
PERFORMANCE CHARACTERISTICS OF ROOF INSULATION

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Thermal insulation is a material or combination of materials, that, under ordinary conditions, efficiently retards heat transfer. This heat-retarding property generally requires a low coefficient of thermal conductivity. But highly conductive materials – notably aluminum – may also qualify as thermal insulation. Despite its high coefficient of thermal conductivity (roughly 5000 times that of conventional low temperature insulation) aluminum foil's high heat reflectivity makes it a good insulator for lining an airspace.

With the exception of the thermos bottle, the insulating value of most materials is approximately proportional to their thicknesses. If the material is thick enough, it will effectively retard heat flow. Under steady state-thermal conditions, a common brick wall 36 inches thick transfers heat at the same rate as a reasonably well insulated frame wall 6 inches thick.

Long before the scientific approaches to insulation, homeowners discovered good natural insulating materials. Farmers along the New England coast and in Nova Scotia banked dried eel grass around their houses in the Fall to conserve the heat from their fireplaces and stoves during cold weather. The Pierce House in Dorchester, Massachusetts, built in 1635, was insulated with eel grass stuffed between the studding. Dried eel grass (*Zostera Marina*) is an excellent insulator.

Roof insulation has several purposes:

- to conserve heating and cooling energy
- to enhance thermal comfort
- to prevent water-vapor condensation within the roof system
- to reduce thermal expansion and contraction of the roof deck and structural framing
- to provide a smooth substrate for the application of roofing on steel decks and other materials with irregular surfaces.

Energy conservation is the major purpose of thermal insulation – a vital goal in view of the virtual certainty of continued energy price escalation far into the foreseeable future and threats of periodic fuel shortages.

HEAT-TRANSFER MECHANISMS

Heat is transferred via three mechanisms: conduction, convection, and radiation.

Conduction depends on direct contact between molecules transmitting energy directly through the material, without displacement of the molecules themselves. A poker whose point is inserted in a fire may soon burn your hand, from the rapid transfer heat due to the steel's high thermal conductivity.

Convection, in contrast with conduction, requires a fluid (gas or liquid) to convey heat energy from place to place. Heating a volume of air expands it. As its volume increases its density decreases and it rises. As the warm air rises, it displaces cooler, denser air, which is forced down toward the floor. This denser air, in turn, is heated, and expanded. On rising, it creates a convective current within the space. The continuing process transfers thermal energy from the lower to the upper parts of the space.

Radiation is the transmission of energy via electromagnetic waves. In the radiative heat exchange between a warm body and a cooler body, the cooler body gains heat energy. Meanwhile, the space between the two bodies is unaffected, remaining at essentially the same temperature.

With roof insulation, we are concerned mainly with retarding energy transfer by conduction, and so we choose materials of low conductance – i.e., materials with numerous voids and obstructions. (In the very small cells under consideration, there is little if no radiant heat transfer.) Pockets formed by cells or intermeshed fibers provide the voids and obstructions to energy movement. Voids may be filled with inert gases, which will enhance the material's insulating quality.

Remember that heat always moves along a temperature gradient, from warm to cool, just as air tends to fill a vacuum. You can't stop heat movement; you can only retard its flow. But you can do that very effectively.

Still (non-convective) air is an excellent insulator. But air is seldom still, and temperature changes make air expand or contract; warmer air becomes lighter and rises above cooler, heavier air. So our job is to keep air as still as possible. One method is to enclose small quantities of air within closed cells, as in cork, cellular glass, or foamed plastics. Another is to trap the air in deep passageways between particles as in granular materials such as pumice or vermiculite. A third method uses the natural tendency of air to cling to surfaces in thin films, and so we use masses of fine fibers, creating vast surface areas to which this air film can adhere. Fur, wool, feathers, and mineral wool insulations illustrate this principle.

Animals fluff up fur or feathers in cold weather to create many air spaces that retard the loss of body heat. According to one writer, human goose pimples are the last vestige of the fur our presumed ancestral apes wore. When we are chilled, the goose pimples once made our hair stand nearly on end providing us with many insulating air spaces.

Different insulations exploiting this trapped-air principle differ in thermal conductivity for the following reasons:

1. Materials forming the fibers or cells have different conductivities to conduct heat along their length. Measured under identical conditions, solid glass may have a conductivity between 4.7 to over 9 BTUs, whereas some plastics conduct 1 or 2 BTUs and some minerals over 15 BTUs. Fiber or cell wall thickness also affects heat transfer by conduction.
2. Conduction also depends on the ability of adjacent fibers or cellular particles to transmit heat to each other. Large cylindrical fibers or hard round granules have infinitely small points of contact through which little heat energy can move. Soft fibers of flat surface materials have larger contact surfaces that let more heat energy pass from one fiber or cellular particle to another.
3. Orientation of the fibers or cellular particles also affects the thermal conduction rate. A long, tortuous path will conduct less heat through a material than a short direct path.
4. The nature of trapped-air films affects conductance. If fibers or granules are too coarse, the air films adhering to thin surfaces may not be in contact. Free air can move through the gaps, and the resulting convection currents will impair insulating quality.

The foregoing paragraphs explain why one insulating material, 1-in. thick, may transmit only 0.22 heat units per square foot while another 1-in. thick insulation transfers as much as 0.48 heat units per square foot under otherwise identical conditions.

THERMAL INSULATION CRITERIA

To qualify as a satisfactory roof insulation, a material requires more than low thermal conductivity. Here are the other requirements:

- Surface smoothness
- Light weight
- Dimensional stability
- Shear strength
- Heat resistance
- Moisture resistance
- Compatibility with other components
- Toughness
- Impact resistance
- Wind resistance
- Fire resistance
- Chemical stability

Surface smoothness is a requirement imposed by the insulation's role as a substrate for the membrane – an indispensable function on steel decks, which require insulation to serve as a leveling board.

Light weight characterizes an ideal insulation, which should add little dead load to the structure. Since insulation may be stacked on the roof prior to application, a relatively heavy insulation might overload the structure.

Dimensional stability is required under daily temperature changes and varying moisture content. A dimensionally unstable insulation can contribute to a ratchet effect, stemming from membrane temperature changes, that can ultimately destroy the membrane. And an insulation material that does not change dimensionally in a uniform way can contribute to a phenomenon called "thermal warp," which can also result in the roof system's ultimate destruction.

Roof insulation must be capable of absorbing and resisting membrane stresses produced by the wide daily temperature variations that can occur. The insulation requires high internal strength to resist horizontal shear stresses induced by temperature change.

Heat resistance is required during application. Materials that melt or deteriorate from high heat will impede roofing operations.

Moisture resistance is a desirable property for insulation before and during the roof system's service life. Even the best roofing contractor gets into occasional trouble, and this trouble frequently involves insulation that got wet before it was installed and covered by the membrane. Insulating material must be moisture resistant and capable of resisting alternate wetting-drying cycles without deterioration. A material that can be dried after it gets wet is far more useful than a material that breaks down or rots before it can be dried.

Compatibility with other roof system components is an obvious requirement. Insulation materials affected chemically or physically from contact with bituminous materials are of little use in a conventional bituminous built-up roof system. Insulation must also be compatible with other roofing materials and with adhesives used to bond these materials into a structural unit. It must provide a suitable surface for interfacing and bonding with other roof system components. The insulation must be capable of bonding to the deck or substrate, the vapor retarder, and to the membrane.

Toughness is required to get the insulation safely through the installation operations. A material that requires special handling and extra care during application is less desirable than a material that can withstand "normal" handling and tolerate minor abuse by the roofing mechanic.

Impact resistance, along with compressive strength, is needed throughout the roof system's service life. Today's roofs frequently become extensions of the building interior, supporting HVAC units, solar collectors, and other mechanical equipment that threaten roof system integrity. Despite the provision of such protective features as walkways, the roof is often subjected to the impact of dropped tools and traffic. Sandwiched between deck and membrane, the insulation must resist such ever present mechanical abuses.

Wind-uplift resistance is a familiar requirement, needed for the roof system's survival when high wind uplift forces accompany high speed winds blowing over parapet walls or over corners. Insulation plays a critical role in the roof system's wind uplift resistance. It must be capable of supporting or holding mechanical fasteners, or be compatible with adhesives of other bonding materials that can provide required wind-uplift resistance.

Fire resistance is closely associated with wind-uplift resistance in both Factory Mutual and Underwriters' Laboratories' requirements. A roof insulation and its anchoring adhesive or fasteners must pass the FM and UL fire test.

Chemical stability is still another desirable property required by thermal insulation. A material that requires time to cure or to achieve chemical stability after its installation presents practical obstacles in scheduling and application.

With an insulation possessing all these desirable properties, we can return to our primary concern – energy conservation. For this purpose, the best insulation will provide a high thermal resistance/thickness ratio. It will contribute little dead load, thus economizing in structural cost.

Insulation cost should never be the prime factor in selection, although it is obvious that in today's world of life-cycle cost analysis the bottom line will still have a great influence.