

Still Cool After All These Years: White Reflective Roofing Stands Up to Scientific Scrutiny

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Perhaps one of the most significant developments in the low slope commercial roofing industry over the past decade and a half is the increase in the awareness of, and the adoption of, the concept of cool roofing. Although there have been refinements over time, “cool” roofs are anything but new. Light colored, reflective thermoplastic roof membranes have been in use since the 1960s in Europe, and the 1970s in North America. A number of the companies that pioneered the introduction of these materials into the low slope roofing market continue to thrive and prosper today.

Cool roof materials, which are typically light colored, reflect a significant portion of the incident solar radiation back up into the atmosphere (reflectance), and also quickly release the fraction of energy that is absorbed by the roof (emittance) into the atmosphere. This results in a lower roof surface temperature during the hot summer months when compared to black or dark colored roofs. Although this provides a number of benefits, the two most important ones are a reduction in cooling energy consumption and a reduction in the Urban Heat Island Effect (UHIE). With a roof surface that can be more than 40 °F cooler with a white or other light colored membrane, less energy is required to cool the space below. Significant portions of our urban landscape are covered with dark colored parking lots, roads and roofs. These surfaces absorb significant amounts of the incident solar radiation, increasing their surface temperatures. Collectively they contribute to the UHIE, whereby the ambient temperature in a city is hotter than the temperature in rural areas. This elevated temperature increases smog formation amongst other negative consequences. Converting these dark surfaces to light colored reflective surfaces can help mitigate the UHIE.

Although some of the “cool” roof membranes remain largely unchanged from their earliest days, the recognition of the potential benefits of such materials has grown dramatically since the late 1990s. Newsweek first highlighted the benefits of cool roofs in their Millennium Notebook in November, 1998. The article featured the R.C. Wiley Furniture Warehouse in Salt Lake City. The 865,000 square foot building is clearly visible in aerial photos (Figure 1), however its cool PVC roof made it almost invisible to heat sensors (Figure 2). The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (ASHRAE) was the first to recognize the concept in a standard in ASHRAE 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings in 1999. Since that time various entities ranging from the State of California’s Energy Commission, green building rating systems such as the U.S. Green Building Council’s LEED and the Green Building Initiative (GBI)’s Green Globes, to various cities such as Chicago, New York and Toronto have implemented cool roofing strategies or requirements.





Fig. 1: R.C. Wiley, aerial photograph

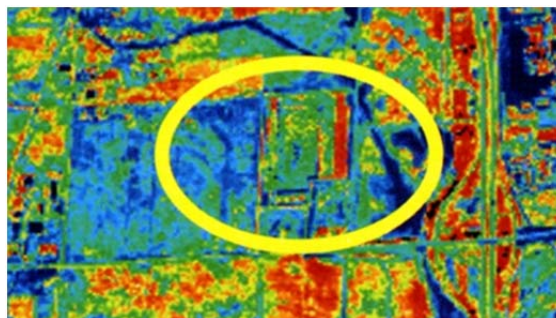


Figure 2: R.C. Wiley, Thermal Infrared Image

Despite the exceptional track record of some cool roof technologies such as thermoplastic PVC membranes and some coatings over decades, certain individuals, and some companies within the low slope roof industry have attempted to cast doubts on the fundamental science behind cool roofs, the energy impact of cool roofs in northern climates as well as the overall performance of cool roof products. The following paper will address each of these and other alleged issues.

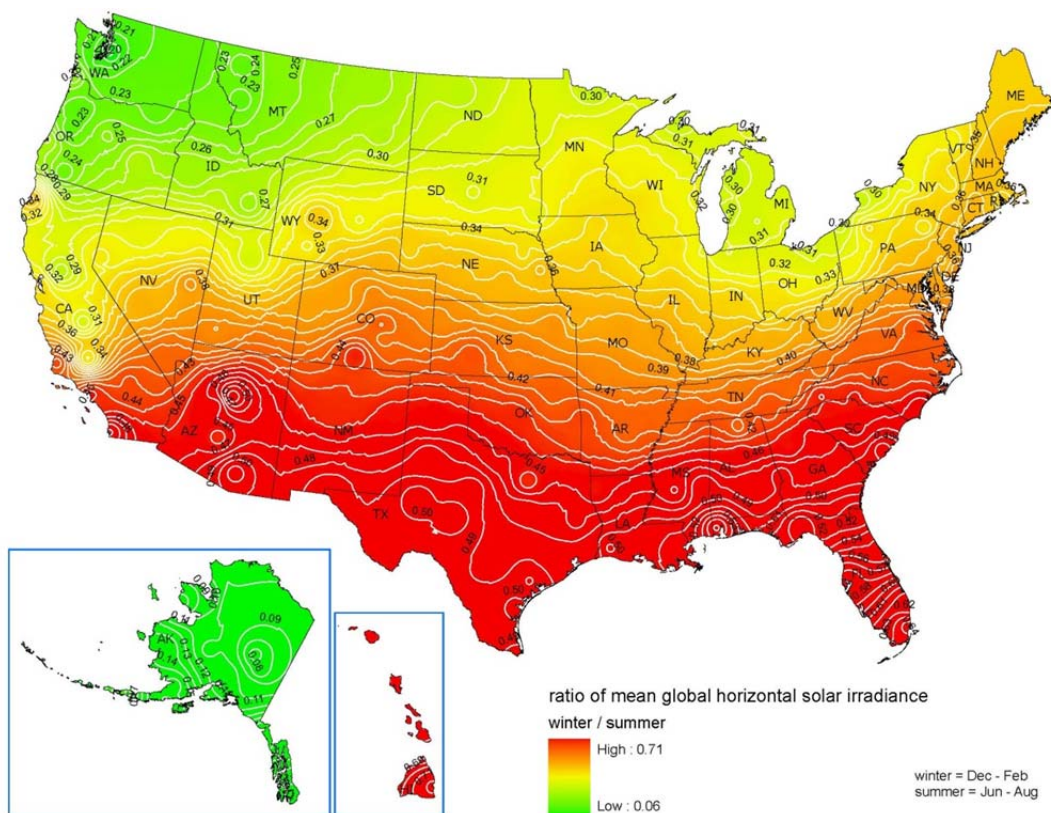


Figure 3: Ratio of mean global solar irradiance winter/ summer

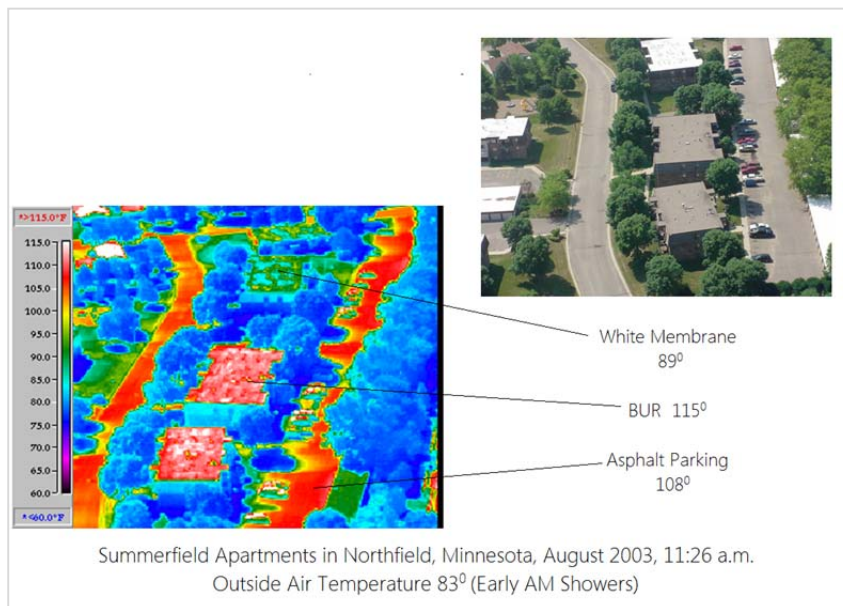
ENERGY

Lawrence Berkeley National Laboratory (LBNL) was one of the first to measure the cooling energy savings associated with the use of cool roofs. In their 2001 study of a retail store in Austin, Texas, they determined that simply by switching a black colored membrane to a white membrane, the average summertime rooftop surface temperature on the facility decreased from 168 °F on the black to 126 °F on the white. This resulted in peak hour cooling energy savings of 14% and overall annual energy savings of 7.2¢/ft². Adjusted for inflation in 2013, this would be the equivalent of 9.5¢/ft².

Over time the energy benefits of reflective roofs in southern climates has come to be broadly accepted and recognized. If one accepts that cool roofs provide energy saving benefits in cooling dominated climates, the intuitive corollary is that reflective roof surfaces are disadvantageous in heating dominated climates, where one might assume the black, minimally reflective surfaces will absorb the sun's energy in the winter, presumably reducing heating energy loads.

The answer is not quite as simple as it might first appear. Winter days are shorter than summer days, with more overcast skies. Most importantly, the sun is much lower to the horizon in the winter and generates much less heat. As can be seen in Figure 3, in the northern states, winter solar irradiance is typically 20 to 35% of the summer time irradiance for a given location, therefore a roof surface receives three to five times more sun in the summer than in the winter in northern states. Furthermore in many northern states, roofs will be covered by a highly reflective blanket of snow for extended periods of time, further reducing the impact of a darker colored roof surface on heating energy.

LBNL simulated the potential impact of substituting conventional dark colored roofs with cool roofs on conditioned commercial buildings in 236 cities. Using the Department of Energy's DOE-2.1E energy model, they determined the differences in cooling and heating energy use between traditional dark roofs and aged cool roofs (assumed average reflectivity of 0.55) considering the local building inventory (types, ages, density of construction), local energy sources and other factors.



As would be expected the greatest net energy savings were calculated for the southern states such as Arizona, New Mexico and Nevada. Their modeling also showed that there can be a "heating energy penalty" associated with the use of cool roofs in cold climates. They found however that the magnitude is generally quite small. In Minnesota for example, they calculate it to be on average 0.137 therm/ m² per year for conditioned commercial buildings. Most importantly, according to their simulations, with the exception of the most remote locations in Alaska, the summertime cooling energy savings more than offset any heating energy penalty, resulting in net annual energy savings. A sampling of some of their results, including cooling energy savings, heating energy penalties and net annual energy savings are shown in Table 1. Overall, LBNL estimates that the use of cool roofing materials on 80% of all commercial buildings across the USA would result in 10,400 GWh of cooling energy savings, and approximately \$735 m in overall energy savings. The avoided production of the energy saved could reduce CO₂ emissions by 6.23 Mt annually, the equivalent of removing 1.2 million cars from our roads.

State	Cooling Energy Saving kWh/m ² CRA	Heating Energy Penalty therm/m ² CRA	Energy Cost Saving (\$/m ² CRA)
CA	6.13	0.0292	0.699
NV	6.86	0.0737	0.570
FL	5.72	0.0115	0.448
NH	5.35	0.121	0.482
MN	4.17	0.137	0.136
IL	4.22	0.0994	0.217
US	5.02	0.0645	0.356

Table 1: Calculated average annual results for selected states (Source LBNL)

The LBNL laboratory study is a high level, macro assessment of the potential energy and environmental benefits of cool roofs across the entire USA. Engineers at the HVAC & R Center & Industrial Refrigeration Consortium at the University of Wisconsin (UW) at Madison on the other hand were specifically interested in the impact of cool roofs in the cities of Minneapolis, Minnesota and Denver, Colorado. Their study was based on a typical “big box” retail building. They simulated different combinations of roof colors (black, white), roof insulation values (from none to R24), with and without accounting for snow cover. Not surprisingly, they found the cooling energy cost benefit of a cool roof decreases with increasing amounts of thermal insulation, from 26% with no insulation to 5% with R24 insulation in Minneapolis. Similarly, they found that the “heating penalty” attributable to a cool roof in their simulation also decreased from 12% with no insulation to 3% with R24 insulation. Most importantly, they calculated that in both Minneapolis and Denver overall annual energy savings are achieved using a cool roof. Their results are summarized in Table 2. With R24 insulation, the overall savings are modest at \$10.04 and \$16.09 per thousand square feet of roof surface in Minneapolis and Denver respectively. However, it is important to note that even in such northerly cities, cooling energy savings are sufficient to compensate for any heating energy penalty that may be incurred through the use of cool roof surfaces.

	Minneapolis		Denver	
Roof Insulation	R4	R24	R4	R24
Total Annual Savings (\$/1,000 ft ²)	27.33	10.04	47.74	16.09

Table 2: Calculated savings for installing a white roof (Source HVAC & R Center, University of Wisconsin)

A study was conducted on a correctional facility in Jamesville, New York to compare amongst other things the comparative energy impacts of black, non-reflective and white, reflective, roofs in a northern climate. The study, or at least the reporting of it, has a number of shortcomings. Four apparently identical buildings were re-roofed with four different roof assemblies. Three had a gypsum cover board and 4” of polyisocyanurate insulation, and different roof covers: one black EPDM, one white TPO and a vegetated cover. The fourth consisted of a white TPO with 8” of polyisocyanurate insulation and the same gypsum cover board.

The roofs were instrumented to compare the heat flow across each roof assembly from late Fall of 2009 through the Spring of 2011. For the purposes of this paper we will focus only on the direct comparison of the white and black roofs with the same amount of insulation. The report highlights typical “summer days” May 12, 16 and 29, 2010, the latter for which they note that with an ambient temperature of 71 °F, the black roof surface was approximately 50 °F hotter than the white roof surface. It is unclear why these dates were chosen to represent “summer” conditions, when there were numerous days in July¹ on which, the peak ambient temperature was greater than 90 °F. Unfortunately the only date the authors chose to report the indoor temperatures, immediately below the roof decks, was November 9, 2010. As the structures are heated, it is not surprising that the temperature at this location in all four buildings remained relatively constant around 72 °F. The buildings are not air conditioned and it would have been informative had they reported summertime temperatures below the roof decks of the four buildings. While “the correctional facility does not have cooling” the authors conducted their assessment “assuming the facility did have cooling” and concluded that using the black roof as a baseline, for the cool roof “heating losses and cooling savings tended to cancel out”. The fact there is no net energy loss for the cool roof is a positive when one considers the additional cool roofing benefits described below. However, this conclusion is based on assuming a heating cost of \$1.00 per therm for heating and \$0.12/ kWh. In 2010 the average cost² of natural gas for commercial customers across the state of New York was approximately \$1.00 per therm. However, the average commercial price² of electricity in New York state was approximately \$0.16 kWh in 2010. Calculating cooling energy costs for the “theoretical cooling system” at market price would likely have shifted the scale into a net savings for the cool roof. Additionally, the lower summer time roof top temperature of the building with the white roof no doubt results in more comfortable summer time conditions for the residents of the building with the white roofs.

Although data published by LBNL, UW and others is based on modeling and simulations, the results, as well as those discussed above for the Onondaga study, appear to be consistent with the experience of some major building owners such as retail chains. Target Corporation has approximately 1,900 facilities across the USA. Energy is a significant driver of their operational costs. They constantly track energy consumption and compare actual results across their

¹ Weather Underground: www.wunderground.com

² U.S. Energy Information Administration: www.eia.gov

facilities to the projections generated by their own energy models. For more than two decades now Target has used highly reflective thermoplastic PVC roof membranes on all their facilities. The use of cool roofs is an important component of their energy efficiency program. They have compared cool roofs to black roofs in cold climates and have not measured any difference in heating energy consumption between the two. Although the magnitude of the savings varies with location, even in their northern locations, Target Corporation achieves net energy savings through the use of cool roofs.

A critical point highlighted by the LBNL retail study was the disproportionate impact cool roofs have during the mid-day, peak demand hours. During the study, they measured cooling energy savings of 14% during peak demand hours. Electricity must be used as it is generated. It is not feasible to store electricity on a large scale. Outside of peak demand hours, utilities typically have excess energy capacity. However at peak times, more and more utilities struggle to keep up. Peak energy demand drives power plant construction. As overall energy consumption increases, more utilities are charging premiums on electricity rates during peak demand hours to try and influence behavior and even out the load on their systems. According to the U.S. Energy Administration, buildings currently consume 76% of all electricity produced in the USA. Building cooling systems are generally operated on electricity. Cool roofs can play a significant role in reducing peak demand across all climate zones. This was one of the driving forces behind California's Title 24 energy code, which mandates a variety of energy saving measures, including cool roofs. The importance of reducing peak cooling demand will only increase with time. According to the United Nations Intergovernmental Panel on Climate Change, it is anticipated that for most regions in North America a 1 in 20 year hottest temperature event will likely become a 1 in 2 year event by the end of the 21st century. Additionally, it is projected that the 1 in 20 year maximum daily temperatures will increase 2 to 5 °C in the same time frame.

An alternative way to look at the energy performance of roofing systems is to look at the insulation required to achieve the same "performance". Oak Ridge National Laboratory (ORNL) estimated the energy equivalency of cool roofs vs. non cool roofs with additional insulation. They were looking to calculate the additional amount of insulation that might be required to achieve "energy equal" roofing systems for new construction and retrofit. They selected one city from each ASHRAE climate zone, and assigned a default R-Value for each, for both new construction and retrofit (See Table 3) for cool roofs (Thermal Reflectance: 0.65 and Thermal Emittance: 0.90). Using the Simplified Transient Analysis of Roofs (STAR) model they calculated cooling and heating energy costs. They then determined the amount of additional insulation that would be required under a non-cool roof (Thermal Reflectance: 0.10 and Thermal Emittance: 0.90) to have similar heating/ cooling costs as the cool roof. As can be seen in Table 2, in all climate zones, in both the new construction and retrofit scenarios, additional insulation was required under the non-cool roof to achieve the same energy performance as the cool roof. The additional insulation required to achieve energy equivalency with a cool roof ranged from R3 in Fairbanks, Alaska to R17 in Miami, Florida, with an average of R9 in new construction, R2 to R7, for the same cities respectively, and an average of R4 in retrofit.

Climate Zone	Representative City	Default R Value for White Roof New Con.	Additional R Value required for Black Roof New Con.	Default R Value for White Roof Retrofit Con.	Additional R Value required for Black Roof Retrofit Con.
1	Miami, FL	20	17	6	6
2	Austin, TX	25	16	9	7
3	Atlanta, GA	25	11	9	5
4	Baltimore, MD	30	10	12	5
5	Chicago, IL	30	6	12	3
6	Minneapolis, MN	30	5	12	3
7	Fargo, ND	35	5	15	2
8	Fairbanks, AL	35	3	15	2

Table 2: Amount of additional R-value needed for a black roof to achieve energy equivalency with a white roof (Source: Oak Ridge National Laboratory)

Although cool roofs can reduce overall energy consumption, the use of a cool roof should not be used as justification for using less insulation. Buildings consume 49% of all energy produced in the USA according to the U.S. Energy Information Administration. Designers should be looking to use all available means and technologies wherever

practical and cost effective to reduce building energy consumption, rather than partially substituting one approach for another.

COOL ROOFS AND SOILING

Cool roofs like any other material exposed to the elements are subjected to various forms of soiling. The type and degree of soiling will be dependent on numerous factors such as the type of activities occurring around of and upwind of, the building. Manufacturing, agriculture and some forms of power generation for example can generate significant amounts of airborne particulate which deposits on roofs and other surfaces. Climate may have the greatest impact on the degree of soiling. Hot humid climates for example are more prone to microbiological soiling than colder climates or hot arid regions. For this reason both the Cool Roof Rating Council (CRRC) and the Environmental Protection Agency (EPA) Energy Star program call for weathering of samples in these three climate areas. Samples are placed on racks on “exposure farms” in each of these areas and left to weather for three years, the time in which it is generally accepted that the degree of soiling levels off. The aged values are averaged and reported in each program’s rated product directory.

The CRRC’s rated product directory lists³ 448 low slope roof coatings and membranes (single ply, BUR and modified bitumen), with a minimum initial reflectivity of 0.70 and a minimum initial emittance of 0.75. The average initial reflectivity of this group of 448 products is 0.82. The three year aged average reflectivity of this same group of products is 0.69. More than 90% of these products have aged reflectance values of 0.60 or better. Less than 3% of the products have aged reflectance values below 0.55, the value which LBNL uses as the basis for their simulations and assessments.

Cool roofs can be cleaned. Studies have shown that cleaning can restore practically 100% of many products’ initial reflectivity. The economic pay-back of regular cleaning of a roof surface varies widely depending on location, roof size, configuration and construction, local ordinances, etc. Although some owners have integrated regular cleaning into their roof maintenance program, this is rarely done. However as has been shown by LBNL, cool roofs provide energy savings benefits even at aged reflectivity levels well below the average of that achieved by the products available on the market.

THE URBAN HEAT ISLAND EFFECT

As noted previously, the vast amount of urban surfaces covered by asphalt parking lots and roads, dark colored roofs and other building surfaces collectively absorb significant amounts of the energy radiating from the sun, thereby increasing the overall ambient temperature. The UHIE increases smog formation, which is compounded by the increased greenhouse gas emissions resulting from the power generation required to further condition (i.e. cool) living and working spaces to compensate for the higher urban temperatures.

LBNL predicts that installing cool roofs, cool pavements and trees over about 30% of the surface of the Los Angeles basin could reduce the local ambient temperature by as much as 5 °F. It is estimated that this would reduce smog by 10%. Furthermore, the annual building cooling energy savings would be about 50% greater than that expected for the cool roof alone, as a result of the lower ambient temperature. The net effect is significant reductions in greenhouse gases, such as CO₂.

Recently a study published by Stanford scientists, called into question a number of the premises and the conclusions of LBNL’s work on the macro impacts of cool roofing. It is beyond the scope of this paper to analyze the points raised in detail. It should be noted however that many who do point to the Stanford report to question the general concept always neglect to note a key element of the report. The paper notes the wide margin of error in their assessment and specifically highlights the “highly uncertain” effect on global warming in their modeling. Independent studies by the National Center for Atmospheric Research in America (NCAR), and the University of Perugia in Italy, show that if anything, the LBNL projections of the greenhouse gas reduction benefits are conservative and underestimated.

³ www.coolroofs.org, Rated Products Directory, 04/29/13

COOL ROOF PERFORMANCE

Many people associate, whether intentionally or inadvertently, the relatively recent recognition of the energy and UHIE benefits of cool roofs with the materials being somewhat new to the market and unproven. Although this may in fact be true for some thermoplastic materials, it is definitely not the case for all. Thermoplastic PVC roof membranes, which have always been light colored and highly reflective, were introduced some 50 plus years ago. Since that time many billions of square feet of these materials have been installed across Europe and North America. Decades old thermoplastic PVC roofs continue to perform problem free in all climates zones across the country today.

It is interesting to read articles calling into question the performance of cool roof membranes, particularly as the topic may relate to installations in cold climates. Although the articles start out with dire warnings about the perceived ills of such roof assemblies, abstractly referring to "roof failures", the authors ever so rarely provide specific examples. The papers inevitably turn into treatises on good roof design and installation: use more than a single layer of insulation, do not leave large gaps between insulation boards, control excess air exfiltration, use a vapor retarder when required, etc. Each and every one of these points is of course sound advice and good roofing practice indeed, regardless of the membrane color. For example, the National Roofing Contractors Association (NRCA) has maintained for quite some time now that a vapor retarder should be considered when the average outside temperature January temperature is below 40 °F (4 °C) and the interior winter relative humidity is 45 percent or greater.

The most recent allegation made is that cool roofs are prone to unusual levels of condensation. Most roofs installed in northern climates, particularly those with loose laid membranes (e.g. mechanically attached), if installed without a vapor retarder, may allow small amounts of warm, moist interior air to condense on the underside of the membrane, regardless of the membrane color. The minimal condensate that may form will typically dry out in the summertime without doing any harm to the roofing system components or causing any problems on the building's interior. This wetting/ drying behavior has been a fundamental basis of roof design and performance for many decades. Proponents of black roofs assert that cool roofs allow greater amounts of condensate to form and/or the membrane does not heat up sufficiently to allow all the condensate to dry, resulting in an accumulation of moisture.

SPRI, the trade association representing the single ply roofing industry, sponsored a field study to investigate the phenomenon. They did cut tests during the winter months on ten cool roofs, all located in ASHRAE climate zone 5. All roofs were at least five years old, and consisted of a single layer of polyisocyanurate insulation applied directly to a steel deck, and a "cool" mechanically fastened single ply membrane over climate controlled spaces. In seven of the ten roofs they found no evidence whatsoever of any moisture. In three of the roofs they did detect surface moisture on the face of the insulation. No evidence of detrimental effects to the roof assembly was observed. They did not go back to the same roofs in the summer months to determine whether, as would be expected, the insulation was dry. They did not open dark colored roofs under the same conditions to determine if they exhibited similar levels of moisture within a similar roof construction, over a similar occupied space in the same climate.



First United Methodist Church in Gilford, New Hampshire, Installed in 1976

As noted previously, Target Corporation has over the past decades standardized their roofing designs and use only highly reflective thermoplastic PVC roofing membranes. Target has an exemplary pro-active approach to the maintenance and replacement of their roofs. They systematically monitor and track all of their roofs. As the membrane on a given roof approaches the end of its service life, they pre-emptively remove it and replace it with a new membrane. In doing so, they are able to simply replace the membrane, while preserving the original insulation. They replace dozens of roofs across the country annually in this manner. With the exception of localized leakage at punctures or other similar damage, they do not encounter wet insulation and the existing insulation is left in place to provide decades more service in all cases.

The leading manufacturers of thermoplastic PVC membranes have all been producing membranes in the USA since the 1970s. As in most businesses, their earliest sales were in the same geography as their production facilities. Many of their oldest projects, which continue to perform to this day, are located in these locations in New England, the Mid-West and Canada.

Poorly designed and/or installed roofs, regardless of membrane color will perform poorly. As the Department of Energy has noted in reference to the potential for condensation in cold climates, "while this issue has been observed in both cool and dark roofs in cold climates, the authors are not aware of any data that clearly demonstrates a higher occurrence in cool roofs."

It is estimated, based on SPRI statistics, that over the past decade approximately 5.5 billion square feet of thermoplastic (PVC and TPO) roofing membranes have been installed in ASHRAE climate zones 5 and higher, just under half of the total amount sold over that period for the entire country. More than 2 billion square feet has been installed in zones 6 and 7 alone. In addition to Target Corporation, many of the leading retailers, typically amongst the biggest facility owners in the country, use cool thermoplastic roofs exclusively on their facilities across the country. These numbers speak for themselves.

CONCLUSION

Light colored thermoplastic PVC roof membranes have been in use in the USA since the 1970s. The member companies of the Vinyl Roofing Division of the Chemical Fabrics and Film Association (representing all of the leading manufacturers of vinyl roofing systems in North America) have sold approximately 5 billion square feet of roofing since that time across North America. These products have a track record of proven performance second to none in all climates. The attempts to discredit the use of cool roofs in northern climates do not stand up to informed, scientific scrutiny, and they certainly do not reflect the experience of decades of use thermoplastic PVC membranes in these climates.

As the nation has become more conscious of energy matters, the inherent benefits of these, and other reflective roofing materials, with regards to cooling and net energy savings, have taken on a higher profile. In northern climates where the net energy savings may be modest on a given building, both peak energy demand reduction and mitigation of the UHIE are becoming increasingly important, and there is no sign of these trends reversing themselves in the foreseeable future. The future for long lasting, energy-efficient thermoplastic PVC roof membranes is only going to get brighter.

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