

# TURNING EMPTY AIR SPACE INTO THERMAL RESISTANCE

**P**ost-frame structures have many opportunities for creating enclosed reflective air spaces that have demonstrated thermal resistance (R-value). Enclosed reflective air spaces (reflective insulation assemblies) are regions with a low-emittance material on at least one surface. The low-emittance surface that is part of a reflective insulation is installed in the walls, ceiling, or floor of a building so that it is perpendicular to the direction of heat flow. Reflective insulation is installed to provide thermal resistance between warm regions and cool regions to reduce heating and cooling loads.

Reflective products are represented in the marketplace by reflective insulations, radiant barriers, low-emittance coatings (interior radiation control coatings), and high solar reflectance materials (exterior radiation control coatings).

Reflective insulation systems involve enclosed (unvented) air spaces; radiant barrier systems are usually large ventilated regions (residential attics, for example). Interior radiation control coatings are used to reduce thermal radiation between a surface and the adjacent air space; exterior radiation control coatings are used to reduce the absorption of solar radiation by exterior surfaces.

Reflective technologies for saving energy are evaluated by a number of consensus standards published by the American Society for Testing and Materials International (ASTM International). Examples of these standards include C1224 (ASTM International, 2012a) for reflective insulation, C1313 (ASTM International, 2012b) for radiant barriers, C 1321 (ASTM International, 2012c) for interior radiation control coatings and C1483 (ASTM International, 2012d) for exterior solar radiation control coatings.

## REFLECTIVE INSULATION

Reflective insulation reduces heat flow across the region it occupies by blocking thermal radiation from the warm side to the cool side. A low-emittance surface such as metalized film or aluminum foil gives off radiant energy at a much lower rate than high-emittance surfaces like wood or masonry.

Emittance is a property that indicates how readily a surface gives off thermal radiation (heat). Emittance is commonly reported with values between 0 and 1, where 0 means no radiant heat given off and 1 is the maximum that can be given off at a stated temperature.

For a given type (wave length) of radiation, a low-emittance surface is also a highly reflective surface. This means that a large fraction of the thermal radiation striking a low-emittance surface will be reflected away from the surface. As a result, a low-emittance (high-reflectance) material on either side of an enclosed air space is effective in reducing heat transfer by radiation in both cold and warm weather.

Much of the commonly used building insulation relies on the low thermal conductivity of air to provide thermal resistance. This is true of fibrous or mass insulations like fiberglass, rock wool, cellulose or open-cell foams. The same is true for reflective insulation systems.

When one is considering thermal insulation, the purpose of insulations such as those listed above is to reduce heat transfer by convection (air movement) and thermal radiation. If convection and radiation are eliminated, then a ther-

mal resistivity (R per inch of thickness) at 75 °F near 5.6 ft<sup>2</sup>·h·°F/Btu·in. can be achieved. Actual air-based insulations, however, have R-per-inch values much less than 5.6 because they do not completely eliminate radiation and convection. The fibrous insulations are very effective in suppressing convection and reducing radiation, while reflective insulations are very effective in suppressing radiation with some reduction in convection.

Natural convection is the movement of air inside a cavity due to temperature differences that affect the density of air (buoyant forces). Air moving through a region (forced convection, infiltration) has an adverse affect on most insulation materials. Air infiltration is prevented by air barriers or solid materials such as wood sheathing or masonry block.

**Table 1** contains a qualitative description of the effect of mass insulations and reflective insulations on heat flow by conduction, convection and radiation.

Post-frame construction is well suited for the use of reflective insulation because of the large open spaces between posts. The distance between posts limits the amount of thermal radiation from warm sheathing or siding that is absorbed by the posts and then conducted to the cool side of the wall.

Reflective insulations in an enclosure reduce radiation to near zero, as illustrated for a warm-side temperature of 100 degrees Fahrenheit and a cold-side temperature of 70 degrees Fahrenheit. The results for “net thermal radiation in Btu per hour” in **Table 2** are shown for

**Table 1.** Effect of Insulation on Heat Flow

Material	Conduction	Convection	Radiation
Mass insulation	Increase	Large decrease	Decrease
Reflective insulation	Small increase	Decrease	Large decrease

**Table 2.** Effect of Effective Emittance on Net Radiation Between Large Surfaces

Side 1	Side 2	Effective Emittance*	Net Radiation (Btu/hr)	% Reduction
Wood	Wood	0.77	2,560	—
Wood	Foil or film	0.04	133	95
Foil or film	Foil or film	0.02	66	97

\* $1/E = 1/E_1 + 1/E_2 - 1$  (ASHRAE, 2013b)

100 square feet of wall cavity. The “effective emittance (E) values” in Table 2 are based on emittance (€) of 0.87 for wood and 0.04 for aluminum foil or metalized aluminum film. Heat also moves across the region by conduction and convection, and this must be taken into account.

Radiation does not change if the heat-flow direction changes. Natural convection, however, depends on the heat-flow direction, with minimum convection occurring when the warm surface is on the top of the enclosure and maximum convection occurring when the warm surface is on the bottom. Heat flow by conduction does not depend on orientation or heat-flow direction.

The net heat flow by radiation for the three situations in Table 2 were calculated from the Stefan-Boltzman Law (American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE], 2013a) for parallel surfaces that are large enough to allow for heat loss perpendicular to the two sides (edge loss) to be neglected.

The footnote to Table 2 gives the equation for calculating effective emittance, E, from the emittances, €<sub>1</sub> and €<sub>2</sub>, of the surfaces bounding the enclosed air space. The radiation across the air space is directly proportional to E. Interchanging €<sub>1</sub> and €<sub>2</sub> does not change the result for E. This shows that the low-emittance sur-

face for an enclosed reflective air space can be on either side of the air space without changing the resulting heat flow by radiation.

#### THERMAL RESISTANCE (R-VALUE)

The thermal resistance of an enclosed reflective air space depends on several factors, the most important of which are the effective emittance (a combination of individual emittances), the heat-flow direction, the distance across the air space and the temperature difference across the air space.

The effective emittance depends on the facing materials used by the reflective insulation manufacturer, the air space



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**Table 3.** Heat-Flow Components for Nonreflective and Reflective Air Spaces

Nonreflective Air Space			Heat-Flow Direction	Reflective Air Space		
% cond.-conv.	% rad	Flux		Flux	% cond.-conv.	% rad
32	68	37.9	up	13.6	90	10
27	73	35.2	horizontal	10.9	88	12
7	93	27.6	down	3.3	59	41

dimensions depend on the design of the enclosure, and the temperatures depend on the outdoor and indoor conditions.

The results in Table 2 illustrate that a major reduction in heat transfer by radiation occurs with installation of a single low-emittance surface in an enclosure. The small increase in savings that results from going from one low-emittance surface in an enclosed reflective air space to two low-emittance surfaces in the same enclosed reflective air space seldom justifies the added material cost.

**Table 3** shows the importance of thermal radiation across an enclosed air space that does not contain insulation. The heat-flux percentages in the table were calculated for large parallel surfaces that are 5.5 inches apart and have temperatures of 100 degrees Fahrenheit and 70 degrees Fahrenheit. The effective emittance for the nonreflective air space is 0.77; the effective emittance for the reflective air space is 0.04.

The percentages in the nonreflective section show that thermal radiation (percentage rad) dominates the heat flow for a region that does not contain insulation. The reflective section of the table shows the result of adding a low-emittance surface.

The percentage of heat transfer by conduction and convection is represented in Table 3 for each heat-flow direction. The heat flux (heat flow per square foot of area, Btu/h·ft<sup>2</sup>) is shown for each heat-flow direction for nonreflective and reflective air spaces.

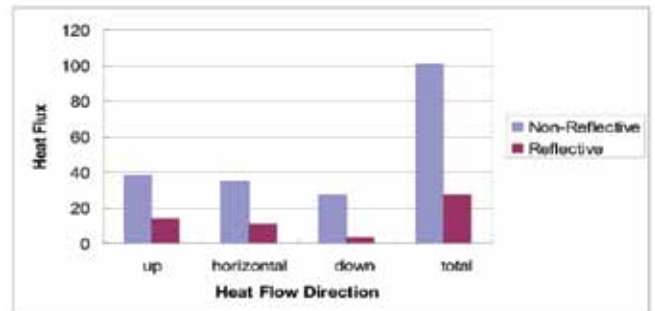
In addition to changing the way heat is transferred from the hot side to the cold side, there is a significant reduction in the total heat flow, as shown by the increase in R-value when a reflective insulation is added to the region. This is demonstrated by the results in Table 3 and **Figures 1a and 1b**.

Figure 1a compares the data from Table 3 for the heat flux for three heat-flow directions and the total heat flux for a nonreflective air space and a reflective air space.

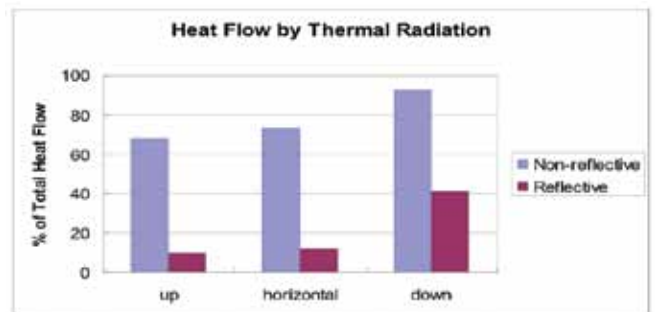
The reduction in thermal radiation is a major contribution to the R-value for reflective insulations. Figure 1b shows the significant reduction in thermal radiation for heat flow up, horizontal or down that occurs when the enclosed air space is changed from nonreflective to reflective.

Consider, for example, a building element with reflective insulation installed in a cavity, as illustrated in **Figure 2**. The reflective insulation material is attached to the framing member to form two air spaces of equal size in a cavity that is enclosed on all six sides. The diagrams in Figure 2 are valid for post-frame construction as well as conventional wood framing.

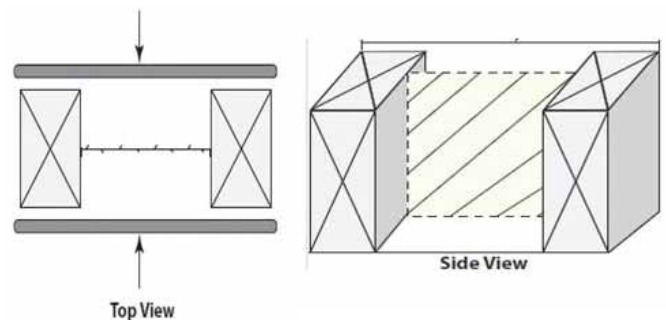
R-values for the reflective insulation assembly can be determined for a warm-side temperature of 100 degrees Fahrenheit, a



**Figure 1a.** Heat flux up, horizontal and down with units Btu/h·ft<sup>2</sup>



**Figure 1b.** Comparison of reflective and nonreflective air space



**Figure 2.** Reflective insulation in a wood-frame or post-frame cavity

cool-side temperature of 70 degrees Fahrenheit and sheathing to form two enclosed reflective air spaces by either measurements using a hot-box facility (ASTM International, 2013e) or by calculations (Desjarlais & Yarbrough, 1991). The subdivision of the region between nominal 2- by 6-inch framing 24 inches on center shown in Figure 2 results in reduced temperature differences across the two air spaces.

**Table 4.** Details of a Reflective Insulation Assembly with Two Air Spaces

Location	Heat Flow Up	Heat Flow Horizontal	Heat Flow Down
Outside exterior sheathing	100 °F	100 °F	100 °F
Inside exterior sheathing	97.3	97.5	98.6
Warm side of reflective insulation	87.0	86.8	86.3
Cool side of reflective insulation	83.0	83.2	84.2
Inside interior sheathing	72.7	72.5	71.4
Outside interior sheathing	70.0	70.0	70.0
R-value of cavity with reflective insulation	6.3	6.9	12.9
R-value without reflective insulation	0.79	0.85	1.09



**Figure 3.** Reflective insulation installed in floor and wall applications

A set of calculated steady-state temperatures for this assembly is shown in **Table 4**, along with calculated R-values for three different heat-flow directions. The temperature differences across the individual air spaces are 10–12 degrees Fahrenheit, while the overall temperature difference is 30 degrees Fahrenheit. The reduced temperature difference and air-gap width result in less natural convection than would be present in the empty cavity.

The calculated R-values in **Table 4** include a two-dimensional correction for radiation striking the framing material inside the enclosed air space (Glicksman, 1991).

The reflective insulation in the calculation was taken to have thickness 0.25 in. and R-value 1.0 ft<sup>2</sup>·h·°F/Btu. The material R-value of the insulation is added to the R-value for the enclosed reflective air spaces to obtain the R-value for the region between the outside and inside sheathing.

The last row in **Table 4** shows R-values for the cavity without reflective insulation.

The R-values in **Table 4** show the increase in thermal resistance that results from the installation of reflective insulation in the air space. In many cases, these R-values alone will not provide all of the thermal resistance required by code for residential or commercial buildings. Enclosed reflective air spaces are



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used in combination with other types of insulation to form hybrid insulation systems that satisfy code requirements.

Reflective insulations find application in use in agricultural buildings and structures requiring easily installed intermediate levels of thermal resistance. The R-value for an enclosed reflective air space can be made higher than the values shown in Table 4 by increasing the number of reflective air spaces (using multilayer reflective insulation).

### APPLICATIONS

The process of installing reflective insulations varies with the type of product. Attaching reflective insulation below floor joists or rafters to enclose a region can be accomplished with stapling and taping. Positioning reflective insulation to subdivide a cavity into two enclosed reflective air spaces also involves stapling and taping.

Figure 3 shows a reflective insulation below floor and wall cavity before closure. When the work is completed, the region containing the reflective insulation material is enclosed on all six sides.

Reflective insulations can be combined, for example, with spray-foam insulation to form a hybrid insulation assembly, as shown in Figure 4. The middle cavities in the picture show the cavity partly filled with foam. The cavities to the left of the middle have been enclosed with a reflective insulation to create an enclosed reflective air space. The total R-value is the sum of the foam R-value and the R-value for the enclosed reflective air space.

Combinations of insulation technologies like this greatly increase the possibilities for effective and economical insulation packages.

### SUMMARY

The family of thermal insulations available to the builder includes easily installed reflective insulations that deliver R-values by blocking radiation. The performance of a reflective insulation assembly comes primarily from the enclosed air space next to the reflective insulation. An available air space can provide thermal resistance with one reflective (low-emittance) surface, with greater thermal resistance provided by dividing the air space into two or more enclosed reflective air spaces.

The thermal resistance for a reflective assembly is valid in winter or summer, provided that heat-flow direction is taken into account. R-values for an assembly can be measured, estimated from handbook data or calculated from well-established correlations. Reflective insulations can be combined with other types of insulation to form hybrid insulation systems that satisfy code requirements.

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Figure 4. A hybrid assembly that combines technologies

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