i.e. Innovative Energy, Inc.
10653 W. 181st Avenue
Lowell, IN 46356
Phone: 1-800-776-3645 (FOIL)
(219) 696-3639 (Local)
(219) 696-5220 (FAX)

PHYSICS OF FOIL

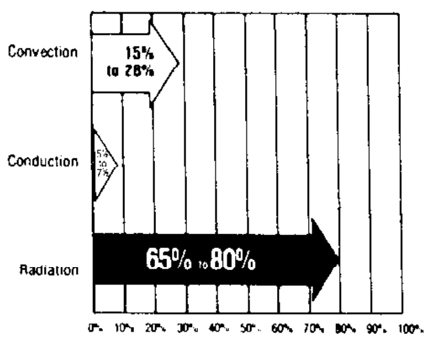
HEAT GAIN / LOSS IN BUILDINGS

There are three modes of heat transfer: CONDUCTION, CONVECTION, and RADIATION (INFRA-RED). Of the three, radiation is the primary mode; conduction and convection are secondary and come into play only as matter interupts or interfers with radiant heat transfer. As the matter absorbs radiant energy, it is heated, developes a difference in temperature, and results in molecular motion (conduction in solids) or mass motion (primarily convection with some conduction in liquids and gas).

All substances, including air spaces, building materials, such as wood, glass and plaster, and insulation, obey the same laws of nature, and TRANSFER heat. Solid materials differ in the rate of heat transfer which is affected by differences in: density, weight, shape, permeability and molecular structure. Materials which transfer heat slowly can be said to RESIST heat flow.

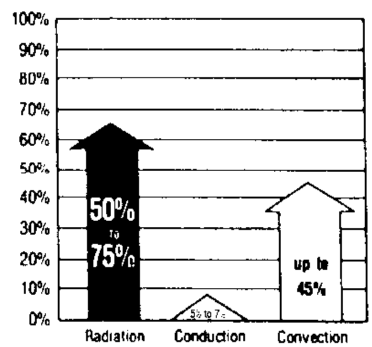
Direction of heat transfer is an important consideration. Heat is radiated and conducted in all directions, but convected primarily upward. The figures below show modes of heat loss by houses. In all cases, radiation is the dominant mode.

SIDE HEAT FLOW



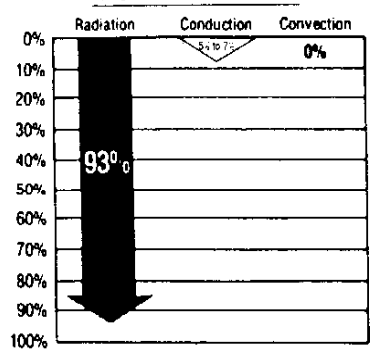
Heat Loss Through Walls

UP HEAT FLOW



Heat Loss Through Ceiling/Roof

DOWN HEAT FLOW



Summer Heat Gain

CONDUCTION is direct heat flow through matter (molecular motion). It results from actual PHYSICAL CONTACT of one part of the same body with another part, or of one body with another. For instance, if one end of an iron rod is heated, the heat travels by conduction through the metal to the other end; it also travels to the surface and is conducted to the surrounding air which is another, but less dense, body. An example of conduction through contact between two solids is a cooking pot on the solid surface of a hot stove. The greatest flow of heat possible between materials is where there is direct conduction between solids. Heat is always conducted from warm to cold; never from cold to warm.

In general, the more dense a substance, the better conductor it is. Solid rock, glass and aluminum, being very dense are good conductors of heat. Reduce their density by mixing air into the mass, and their conductivity is reduced. Because air has low density, the percentage of heat transferred by conduction through air is comparatively small. Two thin sheets of aluminum foil with about one inch of air space in between weigh less than one ounce per square foot. The ratio is approximately 1 of mass to 100 of air, most important in reducing heat flow by conduction. The less dense the mass, the less will be the flow of heat by conduction.

CONVECTION is the transport of heat within a gas or liquid, caused by the actual flow of the material itself (mass motion). In building spaces, natural convection heat flow is largely upward, somewhat sideways, not downwards. This is called "free convection".

For instance, a warm stove, person, floor, wall, etc., loses heat by conduction to the cooler air in contact with it. This added heat activates (warms) the molecules of the air which expand, becoming less dense, and rise. Cooler, heavier air rushes in from the side and below to replace it. The popular expression "hot air rises" is exemplified by smoke rising from a chimney or a cigarette. The motion is largely upward, with a component of sideways motion.

Convection may also be mechanically induced, as by a fan. This is called "forced convection."

RADIATION is the transmission of electromagnetic rays through space. Radiation, like radio waves, is invisible. Infrared rays have wavelengths between light and radar waves (between the 3 - 15 micron portion of the spectrum.). Henceforth, when we speak of radiation, we refer only to infrared rays. Each material whose temperature is above absolute zero (-459.7 F) emits infrared radiation, including: the sun, icebergs, stoves or radiators, humans, animals, furniture, ceilings, walls, floors, etc.

All objects radiate infrared rays from their surfaces in all directions, in a straight line, until they are reflected or absorbed by another object. Traveling at the speed of light, these rays are invisible, and they have NO TEMPERATURE, only ENERGY. Heating an object excites the surface molecules, causing them to give off infrared radiation. When these infrared rays strike the surface of another object, the rays are absorbed, and only then is heat produced in the object. This heat spreads throughout the mass by conduction. The heated object then transmits infrared rays from exposed surfaces by radiation, if these surfaces are exposed directly to an air space.

The amount of radiation emitted is a function of the EMISSIVITY factor of the source's surface. EMISSIVITY is the rate at which radiation (EMISSION) is given off. Absorption of radiation by an object is proportional to the absorptivity factor of its surface which is reciprocal of its emissivity.

Although two objects may be identical, if the surface of one were covered with a material of 90% emissivity, and the surface of the other with a material of 5% emissivity, there would result a drastic difference in the rate of radiation flow from these two objects. This is demonstrated by comparison of four identical, equally heated iron radiators covered with different materials. Paint one with aluminum paint and another with ordinary enamel. Cover the third with asbestos and the fourth with aluminum foil. Although all have the same temperature, the one covered with aluminum foil would radiate the least [lowest (5%) emissivity].

The radiators covered with ordinary paint or asbestos would radiate most, because they have the highest emissivity (even higher than the original iron.). Painting over the aluminum paint or foil with ordinary paint changes the surface to 90% emissivity.

Materials whose surfaces do not appreciably reflect infrared rays, for example, paper, asphalt, wood, glass and rock, have absorption and emissivity rates ranging from 80% to 93%. Most materials used in building construction – brick, stone, wood, paper, and so on – regardless of their color, absorb infrared radiation at about 90%. It is interesting to note that a mirror of glass is an excellent reflector of light but a very poor reflector of infrared radiation. Mirrors have about the same reflectivity for infrared as a heavy coating of black paint.

The surface of aluminum has the ability NOT TO ABSORB, but REFLECT, from 94% to 98% of the infrared rays which strikes it. Since aluminum foil has such a low mass to air ratio, very little conduction can take place, particularly when only 5% of the rays are absorbed.

TRY THIS EXPERIMENT. Hold a sample of FOIL INSULATION close to your face, without touching. Soon you feel the warmth of your own infrared rays bouncing back from the **SURFACE**. The explanation: The emissivity of heat radiation of the surface of your face is 99%. The absorption of aluminum is only 5%. It sends back 95% of the rays. The absorption rate of your face 99%. The net result is that you feel the warmth of your face reflected.

REFLECTIVITY AND AIR SPACES

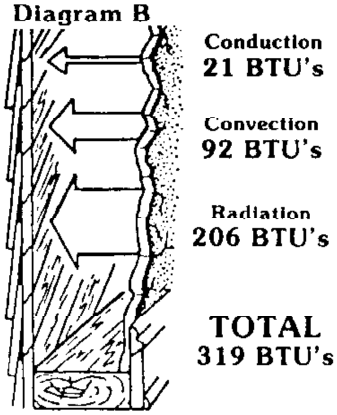
In order to retard heat flow by conduction, walls and roofs are built with internal air spaces. Conduction and convection through these air spaces combined represent only 20% to 35% of the heat which pass through them.

In both winter and summer, 65% to 80% of the heat that passes from a warm wall to a colder wall or through a ventilated attic does so by radiation. Room comfort and temperature are greatly affected by radiant heat transfer form all the surrounding surfaces – walls, floor, ceiling, objects in the room. The radiant energy waves cross the room's airspace to be absorbed or reflected by an opposing surface. The value of air spaces as thermal insulation must always include the makeup of the enclosing surfaces. The amount of energy transferred by radiation varies depending on the emissivity of the material's surface. One way to modify that heat exchange is to change the character of the surface – introducing a material that has a surface with a lower emissivity.

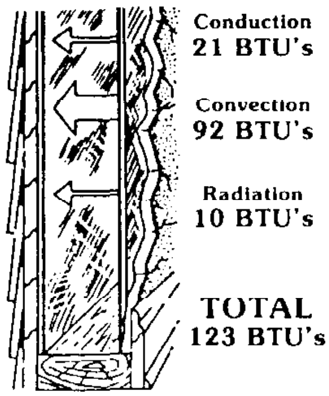
The following test results (see diagram B), illustrate how heat transfer across a given air space may be modified. The distance between the hot and cold walls is 1-1/2" and the temperatures of the hot and cold surfaces are 212° and 32° respectively. in CASE 1, the enclosing walls are paper, wood, asbestos or other similar material. in CASE 2, the walls are lined with aluminum foil. in CASE 3, two sheets of aluminum foil are used to divide the enclosure into three 1/2" spaces.

Reflection and emissivity by surfaces can ONLY occur in SPACE. The ideal space is any dimension 3/4" or more. (3/4" is the separation giving a minimum for the convection coefficient.) Smaller spaces are also effective, but decreasingly so. **Where there is no air space, we have conduction through solids.** When a reflective surface of a material is attached to a ceiling, floor or wall, that particular surface ceases to have radiant insulation value at the points in contact.. Therefore, care must be exercised, when installing Foil Insulation, that it be installed so that the foil surfaces don't touch. Otherwise, conduction through solids will result at the point of contact.

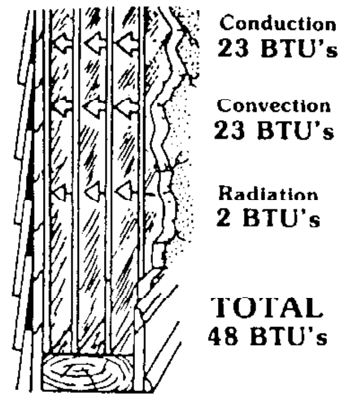
Diagram B



CASE 1, UNINSULATED WALL SPACE. The surfaces of ordinary building materials, including ordinary bulk insulation have a radiation or emissivity rate of about 90%, a heat ray absorption rate of over 90%. Air has low density, so conduction is slight (only 21 BTU's.) Convection currents transfer 92 BTU's.



Case 2, THE SAME WALL SPACE EXCEPT that the inner surfaces were lined with sheets of aluminum foil of 5% emissivity and absorptivity.* Note the drastic drop in heat flow by radiation, from 206 BTU's to 10 BTU's. Conduction and convection are unchanged. The original total heat loss of 319 BTU's drops to 123 BTU's.



CASE 3, TWO SHEET OF (0.05 EMISSIVITY) ALUMINUM FOIL divide the wall space into 3 reflective compartments. Heat loss by radiation drops 94% from case 1. The 2 interior sheets retard convection so that its flow falls 75%. Conduction rises only 2 BTU's; from 21 BTU's to 23 BTU's. The total heat loss drops 85% from case 1.

Note: 65% (206) BTU's of the total BTU's going through this wall space is radiation.
**Note: Aluminum has an emittance of 0.05.*

Heat control with aluminum foil is made possible by taking advantage of its low thermal emissivity and the low thermal conductivity of air. It is possible with layered foil and air to practically eliminate heat transfer by radiation and convection: a fact employed regularly by the NASA space program. In the space vehicle Columbia, ceramic tiles are imbedded with aluminum bits which reflect heat before it can be absorbed. "Moon suits" are made of reflective foil surfaces surrounding trapped air for major temperature modification.

HEAT LOSS THROUGH AIR

There is no such thing as a "dead" air space as far as heat transfer is concerned, even in the case of a perfectly air-tight compartment such as a thermos bottle. Convection currents are inevitable with differences in temperature between surfaces, if air or some other gas is present inside. Since air has some density, there will be some heat transfer by conduction if any surface of a so called "dead" air space is heated. Finally, radiation, which accounts for 50% to 80% of all heat transfer across open air spaces, will pass through air (or a vacuum) with ease, just as radiation travels the many million miles that separate the earth from the sun.

Aluminum Foil, with its reflective surface can block the flow of radiation. Some foils have higher absorption and emissivity qualities than others. The variations run from 2% to 72%, a differential of over 2000%. Most aluminum insulation has only a 5% absorption and emissivity ratio. It is impervious to water vapor and convection currents, and reflects 95% of all radiant energy which strikes its air-bound surfaces.

The performance of most aluminum insulation is unsurpassed for upward winter heat and it has an added efficiency for downward summer heat because of the absence of convection currents.**

HEAT LOSS THROUGH FLOORS

Heat is lost through floors primarily by radiation (up to 93%). When ALUMINUM insulation is installed in the ground floors and crawl spaces of cold buildings, it prevents the heat rays from penetrating down; reflecting the heat back into the building, thereby warming the floor surfaces. Since aluminum is non-permeable, it is unaffected by ground vapors.

CONDENSATION

Water is present as vapor in air under most conditions. As a gas, it will expand or contract to fill any space it may be in. In a given space, with the air at a given temperature, there is a limited amount of vapor that can be suspended. Any excess will turn into water. The point just before condensation commences is called 100% saturation. The condensation point is called dew point. CONDENSATION FORMS WHENEVER AND WHEREVER VAPOR REACHES DEW POINT.

**The National Bureau of Standards, in its booklet BMS52, "Effect of Ceiling Insulation Upon Summer Comfort," lists 2 layers of aluminum foil as the most effective insulation in protecting the ceiling against summer heat.

VAPOR LAWS

1. The higher the temperature, the more vapor the air can hold; the lower the temperature, the less vapor.
2. The larger the space, the more vapor it can hold, the smaller the space, the less vapor it can hold.
3. The more vapor in a given space, the greater will be its density.
4. Vapor will flow from areas of greater vapor density to those of lower vapor density.
5. Permeability of insulation is a prerequisite for vapor transmission, the less permeable, the less vapor transfer.

The average water vapor saturation is about 65%. If a room were vapor-proofed, and the temperature were gradually lowered, the percentage of saturation would rise until it reached 100%, although the amount of vapor would remain the same. If the temperature were further lowered, the excess amount of the vapor for that temperature in that amount of space would fall out in the form of condensation. This principle is visibly demonstrated when we breathe in cold places. The warm air in our lungs and mouth can support the vapor, but the quantity is too much for the colder air, and so the excess vapor for that temperature condenses and the small particles of water become visible.

In conduction, heat flows to cold. The under surface of a roof, when cold in the winter, extracts heat out of the air with which it is in immediate contact. As a result, that air drops in temperature sufficiently to fall below the dew point, (the temperature at which vapor condenses on a surface.) The excess amount of vapor for that temperature that falls out as condensation or frost, attaches itself to the under side of the roof.

Water vapor is able to penetrate plaster and wood readily. When the vapor comes in contact with materials within those walls having a temperature below the dew point of the vapor, they form moisture or frost within the walls. This moisture tends to accumulate over long periods of time without being noticed, which in time can cause building damage.

To prevent condensation, a large space is needed between outer walls and any insulation which permits vapor to flow through. Reducing the space or the temperature converts vapor to moisture which is then retained. The use of separate vapor barriers or insulation that is also a vapor barrier are alternative methods to deal with this problem.

Aluminum is impervious to water vapor and with the trapped air space is immune to vapor condensation.

TESTING THERMAL VALUES

U FACTOR is the rate of heat flow in BTU's in one hour through one sq. ft. area of ceilings, roofs, walls or floors, including insulation (if any) resulting from a 1° F. temperature difference between the air inside and the air outside.

MEMORY JOGGER: U = BTU's flowing in ONE hour, through ONE sq. ft. for ONE degree change.

R FACTOR or RESISTANCE to heat flow is the reciprocal of U; in other words, 1/U. The smaller the U factor fraction, the larger the R factor, the better the insulation's ability to stop conductive heat flow.

There are at present two kinds of techniques generally used by accepted laboratories to measure thermal values: the guarded hot plate and the hot box methods. The results obtained seem to vary between the two methods. Neither technique simulates heat flow through insulation in actual everyday usage. Thermal conductivity measurements as made in the completely dry state in the laboratory will not match the performance of those same insulations under actual field conditions. Most mass type insulating materials become better conductors of heat when the relative humidity increases because of the absorption of moisture by the insulator. (Try keeping you feet warm in a pair of wet socks.) Therefore, mass insulations, which normally contain at least the average amount of moisture which is in the air, are first completely dried out before testing. Moisture (humidity) in mass insulation can significantly reduce its thermal value. In aluminum insulations, there is no moisture problem. Aluminum foil is one of the few insulating materials whose R-Values are not affected by humidity and, consequently, its insulating value remains unchanged from the "bone dry" state to very high humidity conditions.

In spite of the advances made by space technology in insulation systems based on understanding and modifying the effects of radiation, no universally accepted laboratory method has yet been devised to measure and report the resistance of heat flow of reflective insulations. The FTC currently specifies a C 236 hot box for measurements of heat flow through reflective assemblies. Research under way at Oak Ridge Labs and other facilities under a U.S. Department of Energy grant, seeks to develop a test model that will accurately measure reflective insulations performance capabilities and then quantify those values in a standard that will be acceptable to the industry.

There are many different types, grades, and qualities of aluminum foil insulation designed for a variety of applications. Matching the correct foil product to the specific job is extremely important to maximize final performance.