Energy-Efficient Roof Designs with Single-Ply Roofing Membranes

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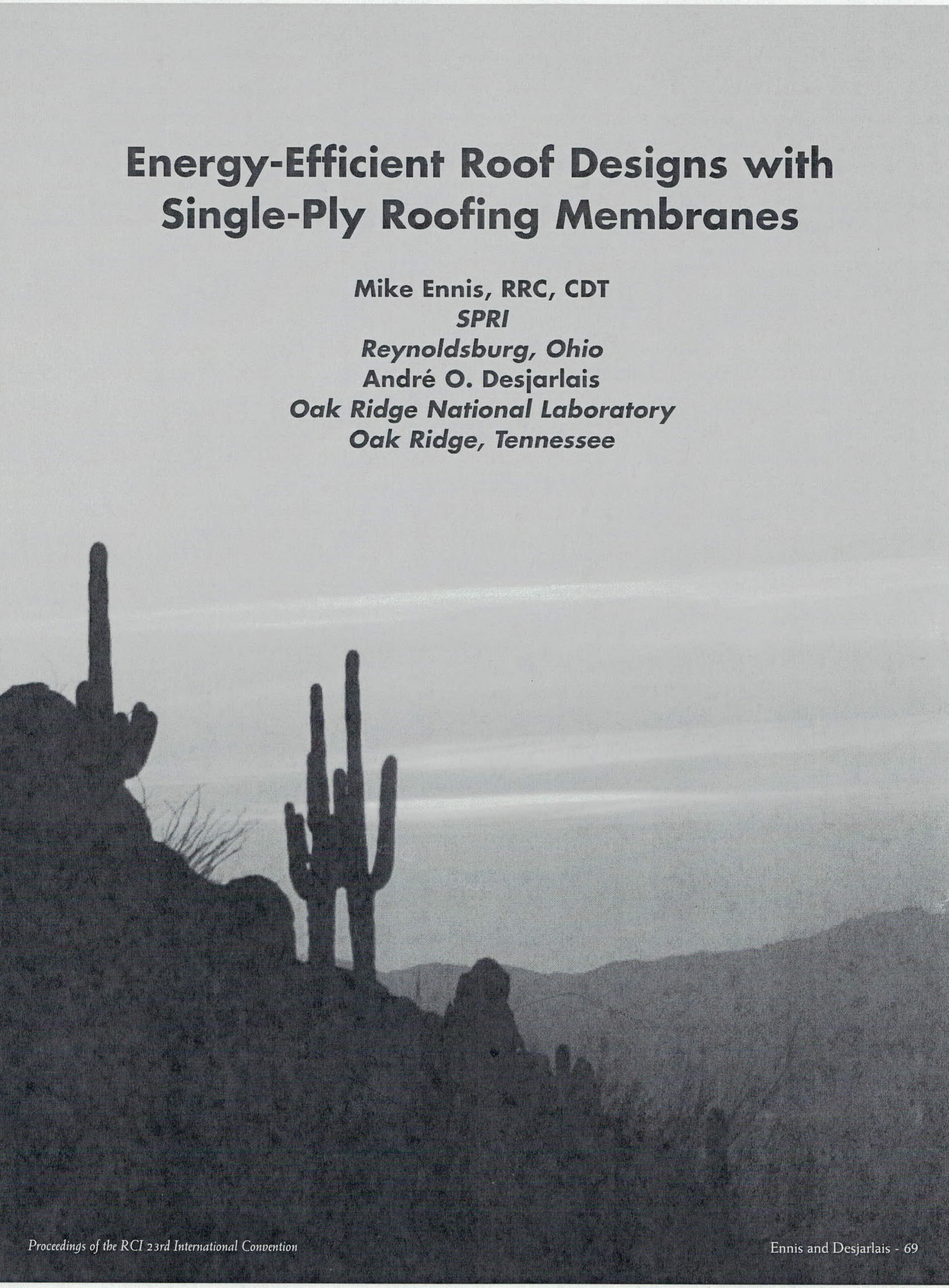

ABSTRACT

Energy-efficient building design is becoming increasingly important as energy costs continue to escalate. In addition, energy efficiency is one of the primary building blocks for sustainable and green building design.

This presentation will summarize research programs that have been sponsored by SPRI and conducted at Oak Ridge National Laboratory. These programs covered:

1. The use of reflective roof single-ply membranes and their value in energy-efficient roof design. This research discusses the long-term impact of using highly reflective roof membranes and the importance of both reflectivity and emissivity. It also discusses geographic locations where the benefits of these membranes are maximized.
2. The energy-efficient benefits of ballasted single-ply roof systems. In this study, the long-term energy saving benefits of both stone-ballasted and paver-ballasted single-ply roofing systems are summarized.
3. The energy-saving benefits of these systems are compared with each other, and the benefit of using thermal insulation in conjunction with these systems is provided.

SPEAKERS

Mike Ennis is a graduate of Ohio State University with a degree in environmental sciences. He worked for The Dow Chemical Company in various research and product development capacities for 30 years and was the North American Application Technology Leader for commercial products in Dow's Building Solutions business unit. Mike is past president of SPRI, Inc., the association representing flexible sheet roofing membrane manufacturers and component suppliers, and is currently its technical director. Mr. Ennis is a member of RCI and is a Registered Roof Consultant and is a member of the Construction Specifications Institute and has received his Construction Documents Technologist certification. He is also a member of the International Concrete Repair Institute (ICRI), The American Architectural Manufacturers Association (AAMA), the Sealant Waterproofing and Restoration Institute (SWRI), the National Roofing Contractors Association (NRCA), and the Western Construction Consultants Association (WESTCON).

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André Desjarlais is the group leader for the Building Envelope and Materials Research Programs at the Oak Ridge National Laboratory. He has been involved in building envelope and materials research for over 35 years, first as a consultant and, for the last 16 years, at ORNL. He is active in the building industry, participating in ASHRAE, ASTM, Cool Roof Rating Council, SPRI, ARMA, Roof Industry Committee on Weather Issues, Federal Roofing Committee, and the Building Environment and Thermal Envelope Council. Areas of expertise include building envelope and material energy efficiency, moisture control, and durability.

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INTRODUCTION

Interest in energy-efficient building design has never been higher. There are many reasons for this, including:

- Double-digit increases in oil, natural gas, and electricity rates since 2005.
- More stringent energy-code requirements designed to decrease energy use by 30%.
- Energy-code requirements designed to shift the peak energy usage to later in the day.
- A focus on sustainable and green building practices that require more energy-efficient buildings.

Many strategies can be employed to reduce the energy usage of a building. This report focuses on methods that can be employed to design more energy-efficient roof systems. Specifically, it will focus on research that has been conducted at Oak Ridge National Lab with the financial support of SPRI, Inc., the trade association representing the single-ply roofing industry, and the Department of Energy. This research explored the energy efficiency of roofing assemblies using highly reflective single-ply roof membranes and ballasted single-ply roof membrane systems. This report will also examine the synergistic impact of insulation and the efficiencies of adding additional insulation to the roof system.

Roof consultants play a major role in assisting their clients with the design of energy-efficient roof systems. Consultants may use the information and strategies contained in this report to help their clients make informed decisions.

HIGHLY REFLECTIVE SINGLE-PLY ROOF SYSTEMS

How does a highly reflective roof surface increase energy efficiency?

Someone standing under a white awning on a hot summer day will be cooler than someone standing under a black awning. This is because the sun generates a tremendous amount of energy in the form of electromagnetic radiation. Part of this energy is absorbed by the earth's atmosphere; the remaining solar irradiance hits the earth's surface. Some of the solar irradiance that hits the earth's surface is reflected back to the atmosphere, and some is absorbed. Once absorbed, the energy is either emitted back to the sky or is released to potentially warm materials below.

All of these phenomena occur within a fraction of a micrometer of the impacted surface and are defined as follows:

Absorptance (a) - the fraction of energy that penetrates the surface.

Reflectance (r) - the fraction of incident radiation that is reflected by the surface.

Emittance (e) - measures how well the surface radiates energy away from itself compared to a black body operating at the same temperature.

The amount of energy that is available to warm materials below the impacted surface is dependent upon the reflectivity and emissivity of the impacted surface. As an example, temperature measurements made at Oak Ridge National Laboratories' (ORNL's) Buildings Technology Center (BTC) show that a roof surface with a high level of reflectivity is typically only 5°F (3°C) warmer than the ambient air temperature, while a dark absorptive roof can exceed the ambient air temperature by more than 75°F (40°C). (Miller, et al., 2002) This means that on a 90° day, the roof surface of a highly reflective roof would be approximately 95°F, while the surface of a black membrane would be approximately 170°F.

This has a direct impact on the amount of heat that will flow into the building. Heat flow is defined by the following relationship:

$$Q = \Delta T / R$$

Where:

Q = heat flow

ΔT = temperature difference between the exterior and interior boundaries

R = resistance to heat flow across the system

Assuming that a roof system with a highly reflective roof and one with a black roof surface have the same R-value through the assembly and the same interior temperature, the heat flow will be higher in the assembly with the black surface. This is because the temperature difference between the exterior and interior boundaries will be much greater.

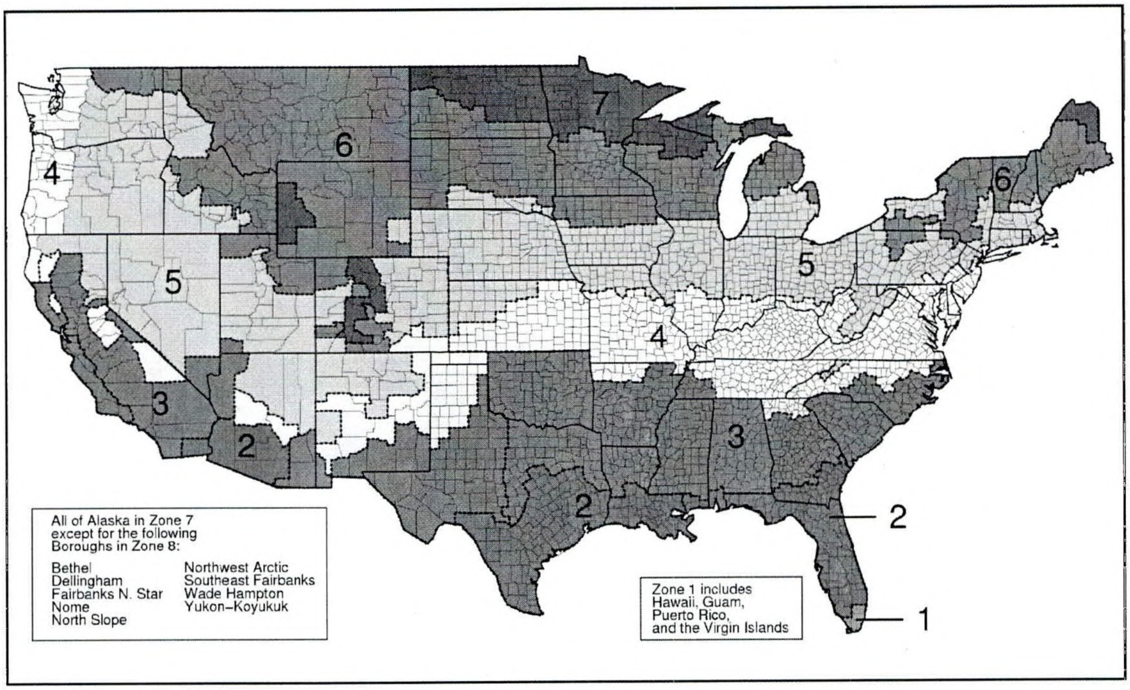


Figure 1 – International Energy Conservation Code (IECC) Climate Zones for the United States.

Since a highly reflective roof surface increases energy efficiency by reflecting incident radiation, these roof coverings are most effective in a cooling-dominated climate. This is a climate where the bulk of the energy bill to condition the space is used to provide cooling. This would include DOE/IECC Zones 1, 2, and the southern part of Zone 3. During the heating season, highly reflective roof membranes may cause an increase in energy usage (*see Figure 1*).

Another benefit of a highly reflective roof system is that the use of these systems will shift the peak energy load so that it will occur later in the day. This is an excellent feature in areas where the power grid is near capacity. In these areas, shifting some of the energy load so that it occurs later in the day helps to spread the load over the entire day and avoid extremely large peak demands that could potentially cause power outages in the grid.

What is a highly reflective roof?

Definitions for highly reflective roofs characterize the initial reflectivity, emissivity, and in some instances, a measure of the retained reflectivity of the roof system.

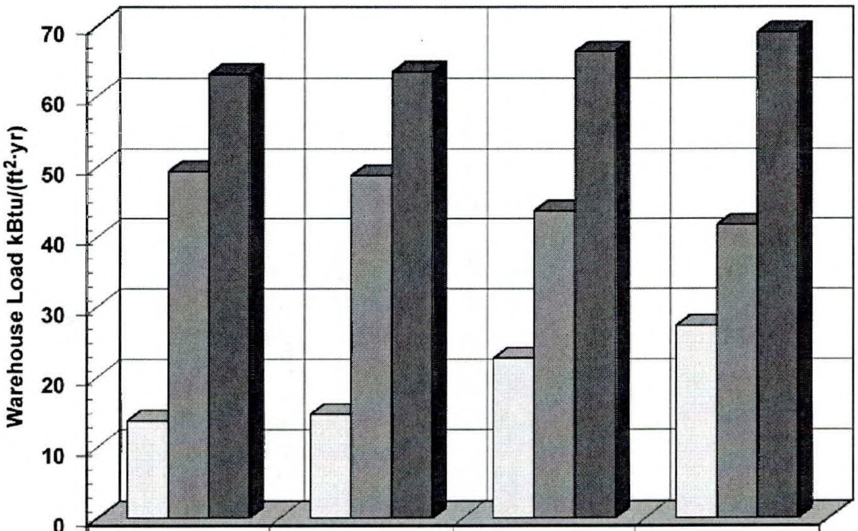
Title 24, Part 6, of the California Code of Regulations: California's Energy Efficiency Standards for Residential and Nonresidential Buildings, defines a reflective roof for low-slope roofs (<=2:12) as one that has an initial minimum reflectivity of 0.70 and a minimum emissivity of 0.75. In the 2008 update to this standard, the California Energy Commission (CEC) added a minimum three-year aged reflectivity requirement of 0.55 or an aged Solar Reflectance Index (SRI) of 65.

SRI is a measure of the surface's ability to reflect solar heat. It takes into account both reflectivity and emissivity. It is defined so that a standard black surface (reflectivity 0.05/emissivity 0.90) is 0 and a standard white surface (reflectivity 0.80/emissivity 0.90) is 100.

The California Energy Commission requires that the Cool Roof Rating Council (CRRC) certify these values. The CRRC has developed a test protocol and has approved various independent testing laboratories to conduct testing on reflective roof surfaces, including single-ply membranes (including modified bitumen membranes), roof coatings, shingles, metal roof panels, and tile roofs.

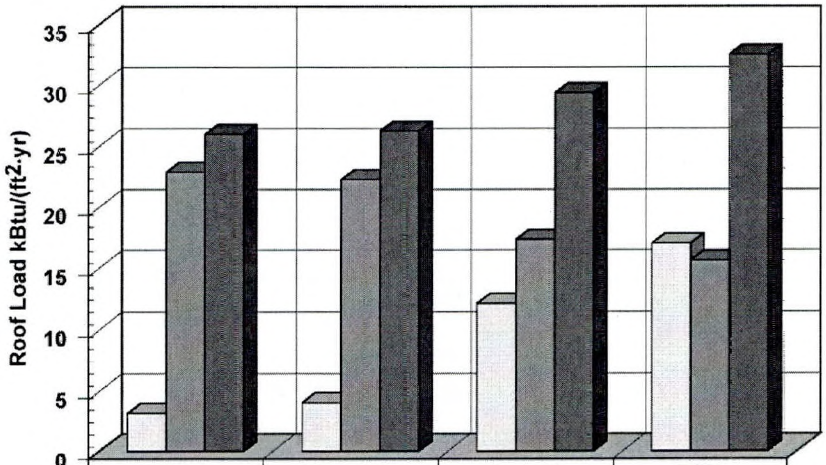
The testing protocol used by the CRRC requires that the highly reflective roof system be exposed in the field for three years in order to obtain the three-year aged reflectivity value required by the CEC. Recognizing that this could potentially limit consumer choices, the CEC allows for the use of a calculated value, based on applying a known reduction to the initial value, until the actual three-year value is obtained from the CRRC.

The Energy Star Program administered by the Environmental Protection Agency (EPA), offers a slightly different definition of a highly reflective roof. The Energy Star Program defines a highly reflective roof as one that has an initial minimum reflectivity of 0.65 and a three-year aged minimum reflectivity of 0.50. The Energy Star program does not currently contain an emissivity requirement.



	Code A	Code I	Code H	BUR
□ Cooling	13.8	14.7	22.7	27.4
▨ Heating	49.3	48.8	43.7	41.7
■ Total	63.2	63.5	66.4	69.1

.a. Annual building loads for warehouse.



	Code A	Code I	Code H	BUR
□ Cooling	3.10	3.97	12.05	16.95
▨ Heating	22.85	22.24	17.29	15.52
■ Total	25.9	26.2	29.3	32.5

.b. Annual roof loads for warehouse with R5 insulation.

Figure 2 – Annual heat flux per ft² entering in cooling season and leaving the building in heating season (Miller, et al., 2002).

The Energy Star program allows manufacturers to self-certify their products based on testing protocols defined by the EPA. For example, to certify the aged reflectivity of its roof membrane, a manufacturer is required to take reflectivity measurements at three locations where the roof membrane is at least three years old following the protocol defined by the EPA. These values are reported and are the basis for certifying the aged reflectivity of the membrane.

As a final example, the United States Green Building Council (USGBC), in its Leadership in Energy and Environmental Design (LEED) program, defines a reflective roof for use on a low-slope roof (<=2:12) as one with an initial SRI of 78. The LEED program references the CRRC as a source of information for reflectivity and emissivity values for various products.

So, as one can see, there are several ways to define a reflective roof surface. When designing a building with an energy-efficient reflective roof system, it will be necessary to verify that the system chosen meets the required performance characteristics.

Summary of Supporting Research Data

SPRI and the Department of Energy initiated a research program to quantify the energy savings associated with the use of highly reflective roof systems. This study also evaluated the impact of field exposure on the reflectivity of the roof system and the subsequent impact on energy savings. Additionally, the data obtained from this study were used to determine if the energy performance of this type of roof system could be modeled.

The objective of this study was to compare the energy performance of highly reflective roof systems with a system with low reflectivity. Thermoplastic (PVC and TPO), ballasted thermoset, and bitumen-based single-ply membranes were used in this study. A total of 18 single-ply membranes ranging in reflectivity from approximately 0.87 to 0.05 were evaluated. A smooth-surface built-up roof (BUR) was used as the low reflective roof as a basis for comparison of energy savings.

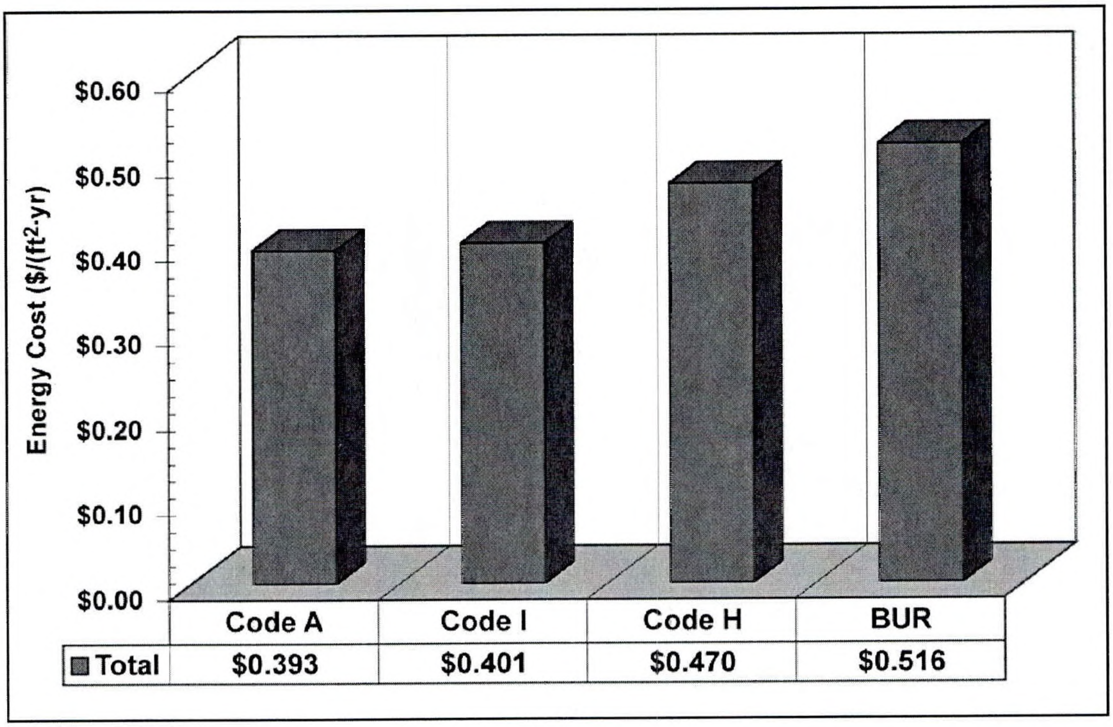


Figure 3 – Energy cost saving is based on R-5 roof insulation and initial membrane reflectivity with HVAC rooftop air-conditioner having seasonal COP of 2.5. (Miller, et al., 2002).

The primary test site for this study was the envelope system research apparatus (ESRA) located at Oak Ridge National Lab (ORNL) in Tennessee. Initial reflectivity and emissivity were measured with follow-up measurements taken three times per year. Temperatures through the roof system and heat flux through the system were continuously monitored.

In addition to the testing conducted at ORNL, reflective single-ply roof membranes were exposed at various locations around the country as part of this study to evaluate the impact of local conditions on the ability of reflective membranes to retain their initial reflectivity.

Conclusions from this study were:

1. In cooling dominated climates, an exterior roof surface with a high reflectance and high infrared emittance will produce energy cost savings. The amount of savings is dependent on the cost of energy and the efficiency of its use.
    - To provide an example of the potential savings associated with the use of a highly reflective roof membrane, the energy performance of a standard warehouse was modeled using the Simplified Transient Analysis of Roofs (STAR). The data to support the use of this model will be provided later in this report.
    - Simulations of a standard warehouse design in Oak Ridge Tennessee (a moderate climate zone) were conducted using roof membranes representing four reflectivity levels. Membrane A has a reflectivity of 0.865, membrane I has a reflectivity of 0.813, membrane H has a reflectivity of 0.245 and the BUR membrane has a reflectivity of 0.05. In all cases, R5 insulation was used for the evaluation. These simulations revealed the following:
    - For a warehouse with a BUR roof system, nearly half of the energy loss in the building occurred through the roof.
    - Using a highly reflective roof membrane (reflectivity of 0.865) in place of the BUR roof (reflectivity of 0.05) decreased energy usage by approximately 50% during the cooling season.
    - Using a highly reflective roof membrane (reflectivity of 0.865) in place of the BUR roof (reflectivity of 0.05) increased energy usage by approximately 18% during the heating season.
    - Overall energy usage was decreased by 9% (see *Figures 2a and 2b*).

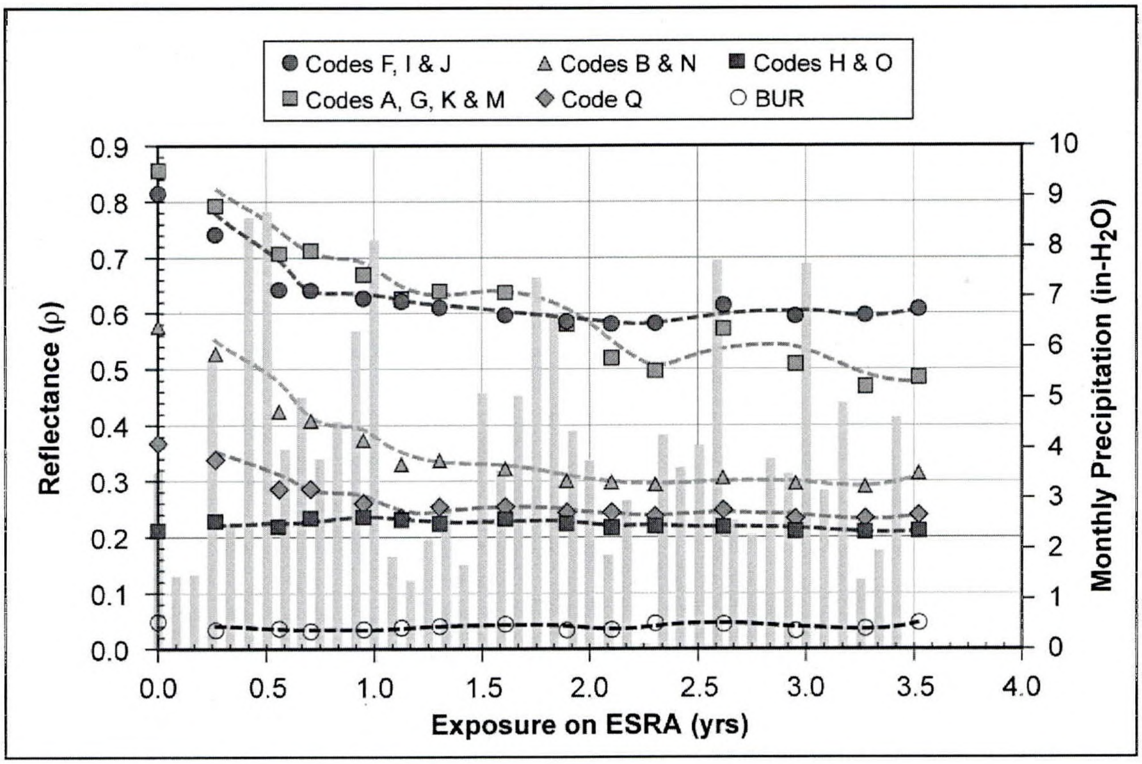


Figure 4 – Reflectivity loss vs. exposure time (Miller, et al., 2002).

- At the time of this study, energy prices in Oak Ridge, TN were roughly $5.50 per deca-therm for natural gas, and about $0.10 per kWh for electricity. Based on these costs, the annual energy savings for the highly reflective membrane (r = 0.865) would be about 12¢ per year per square foot of roof. A membrane with moderate reflectance (r = 0.245) would save about 5¢ per year per square foot of roof (see *Figure 3*). (Miller *et al.*, 2002) In this figure, the initial reflectivity for the referenced membranes was: Code A 0.865, Code I 0.813, Code H, 0.245, and BUR, 0.05.

2. Highly reflective single-ply roof membranes lose some of their reflectivity due to accumulation of dirt and biomass. This will, in turn, decrease the potential energy savings associated with these membranes in highly cooling-dominated climates. The membranes can be cleaned with common cleaning agents to effectively completely restore the initial reflectivity.

   - Highly reflective roof membranes lose 25% to 40% of their initial reflectivity. The loss in reflectivity is due to accumulation of airborne particles that act as a source for microorganisms. These microorganisms grow, and the resulting biomass reduces the reflectivity of these membranes. *Figure 4* provides a summary of the change in reflectivity vs. time in this study. The top two lines summarize the results for highly reflective roof membranes. This chart also shows rainfall levels (background bars) showing that rainfall amounts have little impact on reflectivity.

   - The impact of membrane soiling varies depending on the climate zone. In climate zones with high cooling loads, the impact can be significant. For example, a roof having R15 insulation in Phoenix, AZ is predicted to have an increase in annual roof energy usage of 60% after 3 years of exposure. It should be noted that even with this decrease in reflectivity, the energy savings would still be approximately $0.05/ft^2 as compared to a BUR roof system under these conditions.

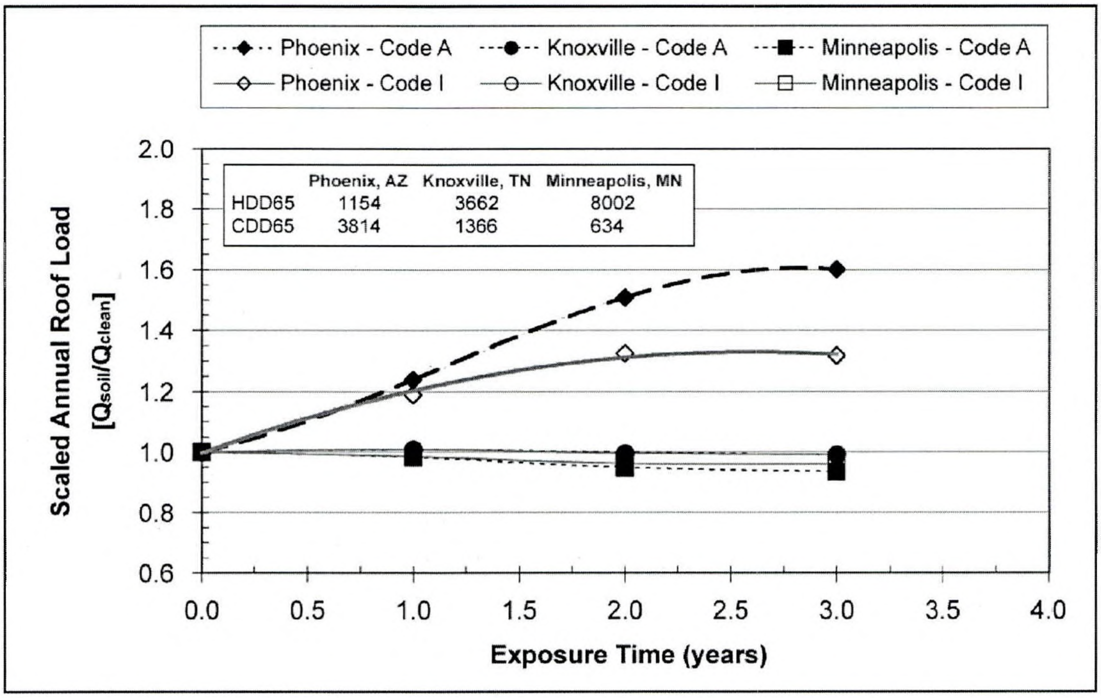


Figure 5 – The scaled annual energy transmitted through a low-slope roof having R-15 insulation is shown for different thermoplastic membranes (Miller, et al., 2002).

- In more moderate and cold climates, the impact on this loss in reflectivity on energy usage is minimal. This is because the increase in cooling-related energy use is offset by a decrease in heating-related energy use. *Figure 5* summarizes the impact of the loss of reflectivity on the predicted energy flow through the roof systems for various locations. In this graph, Q_{soil} represents the annual energy transmitted through a soiled membrane with R-15 insulation. Qclean represents the same membrane with no loss of reflectance.
- The good news is that highly reflective single-ply roof membranes can be cleaned and their initial reflectivity can be almost totally restored. *Table 1* provides a summary of cleaning solutions used and the resultant restoration of reflectivity. Since soiling of the membrane does not have a significant impact on building energy usage in moderate to cool climates, cleaning membranes in these regions is not economically justified. However, in climates that are predominantly cooling, the cost of cleaning the membrane has a very favorable return on investment.

3. The energy savings associated with highly reflective roof systems can be modeled.
   - The Simplified Transient Analysis of Roofs (STAR) computer code was able to predict the membrane temperatures within approxi-

	A, G, K, M	B, N	F, I, J
Water	77.1%	60.6%	57.7%
Trisodium phosphate (TSP)	92.6%	89.6%	85.0%
409 cleaner • degreaser	94.7%	94.9%	95.0%
Restore (2 minutes)	97.1%	95.6%	91.5%
Renovate (5 minutes)	98.3%	95.5%	92.8%

Table 1 – The restoration of reflectance (%) for the membranes exposed on the ESRA. (Miller, et al., 2002.)

Location	Highly reflective roof system R-value	Equivalent BUR system R-value
Phoenix	20	35.7
Knoxville	20	33.6
Minneapolis	20	23.5

Table 2 – BTC Cool Roof Model predictions of required insulation levels for a low reflectivity BUR roof to provide equivalent energy performance to a highly reflective roof system.

mately +/- 5% and heat flow through the assembly to within approximately +/- 10%.

Start here

- The STAR computer code used local meteorological data to predict heating and cooling roof loads for 235 different cities in the United States. These data were used to develop an empirical cool roof calculator (BTC Cool Roof Calculator). Validation of the calculator demonstrated that it predicted the heating and cooling loads within about +/- 10% for roofs with insulation levels ranging from R-5 to R35 (Petrie *et al.*, 2001a).
- The BTC Cool Roof Calculator is a powerful tool that can be used by the designer to compare energy use between a highly reflective roof and a BUR roof with very low reflectivity. To determine energy use and potential energy savings, the user must input the information listed below into the model. The model contains suggested values for many of these variables to make it easier to use.
    - State and city
    - R-value of the proposed roof assembly
    - Reflectance and emittance of the roof membrane
    - Cost of energy (electric, gas, fuel oil, etc.)
    - Efficiency of the heating and cooling systems
- Once these values are provided, the model will predict the following:
    - Net energy savings compared to a low reflectivity BUR
    - Cooling energy savings use vs. a low reflectivity BUR
    - Heating energy savings use vs. a low reflectivity BUR
    - The amount of additional insulation that would be required for a low reflectivity BUR membrane to provide the equivalent energy savings as a highly reflective roof system
    - Cooling loads vs. a low reflectivity BUR
    - Heating loads vs. a low reflectivity BUR
- *Table 2* provides an example of the type of information that can be provided by the BTC Cool Roof Calculator. This table assumes a roof with a highly reflective membrane and R20 insulation, and summarizes the amount of insulation required for a BUR roof to obtain the same energy efficiency in various geographic areas.

Measure	Phoenix	Knoxville	Minneapolis
BUR cooling energy use (BTU/ft^2/year)	9059	3943	2137
BUR heating energy use (BTU/ft^2/year)	2278	5652	9470
BUR total energy use (BTU/ft^2/year)	11337	9595	11607
Reflective surface cooling energy use (BTU/ft^2/year)	2078	739	373
Reflective surface heating energy use (BTU/ft^2/year)	2620	6702	11154
Reflective surface total energy use (BTU/ft^2/year)	4698	7441	11527
Energy savings for reflective roof (\$/ft^2/year)	0.202	0.087	0.04

Table 3 – BTC Cool Roof Calculator predictions for energy use of BUR system vs. highly reflective roof membrane system, assuming R20 insulation.

ASHRAE 90.1-2007 requires R20 insulation in most U.S. climate zones.

- *Table 3* provides another example of the output for this model. This table provides a comparison of the energy savings for a highly reflective roof vs. a low reflectivity roof assuming R20 insulation for both systems.
- The BTC Cool Roof Calculator can be accessed at the following Web address: www.ornl.gov/sci/roofs+walls/facts/CoolCalcEnergy.htm

Meeting Industry Requirements with Highly Reflective Roof Coverings

- A highly reflective roof membrane that meets the requirements of the California Energy Commission can be used to meet the prescriptive requirements for non-residential low-slope roofs in climate zones 2 through 15.
- The USGBC LEED program provides 1 point for installing a reflective roof membrane for reducing heat islands to minimize the impact on microclimate and human and wildlife habitat.

o ASHRAE 90.1 allows for a reduction in insulation R-value if a highly reflective roof membrane system is used in predominantly cooling climates.

o The federal government, states, school districts, and local municipalities are offering financial incentives or are mandating the use of sustainable construction. In most cases these initiatives involve LEED certification. The use of reflective roof membranes help achieve LEED Certification.

The full report summarizing the performance of highly reflective roofs is available free of charge on the SPRI Web site, www.spri.org.

BALLASTED SINGLE-PLY ROOF SYSTEMS

What is a ballasted single-ply roof system?

Ballasted single-ply roof systems were introduced in the 1970s. A conventional ballasted single-ply roof system consists of insulation loose-laid on the roof deck, followed by a single-ply roof membrane that is also loose-laid, covered with ballast. In roofing, ballast comes in the form of large stones or paver systems or lightweight interlocking paver systems and is used to provide uplift resistance for roofing systems that are not adhered or mechanically attached to the roof deck. When stones are used for ballast they are typically nominal 1.5 inches in diameter and are applied at a rate of 10 lb/ft^2. High wind areas or other conditions that result in high wind uplift forces may require the use of nominal 2.5-inch diameter stones applied at a rate of 12 lb/ft^2.

Another form of a ballasted roof system is the Protected Membrane Roof System (PMR). In this type of system, the roof membrane is typically either loose-laid or adhered to the roof deck. The membrane is covered with extruded polystyrene foam insulation and a filter fabric before application of the ballast. In this system, the various types of ballast mentioned above (and, additionally, insulation boards with a cementitious coating) can be used as ballast.

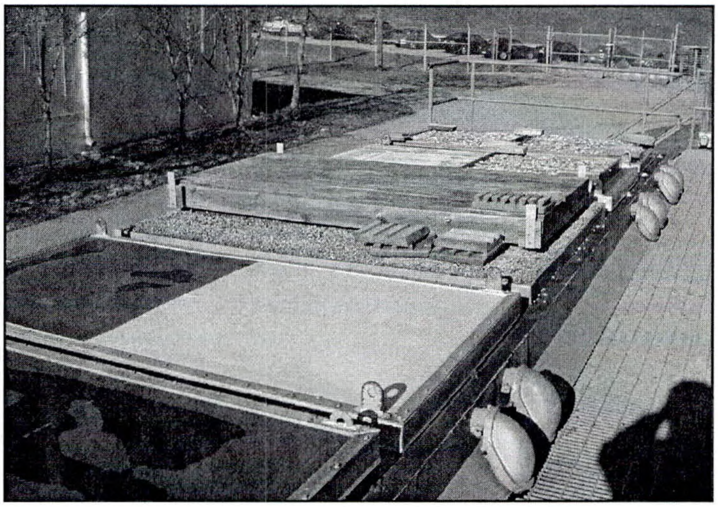


Figure 6 – RTRA configured for ballasted system analysis.

This report will focus on improvements in energy efficiency associated with the use of large stones and paver systems.

How does a ballasted roof increase energy efficiency?

A ballasted roof assembly increases the energy efficiency of the roof system in a completely different manner than a highly reflective roof membrane system.

In 1977, testing conducted by the Cold Regions Research and Engineering Lab (CRREL) of the Army Corp of Engineers determined that PMR Roof assemblies (stone ballasted) were more than 100% thermally efficient. This work is published in CRREL Report Number 77-11 (Schaefer *et al.*). Thermal efficiency is defined as the ratio (expressed as a percentage) of the theoretical to actual energy loss:

$$\eta = \text{theoretical energy loss} / \text{actual energy loss}$$

Recent studies have determined that ballasted systems do reduce heat flow through the roof and are consistent with the observation that these systems are more than 100% thermally efficient.

This is due to the thermal mass effect of the stone or concrete paver ballast as opposed to reflectivity. Instead of reflecting heat energy, as with a highly reflective roof membrane, the stone or concrete paver ballast absorbs the heat energy, and due to its high heat capacity, holds that energy until later in the day. This has the effect of delaying peak energy demand and allowing for release of this energy back to the sky as the ambient temperature decreases, instead of releasing it into the interior of the building.

Like highly reflective roof systems, ballasted roof systems provide their greatest benefit for reducing energy consumption in predominantly cooling climates.

Roof Covering	Reflectivity	Emissivity
Black EPDM	0.06	0.90
White TPO	0.78	0.90
Stone Ballast	0.21	0.90
Concrete Paver	0.52	0.90

Table 4 – Initial reflectivity and emissivity of surface coverings.

SUMMARY OF SUPPORTING RESEARCH DATA

In 2004, a study was initiated to determine if ballasted roof systems provide similar energy efficiencies as reflective roof systems. This study was funded by SPRI and the Department of Energy.

This study was conducted on the same Roof Thermal Research Apparatus (RTRA) as was used for the reflective roof study. In this study, ballasted roofs with 10, 16.8, and 23.5 lbs/ft^2 of stone ballast and one with 2-ft- x 2-ft- x 2-in-thick pavers were evaluated. The paver loading matched the heaviest stone ballast loading of 23.5 lb/ft^2. The thermal performances of these systems were compared to a black EPDM and a white TPO-surfaced test section (see *Figure 6*).

The interior side of the RTRA is maintained between 70°F and 75°F year-round. The temperatures on top of and through the cross-section of each test assembly are continuously monitored with a series of thermocouples. Heat flow through each test section is monitored with a heat flux transducer.

To help determine if reflectivity plays a role in the thermal performance of ballasted systems, initial and periodic measurements of reflectivity and emissivity were taken. Initial values are shown in *Table 4*.

Conclusions from this study were:

1. After 12 months of exposure, ballasted roofs with a minimum of 16.8 lb/ft^2

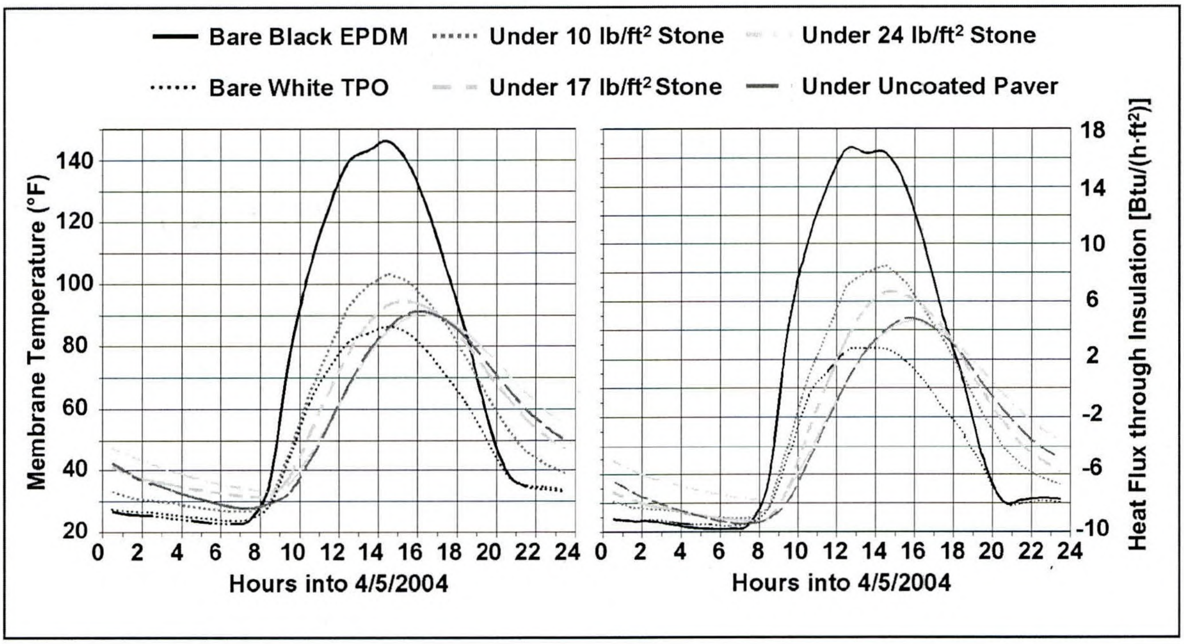


Figure 7 – Initial membrane temperature and heat flux measurements (Desjarlais et al., 2004).

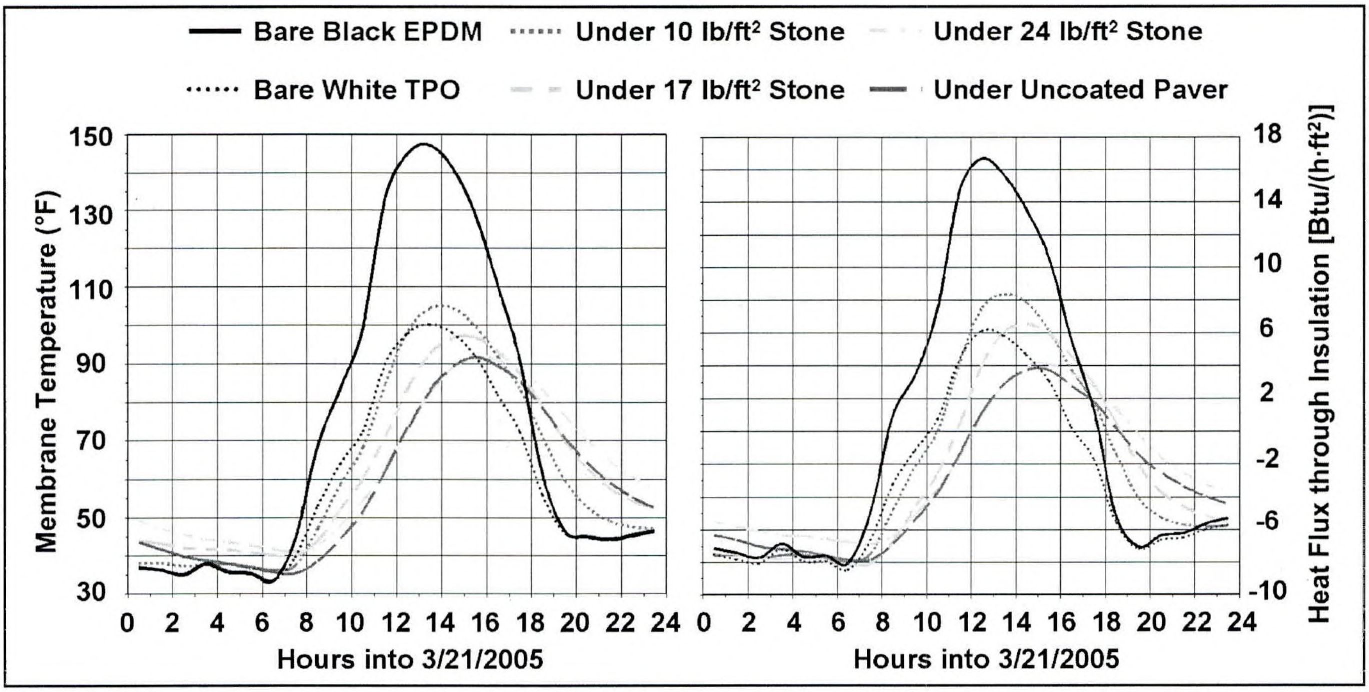


Figure 8 – Membrane temperature and heat flux measurements after one year of exposure (Desjarlais et al., 2004).

of ballast perform equal to or better than a reflective roof system with respect to peak membrane temperatures and heat flux through the system (see *Figures 7* and *8*).

- As can be seen in *Figure 7*, initial measurements of peak membrane temperatures and heat flux through the test sections demonstrated that highly reflective roof systems provided both the lowest peak membrane temperatures and heat flux.
- As can be seen in *Figure 8*, after 12 months of exposure, the peak temperatures and heat flux of the 16.8 lb/ft^2 ballasted system is equivalent to that of the highly reflective membrane and the 23.8 lb/ft^2 ballasted system has lower peak membrane and heat flux values.

2. Ballasted systems shift peak temperatures and heat fluxes in proportion to the weight of the covering.
    - As can be seen in *Figures 7* and *8*, both the peak membrane temperature and heat flux are delayed as compared to the black EPDM membrane system. The delay ranges from 30 minutes to 2 hours and is proportional to the weight of the ballast covering.
3. Thermal mass, not ballast reflectivity, is the controlling variable for the thermal performance of ballasted roof systems.
    - In *Figures 7* and *8* it can be observed that the test section with 23.8 lb/ft^2 of stone ballast and the system with pavers representing the same weight per ft^2 have similar thermal performance characteristics even though they have very different solar reflectances of 0.21 and 0.55 respectively. This would lead one to the conclusion that thermal mass, not reflectivity, is the controlling factor for thermal performance for this type of system.
4. Current heat flux and maximum membrane temperature models are not able to accurately predict the performance of ballasted roof systems.
    - These models rely on accurate boundary temperatures conditions and volumetric heat capacity of the layers in the system. The difficulties for ballasted systems were identified as:
        - o Accurately measuring the temperature

on the top of the ballast.

- o Convection effects in the stone ballast under high solar loads.
- o The wide variability in thermal conductivity of stone ballast.

The full report for this study can be downloaded free of charge from the SPRI Web site at www.spri.com.

Meeting Industry Requirements with Ballasted Roof Coverings

As noted earlier in this report, energy codes and other related industry groups have focused on the improvements in energy and thermal performance of systems due to the use of highly reflective roof systems. Accordingly, industry requirements focus on the use of highly reflective roof membranes. Work continues to gain recognition for the thermal performance enhancements associated with the use of ballasted roof systems.

INSULATION USED IN ROOF SYSTEMS

Insulation for use in low-slope commercial roof systems

The most common type of insulation used in low-slope commercial roof system is foam plastic insulation. Foam plastic insulation is lightweight and possesses excellent R-value per inch. The three most common types of foam plastic insulation are:

Polyisocyanurate foam – Polyisocyanurate foam is manufactured via a chemical stabilization process. Base ingredients are polyol and isocyanate. Polyol (mixed with the catalyst, blowing agent, and surfactant to control foaming) and isocyanate are mixed in a traversing mixing head near the entrance of two slat conveyors mounted one over the other, which can be adjusted for desired board thickness. Top and bottom surfacing materials are preheated and fed into a laminator, the foaming mixture is fed onto the bottom facing, and pressure is exerted by the top slat conveyor. After leaving the laminator, the boards are cut to the desired dimensions.

Molded polystyrene – To make molded polystyrene, loose, unexpanded foam beads containing liquid pentane are poured into mold. Heat expands the beads to 30 times their original size. The beads are then injected into a vacuum mold, and under heat and pressure, are further expanded. After curing, the blocks are cut into required sizes.

Extruded polystyrene – In the manufacture of extruded polystyrene, a mixture of polymer, additives, and blowing agent is pumped through a plasticating extruder at high temperature and pressure. The molten mass is forced through an orifice or die onto a conveying system. The blowing agent vaporizes, causing the polymer to expand. The polymer simultaneously cools and stabilizes into a closed cell structure as the temperature falls.

How does insulation improve the thermal efficiency of the roof system?

Heat flows from warm to cold areas and is transferred by radiation, convection, and conduction.

Radiation transfers heat through electromagnetic light waves. Examples of radiant heat are the sun striking your body, or the heat that is felt when sitting close to a campfire.

Convection typically occurs as a current of air that is warmed and rises due to its lower density. It cools as it rises, increasing in density, and sinks to begin the process over again. Forced air furnaces are another example of convective heat transfer as air is warmed as it moves over a heat exchanger and then subsequently transfers that warmth to objects it touches in the room.

Conduction occurs due to direct contact of molecules. Heat excites the molecules in an object. These molecules excite the ones in direct contact with them. An example of this type of heat transfer occurs when one end of a cooking utensil is left on a hot surface and the other end gets hot.

Insulation slows these different movements of heat transfer. The R-value of insulation is a measure of how effective it is at slowing this movement. The higher the R-value, the more effective the insulation is. Because insulation slows all of the different modes of heat transfer it works in all climate zones.

Discussion regarding the use of insulation

The use of insulation has always been recognized as the most effective way to conserve energy in the building envelope. Due to current and expected future conditions related to energy supplies, there are numerous movements to increase the use of insulation in the building envelope, including the roof system.

For example, ASHRAE 90.1-2007 is scheduled for release this fall. This standard significantly increases energy efficiency requirements. Originally scheduled for release in June 2007, the release date was postponed until the fall to allow for the inclusion of two addenda that increase the energy efficiency of the opaque envelope and of fenestrations (see *Table 5*).

In addition to this immediate change, in the 2010 version of 90.1, ASHRAE has the goal of achieving a 30% energy savings as

	2004 Edition		2007 Edition	
Climate Zone	Non-Res	Res	Non-Res	Res
1	15	15	15	20
2	15	15	20	20
3	15	15	20	20
4	15	15	20	20
5	15	15	20	20
6	15	15	20	20
7	15	15	20	20
8	20	20	20	20

Table 5 – Roof Insulation Entirely Above Deck. Prescriptive Requirements, ASHRAE 90.1/

compared to the 2004 version. It is likely that the 2007 version of ASHRAE 90.1 will be adopted into the 2009 International Building Code, to then be adopted by local communities.

ASHRAE is not the only organization leading this charge to energy efficiency. The American Institute of Architects has issued a challenge to aggressively pursue improvements in energy efficiency until buildings become carbon neutral and use no fossil fuel or greenhouse gas-emitting energy to operate by the year 2030. The U.S. Conference of Mayors has endorsed this challenge and a host of agencies recently pledged to help set the benchmark to measure improvement (Slone *et al.*, 2007).

As another example, effective June 26, 2007, the USGBC LEED program now requires all projects applying for LEED certification to achieve at least two Optimize Energy Performance points.

With all of this activity, it is important for designers to keep current and future insulation requirements so that the buildings they are designing today will meet code when they are constructed. Roof consultants play a major role in making sure that roofs are designed to meet these future requirements.

Optimum Insulation

Instead of only considering energy code requirements, designers are using methods to calculate the optimum insulation amount based on an economic analysis. The optimum amount of insulation is the amount that has the lowest life cycle cost (LCC), expressed as:

$$LCC = FC+M+R+E-RV$$

Where:

LCC = Life Cycle Cost ($)

FC = First Cost ($)

M = Maintenance Cost

R = Replacement Cost ($)

E = Energy Cost ($)

RV = Resale value or salvage ($)

Figure 9 provides an example of an LCC analysis for insulation amount. In this example, First Cost increases as the amount of insulation increases. Energy Cost decreases as insulation amount increases. The lowest LCC is the lowest sum of First Cost and Energy Cost, R20 in this example.

RECOMMENDATIONS AND CONCLUSIONS

Single-ply roof membranes can be a critical component when designing energy-efficient roof systems. Research has demonstrated that both highly reflective single-ply roof membranes and ballasted single-ply roof membranes can enhance the thermal performance of the roof system. Rigid plastic foam insulation is also a critical component of energy-efficient roof systems and reduces heat flow through the roof in all climate zones.

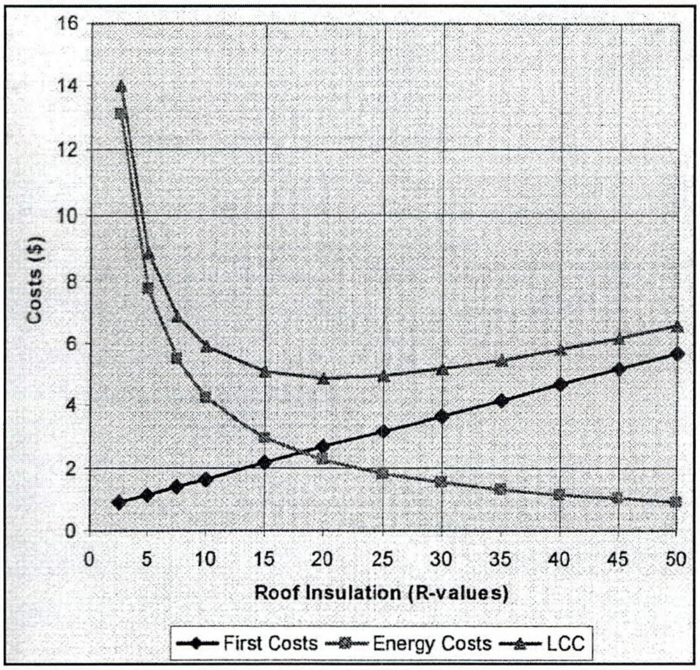


Figure 9 - Life cycle cost analysis (Owens Corning Technical Bulletin, March 2007).

When designing a roof system to maximize its thermal efficiency, consider the following recommendations:

1. Use either a highly reflective roof membrane or a ballasted roof membrane system to enhance the thermal efficiency of the system. These roof coverings have demonstrated the ability to save energy in all warm, moderate, and cool climate zones, exhibiting the most benefit in regions that predominantly require cooling.
2. In predominantly cooling climate zones, consider a maintenance program that includes cleaning the highly reflective roof membrane surface. Analysis shows that this provides a very positive return on investment in these areas.
3. Highly reflective roof membranes can be used to meet many industry-related requirements such as the California Energy Code, USGBC-LEED, and local mandates, to name a few.
4. Always use at least the minimum insulation amount recommended in ASHRAE 90.1-2007 for the given climate zone. Do not use trade-offs to reduce the amount of insulation.
5. Use life-cycle analysis methodology to determine the amount of insulation that should be used to maximize its economic benefit.

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