the most common material used as a radiant barrier. It has no significant mass to absorb and retain heat. It also has very low emittance values "E-values" (typically 0.03 compared to 0.90 for most bulk insulation) which significantly reduces heat transfer by radiation. Reflective insulation is commonly made of either aluminum foil attached to some sort of backing material or two layers of foil with foam or plastic bubbles in between creating an air space to reduce convective heat transfer also. The aluminum foil component in reflective insulation will reduce radiant heat transfer by up to 97%. As reflective insulation incorporates airspace to reduce convective heat flow, it carries a measurable R-Value.

There are several types of radiant barriers including,

1. Foil-faced polystyrene,
2. Foil-backed bubble pack, and

3. Light colored roof shingles.

1. Foil-faced polystyrene.

This laminated high density EPS is more flexible than rigid panels, works as a vapor barrier, and works as a thermal break. Uses include the underside of roof sheathing, ceilings, and on walls. For best results, this should not be used as cavity fill type insulation.

2. Foil-backed bubble pack.

This material is thin, more flexible than rigid panels, works as a vapor barrier, and resembles plastic bubble wrap with aluminum foil on both sides. Often used on cold pipes, cold ducts, and the underside of roof sheathing.

3. Light-colored roof shingles and reflective paint.

Light-colored roof shingles and reflective paint products are often called *cool roofs* and these help to keep attics cooler in the summer and in hot climates. To maximize radiative cooling at night, they are often chosen to have high thermal emissivity, whereas their low emissivity for the solar spectrum reflects heat during the day.

Radiant barriers can function as vapor barriers and serve both purposes with one product. Materials with one shiny side (such as foil-faced polystyrene) must be positioned with the shiny side facing an air space to be effective. An aluminum foil radiant barrier can be placed either way - the shiny side is created by the rolling mill during the manufacturing process and does not affect the reflectivity of the foil material. As radiant barriers work by reflecting infra-red energy, the aluminum foil would work just the same if both sides were dull.

Advantages of Radiant Barriers

- Very effective in warmer climates
- No change thermal performance over time due to compaction, disintegration or moisture absorption
- Thin sheets takes up less room than bulk insulation
- Can act as a vapor barriers
- Non-toxic/non-carcinogenic
- Will not mold or mildew
- Radon retarder, will limit radon penetration through the floor

Disadvantages of Radiant Barriers

- Must be combined with other types of insulation in very cold climates
- May result in an electrical safety hazard where the foil comes into contact with faulty electrical wiring.

Chapter Three
Moisture Migration

Water vapor moves in and out of a building basically in three ways: with air currents, by diffusion through materials, and by heat transfer. Of these three, air movement is the dominant force because, like most fluids, air naturally moves from a high pressure area to a lower one by the easiest path possible. This is generally through any available hole in the building envelope.

Moisture transfer by air currents is very fast and accounts for the vast majority of all water vapor movement in building cavities. Thus it is very important that potential paths that moisture may follow be carefully and permanently sealed. The other two driving forces are much slower processes and most common building materials slow moisture diffusion to a large degree, although never stop it completely.

Older buildings did not need to restrict the flow of airborne moisture, since when the building cavities got wet they also dried quickly due to the "leaky" construction methods that allowed air to move freely through the building envelope. The water vapor movement really did not matter much until the introduction of thermal insulation. When insulation is added, the temperature of the water vapor can drop very quickly since it is being isolated from the heat of the building (in the winter) or from the outdoors in the summer if the building is being air-conditioned.

Some of the less obvious locations where airborne water vapor can move in and out of the thermal envelope include holes around plumbing pipes, ductwork, wiring, and electrical outlets. During the winter in Northern climates, any warm air entering the walls from the house cools and condenses it is water vapor inside building cavities. In the South, humid air does much the same, except it comes from the outdoors and condenses inside the wall cavities during the cooling season.

The laws of physics govern how moist air reacts within various temperature conditions. A psychrometric chart is used to determine at what temperature and moisture concentration water vapor begins to condense. This is called the *dew point*. By understanding how to find the dew point, you will better understand how to avoid moisture problems in buildings.

Figure 4 shows a sample of a psychrometric chart.

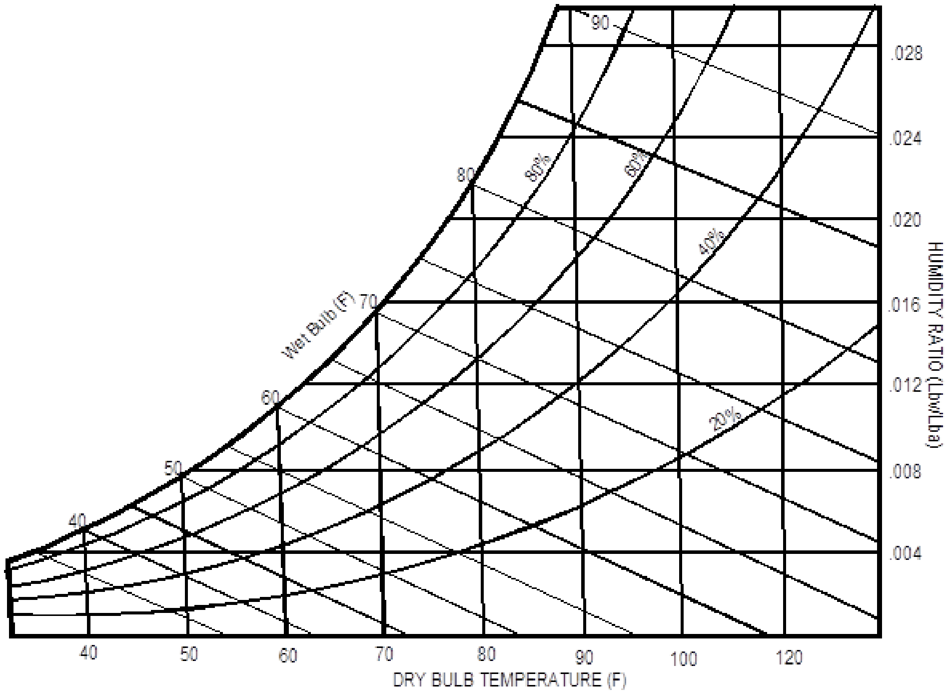

Figure 4

The psychrometric chart has the air temperature on the “x-axis”, which is also called the Dry *Bulb Temperature*. The y-axis is the humidity ratio, which is the ratio of the pounds of moisture (Lbv) to the pounds of air (Lba). The curved lines of the chart are lines of constant relative humidity. *Relative humidity* (RH) refers to the amount of moisture contained in a quantity of air compared to the maximum amount of moisture the air could hold at the same temperature. As air warms, its ability to hold water vapor increases. As air cools this capacity decreases.

Consider the following example where the temperature is 80F at a relative humidity of 100%. Moving up the 80F line to the 100% Relative Humidity line and then moving horizontally we find the humidity ratio is 0.022 lbs water/lbs air. Now, if the temperature decreases to 70F at 100% relative humidity, we find that the humidity ratio is 0.016 Lbv/Lba. At 70F the air can only hold 72% of the moisture of the air at 80F. The moisture that the air can no longer hold condenses on the first cold surface it encounters (the dew point.) If this surface is within an exterior wall cavity wet insulation and framing will be the result.

As you can see in this example, we can control two things;

1. Temperature, and
2. Moisture content.

The R-value of the wall cavity insulation moderates the effect of temperature across the building envelope cavity. An airtight, vapor diffusion retarder, properly installed towards the warm side of this cavity, reduces the amount of moisture entering it. Except in deliberately ventilated spaces, such as attics, these two factors work together to reduce the opportunity for condensation in a house's ceilings, walls, and floors.

Perm Ratings

The ability of a material to retard the diffusion of water vapor is measured by units known as *perms* or permeability. A perm is defined as,

> “A measure of the number of grains of water vapor passing through a square foot of material per hour at a differential vapor pressure equal to one inch of mercury (1" W.C.) at 23C.”

Any material with a Perm rating of less than 1.0 is considered a vapor retarder and VDR ratings of 0.1 or less are common. To prevent trapping moisture in a cavity the cold-side material's Perm rating should be at least five times greater than the value of the warm-side.

Types of Vapor Diffusion Retarders

Vapor diffusion retarders (VDRs) are typically available as membranes or coatings. Membranes are thin, flexible materials, but also include thicker sheet materials sometimes termed "structural" vapor diffusion retarders. Materials such as rigid insulation, reinforced plastics, aluminum, and stainless steel are relatively resistant to water vapor diffusion. These types of vapor diffusion retarders are usually mechanically fastened and the sealed at the joints.

Thinner membrane types of VDRs come in rolls or as integral parts of building materials such as aluminum- or paper-faced fiberglass roll insulation. Foil-backed wallboard is another type commonly used. A plastic sheet material, such as polyethylene, can be used as a VDR for above grade walls and ceilings in very cold climates.

Most paints will retard vapor diffusion. While it was once believed that only special coatings with low perm ratings constituted an effective VDR, it is now believed that any paint or coating is effective at restricting most water vapor diffusion in milder climates.

Chapter 4
Regulatory and Environmental Issues

This chapter covers the regulatory and environmental rules governing insulation.

R-Value

The Federal Trade Commission (FTC) governs claims about R-values to protect consumers against deceptive and misleading advertising claims. "The Commission issued the R-Value Rule to prohibit, on an industry-wide basis, specific unfair or deceptive acts or practices."

The primary purpose of the rule is to ensure the home insulation marketplace provides this essential pre-purchase information to the consumer. The information gives consumers an opportunity to compare relative insulating efficiencies, to select the product with the greatest efficiency and potential for energy savings, to make a cost-effective purchase and to consider the main variables limiting insulation effectiveness and realization of claimed energy savings.

The rule mandates that specific R-value information for home insulation products be disclosed in certain ads and at the point of sale. The purpose of the R-value disclosure requirement for advertising is to prevent consumers from being misled by certain claims which have a bearing on insulating value. At the point of transaction, some consumers will be able to get the requisite R-value information from the label on the insulation package. However, since the evidence shows that packages are often unavailable for inspection prior to purchase, no labeled information would be available to consumers in many instances. As a result, the Rule requires that a fact sheet be available to consumers for inspection before they make their purchase.

16 CFR Part 460 - (Federal Trade Commission regulation) commonly known as the "R-Value Rule," intended to eliminate misleading insulation marketing claims and ensure publication of accurate R-Value and coverage data. The R-value Rule specifies:

> “In labels, fact sheets, ads, or other promotional materials, do not give the R-value for one inch or the "R-value per inch" of a product. There are two exceptions:
> a. The manufacturer can do this if they suggest using a product at a one-inch thickness.
> b. The manufacturer can do this if actual test results prove that the R-values per inch of a product does not drop as it gets thicker.”

The manufacturer can also list a range of R-value per inch. However, they must say exactly how much the R-value drops with greater thickness and they must also add this statement: "The R-value per inch of this insulation varies with thickness. The thicker the insulation, the lower the R-value per inch."

Fiberglass

A 2002 summary by International Agency for Research on Cancer (IAARC) classifies fiberglass insulation into Category 3 carcinogen, "not classifiable as to its carcinogenicity to humans". The summary found inadequate evidence of glass wool causing cancer in humans and limited evidence of it causing cancer in experimental animals. Two unspecified large studies reviewed in the summary showed increased mortality from respiratory cancer in workers exposed to fiberglass production. The longevity of exposure did not affect mortality. Smoking habits were not factored out. Non-occupational indoor settings were found to contain much lower fibers per volume unit.

All fiber glass wools that are commonly used for thermal and acoustical insulation are included in this classification. IARC noted specifically: "Epidemiologic studies published during the 15 years since the previous IARC Monographs review of these fibers in 1988 provide no evidence of increased risks of lung cancer or mesothelioma (cancer of the lining of the body cavities) from occupational exposures during manufacture of these materials, and inadequate evidence overall of any cancer risk."

The IARC downgrade is consistent with the conclusion reached by the U.S. National Academy of Sciences, which in 2000 found "no significant association between fiber exposure and lung cancer or nonmalignant respiratory disease in the man-made vitreous fiber manufacturing environment." However, manufacturers continue to provide cancer risk warning labels on their products, apparently as indemnification against claims.

Others believe there are health and safety issues with fiberglass including potential cancer risk from exposure to glass fibers, formaldehyde off-gassing from the backing/resin, use of petrochemicals in the resin, and the environmental health aspects of the production process. Green building practices shun Fiberglass insulation.

Studies have shown that short time exposure to fiberglass may cause minor irritation of skin, eyes, nose and throat. However, fiberglass exposure is generally considered to not present a significant health risk to the general population.

Cellulose

The sole hazard of cellulose according to the categorization by the OSHA is that it is a dust nuisance, requiring a simple dust mask during installation. This compares very favorably to the potential NIOSH cancer risk of fiberglass.

Studies have shown results that suggest that cellulose may actually protect a building from damage in a fire better than fiberglass because cellulose is denser than fiberglass and doesn't allow the oxygen necessary to burn structural members. Several National Research Council Canada studies have backed these claims.

There are several regulations covering cellulose insulation including,

- 16 CFR Part 1209 (Consumer Products Safety Commission, or CPSC) - covers settled density, corrosiveness, critical radiant flux, and smoldering combustion.
- ASTM Standard C-739 - loose-fill cellulose insulation - covers all factors of the CPSC regulation and five additional characteristics, R-value, starch content, moisture absorption, odor, and resistance to fungus growth.
- ASTM Standard C-1149 - Industry standard for self-supported spray-applied cellulose insulation for exposed or wall cavity application - covers density, R-value, surface burning, adhesive strength, smoldering combustion, fungi resistance, corrosion, moisture vapor absorption, odor, flame resistance permanency (no test exists for this characteristic), substrate deflection (for exposed application products), and air erosion (for exposed application products).

Spray polyurethane foam (SPF)

All polyurethane foams are composed of petrochemicals. Foam insulation often uses hazardous chemicals with high human toxicity, such as isocyanates, benzene and toluene. The foaming agents no longer use ozone-depleting substances. Personal Protective Equipment is required for all people in the area being sprayed to eliminate exposure to isocyanates which constitute about 50% of the foam raw material.

Summary

Building an appropriate thermal envelope in a home will reduce energy costs and improve the homeowner’s comfort. In this course, we have looked at the physics behind heat transfer and how insulation works. We have also reviewed the various insulation products that are in commercial use today. The next step is to know how to effectively and economically apply insulation and volume II in this series will explain the cost/benefits of home insulation and how to appropriately apply insulation to the home.

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