BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

Sustainable Roof Design: More Than a Black-and-White Issue

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ABSTRACT

As energy continues to play a leading role in influencing roof design and material selection, this paper focuses on the impact that roof membrane color and various insulation levels have on energy savings. Other effective strategies that are often overlooked vary from roof-assembly type to building geometry and orientation and roof elevations, all of which are covered. Previous research on the subjects of reflectivity and mandates to influence current codes are discussed extensively, along with regional analysis utilizing various energy models. This paper also includes recommendations on new approaches to energy savings and the reduction of carbon footprint by region.

SPEAKER

Samir K. Ibrahim — Carlisle SynTec Incorporated

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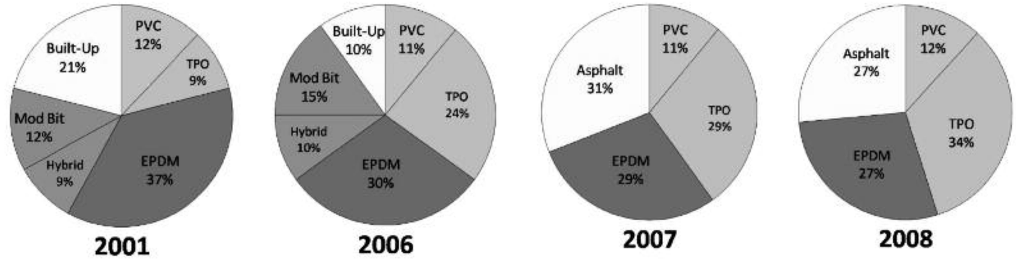
Sustainable Roof Design: More Than a Black-and-White Issue

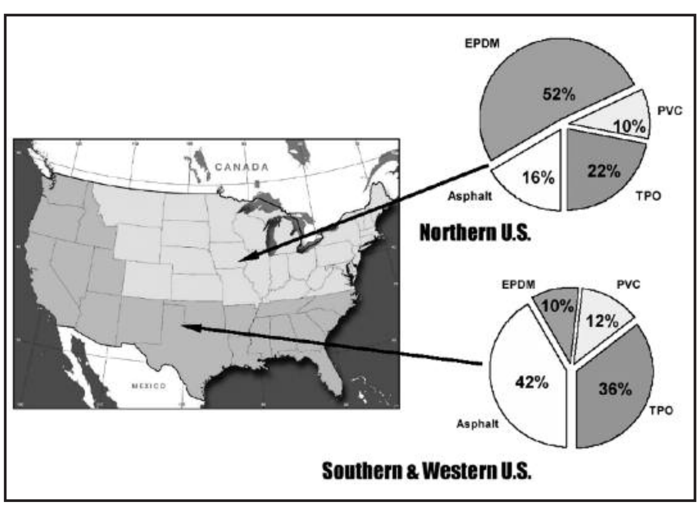
INTRODUCTION

Commercial-roofing products and design in North America have traditionally been geared toward cold climates, with great ability to sustain extreme conditions. Building geometry, heating/cooling cycles, and regional impact have all played a role in the selection of various components, from the types of roofing membranes and systems to be utilized to the level of insulation and its securement method. During the past decade, a shift in the commercial-roofing market is apparent and has been influenced by environmental concerns, the rising cost of energy, and the greater emphasis placed on sustainability and environmental design.



Research over the past decade focusing on reduction of heat islands in large metropolitan areas and the "perceived benefit" of reflective materials continues to be echoed throughout the research community. Right or wrong, the commercial-roofing market has already been influenced by the cool-roof phenomenon, and the debate continues as to whether or not it is the most suitable option, regardless of climatic region! (See *Figure 1*.)

Over the past seven years, the use of reflective membranes has more than doubled in volume in the commercial-roofing market of North America. With such an increase in popularity and a lack of understanding, there has been a backlash, especially in cold-climate regions with moisture-related issues. (See *Figure 2*.)



Looking into membrane market shares, reflective membranes have been and continue to be more popular in the warmer-climate regions in the South and Southwest (predominantly in ASHRAE Climatic Zones 1-3). Over the past five years, the U.S. low-slope market started to experience the migration of cool roofs to the Northern, cold-climate regions, to the extent that certain boroughs and municipalities have begun to mandate cool roofing, either due to either some perceived energy benefits or for the purpose of reducing heat island effect.

REFLECTIVE/COOL ROOF RESEARCH STUDIES

Various studies (Akbari, 2001; Akbari H., 2007; Konopacki, Akbari, Pomerantz, Gabersek, & Gartland, 1997; Akbari & Konopacki, 2005) performed over the past decade failed to realize the varying construction practices used in different regions and the level of insulation typically used in areas with colder climates. Many of the assemblies evaluated incorporated wood construction with below-deck insulation as low as R-11 (today's residential standard being R-38). The studies were geared more toward climatic conditions commonly experienced in southern California, and they offered building owners an economical solution to utilize reflective roofing membranes in lieu of the costly option of adding insulation. (With most of these assemblies using below-deck insulation, adding additional insulation would require, in most cases, major disturbance to the building occupants.)

This has been echoed in the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL) study of May 1997, "Cooling Energy Savings Potential of Light-Colored Roofs for Residential and Commercial Buildings in 11 U.S. Metropolitan Areas." The study notes, "In Florida...the largest savings were found in a building without roof insulation and the least in one with R-19 insulation." (This is half the insulation required by today's standards.) The same study also claimed that buildings in cold-climate regions, i.e., Chicago and Philadelphia, experienced minute or no savings (pp. 17, 29).

While it speaks favorably of cool roofs (page 46) as an energy benefit regardless of geographic location, the 113-page study is prefaced with a disclaimer that most would initially disregard:

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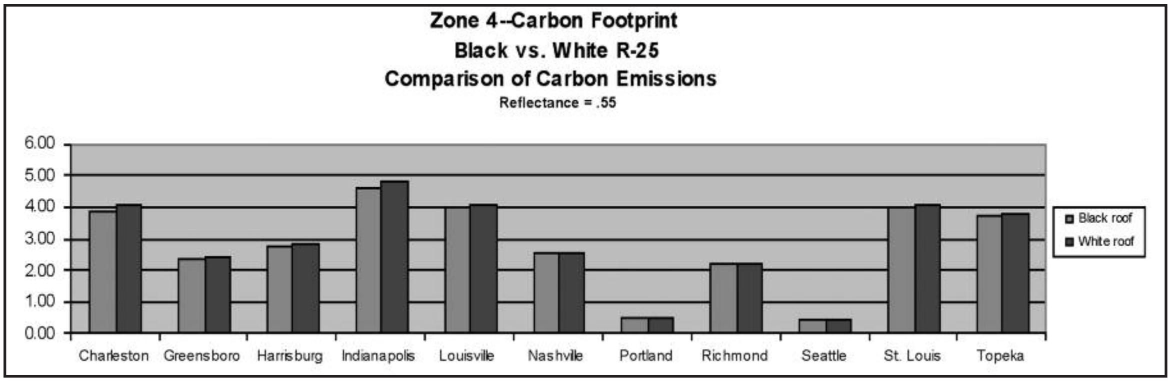

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The research studies, in this author's opinion, neglected to take several factors into consideration and to differentiate between cooling energy costs and an overall energy savings. These studies did not:

- Use acceptable insulation levels more commonly used in the cold regions;
- Use construction assemblies prevalent in cold-climate regions;
- Acknowledge solar gain by dark membranes during wintertime and its positive impact on heating costs;
- Acknowledge wintertime air quality degradation due to increased use of heating energy;
- Acknowledge additional solar gain by windows and glass façades due to increased reflectivity in surrounding structures; or
- Account for the favorable impact of internal loading during the heating season and focused only on the negative impact during the cooling season.

COOL-ROOF IMPACT ON ENERGY AND HEAT ISLANDS

While the use of reflective membranes may yield energy savings in warm climates, their use in cold climates in lieu of insulation does not deliver the same perceived savings. Likewise, cool roofs may also contribute to heat-island reduction in metropolitan areas located in warm zones due to energy reduction during heating and cooling seasons, contributing to lower CO_2 emissions. In a cold-climate region, however, benefits toward heat-island reduction during the summer are offset by higher levels of CO_2 emissions during the heating season, resulting in higher CO_2 emissions and increased levels of greenhouse gases, which are mainly responsible for global warming. Refer to *Figure 3.*

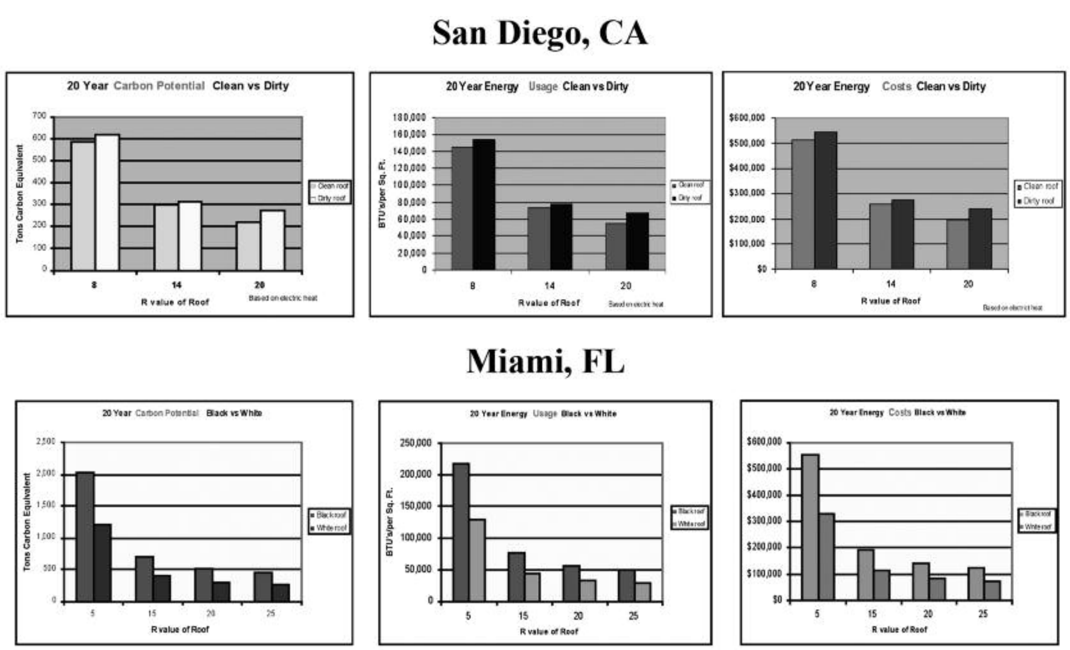
Cool-roof benefits could be realized year-round in areas like San Diego or Miami (generally warm climates), which are predominately cooling zones. (See *Figure 4.*)

In metropolitan areas such as Manhattan or Chicago (locations that are classified predominantly heating zones), cool-roof benefits are only realized during the cooling season. (See *Figure 5.*)

While heat islands are generally perceived as having a negative effect on the environment, in reality, they do offer a benefit during the heating season for those facilities within colder climate regions.

THE GREAT MISCONCEPTION

With a diluted message concerning cool-roof benefits, and with many designers and building owners eager to utilize perceived environmentally friendly concepts, cool roofing began to replace roofs that have



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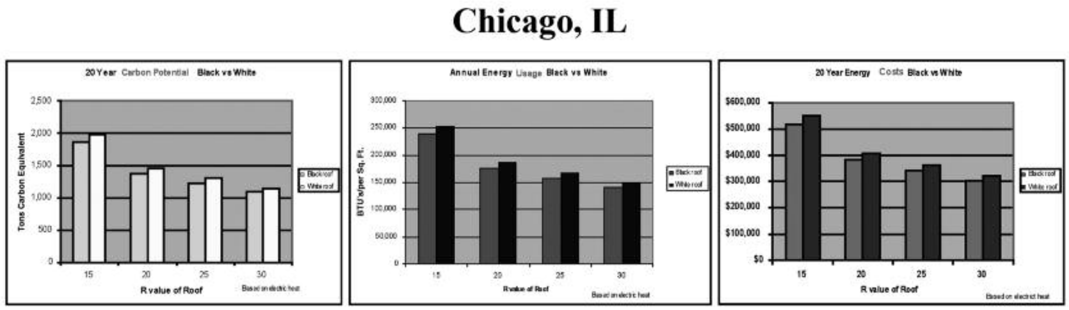


been traditionally darker in color. Very little consideration was given to the impact of the roof color or to the repercussions of what the roofing assembly might experience. Many designers, environmental advocates, and researchers did not comprehend, "It is not as simple as a color change."

While coating of dark roofs may be desirable to reduce membrane surface temperature, reduce thermal shock to the membrane or to achieve energy savings (in some locations), it is important to recognize the difference in behavior between a highly reflective surface versus a dark membrane. Converting dark roofs into lighter-colored material will increase the probability of condensation and promote greater levels of condensation. Depending on geographic location, certain measures may be required to address issues associated with moisture drive.

While it may be the subject of another paper, the long-term effects of reflective coatings and emissive roofs should be investigated as to their life expectancy and the reduction of material thermal shocking.

THE PHENOMENON OF MOISTURE DRIPS

When proper measures are not taken, construction-generated moisture can contribute to high levels of relative humidity and, with the drop in outside temperatures, condensation can begin to form. Condensation can form on the underside of skylight domes, single-pane windows, and uninsulated portions of decks or even on the underside of roof membranes if the roof deck is not properly sealed. Warm air migrating upward can infiltrate the roofing assembly through deck-to-wall joints, gaps around penetrations, or voids in the deck where the underside of the insulation is exposed. Moisture will begin condensing on colder surfaces (below the dew point) and will convert to frost and ice at temperatures below freezing. The higher the level of relative humidity and the greater the temperature differential between the inside and the outside, the more moisture will collect. In extreme cases, and especially with the use of white membranes and a single layer of insulation, ice buildup due to condensation can be significant and is observed by a cracking sound that occurs when one walks on the membrane.

In intense cases (i.e., assemblies with a single layer of insulation), heavy ice formation along insulation joints, due to expansion, can generate a force that pushes laterally, causing insulation joints to widen.

As the temperature rises and the roofing membrane warms up, frozen moisture begins to thaw, resulting in drips inside the building. These drips are not associated with rainfall or snow accumulation on the roof. As a matter of fact, they are likely to occur during sunshine, with temperatures warming above freezing. The intensity of the drips is directly related to the amount of moisture that has infiltrated and condensed beneath the membrane and at insulation joints. However, the concentration is more likely to be seen around the perimeter, deck penetrations, and at deck end-laps.

This phenomenon has been experienced repeatedly throughout the northern part of the U.S. and in the Midwest, predominantly with white membranes (mostly mechanically attached) and, in several cases, where a single layer of insulation has been used. Semiheated facilities, where this phenomenon has been experienced, typically are designed without the use of an air/vapor barrier following ASHRAE published standards. In the past, these assemblies have experienced some negligible moisture migration during the winter season when darker-colored membranes were used. Changing to a white membrane caused the roofing membrane to fall below the dew point frequently and to remain there for longer periods of time, which, in turn, elevated the level of the condensing moisture.

SNOW ACCUMULATION

Another issue that has not been examined thoroughly by designers is the level of snow accumulation. White membranes, due to their lower solar gain, will experience a greater level of snow accumulation. If the designer is not alert to modify various roofing details, especially sleeper-mounted gas lines, the effects of sliding snow can be devastating. Icy conditions can easily occur and are more difficult to detect. Workers and maintenance personnel must be alerted to the danger, and it may be necessary to modify their maintenance schedule.

POSSIBLE MOLD GROWTH

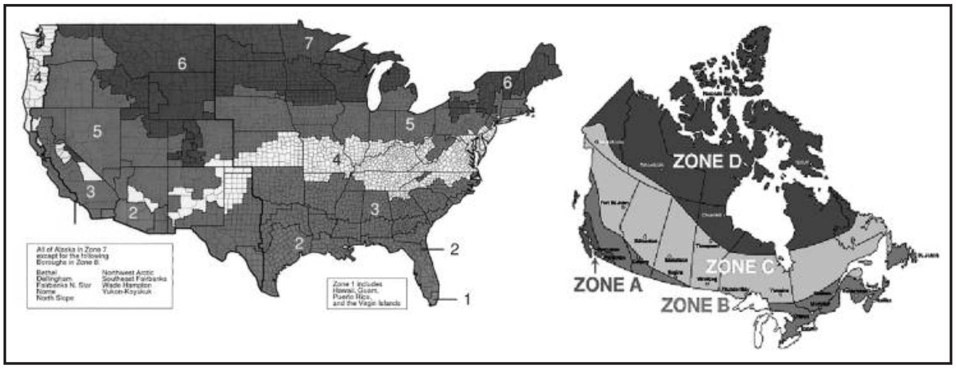
With mold flourishing in shaded areas with temperatures between 68°F and 86°F, sleeper-mounted air-handling units and other roof-mounted equipment should be avoided when a white membrane is being considered. These conditions are not typically found with a black membrane due to the higher surface temperature. Mold forming on roof membranes in locations where fresh-air intakes are found can infiltrate the building interior if not addressed. White roofs, if selected, must be periodically inspected, not only for their performance as roofing membranes, but also for evidence of mold and algae growth. The membranes must be periodically cleaned, not necessarily to restore diminishing reflectivity but to address mold and algae formation.

THE ASHRAE STANDARD 90.1

The American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) has increased the minimum insulation requirement (December 2007) for the entire building envelope and specifically for low-slope roofing by 33%. Another increase is expected by 2010.

Recognizing the benefits versus deficits of cool roofs by climate zones, ASHRAE has limited the reflective-membrane usage to Zones 1 - 3 (for zone designation, see *Figure 6*). This change in ASHRAE's position is reflected in its Addendum F, which is currently in the public review process.

The increase in the ASHRAE 90.1 Standard, which took effect in December 2007 (*Figure 7*), mandates the use of R-20



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as the minimum R-value virtually across North America (Zone 1 remains at R-15). These standards are absolute minimums and should be treated as such. In most cases, with the expected increase in energy costs over the next few years, higher R-values should always be considered, along with the utilization of multiple-layer applications to gain the benefit of continuous insulation.

When designing to achieve a greater level of energy performance, heating and cooling degree days published by ASHRAE (*Figure 8*) should always be considered, especially when measuring various assemblies with different insulation levels and different membrane colors. A quick review of the data will easily guide the designer to the impact of heating versus cooling. For example, San Diego is predominantly a cooling zone, where a cool roof can yield additional benefits not only toward energy savings but also in reducing carbon emissions. On the contrary, in Chicago or Philadelphia, the data suggest a longer heating season, where higher levels of carbon emissions are produced during the winter season. It can be concluded that higher levels of insulation and darker-colored membranes can certainly be the better choice. This is demonstrated later on in the various energy analyses included at the end of the paper.

Zone	Area	2004	2007
8	N. Alaska & N. Canada	R-20	No Change
7	Northern MN, Canada	R-15	R-20
6	Minneapolis, Maine	R-15	R-20
5	Up to Chicago	R-15	R-20
4	VA, St. Louis , etc.	R-15	R-20
3	Southeast & Most of CA	R-15	R-20
2	Primarily the Gulf Coast	R-15	R-20
1	Essentially Miami	R-15	No Change

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Location	Heating	Cooling
San Diego, CA	1256	5223
Sacramento, CA	2794	1144
Seattle, WA	4867	127
Norfolk, VA	3489	1439
Philadelphia, PA	5181	1053
Columbus, OH	5551	799
Chicago, IL	6450	749
Toronto	7306	1963

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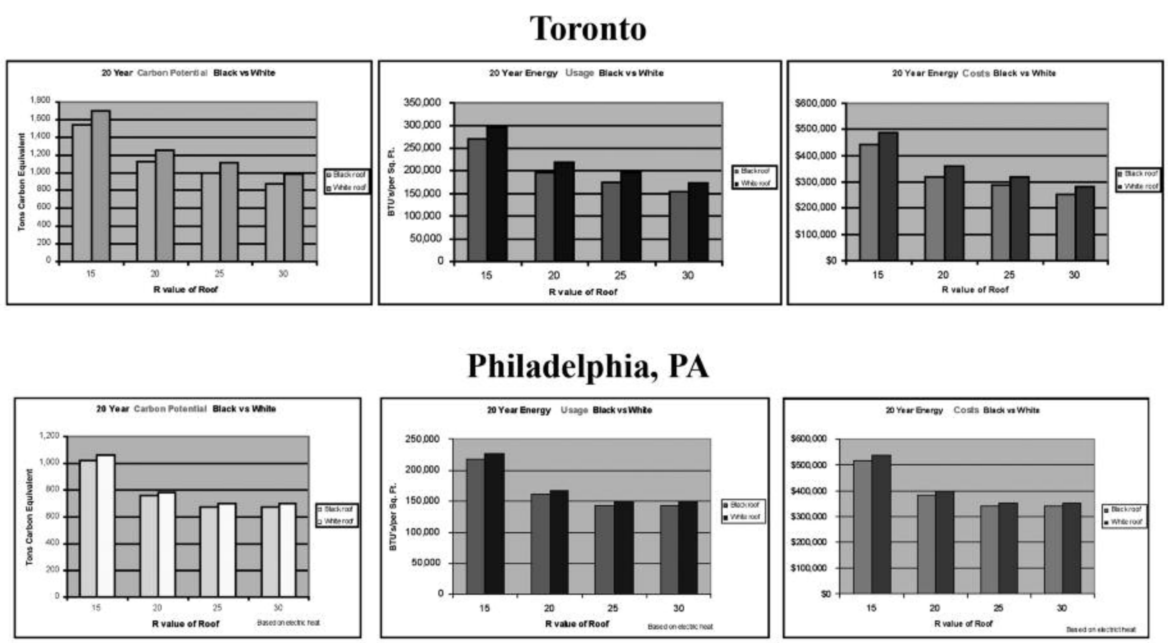

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ENERGY ANALYSES

Energy calculations using simulation software can be used to predict thermal performance and to determine the most feasible approach based on:

- BTUs (energy usage);
- Carbon emissions; and
- Heating/cooling cost.

There are many software packages used to perform energy calculations. Among the most common are:

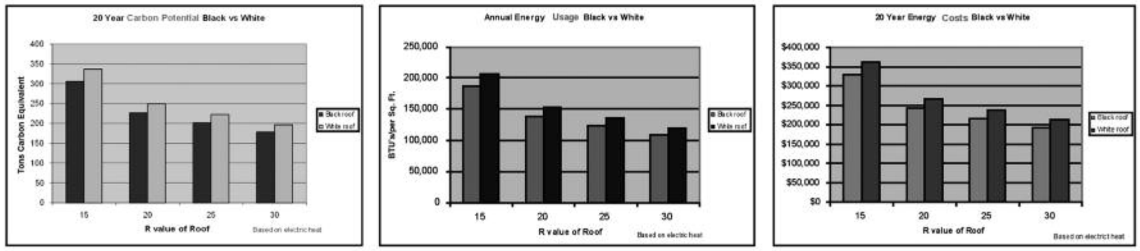
- NRCA calculator;
- DOE Cool Roof Calculator for flat and low-slope roofs;
- Hourly Analysis Program (HAP) by Carrier; and
- RoofSense – a Carlisle life-cycle analysis program.

For this paper, the DOE software was utilized.

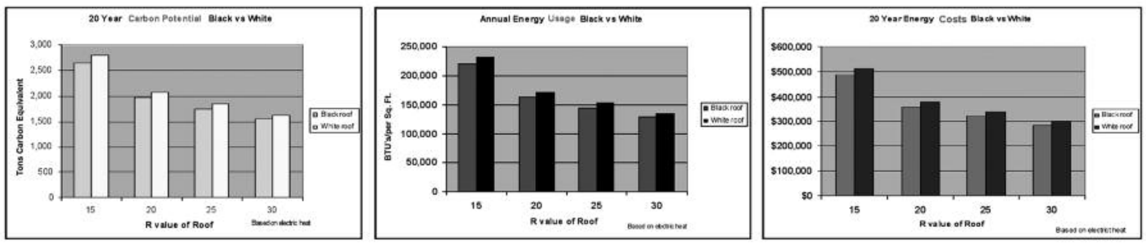
Energy analyses were performed for various major locations in ASHRAE Zones 4 and 5 using the minimum R-value of R-20 and a 60% reflectance. Throughout both zones, black membranes delivered a savings when compared with white assemblies.

Additional analyses were performed on black and white membranes in Toronto and Vancouver, Canada, using R-values from 15 to 30. Energy usage (BTUs), carbon emissions, and cost were evaluated. In both locations, black membrane assemblies fared better, delivering greater savings and reduced carbon emissions. In these same locations, assemblies with greater R-values, regardless of membrane color, delivered lesser carbon emissions, used less energy, and offered greater savings. (See *Figures 9* and *10*.)

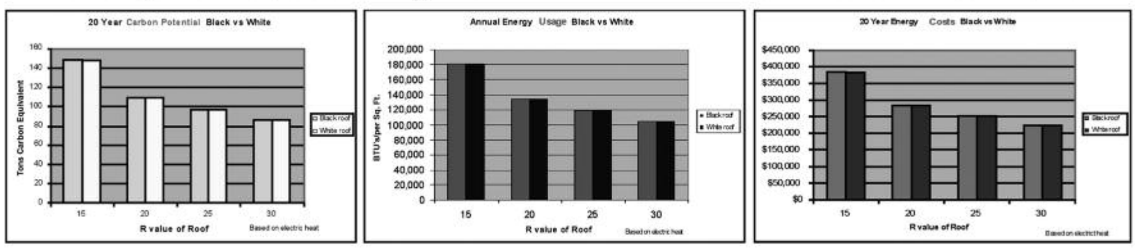
Seattle, WA: Analysis Favoring Dark Membranes in Consumption, Cost & CO_2 Emission



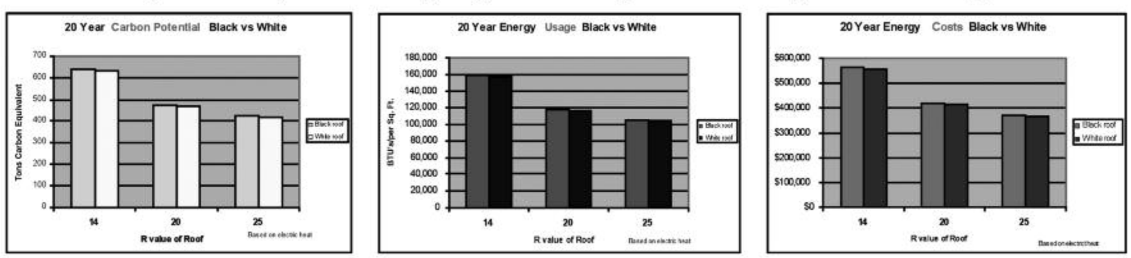
Columbus, OH: Analysis Favoring Dark Membranes in All Categories



Norfolk, VA: Analysis Showing Even Performance for Both Black & White Material



Sacramento, CA: Analysis Showing Slight Advantage When Using White Roofing Membrane



LOSS OF REFLECTIVITY

Studies performed by Oak Ridge National Laboratory (ORNL) by Desjarlais, Petrie, Atchley, Gillenwater, and Roodvoets in 2004 indicated a loss in reflectivity of 15% during the first eight months and a possible loss of reflectivity between 35% and 50% after the first three years. An energy analysis using the same software was also performed to measure impact. White membrane assemblies with reflectivity of 75% were compared to those at 55%. Various R-values from 15 to 30 were used in the evaluation. (See *Figure 11*.)

In Toronto, discolored, low-reflectance membranes delivered greater savings than highly reflective ones. The opposite was the case in Miami, FL. (See *Figure 12*.)

DESIGN RECOMMENDATIONS

With energy costs on the rise, designers must focus their efforts on the various building components and how they contribute to energy consumption. Aside from membrane color and insulation values, solar gain by windows and lighting, as well as the building's internal loading due to occupants, can account for greater levels of

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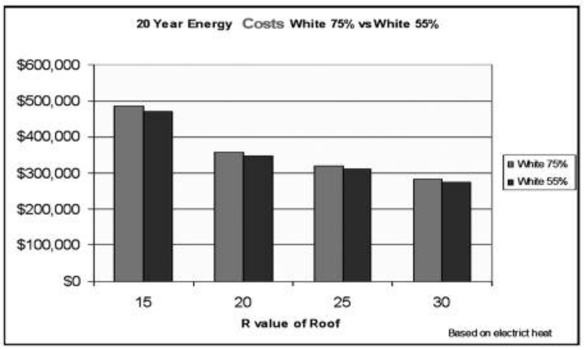
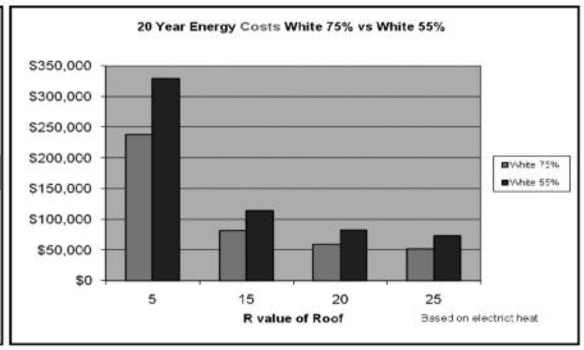
Toronto



Miami



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energy consumption. Solar gain by windows in multistory facilities has greater impact on cooling energy use during the summer than savings delivered by a cool roof. Internal loading, while it increases cooling cost during summer, contributes to a saving during the heating season. Therefore, when designing a roofing system, a designer must always consider the total heating and cooling costs and select the most suitable assembly. (See *Figure 13*.)

Combining a white or a black membrane with the proper level of insulation should be sought geographically. The use of black membranes is strongly encouraged in ASHRAE Zones 4 and above, unless mandated otherwise. Black membranes in these locations will deliver the best savings and produce lower carbon emissions than those with white membranes. (See *Figure 14*.)

In colder regions, energy consumption, mostly dictated by heating demands, will vary based on the type of facility and on internal loading. Multiple layers of insulation are strongly suggested to improve energy efficiency. Depending on the overall thickness of the insulation layer, an 18% improvement in efficiency can be realized using multiple layers versus a single layer. (See *Figure 15*.)

The ASHRAE standards are absolute minimums; exceeding these values will contribute to greater cost savings and lower carbon emissions, as demonstrated in the previous analyses. (See *Figure 16*.)

When designing a facility in a warm, sunny region in particular, building geometry, reflective surfaces, and building orientation should be evaluated to assess the level of UV deflection, sunlight magnification, and possible surface heat acceleration. The use of highly reflective wall flashings should be discouraged when constant reflection/deflection is expected.

1.3.9 Aggregate Commercial Building Component Loads as of 1998 (1)

	Percent of Total Loads	
Component	**Heating**	**Cooling**
Roof	12%	1%
Walls (2)	21%	-
Foundation	11%	-
Infiltration	18%	-
Ventilation	15%	-
Windows (conduction)	22%	-
Windows (solar gain)	-	32%
Internal Gains		
Lights	-	42%
Equipment (Electrical)	-	17%
Equipment (non-electrical)	-	1%
People	-	7%
Net Load	**100%**	**100%**

Note(s): 1) "Loads" represents the thermal energy losses/gains that, when combined, will be offset by a building's heating/cooling system to maintain a set interior temperature (which then equals *site* energy). 2) Includes common interior walls between buildings.

Sources: LBNL, Commercial Heating and Cooling Loads Component Analysis, June 1998, Table 24, p/ 45 and Figure 3, p. 61.

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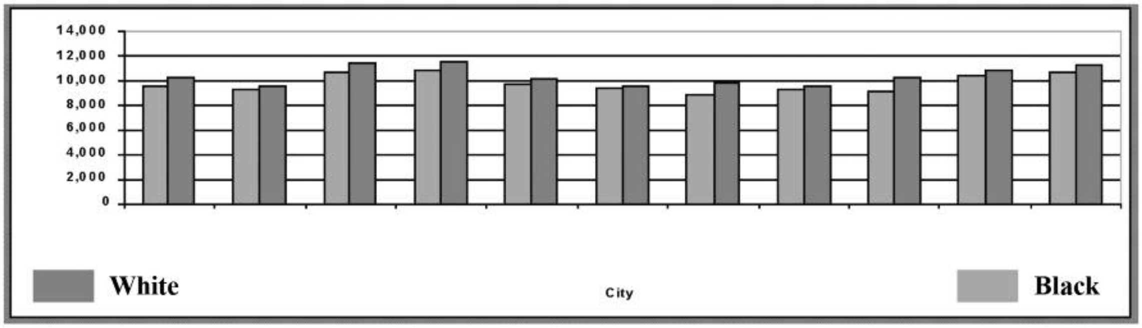
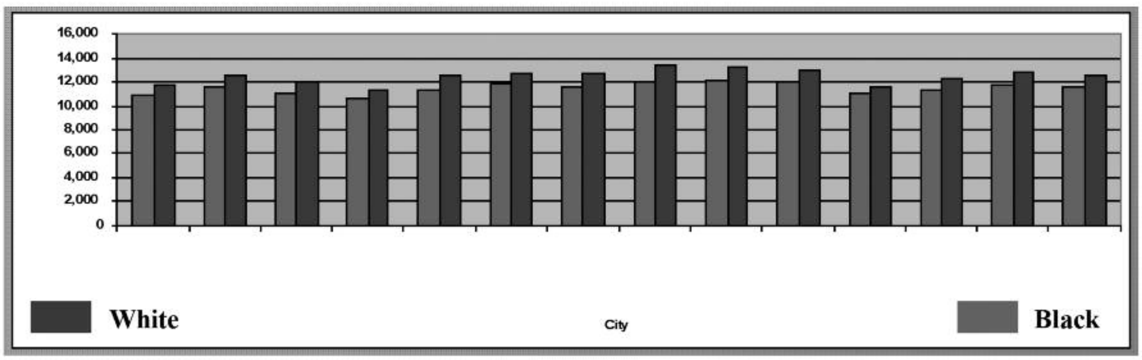
Zone 4 – BTUs



Zone 5 – BTUs



Finally, designers must evaluate the various installation details to assess their suitability when changing the membrane color. Performance of details can be impacted drastically with a change in membrane color. Lighter/reflective membrane will frequently fall below the dew point, increasing the potential for condensation when migrating warm air is not controlled during heating season.

CONCLUSION

The issue of reflectivity has been overstated and can lead to undesirable outcomes. Membranes of different colors can be carefully selected once certain factors have been taken into account. Conserving energy during design of a roofing assembly can be accomplished by a responsible selection of the different components and the proper level of insulation.

Life-cycle analyses are performed frequently on today's projects to predict the level of performance we are seeking. White reflective membranes are only sustainable in certain geographic areas (mostly in warm-climate regions) identified in *Figure 17*.

Energy-cost savings and carbon emissions during cooling and heating seasons must always be considered to avoid deficits.

Leadership in energy cannot be demonstrated by color alone, but by the environmental impact the assembly will have.

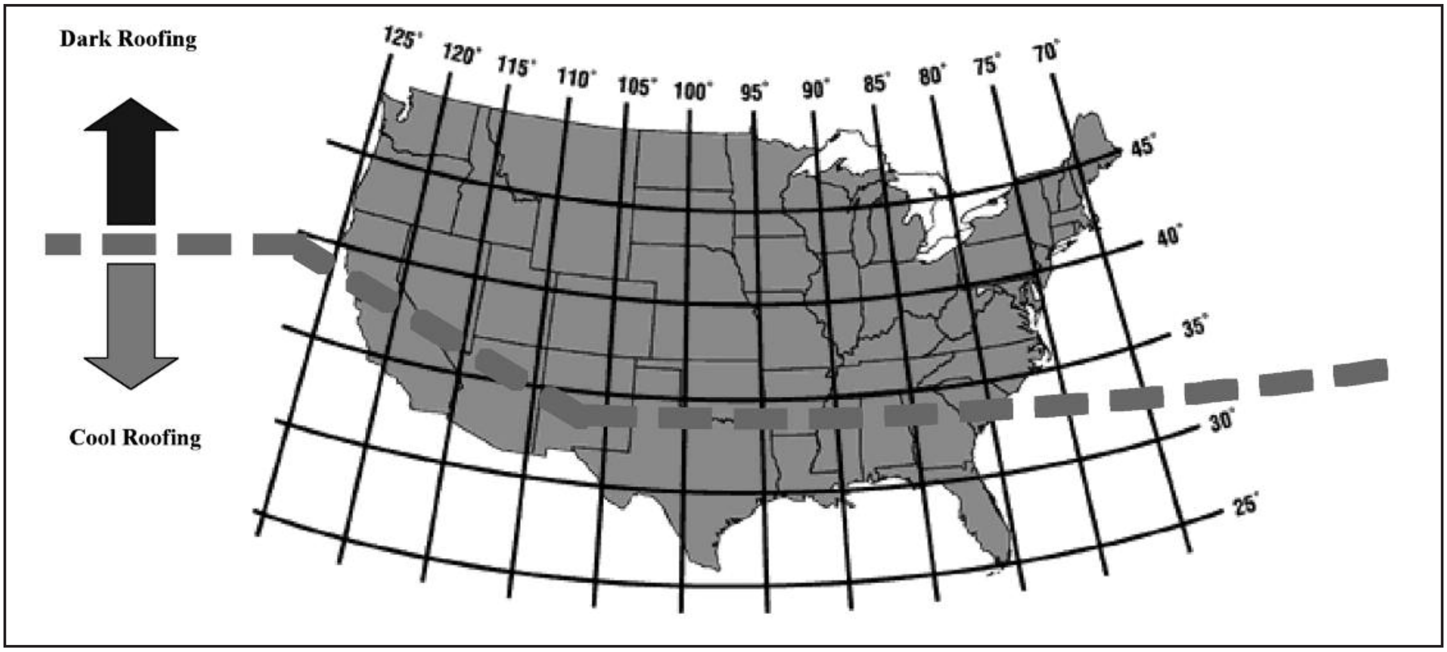
1.3.10 1995 Commercial *Delivered* End-Use Energy Consumption Intensities, by Principle Building Type (1)

	Consumption (10^3 Btu/SF)	
Building Type	Space Heating	Space Cooling
Office	24.3	9.1
Mercantile & Service	30.6	5.8
Education	32.8	4.8
Health Care	55.2	9.9
Lodging	22.7	8.1
Public Assembly	53.6	6.3
Food Service	30.9	19.5
Warehouse & Storage	15.7	0.9
Food Sales	27.5	13.4
Vacant (3)	36.0	1.4
Public Order & Safety	27.8	6.1
Other (4)	59.6	9.3
All Buildings	29.0	6.0

Note(s): 1) Further detail can be found in Table 7.4.1. Parking garages and commercial buildings on multibuilding manufacturing facilities are excluded from CBECS 1995. 2) Includes all end-uses. 3) Includes vacant and religious worship. 4) Includes mixed uses, hangars, crematoriums, laboratories and other.

Source(s): EIA, Commercial Building Energy Consumption and Expenditures 1995, Apr. 1998, Table EU-2, p. 311.

ASHRAE ZONES	R-VALUE
Zone 8	R-35
Zone 7	R-35
Zone 6	R-30
Zone 5	R-25
Zone 4	R-25
Zone 3	R-25
Zone 2	R-25
Zone 1	R-20



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