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Reflective Insulation for Residential and Commercial Applications

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Reflective insulation offers an alternative to conventional bulk materials such as fiberglass batt insulation or loose-fill cellulose insulation often specified to reduce a building's heating and cooling loads. These reflective insulation materials (RIMs) are used to form reflective insulation systems (RIS) that can have one or more enclosed air spaces. These reflective air spaces have at least one major surface that has high thermal reflectance and low thermal emittance, which is positioned perpendicular to the direction of heat flow, dramatically reducing the thermal radiation across the adjacent air space.
A RIS specified to have two opposing reflective surfaces will reduce the radiative heat transfer slightly better than a single reflective surface. In most cases, the difference in performance between a reflective air space with one reflective surface and one with two reflective surfaces is not significant. RIS have thermal resistances (*i.e.* R-values) that can be measured or, in many cases, calculated.

The reflectance of a surface on an opaque material is the fraction of incoming thermal radiation not absorbed by the surface. Thermal emittance, another important property, is the ratio of radiant flux leaving the surface at a given temperature to the radiant flux from a black body which exhibits the maximum possible radiation at the temperature in question. Carbon black, for example, with a reflectance near zero and an emittance near one comes close to qualifying as a black body. There are at two types of thermal emittance values reported for surfaces. The total hemispherical emittance is commonly used for heat flow calculations rather than the total normal emittance. The terms "hemispherical" and "normal" refer to the direction of radiation leaving a surface. Both the reflectance and the emittance of a surface are numbers between zero and one. (In the case of opaque materials, the sum of the reflectance and the emittance equals one.) The emittances of the opposing parallel surfaces in an air space are used to calculate an “effective emittance” for the air space. The smaller the effective emittance the better the performance of the reflective air space as an insulation. The common building materials and paints both black and white have emittances in the range 0.85 to 0.95. Specialized coating with thermal emittances between 0.2 and 0.5 also exist. Table 1 contains effective emittances for a few examples of large parallel surfaces separated by an air space.

Table 1. Effective Emittances for Large Parallel Surfaces

Surface one	Emittance one	Surface two	Emittance two	Effective Emittance*
Al foil	0.03	planed wood	0.90	0.0299
Al foil	0.03	Al foil	0.03	0.0152
planed wood	0.90	planed wood	0.90	0.8182
Al foil	0.03	red birch	0.93	0.0299
Al foil	0.03	plaster	0.91	0.0299
Al foil	0.03	white brick	0.29	0.0279
Coating	0.22	planed wood	0.90	0.2148
Any material	X	black body	1.00	X

** The net thermal radiation across a space is directly proportional to the effective emittance. Multi-dimensional effects are not included in this calculation.*

RIMs most commonly use aluminum foils or metallized films to provide emittances in the range 0.03 to 0.1, with corresponding reflectances of 0.97 to 0.9. The foils or films are bonded to paper or polymer substrates for strength and support. This material provides a way to attach the RIM to framing members, purlins, or inside a cavity to form an RIS. The R-value for the reflective system depends on the following factors:

- distance across the adjacent air space in the direction of heat flow;
- temperature difference across the air space;
- emittances of the surfaces facing the enclosed air space;
  (The two emittance are used to calculate an “effective emittance” for the space.)
- average temperature of the air space; and
- the heat-flow direction.

This final factor is particularly important because natural convection can occur in an enclosed air space. The magnitude of this convective heat transfer depends on the direction of heat flow because it is due to air density differences (*i.e.* buoyancy) caused by temperature differences across the air space. Transfer by convection is less significant for heat flow ‘down’ than for heat flow ‘up.’ As a result, the R-values for RIS are greatest for heat flow down and least for heat flow up when all other factors are equal.

Reflective Materials and Specifications

Reflective insulation materials include aluminum foils or films laminated to kraft or cardboard, foils or films bonded to sheets of polyethylene bubbles, polymer foams, or fibrous materials. Specific products are designed to provide well-defined enclosed reflective air spaces when properly installed. Due to their thickness, many RIMs have a material R-value—generally a small fraction of the system’s total resistance value, which is the sum of the enclosed air spaces and the R-values of any materials that are included. Single sheet products a few hundredths of an inch thick normally have negligible thermal resistance while thicker substrates like polyethylene bubblepack, polyethylene foam, or fibrous insulation have R-Values from 1 to about 3 depending on the thickness. The material R-value is added to the R for the reflective air spaces that are formed to obtain the R-value for the RIS.

Various standards, codes, and regulations guide the use of reflective insulation systems. ASTM International C 1224, *Standard Specification for Reflective Insulation for Building Applications* is complemented by the International Code Council Evaluation Services (ICC-ES) AC-02, *Acceptance Criteria for Reflective Foil Insulations (effective July 2005)*. These documents contain the properties and performance requirements for reflective insulation materials and systems. The Federal Trade Commission (FTC) 16 (CFR) 1460, *Rule for Labeling and Advertising of Residential Insulation,* states how reflective products are labeled. This rule does not apply to commercial applications although the same products can often be used in either type of application. The following four test methods are used to evaluate the thermal performance of reflective insulations.

1. ASTM C 518, *Standard Test Method for Steady-state Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus.*
2. ASTM C 1371, *Standard Test Method for Determination of Emittance of Materials near Room Temperature Using a Portable Emissometer.*
3. ASTM C 1363, *Standard Test Method for the Thermal Performance of Building Assemblies by Means of a Hot Box Apparatus.*
4. ASTM C 335, *Standard Test Method for Steady-State Heat Transfer Properties of Horizontal Pipe Insulation.*

ASTM C 727, *Standard Practice for Installation and Use of Reflective Insulation in Building Constructions,* provides guidance for use of reflective materials. As in the case of all insulation, reflective insulation materials must be installed as specified by the manufacturer in order to achieve the claimed thermal performance

Along with information provided in the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) Handbook, these ASTM standards (found in Volume 04.06 of the *Annual Book of ASTM Standards)* and the ICC-ES AC02 list the important factors for specifying a RIM. Additionally, specific applications for RIM are identified and evaluated by the various manufacturers and members of the Reflective Insulation Manufacturers Association (RIMA).

Thermal Performance

The R-value for a large planar air space bounded by at least one low-emittance surface depends on the distance across the space as shown in Table 2 (page XX). The R-values illustrated do not include the effect of framing members used to support the RIM. These reflective insulation materials serve as water vapor retarders when taped to prevent moisture movement around the edges or across seams. RIMs are perforated when a water vapor permeable material is specified. The perm of perforated RIMs depends on the size and number of holes. In general, the perm for an unperforated RIM is much less than one since aluminum foil does not allow the passage of water vapor. Perforation designs can provide perm values of five or higher if a water vapor transmitting system is needed.

Reflective insulation systems can be especially effective when used with bulk insulation. The R-value of a RIS approaches the value for a layer of still air without radiation when the temperature difference across the air layer is small. A RIS in series with other insulation materials will have a temperature difference a fraction of the temperature difference across the building element. Table 3 (page XX) illustrates performance for two specific air-space widths, with a 24 ˚C (75 ˚F) average temperature (*i.e.* T) and temperature differences (*i.e.* ΔT) across the air space 1.4 to 5.6 ˚C (2.5 to 10˚F).

In Table 3, the ΔT across an enclosed air space that is part of an insulated region is determined by dividing the overall temperature difference across the building element in proportion to the thermal resistance of the material layers. For example, when the overall temperature difference is 27.8 ˚C (50 ˚F) and there are two layers of insulation having R-values of five and ten, the temperature difference across the R-10 layer will be 18.5 ˚C (33.3 ˚F), while the temperature difference across the R-5 layer will be 9.8 ˚C (17.6 ˚F). This concept is used to evaluate the R-value for an enclosed reflective air space that is part of a larger system by an iterative procedure that starts with an estimate for the R-value of the reflective air space, determines the temperature drop across the air space, and then recalculates the reflective air space R-value using the temperatures on the two sides of the air space. This process continues until the calculated R-Value is constant.

Reflective systems with two or more air spaces have R-values that are the sum of the values across individual reflective air spaces (each of which will likely have a small ΔT). These systems can be used in commercial buildings to provide excellent thermal performance for the region below the roof decking or in walls. If a low-emittance surface faces toward the interior, there is also an air-film resistance that is enhanced by the reduced radiation from the low-emittance surface. In the case of occupied enclosures, the mean radiant temperature of the air space bounded by low-emittance surfaces is cooler in the summer and warmer in the winter since radiation to or from the walls or ceiling has been significantly reduced by the presence of exposed low-emittance material.

Reflective Insulations Used on Ducts

Reflective insulation systems for use on the exterior of air-handling ducts usually include spacers to provide a reflective air space between the duct and the insulation. Loosely wrapped reflective insulation can also provide a variable-width reflective air space. The reflective products used for this application have low-emittance facers on both sides so that a reflective air space is formed between the duct and the insulation and the exterior air-film resistance is increased by the non-radiating low-emittance exterior surface. The R-value provided by this type of system depends on the emittance of the facers, the width of the air gap, and the material R-value of the material being used. R-values in the range 4 to 7 ft^2·hr·˚F/Btu have been measured for RIS used on ducts. Reflective insulation systems for ducts continue to be improved as the demands are made for higher thermal performance.

The reflective air spaces used in duct applications vary from about 13 mm (1/2 inch) to 38 mm (1.5 inches). The spacers can be either longitudinal (in the direction of the duct) or radial (around the duct). In the case of rectangular ducts, spacers are placed along each edge either for the entire length or on a spacing (every one or two feet) specified by the manufacturer. The spacer design is part of the assembly that is evaluated for thermal resistance using ASTM C 335. The R-Values for reflective duct insulation are measured using the test method C 335 with calibrated end caps. The use of C 335 for this application became part of the ICC-ES Acceptance Criteria for Reflective Insulation (AC 02) in July of 2005.

The measured R-values are reported with units ft^2·hr·˚F/Btu where the reference area is the exterior surface of the duct. Duct insulation calculations are sometimes based on length of duct rather than area. Material R-values and R-values reported for reflective insulations are based on area.

It is important for a duct insulation system to have high resistance to the transport of water vapor when the duct system is to be used for the movement of chilled air. The exterior facer of the duct insulation must have a near-zero perm and seams must be taped to prevent water vapor from coming into contact with cold duct surfaces with resulting condensation. Aluminum foil or film along with plastic substrates will provide the required low-perm for the system. High-quality foil-faced tape is used to make water-vapor-tight seams.

Condensation on the exterior of duct insulation is prevented by providing sufficient thermal resistance around the duct to keep the outside surface of the insulation system above the dew-point temperature of the surrounding air. The dew-point temperature depends on the actual (dry-bulb) temperature and the relative humidity. The dew-point temperature approaches the dry-bulb temperature as the relative

humidity approaches 100%. The dew-point temperature can be within a few degrees of the dry-bulb temperature when the humidity is high (above 90%, for example). This means that condensation of water on the exterior insulation surface of a duct moving chilled air
is very likely for any insulation system operating in an environment above 90% relative humidity. Ventilation to prevent very high humidity in a space with ducts is a solution.
Movement of air near the exterior surface of a duct insulation system will bring the outside surface temperature close to the exterior air temperature and above the dew-point temperature in many cases.

As with all duct insulations, air leakage from the duct system can be a major energy loss.
The leakage of chilled air can result in increased incidence of exterior surface condensation since there will be a cooling effect on the exterior surface. An inspection of the mechanical system is important before an insulation system is installed. This is necessary for new installations as well as retrofit applications. The inspection before installation is important for reflective insulation systems.

Summary

Reflective insulation systems are suitable in a variety of applications such as walls and ceilings of wood-frame structures or metal buildings, masonry wall structures that have very low thermal resistances, sub-floor spaces, agricultural applications, and air-handling systems. In each case, the thermal performance depends on the factors identified in this article. R-values for RIS are determined by standard engineering techniques and measurements for specific building configurations. This useful type of insulation provides designers and construction specifiers additional options for reducing heating and cooling loads in buildings, offering potential savings in both energy and operating expenses.

Additional Information

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Abstract

When seeking to reduce heating and cooling loads in a project, specifiers traditionally turn to bulk materials such as cellulose. However, reflective insulation materials (RIMAs), forming a reflective insulation system (RIS) can provide an alternative suitable for many applications.

Table 2. R-Values for a Single Reflective Air Space at an Average Temperature of 24 C (75 F)

	T = 11.1 C (20 F)		T = 16.7 C (30 F)	
Air space	**Heat flow up**	**Heat flow down**	**Heat flow up**	**Heat flow down**
19 mm (0.75 in.)	1.93	3.58	1.73	3.55
25.4 mm (1 in.)	2.01	4.51	1.80	4.47
31.75 mm (1.25 in.)	2.07	5.36	1.85	5.29
38 mm (1.5 in.)	2.11	6.12	1.90	6.05
50.8 mm (2 in.)	2.19	7.44	1.97	7.25

Note: Bounding emittances 0.03 and 0.9 (effective emittance 0.0299); ΔT = temperature of the warm surface minus that of the cool surface

Table 3. Calculated R-values for Horizontal Heat Flow at Small ΔT

Air space ΔT	**19-mm (0.75-in.) space**	**25.4-mm (1-in.) space**
1.39 ˚C (2.5 ˚F)	3.65	4.51
2.78 ˚C (5 ˚F)	3.55	4.25
4.17 ˚C (7.5 ˚F)	3.45	4.04
5.56 ˚C (10 ˚F)	3.36	3.87

Note: effective emittance 0.0299.