AN OUTCOME-BASED, MULTI-VARIATE APPROACH TO ROOF SURFACE THERMAL CONTRIBUTION

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INTRODUCTION

As part the new RoofPoint rating program for sustainable roofing systems, the Research Committee of the Center for Environmental Innovation in Roofing (CEIR) developed a unique multi-factor approach to the selection of sustainable roof surfaces. As a foundation for evaluation, RoofPoint identifies different outcomes related to the thermal characteristics of roof surfaces. In almost all cases *net energy savings* is an important outcome, and in many areas of the country the type of roof surface makes a significant contribution in reducing total building heating and cooling costs. In other areas, *peak energy savings* also may be an important outcome, especially in localities with seasonal demand charges for the electricity needed to power air conditioning systems. Finally, reducing *heat island effects* may also be important, especially in dense urban areas.

In addition to recognizing different energy and environmental outcomes, RoofPoint also identifies a broad array of roof surface types to address these energy factors. In many parts of North America, especially in warm, sunny climates, highly reflective roofs may offer significant benefit in all three energy categories, saving both net and peak energy as well as reducing heat island effects. In cooler areas of North America, roofs with slightly less reflectivity may offer a workable trade-off between reducing solar heat gain in summer and minimizing solar heat loss in winter. And in climates with extremely cold winters and cool summers, low-reflective roofs may offer the best overall energy solution. In addition, RoofPoint also recognizes non-reflective surface options such as vegetative and ballasted roofs, which may offer valuable energy contributions in a wide variety of climates.

When these different outcomes are combined with such a diversity of roof surface and climate alternatives, the concept of *cool roofing* employed by many green building rating systems may be inadequate to represent all options and outcomes. As a result, RoofPoint uses a broader concept of *roof surface thermal contribution* to address this variety of outcomes and solutions. In addition, RoofPoint divides roof surface thermal contribution into sub-topics addressing net energy savings, peak energy reduction and heat island mitigation as separate and equal components of roof surface energy efficiency. These energy outcomes and roof surface choices are summarized in the requirements for RoofPoint Credit E3: Roof Surface Thermal Contribution, illustrated in Table A.

Table A
RoofPoint Credit E3: Roof Surface Thermal Contribution
(Source: CEIR, 2012, p. 10)

Climate Zone[1]	Sub-Credit E3a: Net Energy Efficiency		Sub-Credit E3b: Peak Energy Efficiency		Sub-Credit E3c: Heat Island Reduction	
	Roof Surface Type[2]	Points Awarded	Roof Surface Type[2]	Points Awarded	Roof Surface Type[2]	Points Awarded
1	H,B,V	1	H,B,V	1	H,B,V	1
2	H,B,V	1	H,B,V	1	H,B,V	1
3	H,B,V	1	H,B,V	1	H,B,V	1
4	H,M,B,V	1	H,B,V	1	H,B,V	1
5	H,M,L,B,V	1	H,B,V	1	H,B,V	1
6	H,M,L,B,V	1	M,L,B,V	1	H,B,V	1
7,8	H,M,L,B,V	1	M,L,B,V	1	H,B,V	1

Notes to Table A:
1. Climate zones per ASHRAE 90.1-2010
2. Roof Surface Type:
   H = High Reflective (Aged SRI≥64)
   M = Medium Reflective (Aged SRI >20<64)
   L = Low Reflective (Aged SRI ≤20)
   B = Ballasted (Minimum 22 lbs. Zone 1-3, Minimum 15 lbs. Zone 4-8)
   V = Vegetative (Extensive or Intensive)

As compared to one-dimensional rating systems focused solely on highly reflective roofs, RoofPoint's multi-factor approach offers several important benefits. By paying equal attention to net energy, peak energy and heat island issues, RoofPoint encourages better understanding of the relationship between desired energy / environmental outcomes and roof surface type. RoofPoint also provides an expanded list of roof surface options, allowing the roofing designer to consider additional roof surface factors such as maintenance requirements, durability and other roof-related functions. Finally, RoofPoint encourages the exploration of key roof surface factors as a continuum rather than arbitrary minimum performance levels, this allowing for consideration of many different levels and combinations of key thermal characteristics.

As a result of this expanded approach to the roof surface, RoofPoint is able to recognize a variety of sustainable roofing solutions frequently ignored by other sustainable building rating systems. Although the majority of RoofPoint-certified roofs to date feature highly reflective roof surfaces, especially throughout the "sunbelt," RoofPoint roofs in other areas of North America have been able to take advantage of these expanded options. As an example, one the first RoofPoint-certified roofs features a medium-reflective light grey roof surface that would not have been acceptable to either LEED or Energy Star. But because the roof was located in a small town in a very cold climate (in this case, South Dakota), a strong case can be made that a medium-reflective surface offers the best overall energy and environmental solution for the location. In a similar manner, a portion of a RoofPoint-certified roof in Manitoba, Canada features multiple layers of a black EPDM membrane installed over an elevated portion of the building. Although it is highly likely that the black roof membrane adds quite a bit of heat in that portion of the building, that is exactly what the building designer intended. In effect, the heat generated serves as a "solar chimney" to force air ventilation throughout the entire building, providing a significant reduction in overall building energy requirements.

RESEARCH QUESTIONS

Although the previous analysis of RoofPoint Credit E3 suggests that this multi-factor approach offers significant value for the building designer, additional research to quantify and validate the approach is a high priority for the Center. As a result, this research study was commissioned to examine the key factors of the RoofPoint Roof Surface Thermal Contribution matrix and to better understand their interaction. Key questions addressed by this study include:

- **Net versus Peak Energy**. What level of peak and net building energy savings may be expected as a result of roof surface thermal characteristics among the different climate zones?
- **Solar Reflectivity as a Continuum.** How do different levels of solar reflectivity affect net and peak building energy costs among the different climate zones?
- **Critical Modeling Variables.** What is the sensitivity of different energy modeling assumptions in terms of effect on net and peak building energy costs?

In addition to addressing these key research questions, this study also explored the value of non-reflective roof surface alternatives (including ballasted and vegetative roof surfaces) and possible ways to better quantify the relationship between roof surface thermal characteristics and Heat Island effects.

METHODOLOGY

Modeling Tool. The study utilized the *DOE Cool Roof Peak Calculator*[1] to analyze both net energy and peak energy savings associated with different roof surfaces located in cities representing a spectrum of North American climate conditions. The data used in this publically available on-line calculator is based on a modeling program developed and validated at the Oak Ridge National Laboratory (Wilkes 1989), and consists of hour-by-hour predictions of heat fluxes and temperatures for low-slope roofs in various locations. Net energy demand is assumed to be the summation of all hourly demands during the year, and net cooling costs are calculated by applying a seasonal utility rate to the total cooling demand. In addition, any heating penalty for the roofing system is added back to the net cooling cost.

The modeling of peak energy demand within the calculator is based on additional modeling conducted by Oak Ridge National Laboratory (Petrie, Wilkes & Dejarlais, 2004), and peak energy demand is assumed to follow from the peak heat flux for any roof. Peak energy demand is calculated as a monthly peak demand charge for energy based on the highest hourly peak in cooling demand during each month.

Modeling Variables and Assumptions. The following variables and assumptions were used to conduct all calculations:

- **Model Cities / Climate Zones**. A model city was selected for each major climate zone in North America as identified by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2007). The cities selected and their respective climate zones are:
    - Miami, Florida, USA (Climate Zone 1)
    - Houston, Texas, USA (Climate Zone 2)

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[1] Available on-line: http://www.ornl.gov/sci/roofs+walls/facts/CoolCalcPeak.htm

  - Atlanta, Georgia, USA (Climate Zone 3)
  - Baltimore, Maryland, USA (Climate Zone 4)
  - Pittsburgh, Pennsylvania, USA (Climate Zone 5)
  - Milwaukee, Wisconsin, USA (Climate Zone 6)
  - Winnipeg, Manitoba, Canada (Climate Zone 7)

- **Roof System R-Values**. Roof system R-values were based on the prescriptive R-values for "roofs with insulation above deck" for each climate zone as listed in the International Energy Conservation Code (IECC). A higher level of R-value (herein called "High R")was established based on the prescriptive requirements of the most recent 2012 edition of the IECC, while a lower level of R-value was established based on the prescriptive requirements of the 2006 edition of the IECC. The 2012 edition of the IECC was selected as a basis to examine new roofs and roof replacements, while the 2006 edition was selected to examine to application of roof recovers and roof coatings over existing roof systems. R-values for each city and climate zone selected are:
  - Miami (Zone 1): High R = 20, Low R = 10
  - Houston (Zone 2): High R = 25, Low R = 15
  - Atlanta (Zone 3): High R = 25, Low R = 15
  - Baltimore (Zone 4): High R = 25, Low R = 15
  - Pittsburgh (Zone 5): High R = 25, Low R = 15
  - Milwaukee (Zone 6): High R = 30, Low R = 15
  - Winnipeg (Zone 7): High R = 32, Low R = 15
    (Note: The IECC 2012 requirement for Zone 7 is R-35, but R-32 is the highest value available in the DOE calculator.)

- **Roof Surface Solar Reflectivity**. Three basic levels of roof surface solar reflectivity (SR) were modeled, based on typical aged reflectivity values for commonly available roof surfaces:
  - **Low SR** (Typical for an aged dark gray mineral surface or membrane): **Aged SR ≥ 0.10**
  - **Medium SR** (Typical for an aged non-Energy Star white mineral surface or light gray membrane): **Aged SR ≥ 0.30**
  - **High SR** (Typical for an aged Energy Star listed membrane or coating): Aged SR ≥ 0.64

  In addition, an **Extra High SR (Aged SR ≥ 0.70)** surface was modeled in order to examine the relative merit of increasing material reflectivity above current typical values.

- It also should be noted that no discrete data is presented for Low SR roof surfaces because Low SR was treated as the control to measure savings for Medium, High and Extra High SR roof surfaces. However, in any condition where the study data for Medium, High or Extra High SR roof surfaces indicate a negative savings, it may be assumed that a Low SR surface would provide a positive savings.

- **Roof Surface Thermal Emissivity**. Roof surface thermal emissivity (TE) was assumed to be 0.90 for all cases, which is typical for most low-slope roofing systems with insulation above the deck.

- **Heating / Cooling Equipment and Efficiencies**. It was assumed that natural-gas fired heating units were used to supply building heat and that an electric air conditioning system was used to supply building cooling. System efficiencies were assumed to be 0.7 for the gas-fired heating units and a COP of 2.0 for the electric air conditioning system.

- **Heating / Cooling Energy Costs**. Natural gas costs were assumed to be $0.80/therm, as estimated by the U.S. Energy Information Administration to be the 2011 average U.S. cost for commercial customers (EIA, 2012a). Electricity costs were assumed to be $0.10/KWH, as estimated by the U.S. Energy Information Administration to be the 2011 average U.S. rate for commercial customers (EIA, 2012b).

- **Peak Demand Season / Charges.** As part of the development of the Cool Roof Peak Calculator, Petrie, Wilkes and Dejarlais (2004) examined the seasonal variation in cooling demand, and their findings suggest that even though net cooling demand may be significantly higher in warmer, sunnier climates, almost all climates exhibit a seasonal variation in the peaks for this demand. Figure 1 illustrates this common seasonal trend for Phoenix, Arizona (a hot, cooling-oriented climate) and Minneapolis, Minnesota (a cold, heating-oriented climate), modeling a roof with solar reflectivity (SR) of 0.70 and a thermal emissivity (TE) of 0.90.

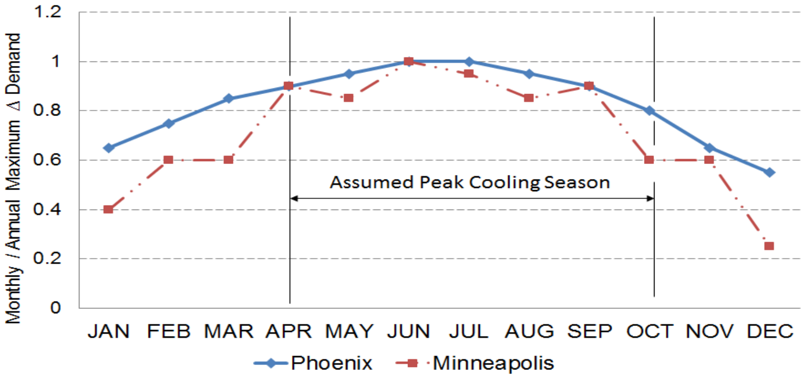

Figure 1: Ratio of Monthly to Annual Peak Cooling Demand for Phoenix and Minneapolis
(Derived from Petrie, Wilkes and Dejarlais [2004], p. 6)

As illustrated in Figure 1, although Phoenix displays a more constant ratio than Minneapolis, the ratio drops off at the beginning and end of the year for both cities, suggesting that a six-month period for peak demand charges would be appropriate for cities located within and between these two extremes.

The presence of a consistent peak cooling season as illustrated in Figure 1 may be critical to understanding the role of demand charges in evaluating peak energy costs. Although demand charges are not applied uniformly throughout North America, more and more utilities are adopting these charges in order to reduce peaks in electrical demand, which not only strain total electrical capacity but also add significant costs to electricity production and frequently increase atmospheric emissions associated with electricity production.

In recognition of this consistent seasonal variation, the current study assumed that all locations would be subject to peak demand charges. In addition, based on a survey of electric utilities in the Petrie, Wilkes and Dejarlais study, the current study assumed these demand charges to be priced at $10 per monthly peak KW during the six-moth seasonal period.

- **Outputs**. Differences in energy costs were calculated per square foot of roof surface.

FINDINGS

Net Energy Savings: High SR Roofs. Similar to findings in previous studies using the DOE calculator (Hoff, 2006), the net energy savings for High SR roofs with High R insulation are highest in the warmest climate zones. However, High SR roofs with High R insulation provide some level of net energy savings in the majority of climate zones, with the break-even point between cooling savings and heating penalty occurring as far North as Milwaukee in Zone 6. Figure 2 illustrates the variance in net energy savings over the seven climate regions studied for a High SR / High R roof.

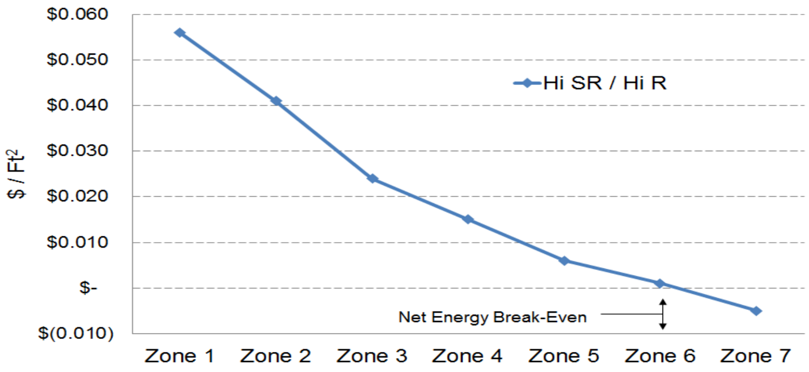

Figure 2: Net Energy Savings* for High SR / High R Roofs
(As Compared to a Low SR Roof with Identical R Value)
*Cooling Savings less Heating Penalty

Net Energy Savings: Extra High / High / Medium SR Roofs. Net energy savings for roofs with different levels of solar reflectivity also varies among the different climate zones. In the case of Extra High SR roofs compared to High SR roofs, the incremental value in net energy savings appears to be marginal except possibly in Zone 1. In the case of Medium SR roofs compared to high SR roofs, net energy savings are much lower in the warmer climate zones but slowly increase until their incremental value exceeds High SR roofs in the colder climate zones. Figure 3 provides a comparison of net energy savings for Extra High, High and Medium SR roofs over the seven climate regions studied.

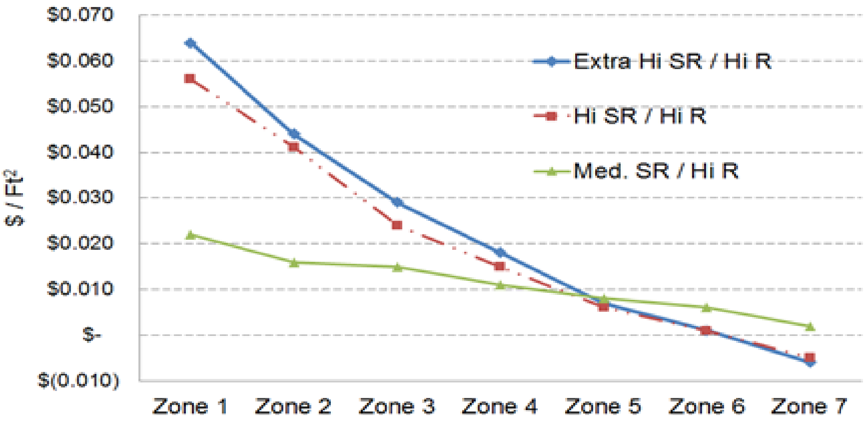

Figure 3: Net Energy Savings* for Extra High SR / High SR / Medium SR Roofs
(As Compared to a Low SR Roof with Identical R Value)
*Cooling Savings less Heating Penalty

Net versus Peak Energy Savings: High SR Roofs. Figure 4 combines the net energy savings illustrated previously in Figure 2 with the peak cooling savings provided by a High R / High SR roof for each major climate zone. Although net energy savings tend to decrease moving south to north along the climate zones, peak energy savings tend to remain relatively constant.

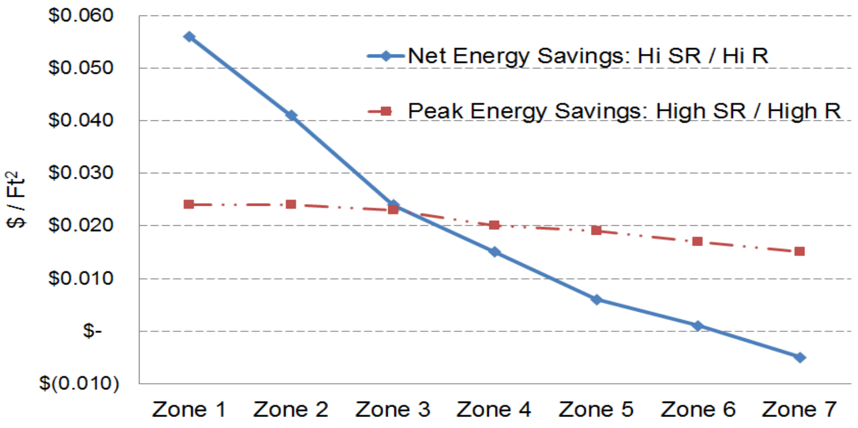

Figure 4: Net Energy versus Peak Energy Savings* for a High SR / High R Roof
(As Compared to a Low SR Roof with Identical R Value)
*Cooling Savings less Heating Penalty

Although it may seem counter-intuitive that similar peak energy savings may be achieved in cold climates as well as warm climates, Figure 1 presented earlier in this paper may help explain this situation. In a hot location such as Phoenix, even though overall cooling loads are very high, the seasonal peak is less pronounced, while the seasonal peak in a cold location such as Minneapolis is much more pronounced even though the overall cooling loads are smaller. In effect, peak energy savings in warm climates may be described as a smaller piece of a larger pie, while peak energy savings in cold climates may be described as a larger piece of a smaller pie.

Peak Energy Savings: Extra High / High / Medium SR Roofs. Peak energy savings for roofs with different levels of solar reflectivity also vary among the different climate zones. In the case of Extra High SR roofs compared to High SR roofs, the incremental value in peak energy appears to be significant in all climate zones, especially in the warmer climate zones. In the case of Medium SR roofs compared to high SR roofs, net savings are uniformly lower, but still well above the break-even point in all climate zones. Figure 5 illustrates this variance in peak energy savings for Extra High, High and Medium SR roofs over the seven climate regions studied.

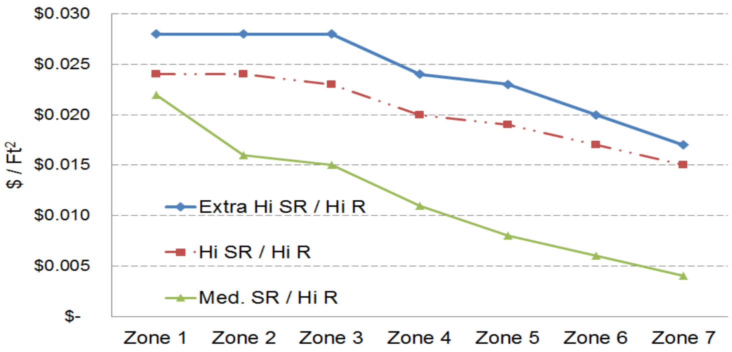

Figure 5: Peak Energy Savings* for Extra High / High / Medium SR Roofs

(As Compared to a Low SR Roof with Identical R Value)

*Cooling Savings less Heating Penalty

Effect of Fuel Costs and Fuel Selection. As stated previously, fuel costs for this study were established using 2011 annual U.S. averages for natural gas ($0.80/therm) and electricity ($0.10/KWH). However, hidden within these national averages are significant variations by state and locality. For commercial natural gas, the lowest average state price in 2011 was $0.60/therm in New Mexico while the highest average state price was $1.30/therm in Delaware. In a similar manner, average 2011 state prices for commercial electricity varied from a low of $0.065 per KWH in Idaho to a high of $0.15/KWH in Connecticut. In the warmest climate zone, increasing the cost of electricity from the study value of $0.10/KWH to the highest state average of $0.15/KWH would increase the level of net energy savings for a high SR roof from $0.056/ft^2 to $0.086/ft^2, an increase of over 53%. In a similar manner, in the coldest climate zone, increasing the cost of natural gas from the study value of $0.80/therm to the highest state average of $1.30/therm would increase the net energy loss for a high SR roof from less than $0.01/ft^2 to over $0.03/ft^2, a negative increase of over 200%.

Changing the type of fuel selected may also have a significant effect on outcomes. As an example, Figure 6 illustrates how net energy savings may be affected if the heating source is changed from natural gas to electricity. In this example, the break-even point (cooling savings less heating penalty) is moved two climate zones to the South, from Zone 6 (Milwaukee) to Zone 4 (Baltimore).

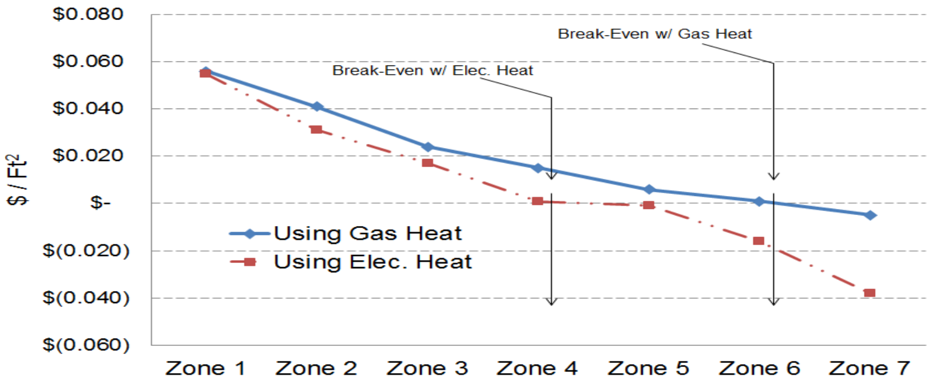

Figure 6: Net Energy Savings* for High SR / High R Roofs

(Natural Gas v. Electric Heat)

*Cooling Savings less Heating Penalty

R-Value Effects. R-value level also may affect net and peak energy savings, especially in the warmer climate zones. Figure 7 illustrates the difference in net cooling savings and Figure 8 illustrates the difference in peak cooling savings for Low R roofs as compared to the High R roof configuration.

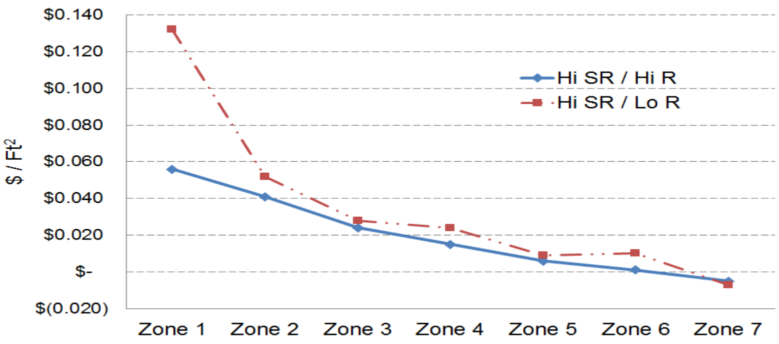

Figure 7: Net Energy Savings* for High SR Roofs
(High R v. Low R)
*Cooling Savings less Heating Penalty

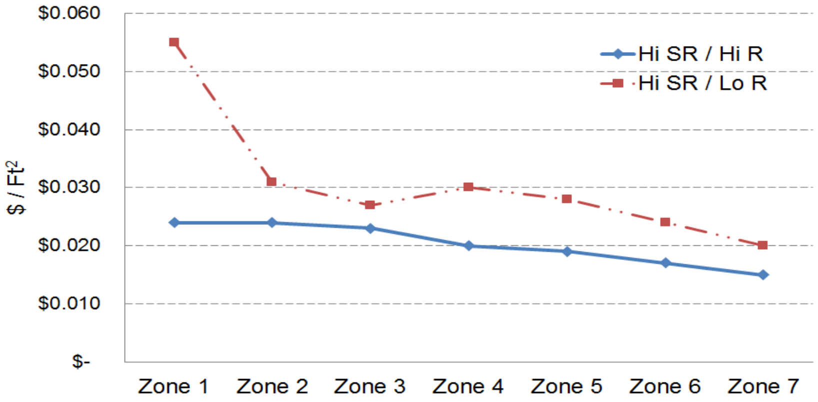

Figure 8: Peak Energy Savings* for High SR Roofs
(High R v. Low R)
*Cooling Savings less Heating Penalty

Figures 7 and 8 also may help to illustrate the increased value of highly reflective roof surfaces when increasing roof system R-value is not an option, such as in roof recovers and roof coatings. In the warmest climate zones, the application of a high SR surface over a low R roof may provide significant energy savings, but this savings opportunity appears to decline rapidly in cooler climate zones.

DISCUSSION

Marginal Value of Increasing Solar Reflectivity Standards. As illustrated in Figures 3 and 5, raising roof surface solar reflectance above current High SR values typically provides a small amount of additional net and peak energy savings. However, it is important to recognize that many currently available High SR products frequently cost no more than similar products with lower solar reflectance. Because of this minimal cost difference, it may be relatively easy to substitute current High SR materials for their lower SR counterparts. However, as solar reflectance is increased above currently available levels, it is likely that the cost of Extra High SR products may be greater than current High SR products. As a result, the relatively small marginal increases in energy savings offered by Extra High SR materials may be offset by increased costs and limited material availability. This reduced marginal value of Extra High SR materials as compared to High S materials may be especially challenging in energy design decisions involving only net energy savings and not peak energy savings.

Perhaps the most challenging aspect of the low marginal utility of increasing solar reflectance above current typical levels may involve the establishment of mandatory standards for Extra High SR levels, especially in building codes. Increased levels of solar reflectance may provide a suitable aspirational target in voluntary roofing guidelines, but it may be difficult to economically justify their incorporation into state and local building energy codes without a careful economic analysis of cost-benefit and market dislocation.

Study Application to Heat Island Effects. Many sustainable building guidelines, including RoofPoint, relate the use of cool or highly reflective roof surfaces with the mitigation of urban heat island effects, or the phenomenon of atmospheric heating in urban areas due to the solar heat absorption of dark roofs and pavements. Although this study does not explore a direct linkage between reflective roof surfaces and urban heat islands, it is possible that the peak energy savings identified in this study may serve as a useful surrogate for quantifying heat island effects. If so, the data from this study would suggest that the value of High SR roofs in mitigating heat island effects tends to be relatively constant across all climate zones. (See Figures 4 and 5.)

Non-Reflective Roof Surface Alternatives. In addition to the Extra High, High and Medium SR roofs analyzed in this study, RoofPoint Credit E3 also recognizes the value of non-reflective approaches to energy savings. These alternatives include ballasted roof surfaces where the roofing membrane is covered by a layer of stones or pavers and vegetative roof surfaces where the roofing membrane is covered by a layer of planting media and vegetation.

In the case of ballasted roofing, research conducted at Oak Ridge National Laboratory (ORNL) suggests that many ballasted roofs may serve as a viable alternative to High SR roofs in reducing net cooling costs (Dejarlais et al., 2008), especially in climates similar to the East Tennessee location of the ORNL test farm. In addition, because ballasted roofs tend to hold solar heat and release it after the peak of daily cooling demand, they may also serve as an alternative approach to reduce peak cooling costs as well. However, because the solar heat is eventually released back into the local atmosphere, they may not provide any reduction in local heat island effects. In the same manner, vegetative roofs with their mass of plant media, moisture and vegetation may offer a viable alternative for reducing net and peak cooling energy through their insulating properties and a similar delay in atmospheric heat release. In addition, the transpiration cooling effects of the surface vegetation may also serve as an effective heat island mitigator by reducing ambient air temperatures due to the cooling effects of transpired moisture release.

Study Implications for RoofPoint Credit E3. Overall, the results of the study tend to support the current RoofPoint E3 credit matrix (Table A). However, some study findings should be investigated further to determine whether some specific adjustments should be made to the credit matrix. Specifically, the following items should be re-evaluated:

- **Net Energy**. Because High SR roof surfaces appear to provide a net energy penalty in Climate Zones 7 and 8, the study findings do not appear to support the inclusion of High SR roof surfaces within these zones in the Net Energy sub-credit. (See Figure 3.)
- **Peak Energy**. Because High SR roof surfaces appear to offer significant peak energy savings compared to either Low or Medium SR roof surfaces in all climate zones, the study findings do not appear to support the inclusion of Low SR and Medium SR roof surfaces within the Peak Energy sub-credit. (See Figure 5.)
- **Heat Island Effects**. As discussed in this paper, although ballasted roof surfaces may serve as a useful alternative to High SR roof surfaces in terms of peak energy savings, their value in reducing heat island effects does not appear to be supported by this study.

In addition to these items in the RoofPoint E3 credit matrix, it should be noted that RoofPoint currently awards an additional ½ point in Climate Zones 1 through 3 for an Extra High SR roof surface for each designated outcome, for a total of 1 ½ additional points. Based on the study findings of the relatively marginal contribution of Extra High SR roof surfaces, it may be advisable to re-evaluate the amount and the extent of this additional point award.

Table B summarizes these suggested revisions to the RoofPoint E3 credit matrix, which will be presented to the CEIR Research Committee for consideration following the publication of this paper.

Table B
RoofPoint Credit E3: Roof Surface Thermal Contribution
(Proposed for CEIR Research Committee Consideration)

Climate Zone[1]	Sub-Credit E3a: Net Energy Efficiency		Sub-Credit E3b: Peak Energy Efficiency		Sub-Credit E3c: Heat Island Reduction	
	Roof Surface Type[2]	Points Awarded	Roof Surface Type[2]	Points Awarded	Roof Surface Type[2]	Points Awarded
1	H,B,V	1	H,B,V	1	H,V	1
2	H,B,V	1	H,B,V	1	H,V	1
3	H,B,V	1	H,B,V	1	H,V	1
4	H,M,B,V	1	H,B,V	1	H,V	1
5	H,M,L,B,V	1	H,B,V	1	H,V	1
6	H,M,L,B,V	1	H,B,V	1	H,V	1
7,8	M,L,B,V	1	H,B,V	1	H,V	1

Notes to Table B:

3. Climate zones per ASHRAE 90.1-2010
4. Roof Surface Type:
   H = High Reflective (Aged SRI≥64)
   M = Medium Reflective (Aged SRI >20<64)
   L = Low Reflective (Aged SRI ≤20)
   B = Ballasted (Minimum 22 lbs. Zone 1-3, Minimum 15 lbs. Zone 4-8)
   V = Vegetative (Extensive or Intensive)

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