Florida
Solar
Energy
Center

FSEC Publication DN-6
May 1994

Radiant Energy Transfer and Radiant Barrier Systems in Buildings[1]

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INTRODUCTION

In Florida and other southern climates we depend on a number of strategies to keep heat out of buildings. Mostly, these affect heat gains by conduction or convection. In the average house, insulating walls and ceilings primarily restricts conduction. Double-glazed windows restrict both conductive and convective heat gain.

We have largely ignored radiation—the third means of heat transfer—except in using window treatments and coatings that reflect, absorb or shade from solar energy. But research points to exciting potential for reducing heat gain in buildings by controlling radiation transfer in walls and ceilings through the use of radiant barriers.

RADIANT ENERGY TRANSFER

The transfer of radiant energy through building components is difficult to understand. It's even hard to simulate with computers. But if we grasp some basic facts about how radiant energy is transferred, we can use the theory to practical advantage.

Heat transfer by all three modes—conduction, convection, radiation—is always from the warmer to the colder region. But while conduction and convection can be transferred only through a medium, radiation can be transferred across a perfect vacuum. It needs only two regions of differing temperatures that "see" each other. Radiant energy travels in a straight line through space; it is the main means of energy transport throughout the known universe.

To better envision how radiation works, think of how your TV set operates: a transmitter emits an electromagnetic wave that travels through space; the wave is "seen" by the antenna and the TV converts it to a video image.

Like a television signal, radiation is a band of electromagnetic waves. With respect to buildings, two radiation bands are important: the solar spectrum and the far-infrared spectrum. Figure 1 illustrates the energy content and respective electromagnetic wavelengths of both of these spectrums.

On earth, regions of different temperatures that see" each other exchange energy via infrared radiation in the ≃ 4 to 40 micron wavelength band. (A micron is a millionth of a meter.) Sunlight consists of much shorter wavelengths: ≃ 0.2 to 2.6 microns. Unlike the visible portion of the solar spectrum (≃ 0.4 to 0.7 microns),

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[1] This document is FSEC Publication DN-6, provided for the Energy Resource CD-ROM by the Florida Energy Extension Service, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: May 1994. First published: 1986.

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The Florida Energy Extension Service receives funding from the Energy Office, Department of Community Affairs, and is operated by the University of Florida's Institute of Food and Agricultural Sciences through the Cooperative Extension Service. The information contained herein is the product of the Florida Energy Extension Service and does not necessarily reflect the view of the Florida Energy office.

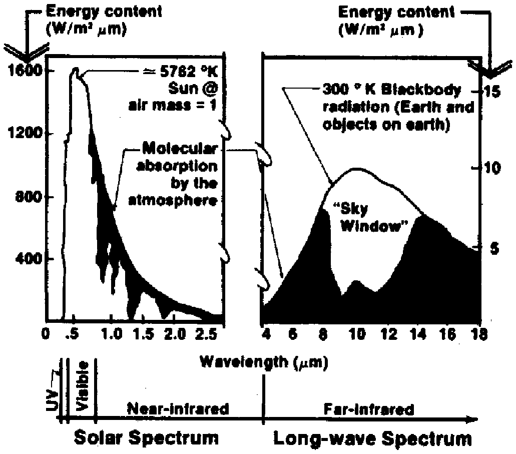

Figure 1. Energy content and electromagnetic wavelengths of the solar and long-wave spectrums.

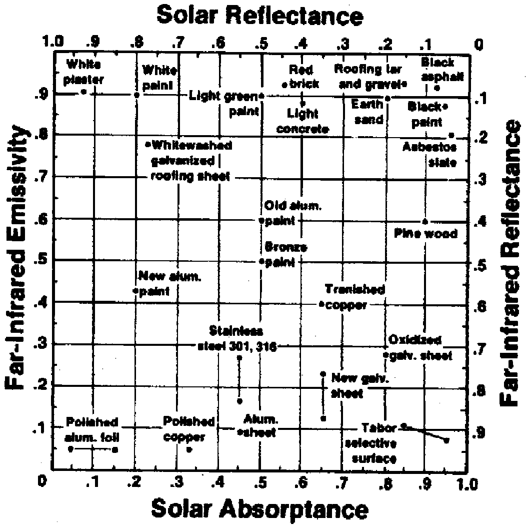

Figure 2. Solar and far-infrared characteristics of some common opaque building materials.

infrared radiation is invisible. There are both "near-infrared" and "far-infrared" radiation. The latter is sometimes called "thermal" or "long-wave" radiation. The effect of both is heat; in summer, this heat is *unwanted*. Radiant barrier systems are a method of stopping far-infrared radiation from getting into building interiors and increasing air-conditioning loads.

RADIANT BARRIER SYSTEMS

Radiant barrier systems comprise an airspace with one or more of its boundaries functioning as a radiant barrier. Radiant Barriers are materials that restrict the transfer of far-infrared radiation across an airspace. They do this by reflecting the radiation that strikes them and—at the same time—by not radiating energy. A material that has this capability is said to have a very ***low emissivity***. The lower the emissivity, the better the radiant barrier.

Emissivity values range from 0 to 1. Any material's emissivity plus transmissivity plus reflectivity must always equal one. A material with an opaque surface has a transmissivity of zero, so its emissivity equals one minus its reflectivity. Materials that radiate very well and absorb a large percentage of the radiation that strikes them have high emissivities. Most common building materials, including glass and paints of all colors, have high emissivities near 0.9. Such materials are capable of transferring 90% of their radiant energy potential. These materials are ineffective barriers to radiant energy transfer. On the other hand, aluminum foil is an excellent radiant barrier. It has a low emissivity (0.05), therefore, it eliminates 95% of the radiant transfer potential.

Aluminum foil is a good thermal conductor. Consequently, it has an extremely low R-value. However, if it is placed between materials that are attempting to transfer thermal energy by radiation (rather than conduction) and if it is separated from these materials by an air layer, the foil effectively eliminates the normal radiant energy exchange across the airspace. This is the operating principle of radiant barrier systems and it often can be used to reduce the flow of heat through building components.

SUNLIGHT AND HEAT

A material's response to far-infrared radiation can be quite different from its response to gunfight. Since a large percentage of sunlight is in the visible range, we characterize materials by color and clarity. We know, for example, that white paint reflects far more solar radiation than does black paint. But in the farinfrared band, white paint absorbs slightly *more* radiation than does black paint. This surprising fact tells us that we cannot judge a material's far-infrared properties by sight. Figure 2 compares the solar and far-infrared characteristics of some common opaque building materials.

Figure 2 shows only opaque materials, but transparent materials also respond differently to solar and far--infrared radiation. Common window glass, for example, transmits more than 85% of incident sunlight but absorbs more than 85% of the far-infrared energy that strikes it. The "solar greenhouse effect" results, in part, from this phenomenon. Solar energy readily passes through the glass and is absorbed by the opaque surfaces within the space. When these heated surfaces begin to radiate to cooler surfaces, the glass absorbs most of this far-infrared radiation, trapping much of the original solar gains inside the space as heat.

ROOF SYSTEMS

A Florida house attic offers excellent potential for use of radiant barrier systems: first because the roof is the surface most exposed to solar radiation, and second, because most of the solar gain absorbed by the roof is transmitted down to the attic floor by radiation. Since the attic airspace separates the hot roof surface from the ceiling, no heat will move down by conduction, and the heat will not convect down from the hot roof to the ceiling because heated air rises.

If you place a radiant barrier (layer of foil) in the airspace between the hot roof deck and the cooler attic floor (insulation), you can eliminate almost all radiant heat transfer. Studies at the Florida Solar Energy Center (FSEC) indicate that, under peak day conditions, total heat transfer down through attics can be reduced by more than 40% in this way. Figure 3 shows air and ceiling insulation temperatures for side-by-side attic spaces monitored at FSEC. Temperature differences across the insulation are significantly reduced by the radiant barrier system.

Heat transferred upward through attics (winter heat loss) won't be affected as much because a greater part of total upward heat transfer occurs by convection. That is why radiant barriers in roof systems are a more effective *cooling* rather than *heating* strategy and why they may be of great benefit to southern homeowners. In a typical Florida home, a radiant barrier roof could cut annual cooling loads by 4-8% and peak cooling loads by 9% depending on the level of attic ventilation. Good ventilation requirements, to meet the upper end of these savings, can normally be provided by continuous soffit and ridge vents.

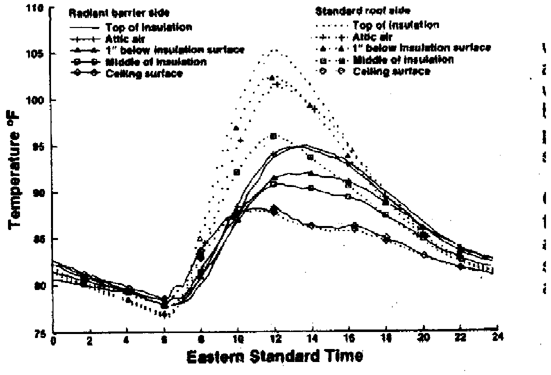

Figure 3. Unvented radiant barrier roof versus unvented standard roof (both ceilings with 6" figerglass insulation).

WALL SYSTEMS

The predominant heat transfer direction through walls is horizontal. Therefore, the overall performance of radiant barrier systems in walls is less dependent on heat flow direction than it is in roofs. But the seasonal performance of a radiant barrier wall system differs for other reasons. In both winter and summer, the radiant barrier airspace will drastically reduce the "sol-air effect." The sol-air effect, caused by solar radiation striking the exterior surface of the building, raises the surface temperature above that of the ambient air. This increases heat gain into the building in summer but reduces heat loss in winter. Radiant barriers drastically reduce this sol-air effect.

An external airspace and radiant barrier will decrease the wall's effective temperature differential in summer but increase it in winter. This means that the radiant barrier will largely negate the benefit of solar radiation in winter. But in much of Florida, where heat gains are a problem most of the year, the winter sol-air liabilities of exterior radiant barrier systems are offset by their summer benefits.

CLIMATE

Sol-air effects, vary with time of day, season, orientation and ambient conditions, so many radiant barrier systems are climate dependent. Exterior radiant barrier systems are most beneficial on roofs and east and west wails in summer. Their greatest winter liability occurs on south walls.

Attic radiant barrier systems may be effective in all climates, but claimed comfort improvements and lower energy consumption in winter have not been firmly established by research. FSEC data show that walls with exterior radiant barrier airspaces vented with ambient air do not perform well in winter. Unvented walls perform much better in winter, and if the radiant barrier airspace is on the interior side of the wall, its performance does not appear to depend on seasonal effects.

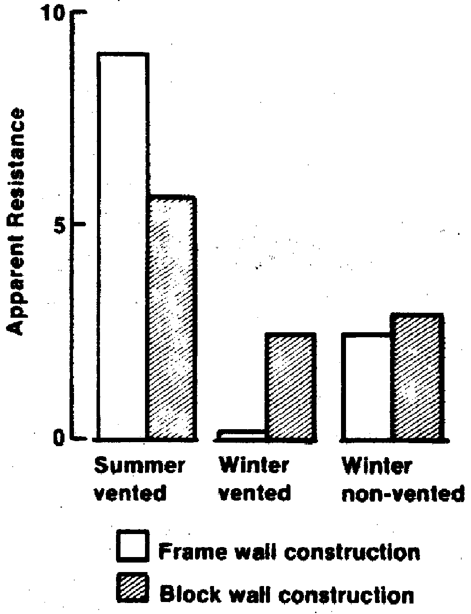

Figure 4. Apparent resistance of exterior radiant barrier systems under peak seasonal conditions in central Florida.

In full-scale tests conducted at the FSEC Passive Cooling Laboratory seven different wall systems were tested. Five systems contained radiant barrier systems, and two did not. Interior and exterior radiant barrier systems showed significant seasonal performance variations as demonstrated in Figure 4.

Interior radiant barrier systems did not show seasonal performance dependence. They maintained an apparent thermal resistance between R-5 and R-6 in both seasonal extremes. As a consequence, they appear to be an effective thermal resistance strategy for a wide range of climate conditions. (Avoid this strategy if you need to couple massive wall systems to the building interior for thermal storage benefits.)

For climates with severe cooling needs and limited heating requirements, exterior radiant barrier systems can perform better than interior systems—this is especially true of peak load performance. However, because of their seasonal performance characteristics much more climate consideration must be given to exterior radiant barrier systems.

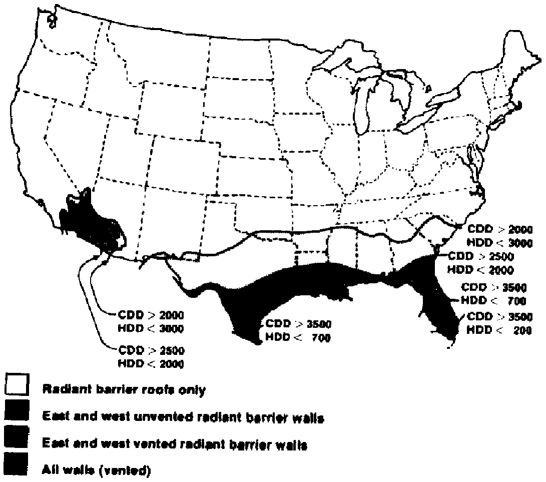

Figure 5. Climatic region recommendations for use of radiant barriers.

Using these criteria, FSEC has developed general climate guidelines for the use of radiant barriers. These guidelines are graphically depicted in Figure 5.

Attic or roof radiant system are likely to be effective where there are 3000 or fewer annual heating degree days and 2000 or more annual cooling days (both measured at a base temperature of 65°F).

Requirements are more stringent for radiant barrier wall systems. Winter penalties are high for south walls with exterior radiant barriers; shading is a better alternative. Usually north walls are not likely candidates because they get little direct sun. But for unshaded east and west walls, radiant barrier construction is an effective option in climates with 2000 or fewer heating degree days and 2500 or more cooling degree days.

Venting is suggested only where there are small winter loads (700 or fewer heating degree days) and severe summer problems (3500 or more cooling degree days). In climates where there are 200 or fewer heating degree days and 3500 or more cooling degree days, vented radiant barriers could be justified for all exterior walls.

BUILDING TYPE

Exterior radiant barriers best apply to skin-load-dominated buildings such as homes, rather than internal-load-dominated structures such as office buildings. Multistory commercial buildings are not good candidates because they do not have dominating roof loads. Even multistory residences located in borderline climates may not warrant radiant barrier protection.

Certain large buildings, however, ***can*** benefit from radiant barrier construction. For example, some open-bay manufacturing buildings will benefit from interior radiant barriers if radiant transfer between the occupants and the building skin otherwise dominates comfort conditions. In the same way, radiant barriers can be used in agricultural buildings that shelter livestock (most living things have high emissivities).

Radiant barriers can reduce energy consumption and/or improve comfort in many buildings. But the radiant barrier strategy and construction technique will have to respond to individual building needs.

CONCLUSIONS

Summer heat gain can be driven by forces different from those that cause winter heat loss. Insulation techniques, therefore, are often different for climates that are dominated by cooling loads. In Florida and similar climate regions, radiant barriers offer significant potential for impeding solar-driven heat gains in buildings. Their effectiveness depends on their location in the building structure, direction of heat flow, building type and occupant needs. Widespread use of radiant barriers in overheated climates will prove their potential for building energy conservation.

FOR FURTHER INFORMATION

Fairey, Philip, "Designing and Installing Radiant Barrier Systems," *Design Note 7*, Florida Solar Energy Center, Cape Canaveral, FL, June 1984.

Fairey, Philip, "Effects of Infrared Radiation Barriers on Effective Thermal Resistance of Building Envelopes," proceedings of the ASHRAE/DOE Conference on Thermal Performance of the Exterior Envelopes of Buildings II, Las -Vegas, NV, December 1982.

Fairey, Philip, et al., "The Thermal Performance of Selected Building Envelope Components in Warm,Humid Climates," proceedings of the 1983 ASME Solar Division Conference, Orlando, FL, April 1983.

Van Straaten, J. F., *Thermal Performance of Buildings*, Elsevier Publishing Company, New York (1967) pp. 142-160.

Wilkes, G. B., "Reflective Insulation," *Journal of Industrial and Engineering Chemistry*, 31D:832. July 1939.