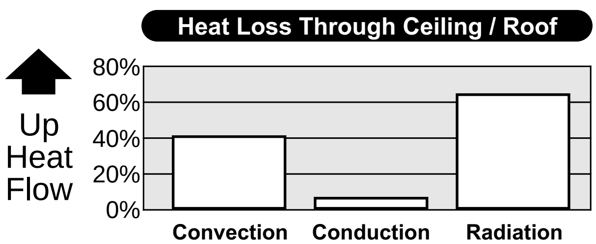
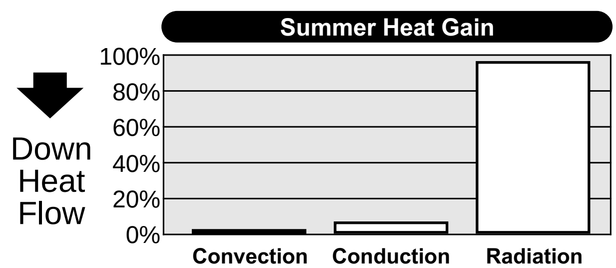
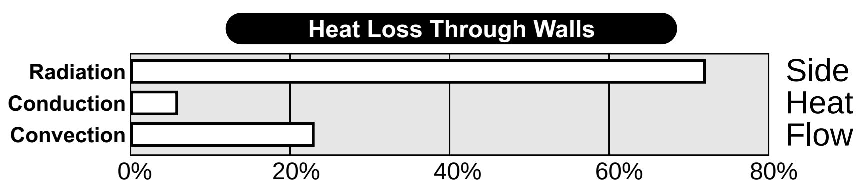
HEAT GAIN/LOSS IN BUILDINGS

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 interrupts or interferes with radiant heat transfer. As the matter absorbs radiant energy, it is heated, it develops a difference in temperature and it results in molecular motion (conduction in solids) or mass motion (convection in liquids and gas). All substances, including air spaces and building materials such as wood, glass, plaster, and insulation, obey the same laws of nature - they all TRANSFER heat. Solid materials differ only in the rate of heat transfer, which is mainly 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.







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 air, which is another less dense body. A cooking pot on the solid surface of a hot stove is an example of conduction through contact between two solids. The greatest possible flow of heat between materials occurs when there is direct conduction between solids. Heat always travels from warm to cold and never from cold to warm. Also, heat always moves via the shortest and easiest route. In general, the more dense a substance, the better conductor it is. Being very dense, solid rock, glass, and aluminum are excellent conductors of heat. By mixing air into the mass, their density and therefore 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 of mass is approximately 1 to 100 of air; most important in reducing heat flow by conduction. The less dense the mass, the less flow of heat by conduction.

CONVECTION is the transfer of heat within a gas or liquid, caused by the actual flow of material (mass motion). In building spaces, natural convection heat flow is largely upward and somewhat sideways, but not downwards, this is called "free convection". For instance, a warm stove, a person, a floor, a wall, etc., loses heat by conduction to the cooler air in contact with it. This added heat activated warms the molecules of the air, which become less dense, expand, 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 cigarette. The motion is turbulently upward with a component of sideways motion. Convection induced mechanically, for example with a fan, is called "forced convection".

RADIATION is the transmission of electromagnetic rays through space. Like radio waves, radiation is invisible. Infrared rays occur between light and radar waves, (between 3 Ü 15 micron portion of the spectrum). Therefore, when we speak of radiation, we refer only to infrared rays. Each material whose temperature is above absolute zero (Ü456.7Á F.) emits infrared radiation, including: the sun, icebergs, stoves, radiators, humans, animals, furniture, ceilings, walls, floors, etc.

All objects radiate infrared rays from their surfaces in a straight line in all directions until they are reflected or absorbed by another object. Traveling at the speed of light, these rays are invisible and have only energy and NO TEMPERATURE. Heating an object excites the surface molecules causing them to give off infrared radiation. When these infrared rays strike the surface of another object they are absorbed which produces heat in that object. This heat spreads throughout the mass by conduction. The heated object then transmits infrared rays from exposed surfaces by radiation directly to the surrounding 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 of 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 be 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 forth with aluminum foil. Although all have the same temperature, the one covered with aluminum foil would radiate the least [lowest emissivity of (5%)]. The radiators covered with ordinary paint or asbestos would radiate the most because they have the highest emissivity, (even higher than ordinary 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 É brick, stone, 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 poor reflector of infrared radiation. Mirrors have about the same reflectivity for infrared as a coating of black paint. The surface of aluminum has the ability NOT TO ABSORB, but REFLECT, 95% of the infrared rays which strike it. Since aluminum 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 it - within a few seconds, you will feel the warmth of your infrared rays bouncing back from the FOIL SURFACE. The explanation: The emissivity of the heat radiation of your face is 99%. The absorption of the aluminum is only 5%, therefore; it sends back 95% of the rays. The absorption rate of your face is 99% - the result - you feel the warmth of your face reflected.

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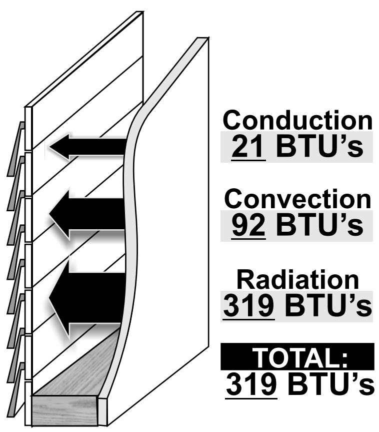
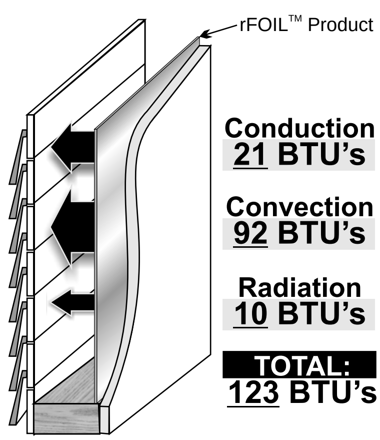
REFLECTIVITY AND AIR SPACES

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 that passes through them. In both winter and summer, 65% to 85% of the heat that passes from a warm wall to a cold wall or through a ventilated attic, does so by radiation. The value of air spaces as thermal insulation must include the character of the enclosing surfaces. Surfaces greatly affect the amount of energy transferred by radiation and depending on the materials absorption and emissivity, are the only way of modifying the total heat transferred across a given space. The importance of radiation cannot be overlooked in problems involving ordinary room temperatures. The following test results 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 212Á and 32Á respectively. In CASE 1, the enclosing walls are paper, wood, asbestos or other materials. In CASE 2, the walls are lined with aluminum foil, and in CASE 3, two sheets of aluminum are used to divide the enclosure into three 1/2" spaces.



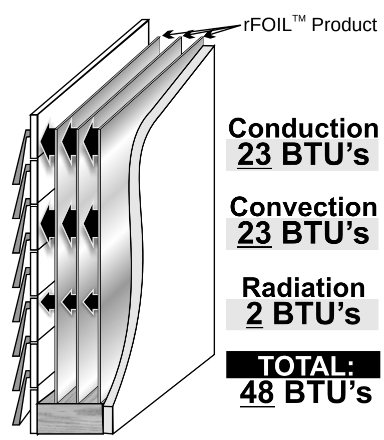
CASE 1

UNINSULATED WALL SPACE. The surfaces of ordinary building materials, including ordinary bulk insulation have a radiation or emissivity rate of about 90%. Air has low density, so conduction is slightly (only 21 BTU's.) Convection current transfers 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 SHEETS OF (5% EMISSIVE) 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 going through this wall space is radiation. Aluminum has 3% to 5% emissivity and absorptivity.

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Reflection and emissivity by surfaces can ONLY occur in SPACE. The ideal space is any dimension 3/4" or more. 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 of contact. Therefore, care must be exercised when installing FOIL INSULATION. It must be stretched sufficiently to insure that any inner air spaces are properly opened up and that metal does not touch metal, otherwise, conduction through solids will result at the point of contact. Heat control with aluminum foil is made possible by taking advantage of its low thermal emissivity and the low thermal conductivity of the 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 "dead" air space as far as heat transfer is concerned, even in the case of a perfectly airtight compartment such as a thermos bottle. Convection currents are inevitably with differences in temperature between surfaces if air or some other gas is present. 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 that accounts for 50% to 80% of all heat transfer will pass through air (or vacuum) with ease, just as radiation travels through the many millions of 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 insulations have only a 5% absorption and emissivity ratio. It is impervious to water vapor and convection currents. Most aluminum insulations reflect 95% of all radiant energy, which strikes its air-bounded surfaces. The performance of most aluminum insulation is unsurpassed for upward winter heat and has an added efficiency for downward summer heat due to 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 vapor is the gas phase of water. As a gas, it will expand or contract to fill any space it may be in. In any given space with the air at any given temperature, there is a limited amount of water 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 the "dew point"
CONDENSATION FORMS WHENEVER AND WHEREVER VAPOR REACHES DEW-POINT.
** The National Bureau of Standards, in its booklet BMS52, "Effects of Ceiling Insulation Upon Summer Comfort," lists 2 layers of aluminum foil as the most effective insulation protection against summer heat **

VAPOR LAWS

1. The higher the temperatures, the more vapor the air can hold - the lower the temperature, the less vapor the air can hold.

2. The larger the space, the more vapor that can be held - the smaller the space, the less vapor that can be held.

3. The more vapor in a given space, the greater its density will be.

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; therefore, the less permeable, the less vapor transfer.

The average water vapor saturation is about 65%. If a room was vapor-proofed and the temperature was gradually lowered, the percentage of saturation would rise until it reached 100%, although the amount of vapor would remain the same. If the temperature was to be 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 because the quantity is too great for the colder air, the excess vapor condenses into small particles of water that become visible. In conduction, heat flows to cold. During the winter, the under surface of a roof extracts heat from the air that surrounds it. As a result, the air falls in temperature sufficiently to below the dew point (the temperature at which vapor condenses on a surface). The excess amount of vapor for that temperature, which falls out as condensation or frost, attaches itself to the underside of the roof. Water vapor is able to penetrate plaster and wood readily and 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 to allow vapor to flow through. Reducing the air space or the temperature converts vapor to moisture, which is then retained. The use of separate vapor barriers or insulation, which is also a vapor barrier, is an alternative method to dealing with this problem. Aluminum is impervious to water vapor and because of its 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, and the better the insulation's ability to stop heat flow.
Note: neither of these factors include radiation or convection flow. There are at present two kinds of techniques 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 laboratory in a completely dry state, will not match the performance of the same insulation 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 your feet warm in a pair of wet socks.) Therefore, mass insulators that normally contain at least the average amount of moisture that is in the air are first completely dried out before testing.

In aluminum insulations, there is no moisture problem. Aluminum foil is one of the few insulating materials that is not affected by humidity and consequently, has an insulating value that remains unchanged from the "bone dry" state to very high humidity conditions. The R Value of mass type insulation is reduced by over 35% with only 1 1/2% moisture content, (i.e. from R-13 to R-8.3). The moisture content of insulation materials in homes typically exceeds 1 1/2%. In spite of the advances made in 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 to heat flow of a multi-layer foil. Until a method that will satisfy rigorous laboratory demands is devised, we must be content to make our judgments on the basis of common sense and experience. 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 in maximizing the final performance.