EnergyIdeas Clearinghouse

Energy Efficiency FACTSHEET

March 2008
Version 1.1

Principles of Heat Transfer

Supplement to Heat Transfer Product Reviews

Many products are available that claim to save energy by controlling ***radiation*** heat transfer, including reflective paint additives, radiant barriers, reflective roof coatings and low-emissivity (low-e) coatings on windows. In an ideal world, the potential energy savings due to controlling radiation losses and gains might be large. In reality, there are many factors that impact how effective these products are.

Radiation Versus Other Heat Transfer Methods

First of all, heat is the energy transferred from one body or system to another as a result of a difference in temperature. Heat always migrates from the hotter object to the cooler object, never the other way around. Heat is transferred by three methods: conduction, convection, and radiation.

Conduction requires the physical contact of two objects. In the case of a wall, heat is conducted through the layers within the wall from the warmer side to the cooler side. ***Convection*** is heat transfer due to fluid or airflow. A common example is when warm air rises (or cool air falls) on a wall's inside surface, inducing air movement.

Heat is transferred by ***radiation*** when surfaces exchange electromagnetic waves, such as light, infrared radiation, UV radiation or microwaves. Radiation does not require any fluid medium or contact, but does require an air gap or other transparent medium between the surfaces exchanging radiation. Radiation exchange occurs between two surfaces when one is warmer than the other and they are in "view" of each other; i.e., there is nothing between the two surfaces.

Low-emissivity = High Reflectivity = Reduced Heat Transfer

Radiation is a significant component of heat transfer in buildings – in both heating and cooling even at typical temperatures and even in the absence of solar radiation – but it is especially important for sun-exposed surfaces and where there are large temperature differences (e.g., radiant heating, refrigeration, industrial settings with warm surfaces, ice rinks, etc.) Reflective (low-emissivity) products will generally be most effective in these applications. In certain applications, however, a high-emissivity (non-reflective) surface will perform better. Therefore, in evaluating a reflective product we should have some understanding of these properties.

Reflectivity and emissivity are properties of a surface that affect radiation heat transfer and how a reflective product will perform. The fraction of radiation arriving at a surface that is reflected by it is called its ***reflectivity***. Another property of the surface is its ***emissivity***, which essentially is the surface's tendency to emit radiation to other bodies. Surfaces with high emissivity are also very absorptive, that is, they

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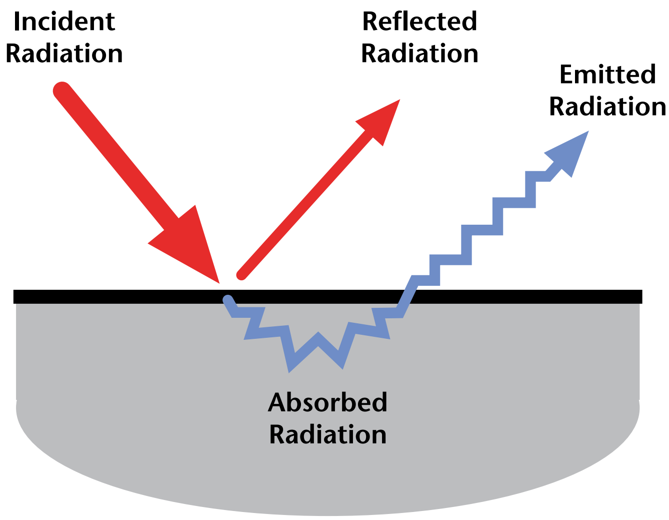
Figure 1

Incident Radiation on an Opaque Surface



For any particular wavelength of radiation striking an opaque material, the sum of radiation that is reflected and that absorbed must equal the incident radiation. The radiation emitted and the radiation absorbed must equal each other at steady state.

will readily absorb radiation striking them. These properties may vary depending on the wavelength of radiation falling on the surface. For example, the surface may reflect much of the visible radiation (i.e., light) falling on it, but not much of the ultraviolet (UV) radiation or infrared radiation falling on it (see Figure 1).

These properties are related to each other and describing how they are related can be helpful in understanding them (see section titled ***More on Heat Transfer Properties of Surfaces*** on page 6).

Reduce Heat Transfer, or Enhance It?

Low emissivity will save energy whenever you want to reduce heat transfer, and vice versa. Places you generally want to reduce heat transfer are:

- Between interior objects in a building (including people) and the interior surfaces of exterior walls – on both hot and cold days (i.e., whenever you are conditioning your space to counter the weather outside).
- Between the exterior surfaces of a building and its surroundings – on both hot and cold days (i.e., whenever you are countering the weather outside).

Low-e coatings on windows save energy in most circumstances because they reduce heat transfer with the surroundings. As another example, a low-emissivity ceiling – such as unpainted aluminum or a reflective aluminum paint product – in an ice rink may have very good energy savings. In this case, low emissivity (over all wavelengths) would reduce radiation heat transfer between the warmer ceiling and the cold surface of the ice.

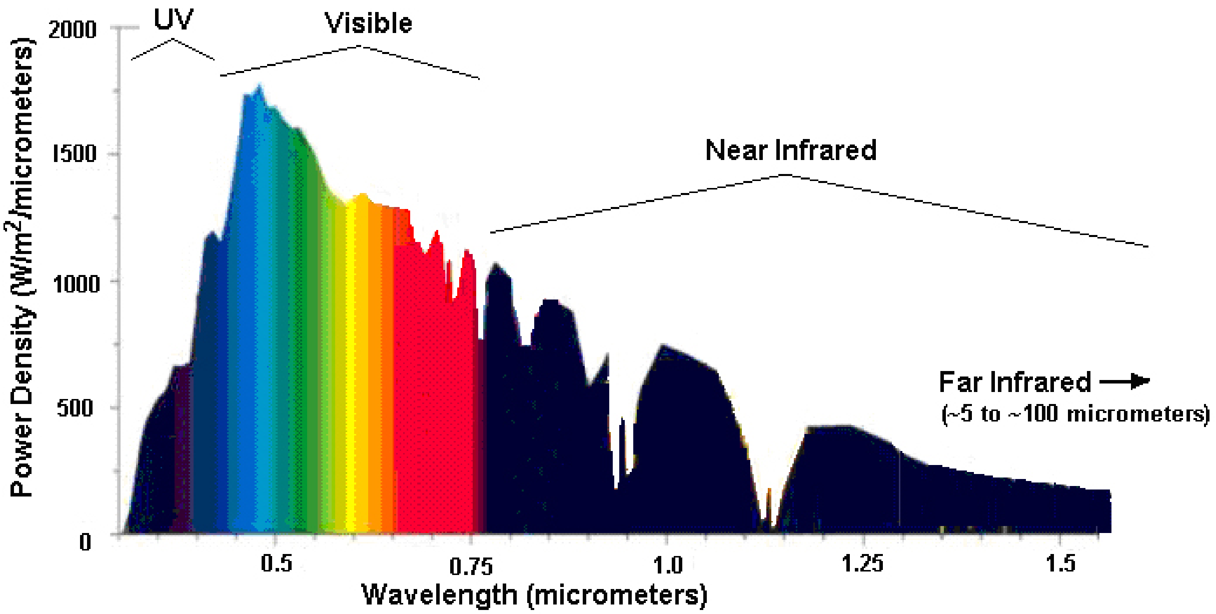
On the other hand, a surface used as a radiant heater – such as a radiant floor or a radiator – is an example of where high emissivity is beneficial because we want to enhance heat transfer from the radiator. Another example of where low-emissivity coatings will increase energy use is a building that requires cooling even on a cool day because, in this case, you generally want to enhance heat transfer (i.e., you are not countering the weather outside). For example, low-e surfaces on windows or walls are bad in rooms with high internal gains, such as computer server or telephone switching rooms, because you generally want to get rid of heat at all times. The only time low-e surfaces will help you in a server room is when it gets so cold outside that you have to start heating (i.e., when you must counter the weather outside).

The Complication with Sun-Exposed Surfaces

Solar radiation is composed primarily of visible and near-infrared radiation. Far-infrared radiation has longer wavelengths than near-infrared and is largely outside the solar band (see Figure 2). (Both near- and far-IR are felt as heat.) Therefore, whenever we are trying to understand how a material behaves when exposed to solar radiation, its emissivity in each of these three bands is more important than its overall value summed over the entire spectrum. For a "cool roof," we want to reflect solar radiation – and whatever heat we do absorb we want to emit back to the surroundings. Therefore, we want high reflectivity in the visible and near-infrared bands, but low reflectivity (i.e., high emissivity) in the far-infrared bands.

If you just look at a single number for emissivity you will miss an important characteristic of

Figure 2
The Solar Spectrum



Far-infrared radiation is largely outside the solar spectrum; that is, solar radiation is very low at such long wavelengths.

certain materials. For example, both unpainted metal surfaces and white surfaces have high reflectivity when summed over all bands and so both reflect much of the solar radiation striking them. But when you look at each of the three bands separately, you can see why unpainted metal roofs become hot in the sun but white surfaces stay cooler. White roofs have high emissivity in the far-infrared band, while unpainted metal roofs have low emissivity in this band.

Tips for Evaluating Products and Their Application

Most surfaces found in buildings – such as walls painted with conventional paints, carpeted or finished floors, and standard roofing materials – have high emissivity. Glass that does not have a low-e coating also has high emissivity. In most situations, we don't have to specify high-emissivity surfaces, since these are typical. On the other hand, reflective or low-emissivity surfaces must generally be specified. The following tips will help in selecting and maintaining reflective or low-emissivity surfaces.

- While R-values are used to quantify an insulation's resistance to conduction heat transfer, they cannot be used to describe a reflective product's effect on radiation heat transfer. Sometimes manufacturers use an "equivalent R-value" to compare the reflective product to an insulation, but such equivalent R-values are only valid under the specific conditions of the test in which they were determined. In general "equivalent R-values" are not useful in evaluating a product's impact on energy use. Be skeptical of any claim of a high R-value or even a high equivalent R-value for reflective products.

- Because heat transfer by radiation requires an air gap or other transparent medium, reflective products have no effect at all when placed in direct contact with an opaque surface. As an example, the foil of a foil-faced rigid foam insulation has no effect whatsoever if the insulation fills the entire cavity.

- Keep in mind also that the size of the air gap matters. Some reflective products, such as reflective bubble insulation, have an air gap built into the construction of the material. If this air gap is small, however, its effect on radiation heat transfer will also be less important and the reflective product will be less effective.

- In order for a reflective product to remain effective, its reflectivity must remain high. Reflectivity declines if the product is dirty and often declines with age and exposure to the sun or weather over time. In contrast, maintaining surface quality is not a concern with insulation products, such as fiberglass or rigid foam insulation.

- In addition, obtaining a high initial reflectivity can be difficult. Paint additives, for example, are generally limited in their ability to make large changes in reflectivity and emissivity. Experimental data for one product indicated that reflectivity was changed by 15% or less.

- For many applications of reflective products, both the solar reflectivity and the far- infrared emissivity are important. A high infrared emissivity will be an advantage in certain situations (e.g., a hot roof or a radiant heater) and a detriment in many other situations (e.g., interior and exterior walls that are not sun exposed.) When analyzing any reflective product, we must consider the particular conditions under which it will be used and whether heat transfer from the surface to its environment is a benefit or detriment in that case.

- Considering the whole building, keep in mind that heat gains and losses of the building component on which these products are applied generally comprise only a relatively small part of the overall heat gains and losses in a building. If a reflective coating is applied to an exterior wall, for example, consider that walls typically account for about a quarter of overall residential building losses, while sun-exposed walls will be a fraction of that. Heating and cooling loads due to roofs are typically a greater share of the total and have more sun exposure, and so have greater potential for reduction.

- Reflective barriers are not generally considered a good application in houses located in climates where heating is dominant.
- Also consider the person interacting with the building as a system. Controlling radiation from occupants to building surfaces often improves comfort. This can result in additional energy savings since, as comfort is improved, occupants are more likely to reduce thermostat settings in the winter and increase them in the summer. Such savings are often not captured in analytical studies or laboratory results.
- The Federal Trade Commission, Bureau of Consumer Protection, publishes and enforces R-value testing and labeling requirements for home insulation. For more information about the rules go to *www.ftc.gov/bcp/conline/edcams/eande/index.html*.

Reflectivity and Emissivity Values

Values for reflectivity and emissivity of materials, paints, reflective coatings and low-emissivity products are often available from manufacturers or on websites of organizations such the Florida Solar Energy Center (FSEC) *www.fsec.ucf.edu*. For example, see the FSEC report, *"Laboratory Testing of the Reflectance Properties of Roofing Materials"* *www.fsec.ucf.edu/en/publications/html/fsec-cr-670-00*.

Data for a variety of surfaces can be found at *http://pdf.directindustry.com/pdf/impac-infrared/mikron-catalogue/4798-11038-_370.html*, (pages 370-374) a website compiled by DirectIndustry, and at *www.tak2000.com/data/finish.htm*, a website compiled by K&K Associates. The following references are also useful sources of data for surface properties:

Edwards, D.K., V.E. Denny and A.F. Mills, *Transfer Processes: An Introduction to Diffusion, Convection and Radiation*, 2nd Edition, McGraw-Hill, 1975.

Reagan, J.A. and Acklam, D.M., "Solar Reflectivity of Common Building Materials and its Influences on the Roof Heat Gain of Typical Southwestern U.S. Residences," *Energy and Buildings*, No. 2, Elsevier Sequoia, Netherlands, 1979.

A handy calculator for comparing heat loss through roofs with different surfaces is available at *www.roofcalc.com/*.

Product and Technology Reviews

The *Energy*Ideas Clearinghouse publishes *Product and Technology Reviews* for Northwest electric utilities. The reviews describe the technology, discuss available data, and suggest additional testing to verify energy saving claims. Products reviewed include:

- *Ultra Concrete Barrier rFOIL™*
  www.EnergyIdeas.org/documents/Factsheets/PTR/UltraCBF_rFOIL.pdf
- *Insuladd®*
  www.EnergyIdeas.org/documents/Factsheets/PTR/Insuladd.pdf

Additional Information

Northwest electric utilities can contact the *Energy*Ideas Clearinghouse for additional information on this or other energy technologies or products. Contact:

Phone: 1-800-872-3568
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WSUEEP08-006, updated March 2008

Even More on Heat Transfer Properties of Surfaces

Reflectivity, emissivity, transmissivity and absorptivity are properties of a surface that affect radiation heat transfer.

At any particular wavelength of radiation, these properties are all related to each other. However, these relations do not generally hold when talking about radiation at different wavelengths; that is, a surface that is reflective to radiation in one part of the electromagnetic spectrum may not be reflective to a different part of the spectrum. In fact, different behavior in different parts of the spectrum can be very important in the effectiveness of a reflective product.

A useful relationship to understand is that the absorptivity and emissivity of a surface are approximately equal[1] (see *Figure 1*). This means a surface that readily absorbs radiation just as readily reemits the energy it absorbs back to the environment. In other words, a dark surface absorbs heat easily, but also easily reemits energy (gets rid of its heat and cools down) when the surface is hot and the surroundings are cooler.

Another useful relationship when thinking about these properties is that for any particular wavelength of radiation, the sum of reflectivity and absorptivity must equal one for an opaque object (see *Figure 2*). That is, a surface that readily reflects a particular wavelength of radiation does not absorb much of that radiation, and vice versa. For example, a surface is shiny if it reflects much of the visible radiation (i.e., light) that falls on it or, equivalently, does not absorb much light. A surface may also be "shiny" (i.e., have high reflectivity and low absorptivity) to non-visible parts of the spectrum, such as UV radiation or infrared radiation. Remember we can think of emissivity and absorptivity as approximately equal, so low absorptivity also means low emissivity.

In evaluating sun-exposed building products or products used in solar applications, we are often particularly concerned with a surface's "total solar reflectivity" and its "far-infrared emissivity" because both these properties affect radiation heat transfer of a sun-exposed surface. Total solar reflectivity is the surface's reflectivity just to those wavelengths that compose solar radiation; i.e., it is the fraction of solar radiation[2] that is reflected by the surface and not absorbed by it. Far-infrared emissivity, usually referred to in product data as simply infrared emissivity, is the surface's ability to emit radiation in the far-infrared wavelengths, which we feel as heat[3].

Importantly, a surface absorbing solar radiation (of which only about half is infrared radiation) will reemit that radiation at a longer wavelength (100% infrared radiation). For this reason, to keep roofs cool in sunny weather when the surface of the roof gets hotter than its environment, it is desirable for the roof surface to have both high solar reflectivity and high infrared emissivity. This way, the portion of solar energy that is absorbed by the surface is then readily reemitted back to the environment at the longer, infrared wavelengths. As an example, an unpainted aluminum or tin roof with 70% solar reflectivity and 4% far-infrared emissivity will be warmer on a sunny day than a white metal roof with 70% total solar reflectivity and 85% far-infrared emissivity ("cat on a hot tin roof," not "cat on a hot white roof"). If on the other hand, we want to enhance solar heating of a surface, a surface with the opposite properties of a good "cool roof" is desired. That is, for a good solar absorber on, say, the tubes of a solar water heater, we want low solar reflectivity as well as low far-infrared emissivity.

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[1] *Technically, this is true only at steady state but is a useful approximation for non-steady state. It is also true only when speaking of total absorptivity (i.e., absorptivity over all wavelengths) and total emissivity. This relationship is derived from an energy balance on the surface. If a body does not emit all the energy it absorbs, then its temperature will not be constant and hence it will not be at steady state.*

[2] *Solar radiation consists primarily of 46% visible, 49% near infrared, and 5% ultraviolet radiation. Other components, such as far-infrared radiation, make up a tiny fraction.*

[3] *Total solar reflectivity and far-infrared emissivity are not simply related and so must each be experimentally determined independently of each other. Summed over the entire spectrum, reflectivity and emissivity must equal one. However, total solar reflectivity and infrared emissivity do not generally equal one since they pertain to radiation of different wavelengths; that is, they each pertain to different fractions of the spectrum of electro-magnetic radiation. Reflective paint additives, for example, may increase the total solar reflectivity of the paint, but may or may not decrease the infrared emissivity, depending on the paint product.*