# Cool Roofs in Use in Northern Climates: A Case Study

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## Introduction

Although the use of cool roofs is more or less universally accepted as being beneficial in southern climates, some have questioned the merits of using them in northern regions. Specifically some have reservations as to whether or not net energy benefits can be achieved using cool roofs in colder locales, and postulate that cool roofs are more prone to condensation than alternative materials. Although a number of articles and papers have been written on these topics, they are typically based on opinions, hypotheses, and in some instances on some form of computer modeling. There is little, if any, information generated from actual buildings in operation presented.

Target Corporation has for approximately two decades installed, almost exclusively, white, mechanically attached thermoplastic PVC roofing membranes on their retail stores as well as on their distribution centers and other facilities. These roof systems, which are typically installed over steel decks, without a vapor retarder, have performed very well in all climates and they are still to this day the base design for all of Target's facilities.

The following summarizes Target's experience with these roof systems.

## Field Experience With Regards to Condensation

Except in cases of extreme interior conditions such as in natatoriums, high humidity manufacturing, etc., the majority of roofs in America are constructed without vapor retarders, even in northern climates. This approach to roof design and construction is founded on the principle of the "self-drying roof".

The concept has been one of the basic elements of roof design in America for generations. Some of the earliest research on the subject was conducted by Frank Powell at the National Bureau of Standards (now the National Institute of Standards and Technology – "NIST") in the 1960s. It is based on a simple premise. In the absence of a vapor retarder, in the winter months, the vapor drive results in moisture laden air working its way up through the assembly, where it may condense on the underside of the somewhat impermeable membrane, particularly in cases where the membrane is not bonded to the insulation substrate. In the warmer months, the vapor drive is reversed and is directed to the interior. The moisture can migrate to the interior space through joints in steel decks, openings in the deck for penetrations, etc. In order for the self-drying roof concept to be effective, complete drying of any condensate that may form must be achieved yearly. Should any condensate that forms in the colder months not dry out completely in the subsequent warmer months, moisture would accumulate annually, to the detriment of the roofing system over time. Experience has shown that for most roofs, any condensate that may form over the winter period fully dries out in the following summer months, and therefore there is no moisture accumulation in the system as the roof cycles through subsequent yearly wetting/ drying cycles. The principle has been validated on countless buildings across America over many decades.

Some have hypothesized that the mechanism may not be as effective below reflective roof membranes. The premise advanced is that "cool membranes" may allow greater amounts of condensate to form in the winter months than darker membranes, and furthermore that they will not heat up sufficiently in the summer months to dry out completely. The net effect, they postulate, is residual moisture accumulating in each subsequent year, eventually compromising the system's performance.

In a paper[1] presented at the 2011 NRCA International Roofing Symposium SPRI reported on a study done to verify whether cool roofs were in fact susceptible to condensation issues. The project consisted of a field survey and a computer modeling of the roofs inspected. The study was designed to achieve the greatest likelihood of observing condensation within the roofs. The roofs studied all consisted of a cool roof membrane mechanically fastened over a single layer of insulation on a steel deck without a vapor retarder. The roofs were surveyed during the months of February and March, 2010. Two cut tests were done on each of the roofs. All cuts were done in the morning to minimize the impact of any heating of the roof surface that might occur under the afternoon sun. In seven of the roofs there was no evidence whatsoever of any moisture in the assembly. In three of the roofs moisture was observed on the top face of the insulation and/or the underside of the membrane. They did not however observe any detrimental effects due to moisture in any of the roofs, which ranged in age from 2 to 12 years.

WUFI modeling was done for the 10 roofs included in the study, with simulations done for both a black and a white surface in each case. Although the modeling showed that all of the roofs would be subjected to condensation in the winter months, it predicted higher levels of condensation below a cool white membrane than below a black sheet. However in all cases, for both white and black membranes, the modeling showed that the resulting moisture would dry out completely in the summer months.

The SPRI paper authors concluded that the field observations were consistent with the behavior predicted by the WUFI modeling.

The SPRI study provided important information on the topic, and demonstrated that even in the most critical conditions (mechanically fastened roof over a single layer of insulation without a vapor retarder) cool roofs are performing in cool climates. SPRI confirmed that in some instances condensation can form within mechanically fastened systems, and although they did not observe any signs of damage or reduction in performance of the three assemblies where moisture was observed, they did not return to these roofs in the summer months to confirm that they did in fact dry out. An additional study might address this open point.

Anecdotal evidence acquired through the re-roofing of stores over many years indicated that the self-drying design principle was effective on Target stores, even in northern locations with cool roof

[1] Ennis, M., Kehrer, The Effects of Roof Membrane Color on Moisture Accumulation in Low Slope Commercial Roof Systems, Proceedings of the 11th International Roofing Symposium, Washington, DC, September 7, 2011

membranes. It was decided however to systematically survey stores to confirm that this is in fact the case.

Surveying the Target stores presents a unique opportunity in that all stores are operated to maintain essentially the same interior conditions, regardless of a store's location. During the winter months, the interior temperature is 68 °F during operating hours, typically from 8:00 AM to 10:00 PM, and 59 °F the balance of the time. During the summer months, the interior temperature is 74 °F during occupied hours, and 81 °F, otherwise. The stores are kept at a relative humidity of approximately 57%. Stores are typically open in excess of 360 days per year.

Field Technicians from a membrane supplier to Target, investigated the roofs on 26 stores located throughout the states of CT, IL, MA, MI, MN, NY, WA and WI. The roofs were located in ASHRAE climate zones 4, 5 and 6.

The general approach to the survey was similar to that conducted by SPRI. The technicians randomly chose two locations on each roof for cut tests. Each cut test was to be made over a board joint. Contrary to the SPRI study which was done in the winter, the Target store survey was conducted during the months of August and September of 2013, with cut tests typically done in the afternoon. A summer survey was conducted, as the authors believe this provides for a better assessment of whether or not the roofs are being subjected to cumulative moisture accumulation. Should moisture be observed within the roof assemblies during the summer, it would be indicative that the vapor drive in the warmer months is insufficient to fully dry out any condensate that may form in the winter months. All 26 of the roofs inspected were installed between 1999 and 2003. With all of the roofs surveyed ranging in age from 10 to almost 14 years, should there have been even minute residual condensation from each subsequent seasonal change in the direction of the vapor drive, it would have accumulated sufficiently to be visible or detectable to the touch, or to have resulted in some form of damage to the insulation or cover board facer.

All of the roofs surveyed had a white 60 mil PVC membrane mechanically attached to a steel deck. The stores were chosen at random (subject to being at least 10 years old), and a variety of build-ups were found below the single ply thermoplastic membrane. The 26 stores can be divided into three categories. The most critical construction is a steel deck, with a single layer of insulation (Table 1). In all 11 of these roofs, polyisocyanurate (iso) insulation was observed, with thicknesses ranging from 1.7" to 3". Both glass and organic insulation facers were found, the majority of which were organic.  The second group of stores had a base layer of iso insulation installed directly on the steel deck, with an additional layer of iso and/or a cover board (Table 2). As can be seen in Table 2 a variety of combinations were found over these 11 stores. The last group of 4 stores consisted of roof recovers with either a ¼" gypsum or ½" iso cover board installed over an existing roof system (Table 3).

Cut tests were all approximately 12" x 12" in size. The technicians were instructed to cut through all layers down to the steel deck. They were to observe and document the condition (moisture, staining, and mold) at the interface between each adjacent layer of the roof system's components and document their observations on a form provided to them (Appendix A).

Target has for many years taken a pro‐active approach to roofing. As any of their roofs approached the end of its service life, but before it deteriorated to the point where the insulation was comprised, they recovered it. A cover board was fastened through the original roof to the steel deck and a new mechanically fastened membrane was installed. This approach diverted approximately 25,000 cubic feet of material from being landfilled on a typical store re‐roof. Four such roofs were part of the survey. In three of them a gypsum based cover board had been installed, in the fourth a 1/2" layer of iso had been used. The four roofs were recovers of EPDM and PVC roofs. Photos 1, 2, 3, 4 taken of a cut test on the Cheektowaga, NY store was typical of all four. No evidence of moisture was detected in any of these assemblies, neither between the new and old membrane, nor below the original membrane. The only notable staining observed was a small section along one edge of an insulation board on the Flint, MI store. The fact that no staining was observed on the adjacent board (or in the second cut), and additionally that a boot print was super imposed over the stain (Photo 5) would indicate that the edge of that particular panel had been wetted prior to being installed. It is interesting to note that there was no difference in the appearance of the insulation below the original roof between the "cool" PVC and "non‐cool" black EPDM roofs.

In multi layered systems good practice dictates that joints of adjacent layers should be staggered in order to, amongst other things, eliminate thermal shorts. In all 11 roofs listed in Table 2, this was found to have been done at all cut test locations. In one cut test on a store in Newington, CT both layers of insulation were found to be wet. Further investigation revealed the source of moisture to be leakage into the roofing assembly from an adjacent HVAC unit. Two other cut tests were done in other locations on the roof. No moisture was detected at any roof component interface, nor was any staining or mold or other evidence of deterioration observed in either of these two cuts, or in any of the other cuts taken on the balance of the roofs with multiple board layers. Photos 6, 7, 8, 9, 10 of one of the cut tests done on the Chaska, MN store are typical of what was observed in all locations but the leaking area on the CT store.

As shown in Table 1, 11 of the roofs investigated had a single layer of insulation, which depending on the location was typically 2" or 3" thick. Photos 11, 12 of one of the cut tests from the Novi, MI store provide a typical representation of the observations made in all stores. No moisture was detected nor was any staining or deterioration of any kind seen in any these 11 roofs ranging in age from approximately 10 to 13 years old, located in the states of MA, MI, MN, NY and WA.

With two exceptions, the steel decks observed in the other 51 openings (2 per roof except Newington, CT, which had three) were in very good condition. In the location of the leak in the Newington, CT store the top surface of the steel deck flutes was rusted over the entire contact area with below the wet insulation. The rust transferred to the underside of the bottom insulation layer. On the Poughkepsie, NY store localized rust (Photo 13) was observed on the top flange of the deck in one of the cut tests. As no rust stains were observed on the underside of the insulation in this location (Photo 14), it is assumed that the rust had formed prior to the installation of the roof assembly. There was no evidence of rust in the second cut test location.

In the balance of the cuts, random, superficial corrosion of scratches or minor abrasions, often at the vertical to horizontal bend at the top of flutes, was seen in some locations. These observations were consistent with the surface damage which typically occurs during steel deck installation, and the minor amount of rust had likely formed before the roof was installed. This hypothesis is supported by the lack of rust stains on the back of the insulation in these locations.

Although Target continues their pro-active approach to maintaining the roofs on their facilities watertight, the procedure was altered slightly in 2007. With the advent of post- consumer recycling of PVC roof membranes, Target started removing existing PVC roof membranes as they approach the end of their service life, prior to installing a new PVC membrane. With the exception of areas of localized leakage, the insulation, regardless of the store's location, is found to be sound, dry, fit for re-use and left in place to serve within the new membrane installation. The membrane is collected by their membrane supplier and recycled back into new membrane. The results of this survey are fully consistent with Target's experience on more than 100 roofs across the continental USA on which the PVC membrane recycling and insulation re-use was implemented over the past 7 years.

Condensation issues in roof assemblies can lead to serious, costly problems, often compromising performance and necessitating premature replacement. There is a general consensus amongst stakeholders in the low slope roofing industry that there appears to be increasingly more condensation related issues. That may be the case, as cost and time pressures in construction projects steadily increase with time. Concrete floors are poured below newly installed roof assemblies releasing thousands of gallons of moisture which if not handled properly ends up in the roof assembly where it will likely condense. Forms are no longer removed from concrete decks, preventing inward drying of residual moisture in concrete. Thermal insulation is typically adhered to concrete decks in low rise foam without a vapor retarder rather than hot mopped in hot asphalt, allowing moisture to migrate from the concrete to the underside of the roofing membrane where it can condense. The problem is compounded when lightweight structural concrete, which typically has much higher water content, and is not often, allowed to dry out sufficiently before the roof is installed. These problems which are occurring under all types (and color) of membranes, have been the topic of numerous papers and advisories by trade related associations[2],[3],[4]

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"[5].

COOL ROOFS AND ENERGY CONSUMPTION IN NORTHERN CLIMATES

[2] Graham, M.S, A troubling issue: Moisture in lightweight structural concrete presents concerns, Professional Roofing, December, 2013

[3] Condren, S., Pinon, J., Scheiner, P., What you can't see can hurt you" Professional Roofing, August, 2012

[4] Doelp, G.R., Moser, P.S., Reducing the Risk of Moisture Problems in Concrete Decks, RCI Annual Meeting, 2013

[5]

Target has long been a leader amongst retailers in adopting energy efficient practices. Target sets ambitious objectives for continuously reducing their Greenhouse Gas Emissions. They achieve these goals in large part through ongoing improvements in energy efficiency in all aspects of their organization. Energy is a very significant cost in the operation of large retail facilities. The roof represents about three quarters of the building envelope of a typical Target store, and therefore has a disproportionate impact on energy consumption.

Specific operational and other costs are confidential information and cannot be disclosed. However it can be stated unequivocally that although the magnitude varies, Target has experienced net energy savings from the use of cool roofs in all but the most extreme climates. Although the savings in northern states are clearly less than those achieved in southern locations, experience over approximately two decades has validated the ongoing use of cool roofs across the entire real estate portfolio. Even in climates with lengthy heating seasons, overall cooling costs exceed heating costs in Target's facilities.

Additionally, on the few "non-cool" dark roofs Target has in northern climates they have not seen any measurable reduction of energy consumption during heating seasons that can be attributed to heat gain via the roof.

PERFROMANCE AND UNIFORMITY OF DESIGN

As important as the energy efficiency of their roofing systems is, Target cannot sacrifice performance to achieve it. Keeping their facilities dry in all climates is critical, as is durability. In settling on a system with decades of proven performance and making it the base design standard for all of their facilities, Target has achieved a number of additional important benefits. All roofing and re-roofing processes are smoother and more efficient as a result of the collective experience of hundreds and hundreds of projects. Higher quality installations are achieved through standardized detailing and installation procedures which are used on every roof. Maintenance processes are consistently applied and replacement cycles are predictable facilitating the asset management plan. Since 2007, they have been able to have any PVC roof membrane removed from their roofs recycled back into new membrane products, helping them achieve their goal of zero construction waste. The institutional knowledge developed within the Target organization enables them to manage all aspects of their roofs in the most cost effective manner throughout the entire life cycle of their buildings.

With more than 2,000 stores, distribution centers, offices and other buildings, and by the very nature of the geometry of most of their buildings, roofs are a critical element to Target Corporation. Over the past two decades, the use of thermoplastic "cool" PVC roofing systems have been an important component in achieving performance, energy efficiency, sustainability and operational goals in their facilities.


Photo 1: Cheektowaga, NY, Top membrane recoverboard interface


Photo 2: Cover board original membrane interface

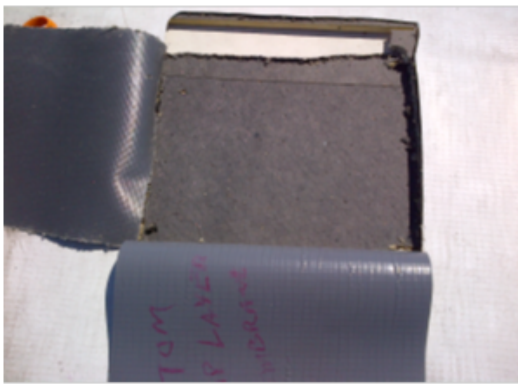

Photo 3: Original membrane insulation interface

Photo 4: Steel deck

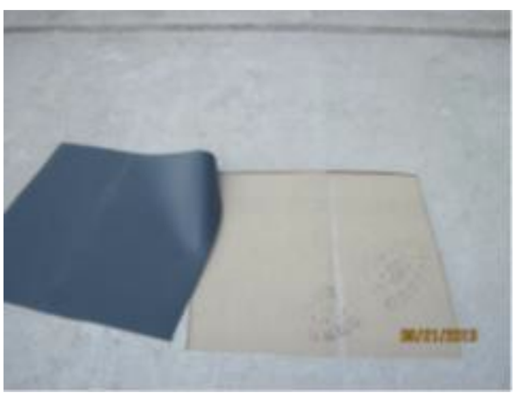

Photo 5: Flint, MI Recover board


Photo 6: Chaska, MN Membrane top layer insulation interface


Photo 7: Top insulation underside


Photo 8: Bottom insulation topside


Photo 9: Bottom insulation underside


Photo 10: Steel deck

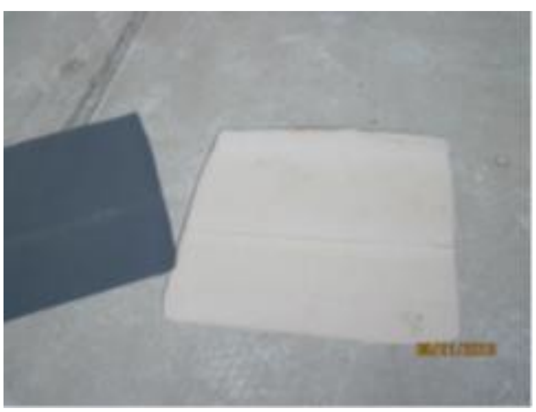

Photo 11: Novi, MI Membrane insulation interface

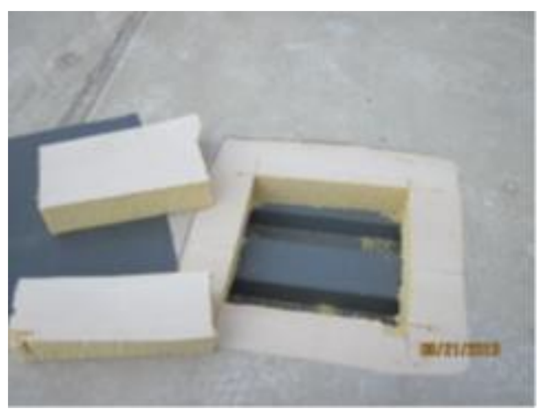

Photo 12: Insulation underside, deck

Photo 13: Poughkepsie, NY Localized rust on deck

Photo 14: Insulation underside

Table 1: Roofs with a single layer of insulation

| Location | Year Installed | Insulation Thickness |
|---|---|---|
| Coon Rapids, MN | 2000 | 3” |
| Vancouver, WA | 2001 | 2” |
| Lacey, WA | 2000 | 2” |
| Milbury, MA | 2003 | 2.7” |
| Worcester, MA | 2001 | 3” |
| Framingham, MA | 2001 | 2” |
| Marlboro, MA | 2003 | 2.25” |
| Watertown, MA | 2002 | 2” |
| Kingston, NY | 2000 | 2.5” |
| Wilton, NY | 2002 | 2” |
| Novi, MI | 2002 | 2.5” |

Table 2: Roofs with multiple layers of insulation/ cover board

| Location | Year Installed | Bottom layer (Iso) | Middle layer (Iso) | Top layer |
|---|---|---|---|---|
| Chaska, MN | 2001 | 1.7” | NA | 1.7” Iso |
| Shakopee, MN | 1999 | 1.7” | NA | 1.7” Iso |
| Ashwaubenon, WI | 2000 | 2” | 2” | ¼” gypsum |
| Bellevue, WI | 2002 | 2” | 2” | ¼” gypsum |
| Eau Claire, WI | 2000 | 2” | NA | ¼” gypsum |
| Newington, CT | 2003 | 1.5” | NA | 1.5”Iso |
| Poughkepsi, NY | 2003 | 1.5” | NA | 1.5”Iso |
| Renselar, NY | 2003 | 1.5” | | 1.5”Iso |
| Machesney Park, IL | 2002 | 3” | | ½” gypsum |
| Algonquin, IL | 2002 | 2” | 2” | ½” gypsum |
| Holland, MI | 2002 | 2.5” | | ¼” gypsum |

Table 3: Recovers

| Location | Original Roof | | Recover | |
|---|---|---|---|---|
| | Insulation (Iso) | Membrane | Year Recovered | Cover Board |
| Schofield, WI | 2” | PVC | 2001 | ¼” gypsum |
| Cheektowaga, NY | 2” | PVC | 2002 | ½”Iso |
| Walker, MI | 2.25” | EPDM | 2002 | ¼” gypsum |
| Flint, MI | 2” | EPDM | 2000 | ½” |

APPENDIX A

## Cool Roof Survey Report

| |
|---|
| Building name: |
| Address |
| |

| |
|---|
| Date and time of visit: (**Test cuts must be taken in the afternoon).** |
| Weather conditions and temperature |
| Location of test cuts. Attach a rough sketch or describe locations ie: northeast corner.<br><br>Test cut# 1 Test cut# 2 |
| Roof assembly from deck up. For example; (Metal deck/2 layers of 2" iso, S327 60 mil membrane). |

**Two test cuts are required for each building. Test cut size---12"x12". They should be taken out in the field of the roof away from any penetrations if possible and over an insulation board joint.**

**Remove each layer one at a time, make observations and take a photo of each surface.**

Place a check mark in the appropriate block for each interface for each test cut.

| **Interface** | **Dry** | | **Visible Moisture/damp** | | **Moisture staining** | | **Mold growth** | |
|---|---|---|---|---|---|---|---|---|
| | TC#1 | TC#2 | TC#1 | TC#2 | TC#1 | TC#2 | TC#1 | TC#2 |
| Bottom side of membrane | | | | | | | | |
| Top layer Insulation/coverboard | | | | | | | | |
| Bottom of insulation/coverboard | | | | | | | | |
| Top of next insulation layer | | | | | | | | |
| Bottom of next insulation layer | | | | | | | | |
| Top of substrate | | | | | | | | |

| | | | | |
|---|---|---|---|---|
| Other layer(s) | | | | |

Other comments

Any abnormalities found on this roof, (punctures, loose HVAC door etc).