Radiant Barriers in Roof Insulation Systems

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With today's emphasis on sustainable building construction, insulation systems are an important part of controlling heat loss or gain which directly impacts a building's energy requirements. While insulation materials have been around for some time, there are new concepts and products on the market intended for building applications. This paper looks at the application of radiant barriers in roof insulation systems including an investigation of proper installation methods and how that might impact the performance of the system.

Key Words: Radiant Barrier, Insulation, Roof Insulation, Attic Insulation

Introduction

Buildings require a substantial amount of energy to heat and cool interior spaces. Heating and cooling costs are directly related to how much heat is gained or lost through a building's exterior. The heat loss or gain through roofs account for 20-30% of the total heat transfer through the building envelope (DOE, 1991). As energy costs increase, building owners look at ways to reduce operational costs. Energy codes are becoming more stringent and are allowing less energy use. The public is becoming more concerned with issues related to energy consumption. An obvious area to reduce building energy use is to incorporate better insulating systems.

Radiant barriers can generally be described as a sheet of aluminized material which resembles a sheet of aluminum foil. They may be shiny on one or both sides, may utilize a different material as a backing, and may sandwich another material for rigidity or additional insulating properties. A radiant barrier may be perforated to allow the passage of moisture so the material won't act as a vapor barrier. The selection of a particular variation is dependent on the application and installation methods used for the barrier.

Heat is transferred into, or out of, a building in 3 ways: radiation, conduction, and convection. Conventional fiberglass insulation primarily insulates against heat transfer due to conduction. As the name implies, radiant barriers are intended to reduce heat transfer due to radiation. Radiant barriers do not offer any resistance to heat transfer due to conduction (Energy, 2008), therefore they do not replace the use of conventional fiberglass insulation. Radiant barriers are intended to supplement conventional insulation methods. (Ober, 1990).

Case Study

A local building owner purchased a 6000 square foot metal building to be used as a retail store, parts storage, and repair shop for a large truck maintenance facility. The building manufacturer offered a radiant barrier product as an option in the roof and wall insulating systems. The building manufacturer claimed that using two inches of conventional fiberglass insulation along with a radiant barrier would perform better than their standard application of four inches of conventional fiberglass insulation. The radiant barrier option was offered with no cost difference between the two systems. Were the manufacturer's claims as to the effectiveness of the radiant barrier legitimate?

The owner chose to incorporate the radiant barrier which, as described by the building manufacturer, was to be placed between the conventional fiberglass insulation and the metal roof deck as shown in figure 1. The construction personnel on site were not aware of the radiant barrier material being incorporated into the project and installed the roof deck with only the conventional fiberglass insulation. A 2-inch fiberglass blanket insulation with a white vinyl covering was placed between the interior structural frame and outer metal roof deck. The majority of the roof system had been installed before the mistake of leaving out the radiant barrier was caught. The manufacturer's solution was to apply the radiant barrier to the underside of the interior steel framing as indicated in figure 2. The radiant barrier was applied using silver metal tape and screws to the underside of the steel framing approximately 6 inches below the fiberglass insulation.

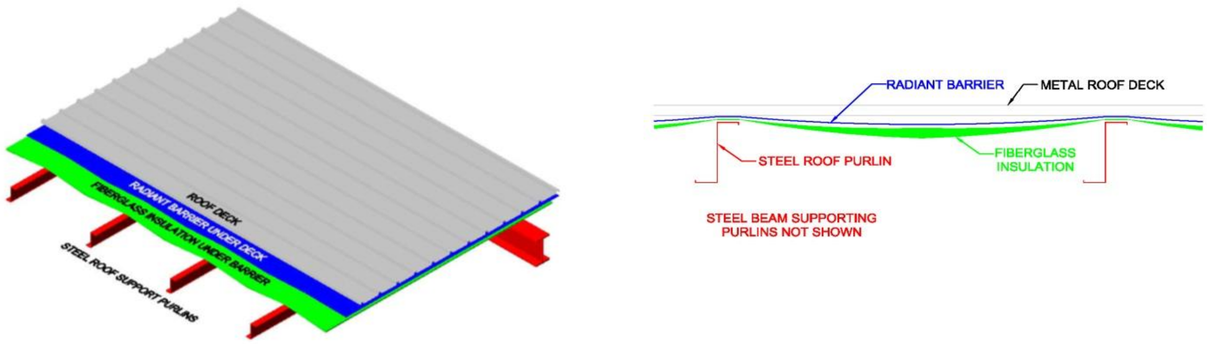

Figure 1: Proposed barrier installation under roof deck.

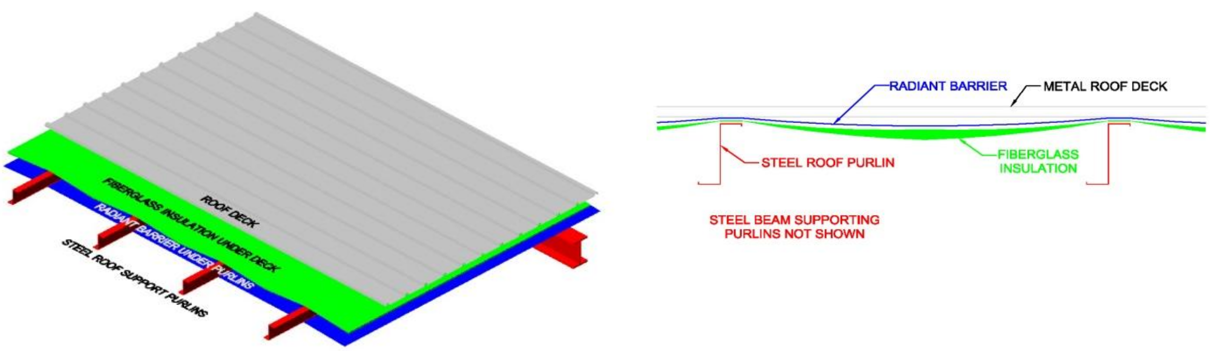

Figure 2: Barrier installation under support purlins.

The owner questioned what effect the alternative placement of the barrier had on its performance. The original plan called for the radiant barrier to be placed just below the metal deck, between the deck and fiberglass insulation. What effect did placing the barrier six inches below the fiberglass insulation have on the effectiveness of the barrier?

There was also another non-performance issue that occurred with the alternative installation. The building was not designed to have a secondary interior ceiling system, so the radiant barrier was visible. With 6-inch metal purlins spaced five feet apart the barrier, attached below the purlins, was relatively loose and moved with air currents caused by open doors, louvers and other air infiltration. The barrier selected was aluminum faced on both sides and with the movement, created a shimmering effect which was not acceptable to the owner (Johnson, 2008).

Method

Two information sources were found for radiant barrier application and installation. Sales information from several leading companies manufacturing and selling radiant barriers was studied to determine the claims made as to the benefits of using radiant barriers and the applications suggested. This information was then compared with research conducted by third parties including both state and federal agencies that have studied and tested the use of radiant barriers.

Results

Legitimate third party and governmental research focused on utilizing radiant barriers in residential attic applications. No research was found field testing the use of radiant barriers in a commercial, low slope roof application similar to the case study. As stated in a document published by the US Department of Energy (DOE), "*New insulation products are developed by individuals or other organizations that sometimes have insufficient technical knowledge of thermal performance evaluation. Therefore, an unbiased third party needs to take a leading role in measuring properties of insulation materials, developing test methods, and disseminating information and recommendations about the thermal performance of insulation to the building industry*" (ORNL, 2008).

In general, sales claims reference research results published by two third party entities: the Florida Solar Energy Center (FSEC) and the Oak Ridge National Laboratory (ORNL). These studies were done in 1985 and 1986, respectively. No new research was found that significantly altered or added to the findings in these reports.

While sales literature tends to offer radiant barrier benefits in many different applications, research shows that beneficial energy savings due to the application of radiant barriers is somewhat limited. One manufacturer's statement published by Radiation Insulation Manufacturer's Association (RIMA) states "We are not aware of any studies that confirm or refute [radiant barriers] usefulness regarding home heating and cooling applications" (RIMA, 2002).

The general principals of radiant barrier operation are relatively simple but depend greatly on how and where the materials are installed. The primary benefit of attic radiant barriers is to reduce cooling loads in warm or hot climates (DOE, 1991).

Discussion

Studies and testing of radiant barriers for building applications began in the early 1980's when the Florida Solar Energy Center (FSEC) indicated that the use of a radiant barrier in an attic would significantly reduce heat transfer through the ceiling. The Tennessee Valley Authority (TVA) and ORNL initiated field tests in 1986. With different protocols and other discrepancies in the testing methods a substantial and sometimes conflicting database was developed (Ober, 1990). Today, advertising claims often exaggerate the effectiveness of radiant barrier use.

Radiant Heat Properties

To understand how radiant barriers work, the following is a list of properties about radiant heat transfer *into* an object (What, 2008):

- Radiant heat is an infrared waveform, much like visible light, that travels through a space – there is no temperature involved, only energy.
- When radiant heat waves strike an object they are reflected and/or absorbed. When they are absorbed they heat the surface of the object. Heat spreads through the object via conduction.

The ability of an object or material to reflect radiant heat waves is known as its reflectivity. This is one property of a radiant barrier. Another important property of a radiant barrier is its emissivity. Emissivity is a function of the amount of radiation that is emitted from an object. The following are properties of radiant heat transfer from an object (What, 2008):

- All objects, because they contain heat, radiate infrared rays from their surfaces into surrounding space.
- If two objects are identical but covered with materials of different emissivity (say 90% vs. 5%), there is a drastic difference in the amount of radiation that would be emitted from the object surfaces.

Aluminum foil has a low emissivity and a high reflectivity for infrared radiation. Aluminum foil will reflect most radiant heat that strikes it (rather than absorb it). When heated, aluminum foil does not emit much radiant heat due to its low emissivity. Most building materials such as brick, paper, asphalt, wood, glass do not reflect much radiant heat and when heated these materials re-emit radiant heat at a rate of 80-94%.

One interesting note is that a common mirror has a high reflectivity to visible light but to infrared it has about the same reflectivity as black paint. This demonstrates the emissivity and reflectivity of materials can vary widely. Aluminum foils vary from one product to another with emissivity and reflectivity variations from 2% to 72% (a 2000% difference) (What, 2008). This further complicates comparison of different radiant barriers. There are many problems in measuring emittance with no modern reference standards and the most available data published in the 1960's (Heat, 2008).

An often overlooked property of radiant heat transfer is that both reflection and emission must occur in *space*. If there is no air space and the radiant barrier is touching another object, heat conduction through solids occurs. An air space of 1" or more is generally accepted as the minimum. Figure 3 shows radiation and conduction in the case study.

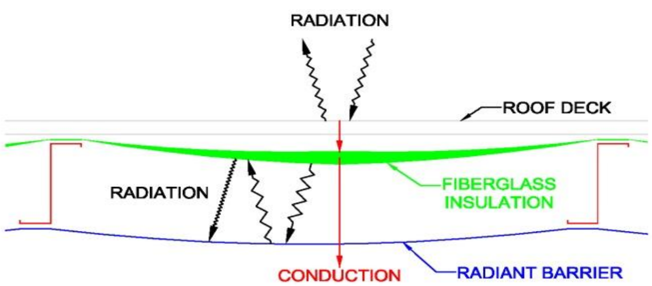

Figure 3: Radiation and conduction thru a metal roof system

Application Options in Attic Spaces

In an attic installation there are four possible installation methods for a foil radiant barrier:

- Attached to the bottom side of the roof sheathing with the foil face facing down toward the attic air space.
- Draped over the top of the roof rafters before the sheathing is applied allowing a small air space between the foil and the sheathing in addition to the air space below the foil on the attic side.
- Attached to the bottom of the roof rafters leaving a larger space between the barrier and the underside of the sheathing.
- Laid on top of the ceiling joists (attic floor) over the ceiling insulation (which is between the joists).

Limiting Investigation to Warm Climate Conditions

When testing these installation methods, research methods consider both heating and cooling modes. The referenced studies and research investigate radiant barrier performance for both hot and cold climates. Radiant barriers are more effective in hot climates (Energy, 2008). Other reports indicate there is a heating penalty when using them to decrease heating loads in cold climates (Solar Radiation Control, 2008).

While radiant barriers reduce indoor heat loss in winter they can also reduce beneficial solar warming during the day. Even though advertising makes claims of energy conservation in both climates, it is reasonable to limit the discussion to warm climates based on available prevailing research.

A Look at Radiant Heat Flow in Warm Climate Conditions

Radiant heat is transmitted from the sun through the atmosphere to the outside surface of the roofing material. No solar radiation is directly transmitted through the opaque roof. The roof surface is heated due to absorption of the radiant energy with some radiant energy being reflected. Heat is then transmitted via conduction to the underside of the roof sheathing. Without a radiant barrier, wood sheathing has a relatively high emissivity. Radiant energy is re-emitted from the sheathing surface thru the attic air space to the attic floor insulation below.

If a foil material is attached directly to the underside of the sheathing, no reflection occurs on the top side in contact with the wood. Since radiation is not transmitted through an opaque surface there is no radiant heat to reflect. However the low emissivity of the foil face on the bottom of the sheathing drastically reduces the amount of radiant heat emitted from the surface to the attic space below.

One additional element that is important, but left out of most discussions, is the fact that the heated roof contains heat energy that will be transferred to a cooler medium. If it is not transferred to the attic space via radiation there are three additional possibilities: the heat energy could be radiated back to the outside from the roof surface, it could be transferred to the outside air via conduction, or it could be transferred to the attic air via conduction. At least one report explains the low effectiveness of radiant barriers in attic installations to this fact. The MIMA report notes "*Radiant barriers delay the time of the peak ceiling heat flow by less than one hour, indicating that radiant barriers will not significantly reduce energy costs by shifting the load to off peak periods*" (Ober, 1990). The idea is that the heat in the roof system is eventually transferred to the ceiling via conduction even if radiant transfer is eliminated. Remember radiant barriers do not inhibit conduction.

With the other options the foil does not touch the bottom of the sheathing. The sheathing is able to emit radiant energy and the foil below reflects most of this back to the sheathing. The sheathing would then reabsorb the reflected energy and absorb it adding heat to the sheathing. While studies show this does not increase roof temperatures significantly (RIMA, 2002), it does not demonstrate that radiant barrier position is important based on refection and or emissive properties alone.

Which Installation Method Works Best

One of the problems with evaluating radiant barrier performance is there are so many other factors influencing the results that cannot be controlled or measured (Harmon, 2001). While all of the attic installation methods are considered acceptable, testing has indicated the attic floor application produces the best results (DOE, 1991).

A major problem with this application is the reduction of reflectivity due to dust accumulation on the reflective surface. Even weathering due to exposure to airborne contaminants can reduce typical new aluminum reflectance values from 60% to about 40% after a few years. Likewise emittance values can increase from 30% to 70% due to weathering.

There are no test results indicating the change in performance of radiant barriers over time.

Conclusions

The only authoritative studies that have been produced to study the effectiveness of radiant barriers have only been done in applications where the barriers have been utilized in residential attic spaces. Major government investigations into the use of radiant barriers are limited and most were done in the 1980's. Advertising claims oftentimes rely on loose interpretations of limited reports.

The use of radiant barriers seems to reduce the amount of heat gain from solar heating but some studies question the cost effectiveness of radiant barrier installation arguing that in some cases the addition of convention fiberglass insulation (or other material resisting conductive heat transmission) would be more suitable (ORNL, 2002).

While not the topic of this paper, care must be observed when installing radiant barriers as aluminum foil is impervious to water transmission and is thus a good vapor barrier. Guidelines for installing vapor barriers must be considered in the application and selection of vapor barrier materials. Some materials are perforated to reduce the chance of condensation on the wrong side of a radiant barrier installation.

Most insulation requirements addressed by codes involve R (Resistance to heat flow) or U (rate of heat flow) factors. These factors are for convective heat flow and *not* radiant or convective flows. Advertising claims may state R values for radiant barrier materials. Equivalent R values for radiant barriers have not been established by any recognized governing authority.

Back to the Case Study

While testing has not been done on commercial low sloped metal roofs used in metal building construction, much of the knowledge about radiant barrier performance and limitations can be applied to formulate reasonable answers to the owner's questions. Even test data on attic installations is not conclusive as to the effectiveness of radiant barriers but a lot of information is available to assist in the decision on how and where to apply radiant barrier technology.

The first question addresses the effectiveness of radiant barriers in lieu of conventional fiberglass insulation. Since the two insulation types address different types of heat transfer, one type does not necessarily replace the other type. While a radiant barrier might reduce cooling load in the summer, the fiberglass insulation might perform better in the winter. The idea that a radiant barrier is equivalent to two inches of conventional fiberglass insulation has no solid foundation.

The next question addresses the alternate installation of the radiant barrier to the underside of the steel roof support structure instead of the originally planned installation between the roof deck and fiberglass insulation. The originally planned installation method would have rendered the radiant barrier useless since there would have been no significant air space on either side of the barrier. An air space of one inch or more is required on at least one side of the barrier. Without an air space no reflection or reduction in emission of radiant energy is possible. Heat transfer takes place via conduc1tion right through the reflective material.

The barrier to be installed was reflective on both sides. The barrier might have been installed below the conventional fiberglass insulation above the roof support structure. This would most likely provide for a tighter fit and reduce the amount of light shimmering due to material movement that was objectionable to the owner. Installation of the barrier below the joists is probably as effective from a performance standpoint and either one of these alternative installations would have the intended effect.

Installing the barrier on the underside of the purlins creates an air space above the barrier. A barrier could be installed with the reflective side up and a white vinyl backing facing down. This scenario would probably fit best with the owner's requirements. With heat flow downward in the summer months the barrier would reflect radiation on the reflective top, but the effect of lower emissivity on the bottom would be reduced by the white vinyl. Any heat *conducted* thru the barrier from the air space above would be re-radiated below due to the higher emissivity of the white vinyl compared to a reflective foil with lower emissivity values.

Reflective radiant barriers have been utilized since the space race of the 1960's where temperature extremes are encountered in the vacuum of space due to solar radiation. Our atmosphere prevents this phenomenon from occurring on earth's surface. While there seems to be some merit to the application of radiant barrier technology in building construction, more testing is necessary to establish more definitive guidelines for its application and measurement of performance.

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