PROCEEDINGS

28TH RCI INTERNATIONAL
CONVENTION AND TRADE SHOW

# WHERE DOES THE HEAT GO?
# A LOOK INTO ENERGY PERFORMANCE OF REFLECTIVE MEMBRANES

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## ABSTRACT

Over the past decade in North American markets, the use of light-colored, cool roof products has been gaining popularity. Environmentalists have heavily promoted light-colored roofing products as the solution to both heat islands and energy conservation objectives, based on the products' inherent reflective properties and the potential for reduced heat retention.

This paper will focus on the issues of deflected heat and the subsequent impact on energy usage for cooling. Additionally, the impact of reflective roofing systems on overall carbon emissions will be examined comparatively with other effective strategies that are available to improve building energy performance. The lack of solar gain by reflective roofing material will also be assessed as to its impact on the roof assembly performance during periods of colder temperatures.

Building orientation and heat deflected from reflective wall flashing and other building components will also be discussed, along with recommendations aimed at improving roof system performance and guidelines to select the appropriate roofing membrane.

## SPEAKER

*SAMIR IBRAHIM — CARLISLE SYNTEC SYSTEMS - CARLISLE, PA*

SAMIR IBRAHIM has been with Carlisle SynTec since 1980. He holds a BS degree in architectural engineering from the University of Alexandria, Egypt. Ibrahim is currently the director of design services and project reviews. He and his group are responsible for all design services provided by Carlisle. His group is also responsible for systems and detail development and all code testing operations.

Ibrahim is also the developer and coordinator of all Carlisle architectural and consultant training programs and holds a patent on an automated seaming device for thermoset applications.

He has authored and coauthored various papers and has conducted several design presentations on various topics concerning industry issues. He is a member of the EPDM Roofing Association (ERA), the American Architectural Foundation, American Institute of Architects (AIA), and the National Roofing Contractors Association (NRCA).

# WHERE DOES THE HEAT GO? A LOOK INTO ENERGY PERFORMANCE OF REFLECTIVE MEMBRANES

## INTRODUCTION

With the emphasis on heat island reduction and energy conservation, the concept of deflecting heat away from buildings has been sought as a method to reduce consumption and achieve a lower carbon footprint. Various agencies, led particularly by the Lawrence Berkeley National Laboratory (LBNL),[1,2,3] have championed the cause, promoting the benefits of white reflective membranes even in colder climates (Minnesota and Alaska) and promising huge savings.

Initiatives intended to advance the "green" movement, while based on good intentions, have led to an increased reliance on a single-component approach in lieu of the system as a whole. For example, initiatives such as ENERGY STAR certification have resulted in increased focus on membrane color and reflective properties that may unintentionally cause designers to take the entire roof assembly for granted. A highly reflective membrane used in conjunction with a single layer of insulation may be perceived as an ENERGY STAR roof, yet it results in significant energy loss (15-18%). An additional loss can be expected due to the potential for condensation during the winter months.

Many, if not all, of the computer models currently used in energy analysis do not take into consideration the typical roof environment. These include building orientation and other variables created by condensation, reduced R-Value, and heat deflected from vertical or other roof surfaces that may increase solar loading on the building's mechanical systems.

According to Dean Rutila,[5] "Under many conditions, cities get hotter because of the reduced vegetation and the heat that's absorbed and retained in buildings, roads, etc. If we can reduce the energy absorbed and retained, we can lower energy use and reduce climate impact." The real question is: Can the roofing membrane, through reflectivity, reduce energy consumption by deflecting heat from the membrane surface? The follow-up question is: Where does the heat go?

*Figure 1 – New York City, NY, HDD 5543 CDD 779.*

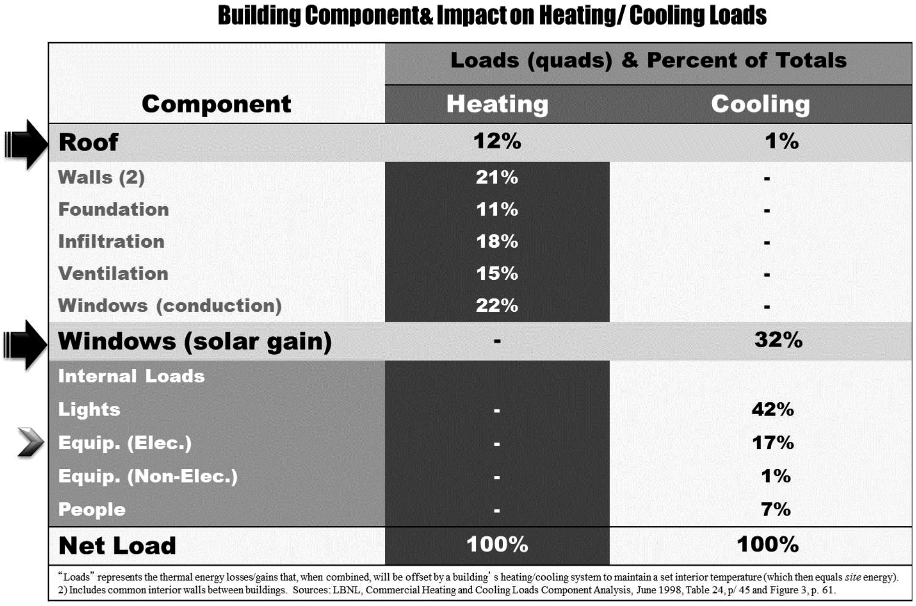
### Heat Island Dilemmas

Have you ever noticed as you approach a large metropolitan area that the city skyline is never flat, nor is it equal? As a matter of fact, cities are more recognized by their unique skylines, with skyscrapers towering over lower buildings and buildings within close proximity to one another (see *Figure 1*).

When approached at nighttime, one usually sees the lights shining through the buildings and reflections from smaller buildings. These congested metropolitan areas are a heat island concern. The LBNL, through its research studies, offers strategies to reduce heat islands—and where exorbitant savings were projected (in the billions of dollars)—by simply deflecting heat away from roofs.

With neighboring buildings at close proximity and at varying heights, an increased amount of heat is deflected from lower roofs and absorbed by these buildings; the heat does not simply disappear! Heat is absorbed through curtain walls and windows of higher structures. Whatever heat is deflected from a roof is redirected to another surface.

According to the LBNL,[1,2,3] as shown in *Figure 2*, roofs (up to six stories high) contribute 12% of the total heating load, while cooling only accounts for approximately 1%. These values fluctuate as the building increases in height. By redirecting heat from lower roofs to windows and curtain walls, the reflective membranes increase solar gain significantly in a component,

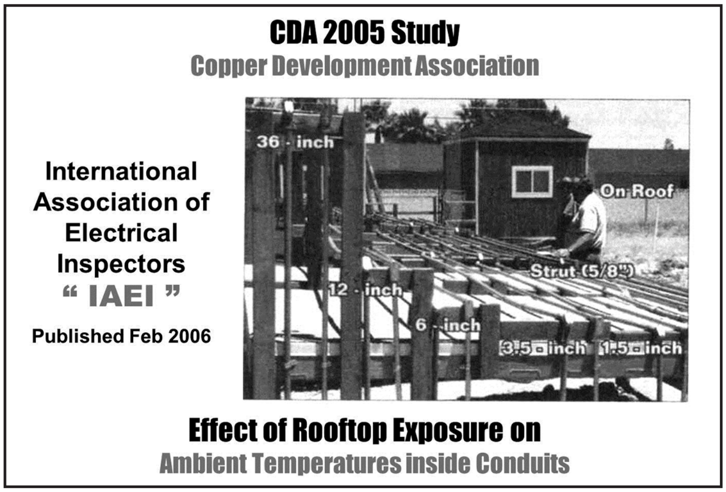


**Building Component& Impact on Heating/ Cooling Loads**

| Component | Loads (quads) & Percent of Totals | |
|---|---|---|
| | Heating | Cooling |
| **Roof** | 12% | 1% |
| Walls (2) | 21% | - |
| Foundation | 11% | - |
| Infiltration | 18% | - |
| Ventilation | 15% | - |
| Windows (conduction) | 22% | - |
| **Windows (solar gain)** | - | 32% |
| Internal Loads | | |
| Lights | - | 42% |
| Equip. (Elec.) | - | 17% |
| Equip. (Non-Elec.) | - | 1% |
| People | - | 7% |
| **Net Load** | 100% | 100% |

"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.

*Figure 2*



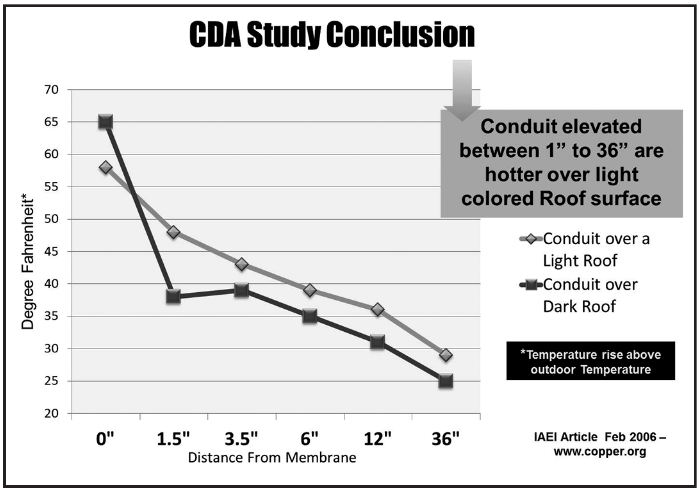
**CDA 2005 Study**

Copper Development Association

International Association of Electrical Inspectors
“ IAEI ”
Published Feb 2006

**Effect of Rooftop Exposure on Ambient Temperatures inside Conduits**

*Figure 3*



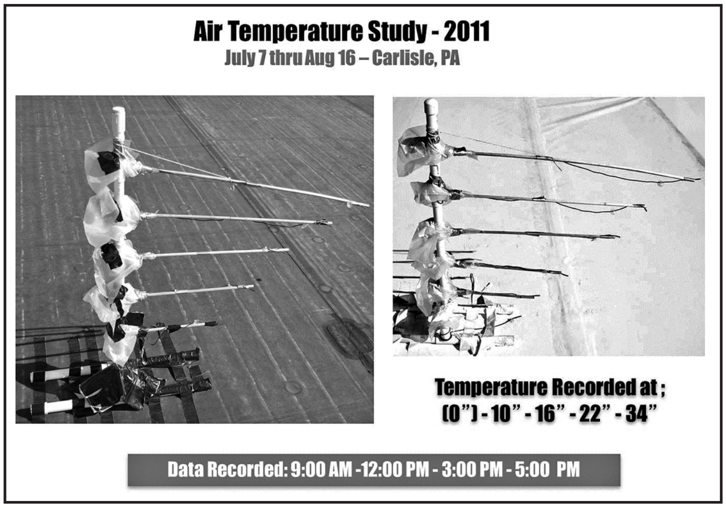
**CDA Study Conclusion**

Conduit elevated between 1” to 36” are hotter over light colored Roof surface

*Temperature rise above outdoor Temperature

IAEI Article Feb 2006 – www.copper.org

*Figure 4*



**Air Temperature Study - 2011**

July 7 thru Aug 16 – Carlisle, PA

Temperature Recorded at ;
(0”) - 10” - 16” - 22” - 34”

Data Recorded: 9:00 AM -12:00 PM - 3:00 PM - 5:00 PM

*Figure 5*

which, according to LBNL, accounts for 32% of total consumption.

## Effect of Roof Color on Ambient Air

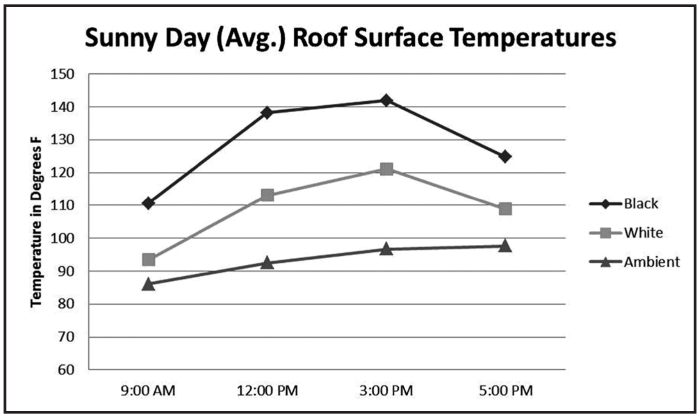
Two studies have been conducted that illustrate the effects of roof color. The first study was conducted by the Copper Development Association (CDA) to evaluate the impact of deflected heat on conduits and wiring used to control the operation of rooftop HVAC equipment. This study was published in the January-February 2006 issue of the *IAEI News* (International Association of Electrical Inspectors).[4] See *Figure 3*.

Heat sensors were mounted inside electrical conduits and placed at various elevations above black and white roof membranes beginning at 0 in. and ending at 36 in. The change in ambient temperature inside the conduit was measured and recorded. The data led to the conclusion that the air temperature became hotter inside the conduits mounted above white membranes than those above black membranes (see *Figure 4*).

Carlisle SynTec Systems conducted the second study in July-August of 2011 in order to do the following:

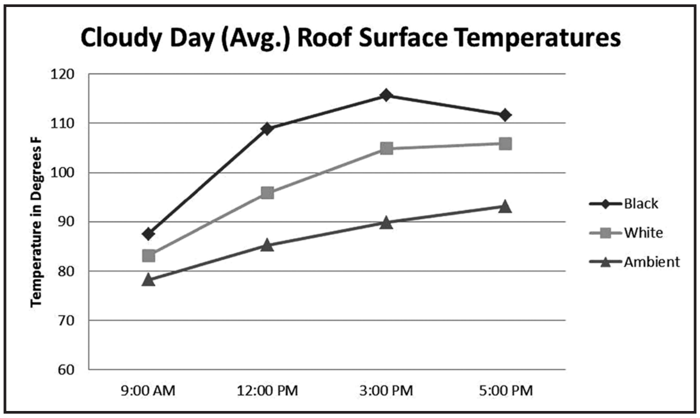
- Determine roof color impact on ambient air at various levels
- Evaluate the impact of reflective wall flashing
- Establish a more realistic understanding of membrane surface temperature:
  - — During the course of day
  - — During both sunny and cloudy conditions

On a one-story building, two collection towers were constructed of PVC piping and placed with temperature sensors mounted at elevations varying from 0 in. (surface temperature) to 34 in., as shown in *Figure 5*. The collection towers were placed on an open roof area consisting of white TPO and black EPDM. The collection towers were mounted in the center of each roof. Both roofs were located over the same interior space, and the R-value beneath the



**Sunny Day (Avg.) Roof Surface Temperatures**

*Figure 6*



**Cloudy Day (Avg.) Roof Surface Temperatures**

*Figure 7*

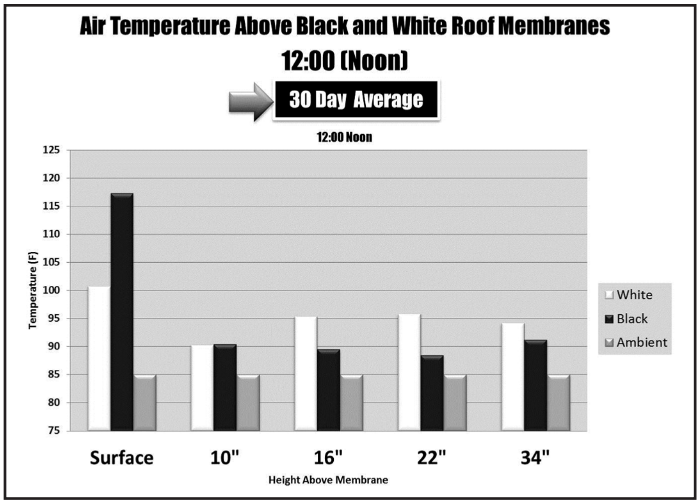


Figure 8

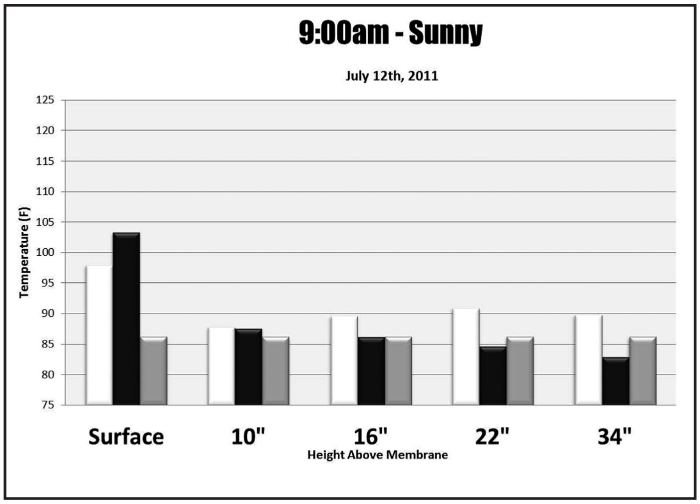


Figure 9

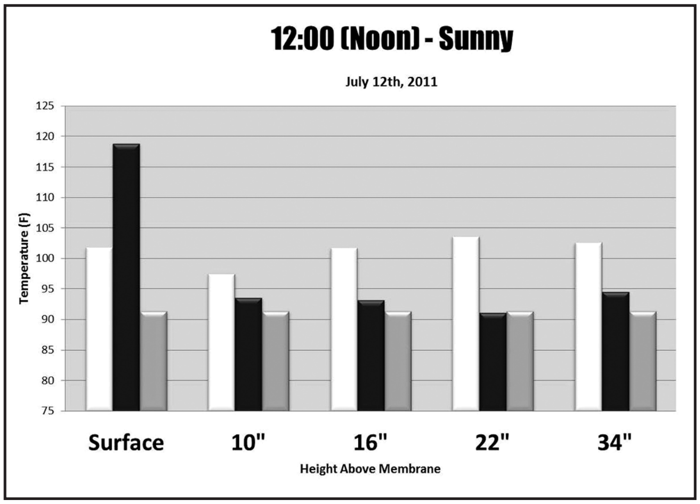


Figure 10

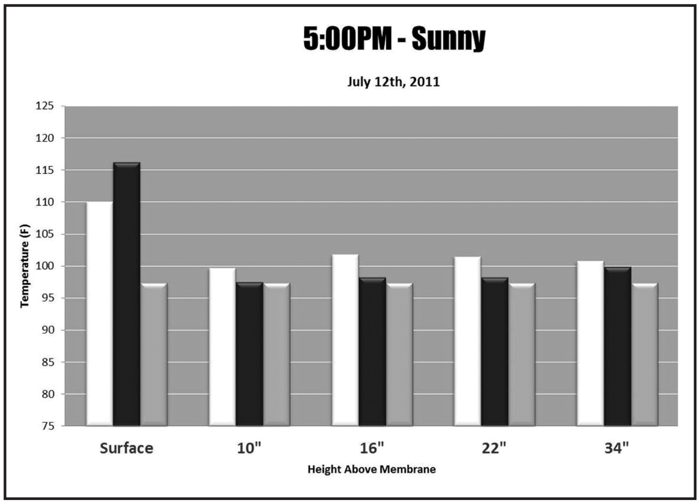


Figure 11

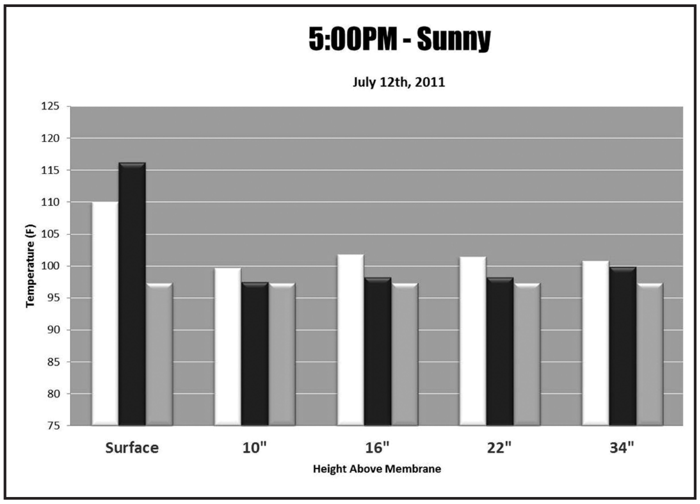


Figure 12

membrane was R-20. In addition, surface temperature sensors were mounted along a perimeter area of the white TPO roof to record the effect of heat deflected from the wall flashing. Temperature readings were taken five days a week at 9:00 AM, 12:00 PM, 3:00 PM, and 5:00 PM. (The daily recorded data will be available at www.sustainableroofingalliance.com.)

## Membrane Surface Temperature

On both the white and black membranes, surface temperatures fluctuated throughout the day. The readings were impacted by bright, sunny conditions as well as cloudy periods, as shown in *Figures 6* and *7*. While the white, nonsoiled, reflective membrane reached between 17°F and 23°F above ambient, the black material reached temperatures above ambient varying from 11°F to 47.3°F. This part of the study helped to shed some light on actual membrane surface characteristics regarding heat gain, which has been overestimated in many of the energy models used today. The theory of white membrane temperatures remaining within 5° of ambient temperatures and black within 60° to 80° has been overstated.

## Ambient Air Temperature Above White and Black Roofs

This important part of the study revealed results the total opposite of what has been publicly perceived. Until this study, most believed that white reflective membranes contribute to cooler air temperatures above the membrane surface and further reduce energy consumption when the cooler air is drawn into the intake unit.

Quite contrary to everyone's belief, the study proved this theory to be inaccurate and demonstrated a lowering of ambient air

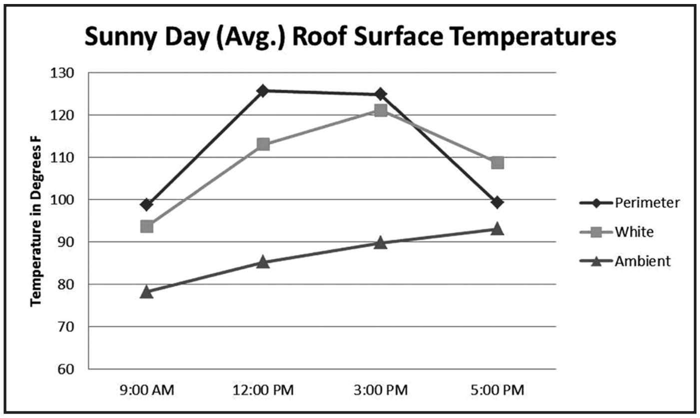


*Figure 13*

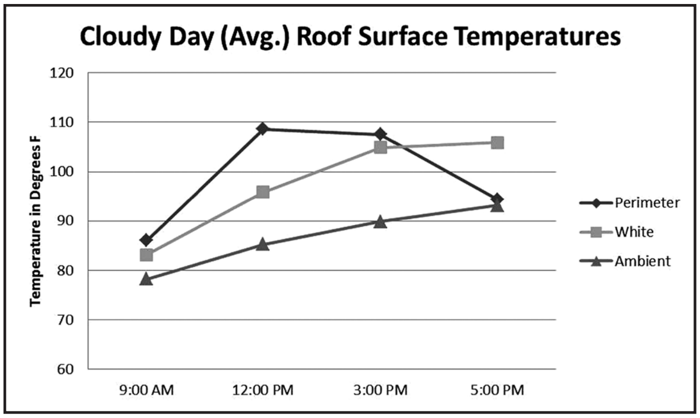


*Figure 14*

temperature when dark/black membrane is used. Rising air temperature can reduce PV energy production, and when drawn into the building, increase energy use during the cooling season. Refer to *Figures 8* through *12* for further information.

This issue was never integrated into any of the energy analysis models currently in use.

### Effect of Reflective Wall Flashings

Sensors mounted within 4 to 6 ft. from southern-facing parapets recorded higher temperatures than those obtained in the open field of the roof. The midday surface temperature readings fluctuated from 25°F to 43°F above ambient, which is twice as much as what was recorded in the field of the roof and almost as much as that recorded for a black membrane on a cloudy day. This elevated temperature has also not been integrated into current energy models (see *Figures 13* and *14*).

Aside from energy performance, these elevated temperatures can become much greater in locations in the Southwest (Nevada, New Mexico, and Arizona)—possibly causing premature aging of the membrane (see *Table 1*). The same theory can apply to other locations throughout the roof where heat is deflected from windows, curtain walls, glazing systems, HVAC units, air ducts, and other reflective metallic objects. Besides premature aging, energy performance is adversely impacted due to reduction in reflective property of the membrane (see *Figure 15*).

### Energy Analysis

Summer and winter energy consumption, among other things, is influenced by geographic location. Buildings of similar operations and sizes in the northern part of the United States consume greater energy during the heating season versus the cooling season. Adopting a cool roof as a single-strategy solution to energy consumption certainly does not appear to be the answer. When analyzing summer and winter consumption for the city of Sacramento, LBNL acknowledged "slight air quality degradation during wintertime, due to increased carbon emissions when a reflective membrane is used."[6] Sacramento does not compare to the cities of Chicago, Boston, Cleveland, Rochester, or Toronto. These are all locations with a greater number of heating degree-days than cooling degree-days. In assessing energy performance and carbon emission reduction, insulation plays a more significant role in reducing both consumption and emission. Combining higher insulating values with the right membrane color offers a better year-round energy management system than the single-strategy approach of relying on a white, reflective roof membrane. See *Figure 16*.

| Ratio Between Flashing Ht. (A) and Membrane Increase of Area (B) | | | | |
|---|---|---|---|---|
| State | Latitude* | City | Ht. (A) | Affected Area (B) % of Flashing Ht. |
| Arizona | 34 | Phoenix | 1 | 0.6 |
| California | 39 | Sacramento | 1 | 0.8 |
| Florida | 26 | Miami | 1 | 0.5 |
| New Mexico | 43 | Albuquerque | 1 | 1.0 |
| Texas | 33 | Dallas | 1 | .07 |

*Latitude degrees are rounded to next number

*Table 1*

Reflective roof membranes are a more effective option for energy savings in ASHRAE zones 1-3. As we move further north to colder climates, emphasis should be placed on increased R-value. Reflective membranes in the north may contribute to some savings during the summertime, due to their lower surface temperatures; however, in the winter they are much colder than darker material, due to lack of solar gain, and tend to fall below the dew point frequently and remain below the dew point for longer periods than darker membranes. This cycle has contributed to greater condensation levels beneath the membrane, which, in turn, impacts the insulation thermal efficiency and negates the older "self-drying roof" concept. Additional measures should be considered when incorporating cool reflective membranes in the northern U.S.

### Recommendations

Geographic locations and building orientation should always be considered when assessing energy performance and making the selection of appropriate membrane color. A lower roof level on the south side of a building will deflect heat and increase solar gain on windows/glazing systems of neighboring structures. Heat deflection could also occur from neighboring windows onto roofing membranes, thereby increasing membrane surface temperatures and

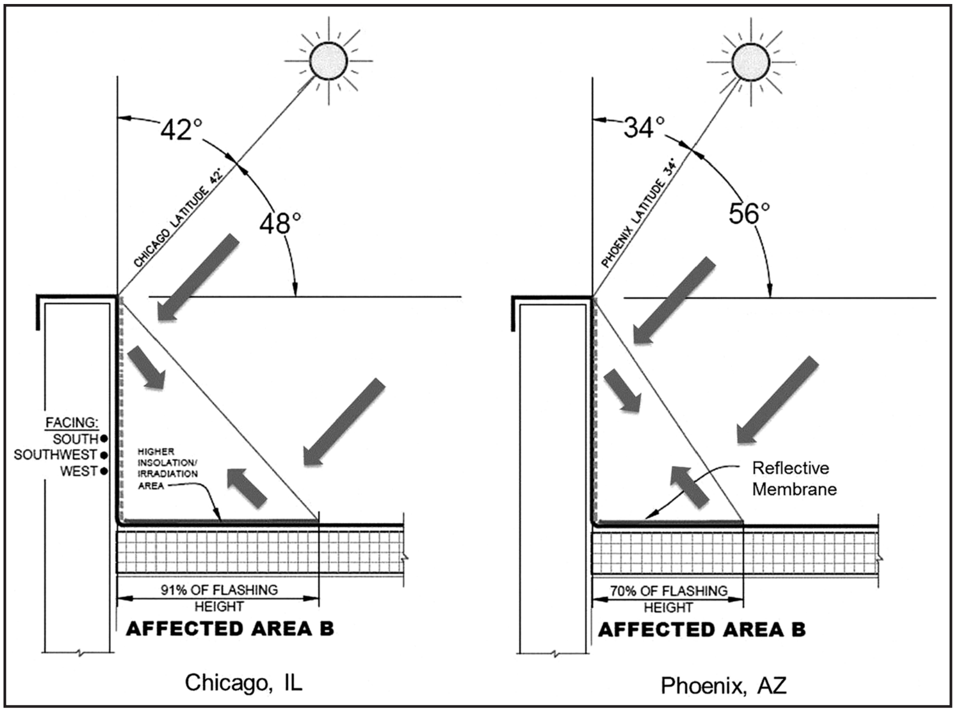


*Figure 15*

impacting energy consumption. For such facilities, the lower roof level should be designed with a darker membrane and inverted assembly, or a vegetated roof as an option. The other roof levels may incorporate reflective or darker membranes with the proper insulation level based on geographic location. An air barrier or a vapor retarder should certainly be considered depending on the expected temperature and humidity level within the building.

Deflection of heat can occur from other shiny surfaces and could impact the membrane's performance or promote premature aging. Efforts should be made, especially in locations with hotter temperatures and bright sunshine, to select nonreflective, dull surfaces when possible.

When feasible, heavy concentration or placement of large mechanical units in a small area, with continuous equipment screens (solid and reflective materials) should be avoided. During the summer, these areas will experience significant heat increase due to the number of reflective surfaces and lack of airflow. When possible, increase distances between large equipment and utilize dull-finished, louvered equipment screens to increase airflow and reduce reflectivity.

Projects with high parapet walls, especially those with southern exposure, should also incorporate dull-finished surfaces. The use of highly reflective membrane to flash the entire wall is counterproductive and could promote premature aging of the membrane used within perimeter areas.

Positive drainage should always be considered to increase reflective roof life expectancy and enhance energy performance, especially in southern U.S. locations (with a greater number of cooling degree-days). Positive drainage decreases membrane soiling and helps to improve service life (see *Figures 17* and *18*).

When considering a sustainable "green" design, the emphasis should be placed on the system as a whole, not the individual component. Combining an ENERGY STAR membrane with a single layer of insulation or a lesser R-Value than recommended could lead to additional problems and wasted energy. Energy loss, at 14%-18%, could be experienced, and such an assembly increases the probability of condensation in colder-climate regions. Resulting condensed moisture could further degrade the insulating property of roof insulation.

When considering cool or reflective membranes for colder climate regions to comply with heat island mandates, think beyond the single-component approach. Combine good insulation levels and the use of air barriers to improve efficiency.

Elevate roof-mounted equipment (non-curb-mounted) to reduce algae and mold growth—especially in southern, humid locations. Shaded moist areas are a perfect breeding ground for algae and mold. Consider a maintenance program that includes periodic assessment and cleaning of reflective roofing material.

## CONCLUSION

The design and construction industry has been influenced more than ever by third-party initiatives and recommendations, some of which have been integrated into building and municipal codes. Unfortunately, despite good intentions, the data used may have been based on laboratory testing and mathematical calculations that did not incorporate real-world conditions.

Initiatives that approve or recommend a single-component certification (i.e., ENERGY STAR, etc.), originally intended for consumer products, do not take into account the whole integrated roof assembly or the geographic location and should be carefully assessed by the project design team.

The "self-drying roof" concept, which has been practiced for several decades in North America, has always been based on

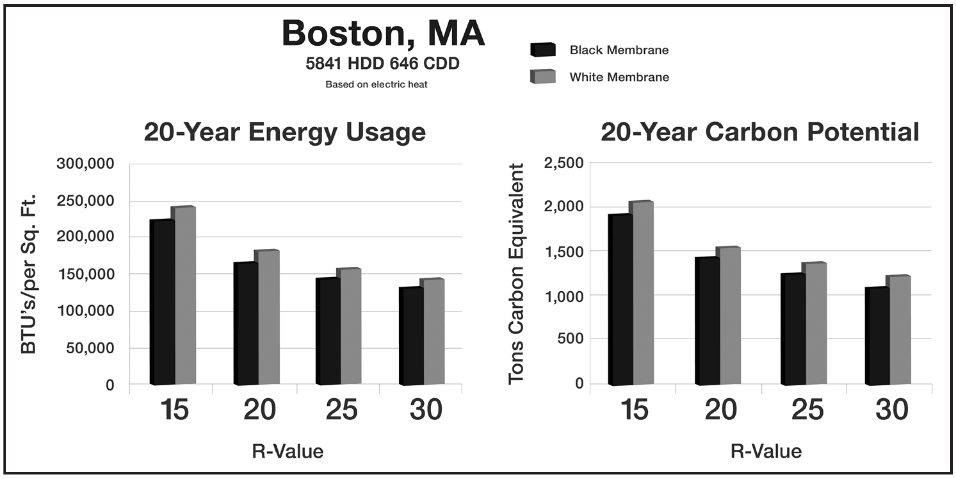


*Figure 16*

*Figure 17 – Well-drained reflective roof.*

*Figure 18 – Soiled roof condition (poor drainage).*

the use of darker membranes. These roofs tolerated certain levels of moisture accumulation during the winter and facilitated the dissipation of moisture during the summer months due to higher surface temperatures. With the shift to white reflective material and not recognizing the impact of the color change, many buildings have experienced greater condensation levels and wet and moldy insulation, resulting in reduced insulation efficiency and a higher carbon footprint. Unfortunately, some of these facilities were designed with the intent to comply with green initiatives or mandates that promote sustainable, long-lasting buildings.

It is time for designers, architects, and consultants to take a leading role in questioning municipalities, government agencies, and building officials regarding their adoption of "green" initiatives and the theories and methods these initiatives use. Those who initiate mandates without understanding some underlying principles should ultimately be held accountable for their misuse.

Changing roof color for the sole purpose of making a sustainable statement should never be practiced or accepted by a building owner. There is no single-component approach suitable for all climates. The roof color and insulation level, as well as the use of air and vapor barriers, should always be analyzed as a whole-system approach toward a sustainable roof design.

Owners, designers, and building officials should always be alert to sustainable practices that can contribute to problems with neighboring buildings.

We must remain focused on the true meaning of sustainability. It is not about a change of color, obtaining a point of credit, or adopting a trend. It is rather "a balanced integration of sound design principles and green, proven products to achieve durability, longer service life, energy efficiency, and a reduced carbon footprint."[7]

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