

PROCEEDINGS

33RD RCI INTERNATIONAL CONVENTION AND TRADE SHOW

ONONDAGA COUNTY REROOFING PROJECT: IMPACTS OF REFLECTANCE AND THERMAL RESISTANCE

MICHAEL D. FISCHER

KELLEN COMPANY

529 14th Street NW, Suite 750, Washington, DC 20045

Phone: 202-591-2438 • E-mail: mfischer@kellencompany.com

HUGH HENDERSON, JR. AND NICHOLAS GENZEL

CDH ENERGY

2695 Bingley Road, Cazenovia, NY 13035

Phone: 315-655-1063

AND

MARCIN PAZERA

PIMA

1220 North Fillmore Street, Suite 400, Arlington, VA 22201

Phone: 703-258-0093 • E-mail: mpazera@pima.org



ABSTRACT

The 2009 roof replacement project at the Onondaga County Correctional Facility in Jamesville, NY, provided a unique opportunity to evaluate the relative performance of roofing systems with different energy efficiency strategies. Because the project included roofs on four identical buildings on the same site, the setup allowed comparison of insulation R-value and roof reflectance values, as well as the thermal performance of vegetative roofing systems in northern climate zones. By reviewing thermal transmittance data and correlating the results with local weather conditions, this paper provides insight into various roofing design options to maximize building energy efficiency and overall roofing performance.

SPEAKER

MICHAEL D. FISCHER — KELLEN COMPANY



MICHAEL FISCHER is a 34-year veteran of the building products industry. He has held management positions in manufacturing, marketing, and regulatory affairs. Fischer is a member of the International Code Council (ICC), ASHRAE, IAPMO, and ASTM International, and represents the Asphalt Roofing Manufacturers Association (ARMA) and the Roof Coatings Manufacturers Association (RCMA). In addition, he serves as codes consultant to the Polyisocyanurate Insulation Manufacturers Association (PIMA) and the Center for the Polyurethanes Industry (CPI) of the American Chemistry Council (ACC). Fischer has testified before code, regulatory, and legislative bodies and is a frequent presenter at building industry events and conferences.

NONPRESENTING COAUTHORS

HUGH HENDERSON, JR. — CDH ENERGY

NICHOLAS GENZEL — CDH ENERGY

MARCIN PAZERA — PIMA

ONONDAGA COUNTY REROOFING PROJECT: IMPACTS OF REFLECTANCE AND THERMAL RESISTANCE

Energy efficiency requirements for roofing assemblies in model codes include consideration of thermal resistance, air leakage, and roofing reflectance. The introduction of cool roofing via reflectance requirements in the International Energy Conservation Code (IECC) prescriptive path for commercial buildings in southern climate zones was an important step forward to advance energy efficiency. The potential energy use benefits of cool roof strategies for commercial buildings in northern climate zones have been studied (Hosseini, Akbari 2015). The use of vegetative roof assemblies to manage stormwater runoff, as well as other environmental and sustainability benefits, represents another roofing design parameter.

EXECUTIVE SUMMARY

In 2009, Onondaga County sought to evaluate and compare the energy performance of green or vegetative roofing systems relative to other roofing options. A major roof replacement project on a multiple building site at the Jamesville Correctional Facility near Syracuse, NY, offered the opportunity for a side-by-side test to evaluate different roofing systems. This evaluation was initiated to provide guidance for future roofing renovations on other county-owned buildings. A final report was completed (CDH Energy 2011) comparing four different roofing assemblies:

1. A conventional absorptive roof with 4 inches of polyisocyanurate insulation (R-value of 22, or R-22) with a black ethylene propylene diene monomer (EPDM) single-ply rubber roof membrane
2. A reflective or “cool roof” with R-22 polyisocyanurate insulation and a thermoplastic polyolefin (TPO) single-ply membrane
3. A vegetative roof with R-22 insulation
4. A highly insulated cool roof (R-45) with a TPO single-ply membrane

A coalition of roofing industry associations, including the Asphalt Roofing Manufacturers Association (ARMA), the

EPDM Roofing Association (ERA), and the Polyisocyanurate Insulation Manufacturers Association (PIMA) provided funding to continue the field testing in order to assess the long-term performance of the different roofing membranes. This side-by-side test arrangement—with different roof assemblies installed at the same location on very similar buildings—offered a unique opportunity to compare the long-term performance of various roof types. One of the issues with post-occupancy analysis of buildings is the variability of internal loads and other temperature impacts resulting from building use. The Jamesville facility buildings are located on the same site, have almost identical operating hours and occupancy conditions, and are served by the same heating plant, thus providing an excellent basis for building performance comparison. This report summarizes the measurements and observations based on 6½ years of data, collected from November 2009 through May 2016.

The objective of the extended testing effort was to compare the thermal performance of conventional (EPDM) and cool (TPO) roof assemblies. Cool or reflective roofs, such as TPO, lower summertime heat gains and, therefore, reduce cooling loads. However, the lower roof temperatures may increase heating loads in the heating season. Therefore, it is unclear if cool roofs provide net annual benefits in heating-dominated climates such as Syracuse, NY. It is also possible that over the long term, the benefits of a cool roof diminish as the membrane properties change with time as surfaces become soiled or degrade. While the buildings are not air-conditioned, heat-flux measurements can provide a basis for comparing the relative thermal performance of the various roof assemblies.

Note that comparisons of various roof-covering types are made only on the basis of their reflective and thermal properties. No conclusions regarding other features and benefits for TPO, EPDM, or vegetative roof coverings should be drawn from this paper.

The specific goals of this follow-up study were to:

- Track and evaluate any long-term changes in heat flux or surface temperature that might occur due to aging or soiling of the EPDM or TPO membranes.
- Compare the long-term thermal performance between roof assemblies.
- Evaluate the energy use and cost differences between the roofs for the heating and cooling seasons.
- Evaluate the impact that snow cover has on roof heat loss, and compare ground snow cover to the inferred snow cover on each roof assembly.

The extended field-testing of the different roof systems tracked the thermal performance over the 6½-year monitoring period. Data were collected at 15-minute intervals. Some of the initial findings (CDH Energy 2011) continued over the long term:

- The EPDM membrane had roof temperatures that were as much as 60°F higher than the TPO surfaces, and had higher heat gains in the summer and more modest heat losses in the winter.
- The TPO membrane significantly reduced the surface temperatures in the summer but also resulted in greater heat losses in the heating season (since beneficial solar gains are reduced).
- The vegetative roof adds thermal mass to the roof assembly that dampens temperature swings. Evaporation at the surface also provides cooling in the summer and swing seasons. The vegetative roof also retained more snow cover more often and had lower heat losses in the winter.

MONITORING APPROACH

CDH initially considered several approaches to quantifying the energy impact of the different roof systems, including measuring the heating energy use of the HVAC system before and after retrofit. Ultimately, we determined that measuring the temperature differences within the roof

| Point | Description | Instrument | Units |
|-------|--|------------------------|-------|
| TRO | Roof temperature (on top of insulation, under roof board) | Type-T Thermocouple | °F |
| TRI | Roof temperature (under roof insulation, above deck) | Type-T Thermocouple | °F |
| TAI | Indoor temperature (just below the ceiling) Thermocouple | Type-T | °F |

Table 1 – Instrumentation for each measurement location or station.

assembly was the most compatible with the project schedule, building configuration, and limited access in the facility. A mix of hardwired and wireless networking was used to connect the loggers. Transmission of the data back to CDH was achieved via a modem link.

Each monitoring station was based around a Campbell Scientific CR800 or CR1000 datalogger (Station 2A uses a CR1000 to accommodate extra data points). Communication between the loggers was provided by wired serial communications (RS-485) or wireless connections (915 MHz spread spectrum radio). The dataloggers were programmed to sample all sensors once per second. Calculated averages and totals were recorded for each 15-minute interval. After all records were created at each station, the datalogger located at 3A collected each record from all the other dataloggers. That master datalogger was called, and data was downloaded each night by phone modem. The data was loaded into a database at CDH Energy for automatic verification and analysis.

INSTRUMENTATION

A monitoring system was installed to measure the performance of each roofing system. The overall experimental approach was to measure and compare the temperatures in the different roofing systems in a side-by-side test in both seasonal and annual comparisons. The heat transfer through the roof surface is proportional to the temperature difference through each layer. Since all of the roof systems are exposed to the same ambient conditions, as well as similar

indoor temperatures, the performance of the different systems can be directly compared at each time step. The measurements listed in *Table 1* were taken at two separate locations (A and B) on each building (Units 1, 2, 3, and 4), resulting in a total of eight monitoring locations.

DESCRIPTION OF ROOF ASSEMBLIES

The four buildings included in this test program are shown in *Figure 1*. Each unit had a different roofing system installed, as

| Location | Insulation | Surface |
|----------|---|------------------------------------|
| Unit 1 | 4 inches Polyiso ¹ (R-22) | EPDM rubber ² |
| Unit 2 | 4 inches Polyiso ¹ (R-22) | TPO white ³ |
| Unit 3 | 4 inches Polyiso ¹ (R-22 + vegetative layer) | EPDM w/ vegetative assembly on top |
| Unit 4 | 8 inches Polyiso ¹ (R-45) | TPO white ³ |

- 1- Polyisocyanurate foam board applied in 2-in. layers
- 2- Black EPDM single-ply rubber roof membrane
- 3- White TPO roof membrane

Table 2 – Construction details for the roofs on each unit.

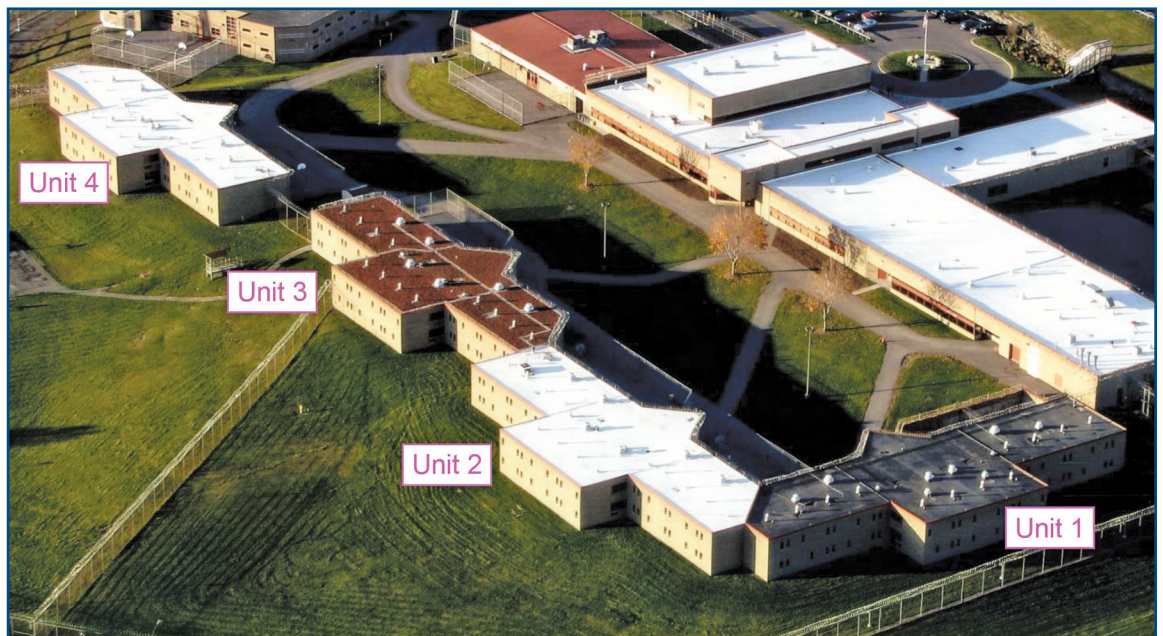


Figure 1 – Aerial view of the four units at the Jamesville facility.

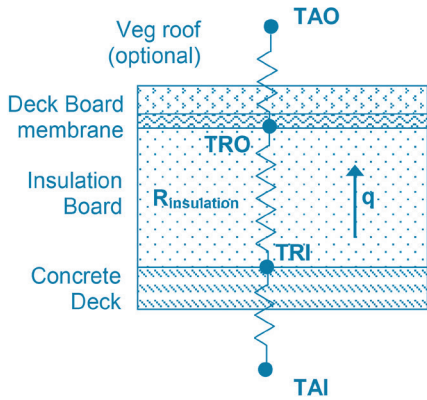
described in *Table 2*. The TPO membrane is rated by the Cool Roofing Rating Council (CRRC) to ASTM D1519 with an initial reflectance of 0.79 and three-year reflectance of 0.70, per Carlisle TPO-2007-18 (July 2007) and Carlisle Spec Sheet from December 2015.

DATA ANALYSIS AND RESULTS

The data collection system at the site was fully commissioned starting on October 22, 2009. This section analyzes the data collected from November 1, 2009, through May 31, 2016.

ROOF THERMAL ANALYSIS

Our experimental analysis of heat transfer through the Jamesville, NY, roof assembly in the original report (October 2011) made several key assumptions. The analysis in the original report ignored heat storage in the concrete layer and assumed the insulation layer had insignificant thermal mass.



$$q = \frac{(TRI - TRO)}{R_{insulation}}$$

Where:

$R_{insulation}$ - R-value for Insulation layer
($^{\circ}\text{F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}$)

q - Heat flux through the roof assembly ($\text{Btu}/\text{h}\cdot\text{ft}^2$)

Equation 1

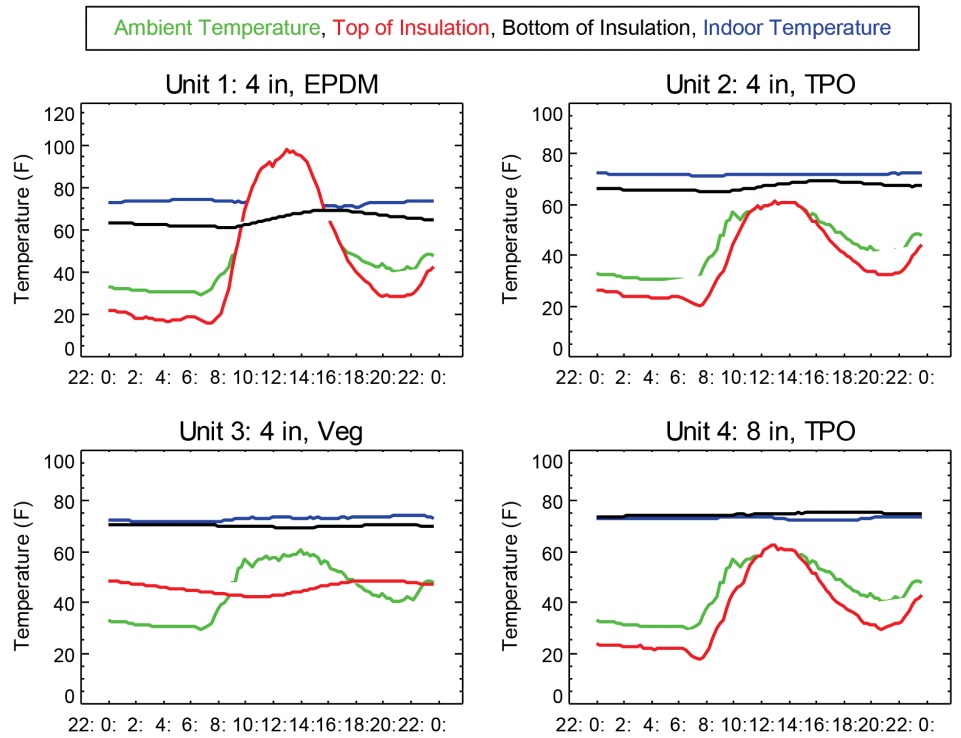
$$q = m * cp * \frac{TRI' - TRI}{t' - t} + \frac{TRI' - TRO'}{R_{insulation}}$$

Equation 2

A simplified one-dimensional, steady-state heat flux through the insulation layer was assumed to represent the heat flux through the entire roof assembly.

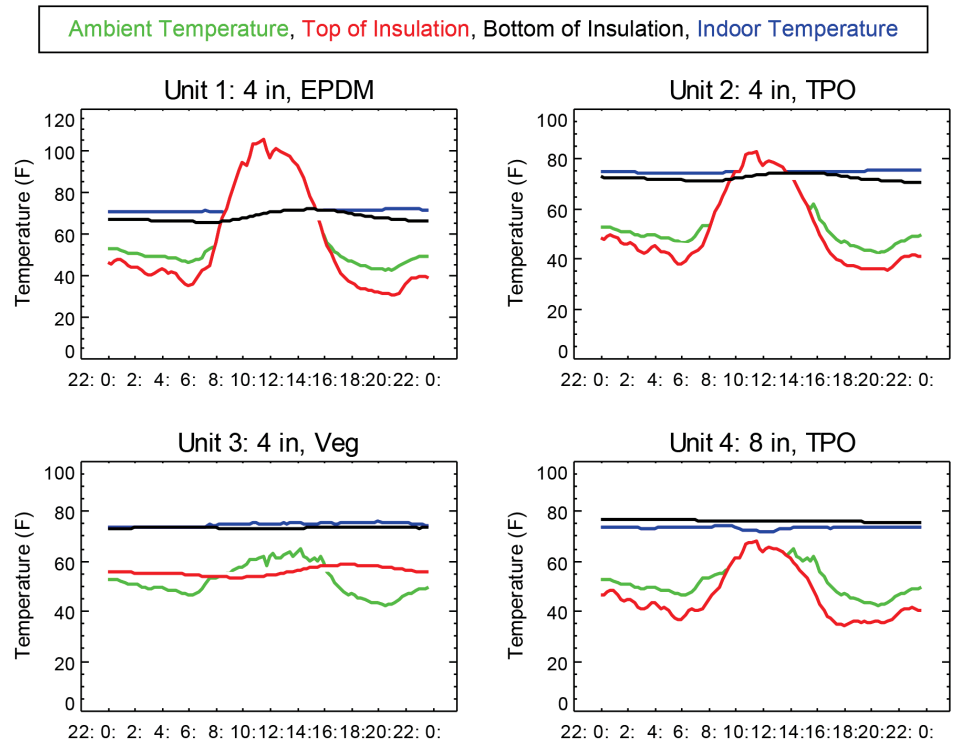
An EnergyPlus model was developed and compared to the simple model (Equation 1) to test the validity of this assumption. The EnergyPlus analysis, using the finite difference method, showed that the simple model (Equation 1) accurately represented the heat flux at the top of the roof assembly (i.e., into the top of the concrete layer). However, the heat flux into the space (i.e., from the bottom of the concrete layer) was much different. We found that the heat flux into the space predicted by EnergyPlus was reasonably represented by applying Equation 2 to the 15-minute interval data from EnergyPlus. Therefore, this equation provides an approximate correction for the field test data for the thermal mass (assuming the concrete layer is highly conductive relative to the insulation layer and is essentially at a uniform temperature represented by TRI).

The variable q is defined as positive heat loss from the space through the roof to ambient. On each roof, a different amount of insulation board (with an R-value of $5.7 \text{ ft}^2\cdot\text{h}\cdot^{\circ}\text{F}/\text{Btu}$ per inch) was installed on



11/02/09

Figure 2 - Daily temperature profiles for each roof type (November 2, 2009).



11/02/15

Figure 3 - Daily temperature profiles for each roof type (November 2, 2015).

each unit (see Table 2). The variable m is defined as the mass per area at $46.6 \text{ lb}/\text{ft}^2$. The variable cp represents specific heat at $0.1996 \text{ Btu}/\text{lb}\cdot^{\circ}\text{F}$. In these tables, the overall, long-term heat transfer is calculated using both methods (Equations 1 and 2),

which are shown to yield similar results.

Figures 2 and 3 show the temperatures for the four different roofs during a fall day in 2009 and 2015. The top of the insulation beneath the EPDM membrane on Unit 1 is at a warmer temperature during the day

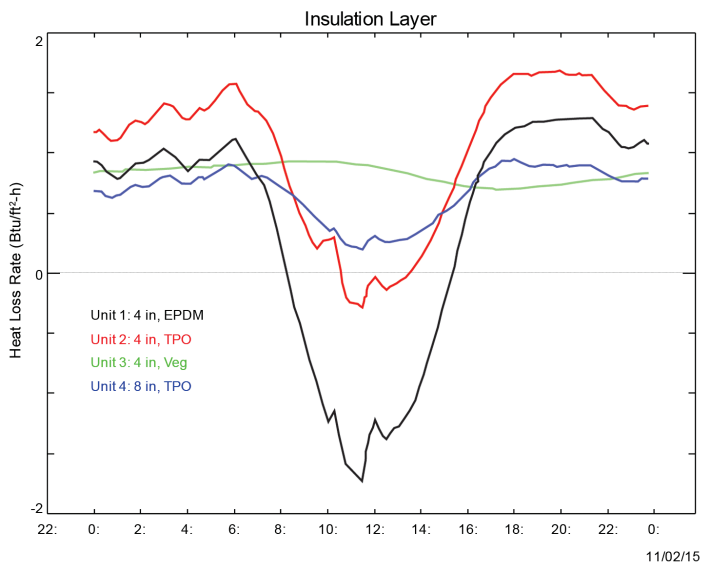
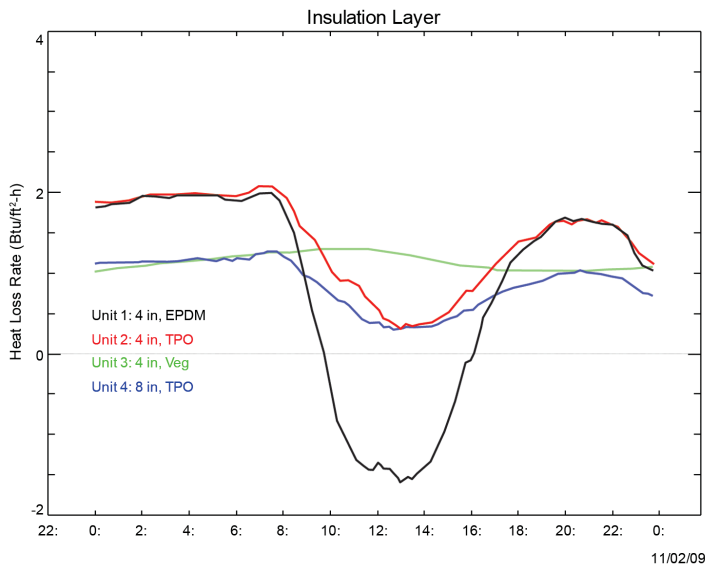


Figure 4 – Heat transfer rates for each unit on November 2, 2009.

Figure 5 – Heat transfer rates for each unit on November 2, 2015.

since more heat is absorbed from the sun. The TPO roofing surface on Unit 2 is significantly cooler since its higher reflectivity reduces solar gains. The vegetative roof provides additional thermal mass that smooths out the fluctuations across the daily cycle. The difference in peak temperatures between the EPDM and TPO roofs in November 2009 (six months after installation) was 37°F. For the similar November day in 2015, the temperature difference had

dropped to 23°F. Figure 4 and Figure 5 show the heat transfer performance at the roof surface (using Equation 1) for each roof type. A positive number represents net heat loss through the roof. The assemblies all experience heat loss in the early morning hours. The heat flow reverses direction for the EPDM roof as the roof surface heats up and drives heat into the roof assembly.

COMPARISON OF DAILY, SEASONAL, AND ANNUAL PERFORMANCE

Daily Trend With Outdoor Temperature

Figure 6 plots the heat loss (at the roof surface, Equation 1) for each day versus the daily ambient temperature. Each data point plotted corresponds to one day in the 6½-year period; the roof system on each unit is shown as a different color. Each daily value is the average of the A and B locations on each roof. All the roof systems show the general trend of more heat loss at lower outdoor temperatures, though the trend is not perfectly linear.

The EPDM roof (black) shows the strongest linear trend, while the vegetative roof (green) shows an especially nonlinear trend, with a “knee” corresponding to the freezing point (32°F). The knee for the vegetative roof occurs because the formation of ice in the vegetative layer keeps the roof surface temperature (TRO) near freezing and flattens the trend of heat transfer with lower outdoor temperatures. In contrast, the EPDM roof is less affected by formation of melting ice and snow at the roof surface since the black EPDM material heats up and causes more melting (so that less snow can accumulate on the roof). The two TPO roofs fall in between these two extremes. The TPO roof with 4 inches of insulation (red) has a slight knee in the trend since more snow can build up on the roof and create a freezing liquid-solid layer at the roof surface. The TPO roof with 8 inches of insulation (blue) has less of a knee in the trend, mainly because the lower rate of heat transfer means that the

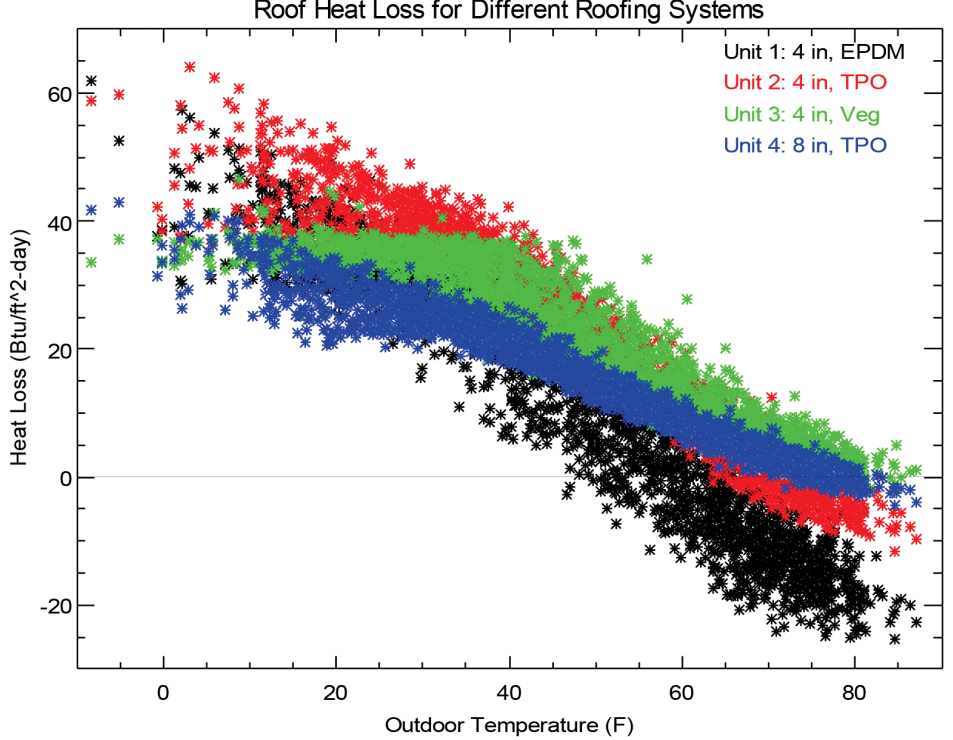


Figure 6 – Daily heat loss vs. outside temperature (November 2009 through May 2016).

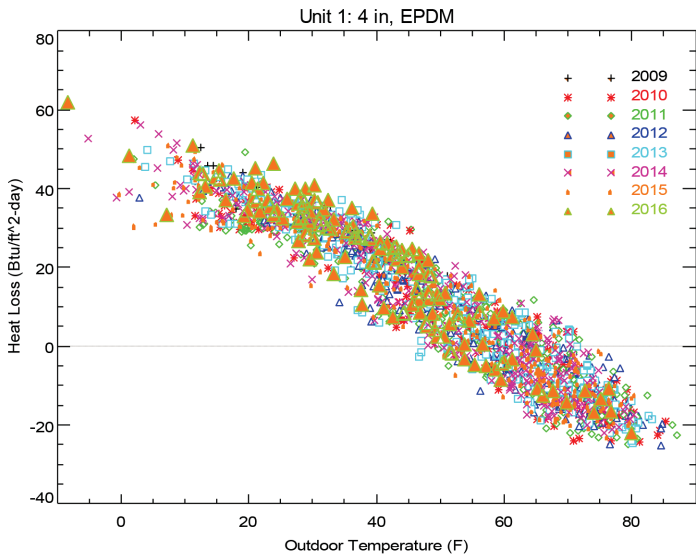


Figure 7 – Daily heat loss vs. outdoor temperature, EPDM roof.

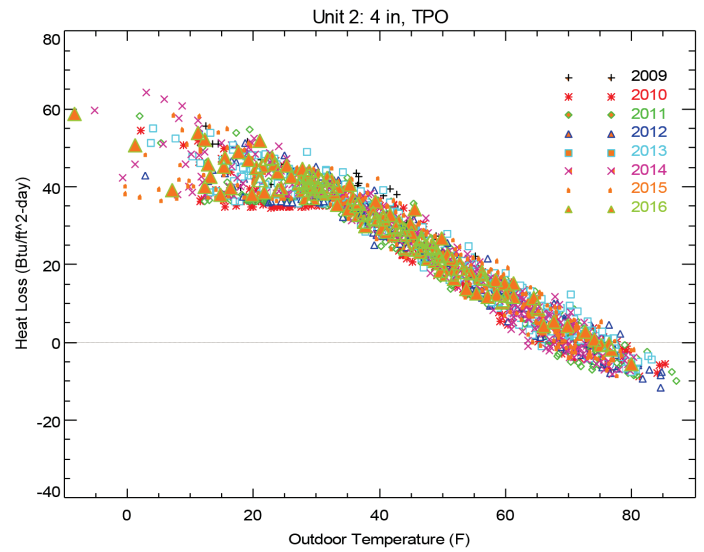


Figure 8 – Daily heat loss vs. outdoor temperature, TPO roof (4 in.).

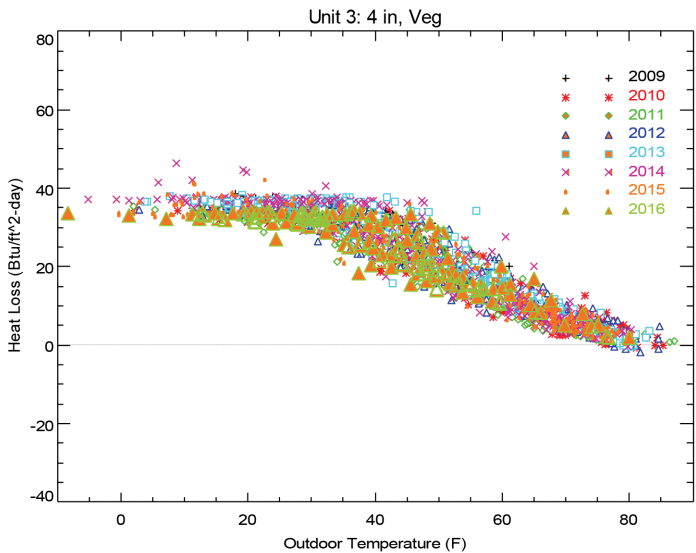


Figure 9 – Daily heat loss vs. outdoor temperature, vegetative roof.

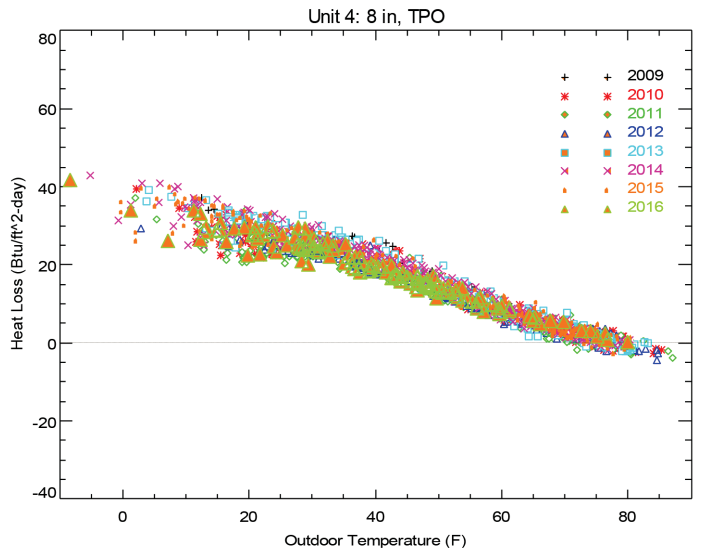


Figure 10 – Daily heat loss vs. outdoor temperature, TPO roof (8 in.).

melting/freezing does not occur at roof surface. Therefore, there is no change of phase to create the nonlinear trend.

Figures 7 through 10 show the heat loss versus outdoor temperature separately for each roof type. Different symbols and colors are used on each plot for the different years over the 6½-year period.

The dotted line represents the difference between heat loss (above the line) and heat gain (below the line). The linear and nonlinear trends described above for each roof assembly are more obvious in these plots. While outdoor temperatures and the impact of snow might change from year to year, there is little to no discernable change in the trends from year to year.

The EPDM roof with 4 inches of insu-

lation has the most heat gain during the summer and the lowest amount of heat loss in the winter (as also shown by Table 3). Figure 7 indicates for the EPDM roof that heat gain begins to occur at an ambient temperature around 50°F to 60°F (10 to 15.5°C). The TPO roofs with 4 and 8 inches of insulation (Figure 8 and Figure 10) do not experience heat gain until ambient temperatures reach 70°F to 80°F (21 to 27°C). It is not until temperatures reach above 80°F that the vegetative roof (Figure 9) may have some heat gain.

The ability of the TPO and vegetative roofs to reduce solar gains becomes a disadvantage in the winter. The figures show a heat loss of 35 to 40 Btu/ft²-day at 30°F (-1°C) for the TPO roof with 4 inches of insu-

lation and the vegetative roof, respectively. The EPDM roof has a slightly lower heat loss of 30 Btu/ft²-day at the same ambient temperature. Higher heat loss in the winter is observed at all temperatures for the 4-in. TPO roof, especially when the roof is clear of snow (i.e., days at the top of the trend). The TPO roof with 8 inches of insulation shows a commensurate reduction in heat transfer.

Table 3 shows the seasonal heat loss (and heat gain) for each roof type calculated two different ways:

- Without the thermal mass correction (Equation 1) to calculate heat flux at the top of the roof
- With the thermal mass correction applied (Equation 2) to calculate heat flux into the space

| | No Correction | | | |
|---------------------------------------|----------------------------------|--------------------|--------------------|--------------------|
| | Heat Loss (Btu/ft ²) | | | |
| | Unit 1 4 in EPDM | Unit 2 4 in TPO | Unit 3 4 in Veg | Unit 4 8 in TPO |
| 2010 Htg Season (Jan-Apr, Oct-Dec) | 4,885 | 6,361 | 6,033 | 4,367 |
| | Diff | 1,475 | 1,147 | (519) |
| | % Diff | 30% | 23% | -11% |
| 2011 Htg Season (Jan-Apr, Oct-Dec) | 3,958 | 5,726 | 5,154 | 3,407 |
| | Diff | 1,767 | 1,195 | (551) |
| | % Diff | 45% | 30% | -14% |
| 2012 Htg Season (Jan-Apr, Oct-Dec) | 4,483 | 6,479 | 5,942 | 4,089 |
| | Diff | 1,995 | 1,459 | (394) |
| | % Diff | 45% | 33% | -9% |
| 2013 Htg Season (Jan-Apr, Oct-Dec) | 5,334 | 7,180 | 6,508 | 4,937 |
| | Diff | 1,846 | 1,174 | (396) |
| | % Diff | 38% | 24% | -8% |
| 2014 Htg Season (Jan-Apr, Oct-Dec) | 5,430 | 7,334 | 6,567 | 5,062 |
| | Diff | 1,904 | 1,137 | (368) |
| | % Diff | 35% | 21% | -7% |
| 2015 Htg Season (Jan-Apr, Oct-Dec) | 4,924 | 7,089 | 5,997 | 4,804 |
| | Diff | 1,659 | 567 | (625) |
| | % Diff | 31% | 10% | -12% |

| | w/ Thermal Mass Correction | | | |
|---------------------------------------|----------------------------------|--------------------|--------------------|--------------------|
| | Heat Loss (Btu/ft ²) | | | |
| | Unit 1 4 in EPDM | Unit 2 4 in TPO | Unit 3 4 in Veg | Unit 4 8 in TPO |
| 2010 Htg Season (Jan-Apr, Oct-Dec) | 4,912 | 6,365 | 6,046 | 4,322 |
| | Diff | 1,454 | 1,135 | (589) |
| | % Diff | 30% | 23% | -12% |
| 2011 Htg Season (Jan-Apr, Oct-Dec) | 3,863 | 5,605 | 5,031 | 3,308 |
| | Diff | 1,742 | 1,168 | (555) |
| | % Diff | 45% | 30% | -14% |
| 2012 Htg Season (Jan-Apr, Oct-Dec) | 4,487 | 6,467 | 5,953 | 4,113 |
| | Diff | 1,979 | 1,469 | (370) |
| | % Diff | 44% | 33% | -8% |
| 2013 Htg Season (Jan-Apr, Oct-Dec) | 5,330 | 7,170 | 6,470 | 4,938.5 |
| | Diff | 1,840 | 1,141 | (391.0) |
| | % Diff | 35% | 23% | -8% |
| 2014 Htg Season (Jan-Apr, Oct-Dec) | 5,377 | 7,311 | 6,529 | 5,073 |
| | Diff | 1,934 | 1,152 | (304) |
| | % Diff | 36% | 21% | -6% |
| 2015 Htg Season (Jan-Apr, Oct-Dec) | 4,974 | 7,102 | 5,955 | 4,770 |
| | Diff | 1,672 | 525 | (660) |
| | % Diff | 31% | 10% | -12% |

| | No Correction | | | |
|------------------------------|----------------------------------|--------------------|--------------------|--------------------|
| | Heat Loss (Btu/ft ²) | | | |
| | Unit 1 4 in EPDM | Unit 2 4 in TPO | Unit 3 4 in Veg | Unit 4 8 in TPO |
| 2010 Clg Season (May-Sep) | (1,189) | 642 | 1,141 | 698 |
| | Diff | 1,831 | 2,330 | 1,886 |
| 2011 Clg Season (May-Sep) | (1,204) | 477 | 1,009 | 559 |
| | Diff | 1,681 | 2,214 | 1,763 |
| 2012 Clg Season (May-Sep) | (1,333) | 568 | 1,178 | 628 |
| | Diff | 1,902 | 2,512 | 1,961 |
| 2013 Clg Season (May-Sep) | (943) | 1,050 | 1,409 | 882 |
| | Diff | 1,993 | 2,352 | 1,825 |
| 2014 Clg Season (May-Sep) | (1,037) | 803 | 1,293 | 833 |
| | Diff | 1,839 | 2,330 | 1,870 |
| 2015 Clg Season (May-Sep) | (1,801) | 76 | 551 | 154 |
| | Diff | 1,113 | 1,588 | 1,191 |

| | w/ Thermal Mass Correction | | | |
|------------------------------|----------------------------------|--------------------|--------------------|--------------------|
| | Heat Loss (Btu/ft ²) | | | |
| | Unit 1 4 in EPDM | Unit 2 4 in TPO | Unit 3 4 in Veg | Unit 4 8 in TPO |
| 2010 Clg Season (May-Sep) | (1,220) | 639 | 1,141 | 714 |
| | Diff | 1,859 | 2,361 | 1,935 |
| 2011 Clg Season (May-Sep) | (1,211) | 483 | 1,007 | 559 |
| | Diff | 1,694 | 2,218 | 1,769 |
| 2012 Clg Season (May-Sep) | (1,340) | 565 | 1,187 | 635 |
| | Diff | 1,905 | 2,527 | 1,975 |
| 2013 Clg Season (May-Sep) | (964) | 1,060 | 1,443 | 906 |
| | Diff | 2,024 | 2,407 | 1,870 |
| 2014 Clg Season (May-Sep) | (967) | 839 | 1,335 | 818 |
| | Diff | 1,805 | 2,302 | 1,785 |
| 2015 Clg Season (May-Sep) | (1,864) | 61 | 550 | 132 |
| | Diff | 1,098 | 1,587 | 1,169 |

Table 3

The heating season includes January through April, and then October through December in each calendar year. The cooling season extends from May through September. The overall seasonal heat loss (and gain) calculated by the two methods are very similar when integrated over the long term (more than a few days).

The seasonal winter heat losses and summer heat gains are shown for several different years in Table 3. The heat loss in the winter for the TPO roof was 30-45%

greater than the EPDM roof, depending on the year. The heat loss from the vegetative roof was 10-33% greater than the EPDM roof for different years. The heat loss for the better-insulated TPO roof was 7-14% lower than the baseline EPDM roof.

For the heating season, the roof with the EPDM membrane has lower overall heat loss in the winter (October to April) because the solar gain reduces the heating load. In the summer, the TPO and vegetative roofs reduce the heat gain from the roof since the

surface absorbs less solar energy and is cooler.

In the summer, the TPO and vegetative roofs had significantly lower heat gains than the EPDM roof.

Annual Energy and Operating Cost Differences for Each Roof Type

Table 4 compares the overall heating and cooling loads, energy use, and costs for the different roofs. The EPDM roof is used as the reference or baseline; fuel use and cost savings are compared relative to that roof system, assuming an 80% efficient heating system and a gas cost of \$1.00 per therm. The boxes on the left side of the table show the results without thermal correction (same method as in original report), while the right side of the table shows results with the thermal correction. The results are similar regardless of whether the thermal correction was applied.

The similarly-insulated TPO and vegetative roofs result in slightly higher annual fuel costs in the winter, at \$23 per 1000 sq. ft. per year and \$15 per 1000 sq. ft. per year, respectively. When comparing the results for the TPO roofs on Unit 2 and Unit 4, the extra 4 inches of insulation saves about \$28 per 1000 sq. ft. per year.

The reduction in cooling energy use and costs were determined assuming a seasonal average cooling efficiency of 0.9 kW per ton and an electric cost of \$0.12 per kWh. The TPO roof with R-22 reduced annual costs by \$16 per 1000 sq. ft. compared to EPDM with R-22. The vegetative roof with R-22 reduced cooling costs by \$20 per 1000 sq. ft.

Overall, the cost savings for cooling were slightly smaller than the added costs for heating with the TPO roof. The net annual impact for the TPO roof was to increase costs by about \$8 per 1000 sq. ft.

This analysis assumes that the facility was in the cooling mode from May through September and in the heating mode for the rest of the year. This approximately

corresponds to a building balance point that is around the indoor setpoint (around 65-70°F). In many types of buildings, internal gains from lighting, plug loads, and occupants can reduce the balance point so that space heating is not required in the building until the outdoor temperature drops to 50-60°F. Correspondingly, greater internal gains mean that cooling can be required at lower ambient temperatures. Buildings with differing levels of internal gains can require more cooling and less heating, thus changing the impact of the cool roof on energy costs. If cooling is needed under moderate conditions (around 55 to 65°F), this cooling load could be satisfied by economizer operation at little to no energy use.

One way to approximate the impact of a lower balance point combined with economizer operation is to exclude months from the heating and cooling seasons. If we assume the heating season now only includes five months (November through March) and the cooling season only includes three months (June to August), the analysis can be repeated as shown in *Table 5*. This change reduces the heating penalty of the TPO roof with R-22 but also decreases the cooling benefit. As a result, the net or combined cost impact changes very little for this case.

Comparing Energy and Cost Results to Other Studies

A series of studies at Concordia University (Hosseini and Akbari 2014, Hosseini 2014, and Hosseini and Akbari 2015) used the DOE-2.1E simulation tool to evaluate the annual energy and cost performance of cool roofs in cold climates. They compared the annual energy performance of dark and white roofs and also considered the impact of snow accumulation on the thermal performance of the roof. They looked at various different building and HVAC types with various efficiency levels. Generally, they found that snow buildup on

| Heating | No Correction | | | |
|---|---------------------|--------------------|--------------------|--------------------|
| | Unit 1 4 in EPDM | Unit 2 4 in TPO | Unit 3 4 in Veg | Unit 4 8 in TPO |
| Avg Annual Heat Load (MMBTU per 1000 sq ft) | 4.8 | 6.7 | 6.0 | 4.4 |
| Annual Gas Use (therms per 1000 sq ft) | 60.4 | 83.7 | 75.4 | 55.6 |
| Annual Cost Per 1000 sq ft | \$ 60 | \$ 84 | \$ 75 | \$ 56 |
| saving per 1000 sq ft | | \$ (23) | \$ (15) | \$ 5 |

| Cooling | Unit 1 | Unit 2 | Unit 3 | Unit 4 |
|--|-----------|----------|----------|----------|
| | 4 in EPDM | 4 in TPO | 4 in Veg | 8 in TPO |
| Reduced Cooling (ton-hrs/yr per 1000 sq ft) | | 143.9 | 185.1 | 145.8 |
| Reduced Cooling Power (kW/yr per 1000 sq ft) | | 129.5 | 166.6 | 131.2 |
| Savings per 1000 sq ft | | \$ 16 | \$ 20 | \$ 16 |

| Combined | Unit 1 | Unit 2 | Unit 3 | Unit 4 |
|---------------------------|-----------|----------|----------|----------|
| | 4 in EPDM | 4 in TPO | 4 in Veg | 8 in TPO |
| Net Saving per 1000 sq ft | | \$ (8) | \$ 5 | \$ 21 |

Table 4

| Heating | No Correction | | | |
|---|---------------------|--------------------|--------------------|--------------------|
| | Unit 1 4 in EPDM | Unit 2 4 in TPO | Unit 3 4 in Veg | Unit 4 8 in TPO |
| Avg Annual Heat Load (MMBTU per 1000 sq ft) | 4.2 | 5.5 | 4.9 | 3.6 |
| Annual Gas Use (therms per 1000 sq ft) | 52.7 | 68.8 | 61.4 | 45.5 |
| Annual Cost Per 1000 sq ft | \$ 53 | \$ 69 | \$ 61 | \$ 46 |
| saving per 1000 sq ft | | \$ (16) | \$ (9) | \$ 7 |

| Cooling | Unit 1 | Unit 2 | Unit 3 | Unit 4 |
|--|-----------|----------|----------|----------|
| | 4 in EPDM | 4 in TPO | 4 in Veg | 8 in TPO |
| Reduced Cooling (ton-hrs/yr per 1000 sq ft) | | 83.0 | 114.5 | 93.8 |
| Reduced Cooling Power (kW/yr per 1000 sq ft) | | 74.7 | 103.1 | 84.4 |
| Savings per 1000 sq ft | | \$ 9 | \$ 12 | \$ 10 |

| Combined | Unit 1 | Unit 2 | Unit 3 | Unit 4 |
|---------------------------|-----------|----------|----------|----------|
| | 4 in EPDM | 4 in TPO | 4 in Veg | 8 in TPO |
| Net Saving per 1000 sq ft | | \$ (7) | \$ 4 | \$ 17 |

Table 5

the roof had only a modest impact on overall heating loads and fuel use.

One of the cities they considered was Toronto, which has a comparable climate to the Jamesville test site. They simulated a new small office building that had a new building envelope (the roof had an R-value of 31.5). The heating and cooling system was supplied by a package cooling unit with gas furnace section. The HVAC system used an economizer to provide free cooling when outdoor temperatures were low enough. Several key parameters used in the Hosseini study are compared to our assumptions in *Table 6*.

The cool roof savings from Hosseini (2014) without snow impacts are compared to the savings from this study in *Table 7*. The Hosseini results are based on the

| With Thermal Mass Correction | | | |
|------------------------------|--------------------|--------------------|--------------------|
| Unit 1 4 in EPDM | Unit 2 4 in TPO | Unit 3 4 in Veg | Unit 4 8 in TPO |
| 4.8 | 6.7 | 6.0 | 4.4 |
| 60.3 | 83.4 | 75.0 | 55.3 |
| \$ 60 | \$ 83 | \$ 75 | \$ 55 |
| | \$ (23) | \$ (15) | \$ 5 |

| Unit 1 | Unit 2 | Unit 3 | Unit 4 |
|-----------|----------|----------|----------|
| 4 in EPDM | 4 in TPO | 4 in Veg | 8 in TPO |
| | 144.2 | 186.1 | 145.9 |
| | 129.8 | 167.5 | 131.3 |
| | \$ 16 | \$ 20 | \$ 16 |

| Unit 1 | Unit 2 | Unit 3 | Unit 4 |
|-----------|----------|----------|----------|
| 4 in EPDM | 4 in TPO | 4 in Veg | 8 in TPO |
| | \$ (7) | \$ 6 | \$ 21 |

| Heating | With Thermal Mass Correction | | | |
|---------|------------------------------|--------------------|--------------------|--------------------|
| | Unit 1 4 in EPDM | Unit 2 4 in TPO | Unit 3 4 in Veg | Unit 4 8 in TPO |
| 4.2 | 5.5 | 4.9 | 3.6 | |
| 52.6 | 68.5 | 61.2 | 45.3 | |
| \$ 53 | \$ 68 | \$ 61 | \$ 45 | |
| | \$ (16) | \$ (9) | \$ 7 | |

| Unit 1 | Unit 2 | Unit 3 | Unit 4 |
|-----------|----------|----------|----------|
| 4 in EPDM | 4 in TPO | 4 in Veg | 8 in TPO |
| | 84.4 | 115.7 | 95.3 |
| | 75.9 | 104.1 | 85.7 |
| | \$ 9 | \$ 12 | \$ 10 |

| Unit 1 | Unit 2 | Unit 3 | Unit 4 |
|-----------|----------|----------|----------|
| 4 in EPDM | 4 in TPO | 4 in Veg | 8 in TPO |
| | \$ (7) | \$ 4 | \$ 18 |

DOE-2.1E fuel and electricity reduction differences. Starting with those values, we used the efficiencies from *Table 6* to infer the cooling and heating load impacts. For our results, we determined the load impacts and calculated the change in fuel and electricity using the efficiencies from *Table 6*. The results that were directly determined in each study are shown as bold and shaded in the table.

The results from this study are shown for both Case 1 in *Table 4* and Case 2 in *Table 5*. The Case 2 results are expected to better reflect Hosseini's results for the office building with internal gains and an economizer. The heating penalty we determined is slightly larger than the value Hosseini found for Toronto (1.2 compared to 0.7 MMBtu per 1000 sq. ft.). This could, in part,

| | Hosseini (2014) | CDH Analysis |
|---|-----------------|--------------|
| Roof R-Value (ft ² -F-h/Btu) | 31.5 | 25 |
| Heating Efficiency | 0.8 | 0.8 |
| Cooling Efficiency (kW/ton) | 1.33 nominal | 0.9 avg. |

Table 6 – Comparing key parameters and assumptions.

| | Jamesville Results | | |
|--|-------------------------|----------------|----------------|
| | Hosseini (2014) Toronto | CASE 1 Table 8 | CASE 2 Table 9 |
| Annual Heating Load Reduction (MMBtu per 1000 sq. ft.) | -0.71 | -1.9 | -1.2 |
| Annual Heating Fuel Savings (therms per 1000 sq. ft.) | -8.8 | -23.2 | -16.1 |
| Annual Cooling Load Reduction (ton-h per 1000 sq. ft.) | 561 | 144 | 84 |
| Annual Cooling Energy Savings (kWh per 1000 sq. ft.) | 74 | 129 | 75 |
| Net Cost Savings (\$ per 1000 sq. ft.) | ~0 | --8 | --7 |

Note: Cost savings are based on \$0.12/kWh and \$1.00/therm.

Table 7 – Comparing cost savings from this and other studies.

be explained by the 20% higher R-value used in Hosseini’s simulation model. The cooling energy use values are very similar between CASE 2 and the Hosseini results (75 and 74 kWh per 1000 sq. ft., respec-

tively). Where our study found a slight cost penalty for the TPO roof, the Hosseini data with cost assumptions are cost-neutral. Hosseini (2014) used different utility cost assumptions and found slightly larger net cost savings (approximately \$1 to \$2 per 1000 sq. ft.).

ous locations throughout the United States. Snow cover data are available from station NY-OG-20, which is located 1.9 miles southeast of Syracuse at an elevation of 587 ft. This station is about three miles from the facility in Jamesville, which is at a slightly higher elevation (about 740 ft.). The “Modeled Snow Depth” for the NY-OG-20 station is shown in *Figure 11* and *Figure 12* for the seven winter seasons from 2009 through 2016.

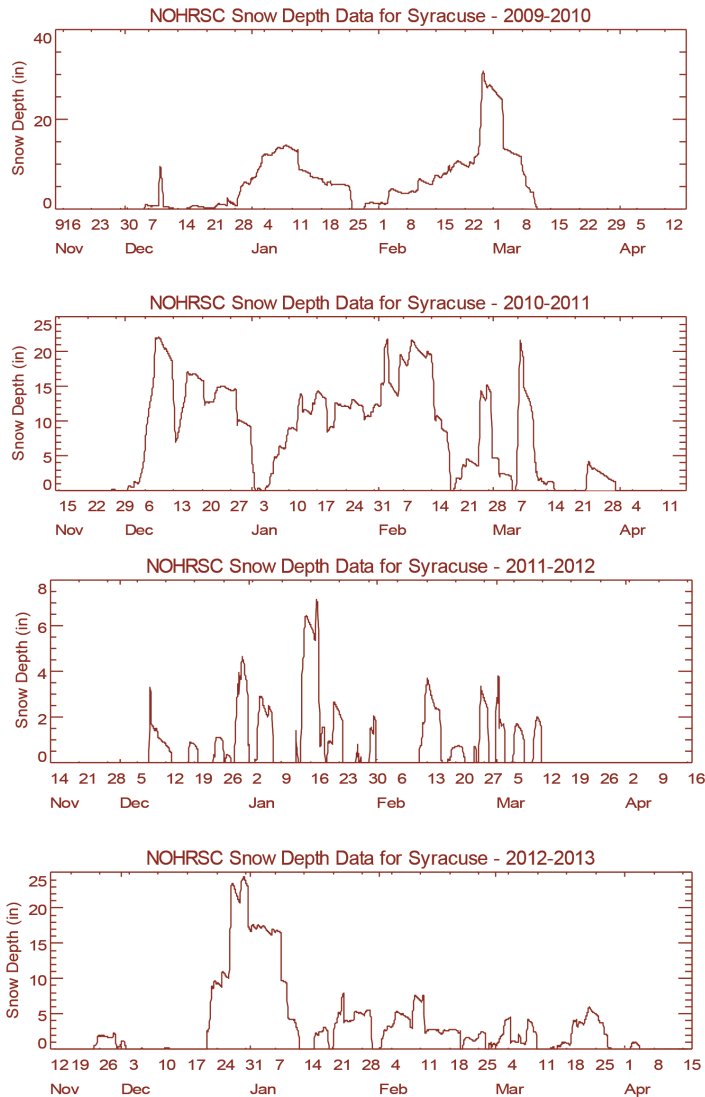


Figure 11 – Snow cover data from NOHRSC showing winters from 2009 through 2013.

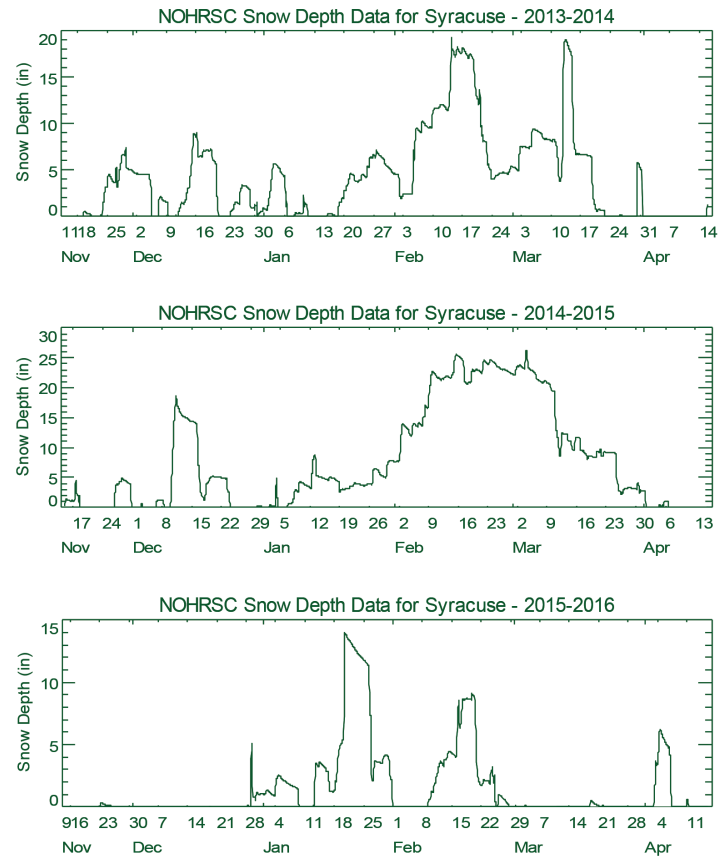


Figure 12 – Snow cover data from NOHRSC showing winters from 2013 through 2016.

HOW GROUND SNOW COVER RELATES TO ROOF SNOW COVER

Obtaining NCDC Ground Snow Cover Data for Syracuse

The National Operational Hydrologic Remote Sensing Center (NOHRSC) in Chanhassen, MN, is a division of the National Weather Service and National Oceanic and Atmospheric Association (NOAA) (<http://www.nohrsc.noaa.gov/>). NOHRSC has developed tools to estimate snow cover at various

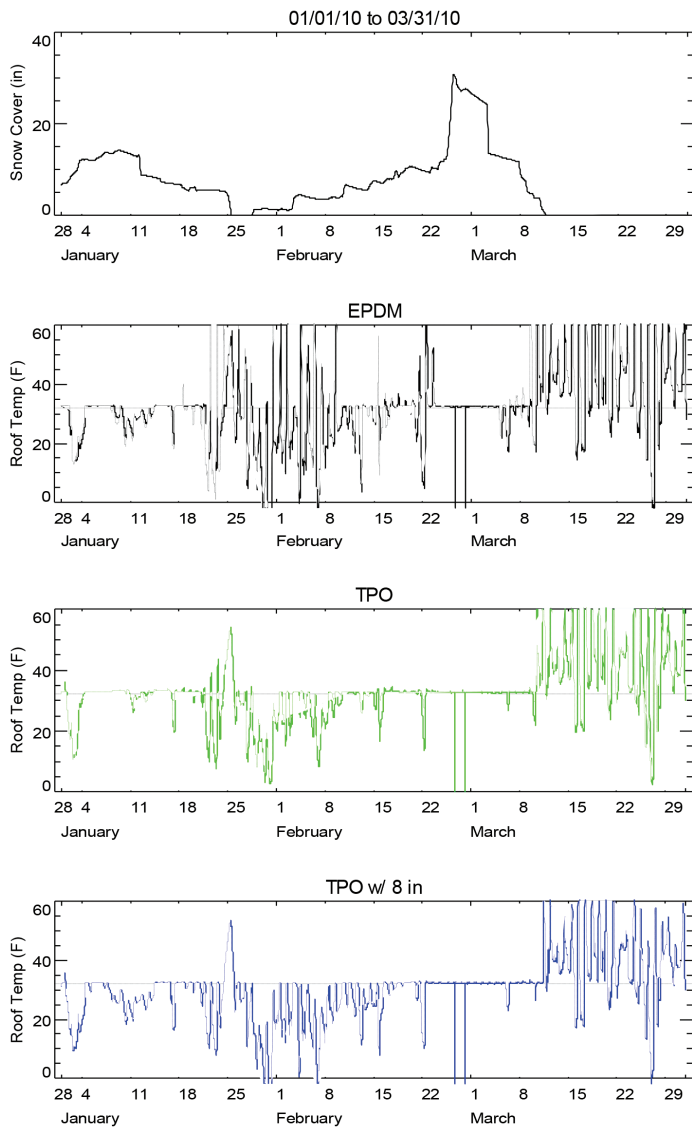


Figure 13 – Comparing snow cover and roof temperatures (TRO) for three roof types, winter 2010.

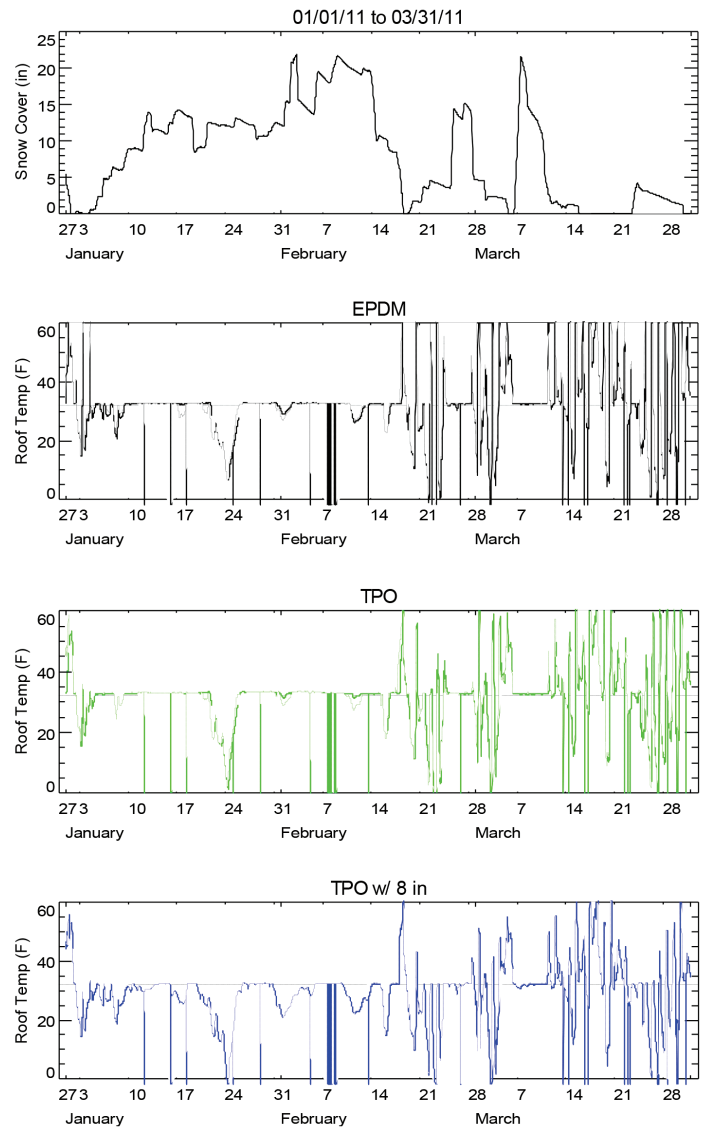


Figure 14 – Comparing snow cover and roof temperatures (TRO) for three roof types, winter 2011.

Comparing Ground Snow Coverage From Roof Temperatures

The plots in Figures 13 through 19 compare the ground snow cover data (top graph) from NOHRSC to the temperatures measured at the top of the roof insulation (TRO) for the EPDM roof (second, black graph), the TPO roof with 4 inches of insulation (green), and the TPO roof with 8 inches of insulation (blue). Station A on each roof is shown with a solid line, while Station B is shown with a dotted line. Figure 13 through Figure 19 compare snow cover and temperature data for the first three months of each year from 2010 through 2016.

From the graphs, it is apparent that the periods with snow cover correspond to periods when the roof temperatures do not exceed the freezing point. The EPDM roof appears to “clear” its snow more quickly

than the other roof types as indicated by a greater number of temperature excursions above freezing when there is a small amount of snow. For the EPDM roof, temperature excursions above freezing start when the ground snow level drops to approximately 5 inches. The TPO roof with 8 inches of insulation holds snow longer, and the temperature excursions above freezing more closely correspond to the periods with any snow cover on the ground. The roof surface temperature data generally all imply that the snow cover on each roof clears sooner than snow cover on the ground.

If we identify days when the modeled snow cover is greater than 1 inch for more than 18 hours, we can determine the number of hours and days per year that there was snow cover on the ground. The number of snow-covered days for each year is shown

as the row labeled “Ground” in Table 8. We assume that roofs have snow cover on days that have ground snow cover and the peak daily roof surface temperature is lower than 35°F. The number of days that meet these criteria is shown in the subsequent rows in the table. Figure 20 uses this data from Table 8 to show the portion of time that each roof has snow cover compared to the ground snow cover.

Generally, the time with snow accumulation on each roof is about 60-80% of the time that snow is on ground. That percentage is lowest for the EPDM roof and is highest for the TPO roof with 8 inches of insulation.

Heat Loss on Snow-Free Days

The daily heat transfer plot in Figure 6 includes all days—both with and with-

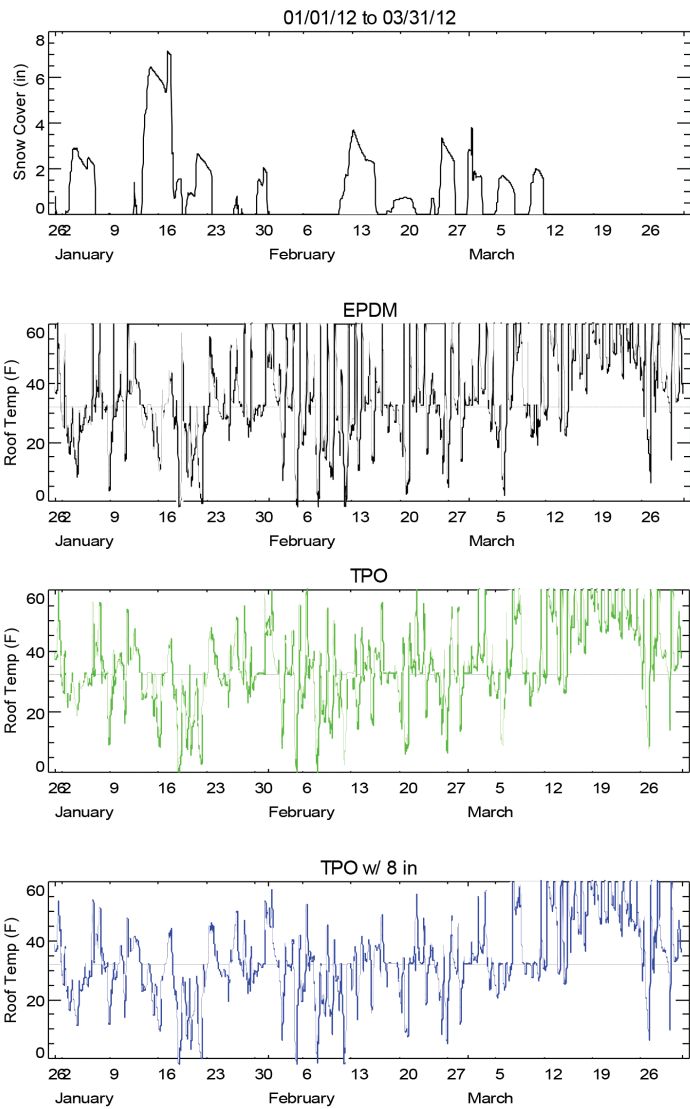


Figure 15 – Comparing snow cover and roof temperatures (TRO) for three roof types, winter 2012.

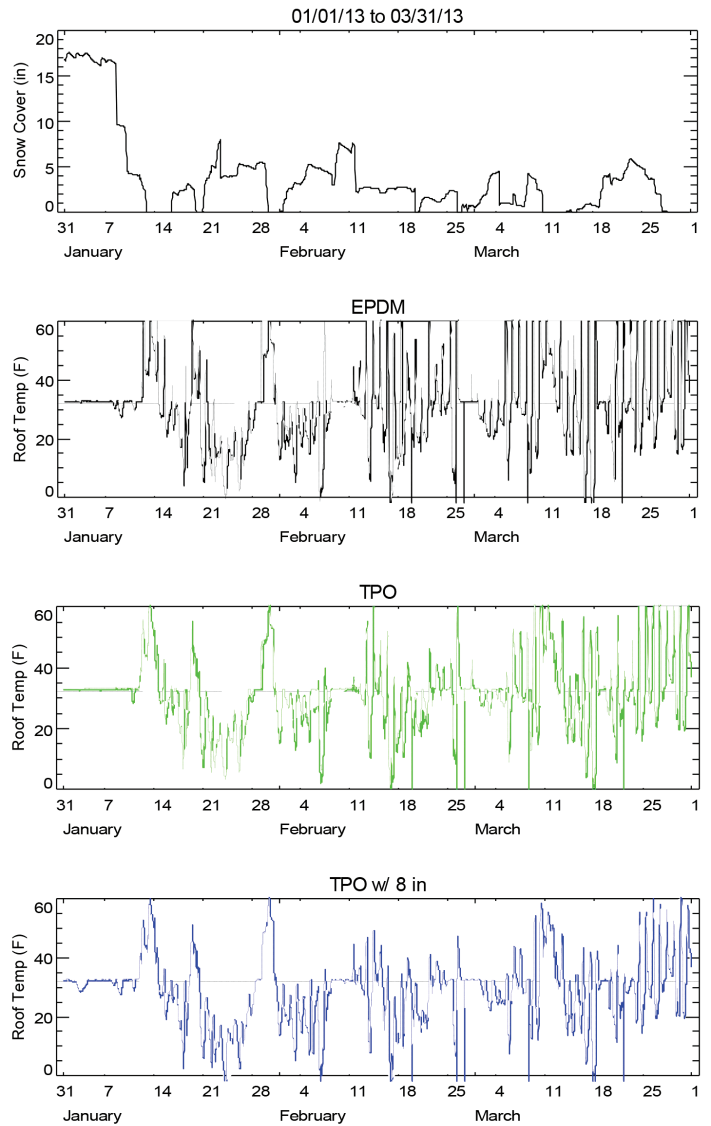


Figure 16 – Comparing snow cover and roof temperatures (TRO) for three roof types, winter 2013.

| | Number of Days with Snow Cover | | | | | | |
|-----------|--------------------------------|------|------|------|------|------|------|
| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | AVG |
| Ground | 93 | 78 | 35 | 88 | 86 | 84 | 77.3 |
| TPO8 Roof | 90 | 60 | 25 | 62 | 66 | 61 | 60.7 |
| TPO4 Roof | 88 | 56 | 24 | 57 | 69 | 59 | 58.8 |
| EPDM Roof | 78 | 52 | 20 | 51 | 65 | 54 | 53.3 |

| | Ratio of Roof-to-Ground Snow Cover | | | | | | |
|-----------|------------------------------------|------|------|------|------|------|-----|
| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | AVG |
| TPO8 Roof | 97% | 77% | 71% | 70% | 77% | 73% | 78% |
| TPO4 Roof | 95% | 72% | 69% | 65% | 80% | 70% | 76% |
| EPDM Roof | 84% | 67% | 57% | 58% | 76% | 64% | 69% |

Table 8

out snow cover. If days with ground snow cover are excluded, then the trends become much more linear, as shown by Figure 21. The knee in the trends at the freezing point is eliminated for all the roofing assemblies, except for the vegetative roof, which still appears to retain moisture after the snow cover is gone.

Table 9 summarizes the regression statistics for the best fit lines shown on the plot. The EPDM roof shows the highest degree of scatter, since variations in the daily solar flux have a larger impact on the heat loss for this roof. The TPO roofs absorb much less solar energy, so the degree of scatter is significantly lower than for the EPDM roof. The greater insulation level further reduces the scatter (or reduces the impact of solar gains).

CONCLUSIONS

Extended field testing of the four different roof systems tracked the thermal performance over 6½ years, from November 2009 through May 2016. Some of the

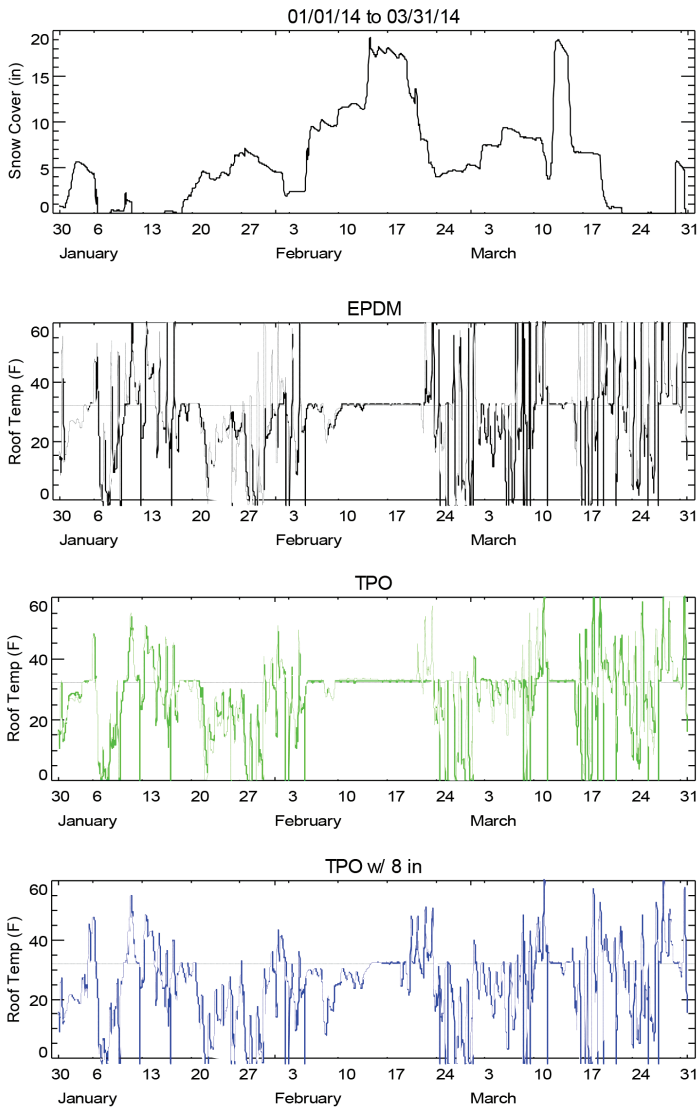


Figure 17 – Comparing snow cover and roof temperatures (TRO) for three roof types, winter 2014.

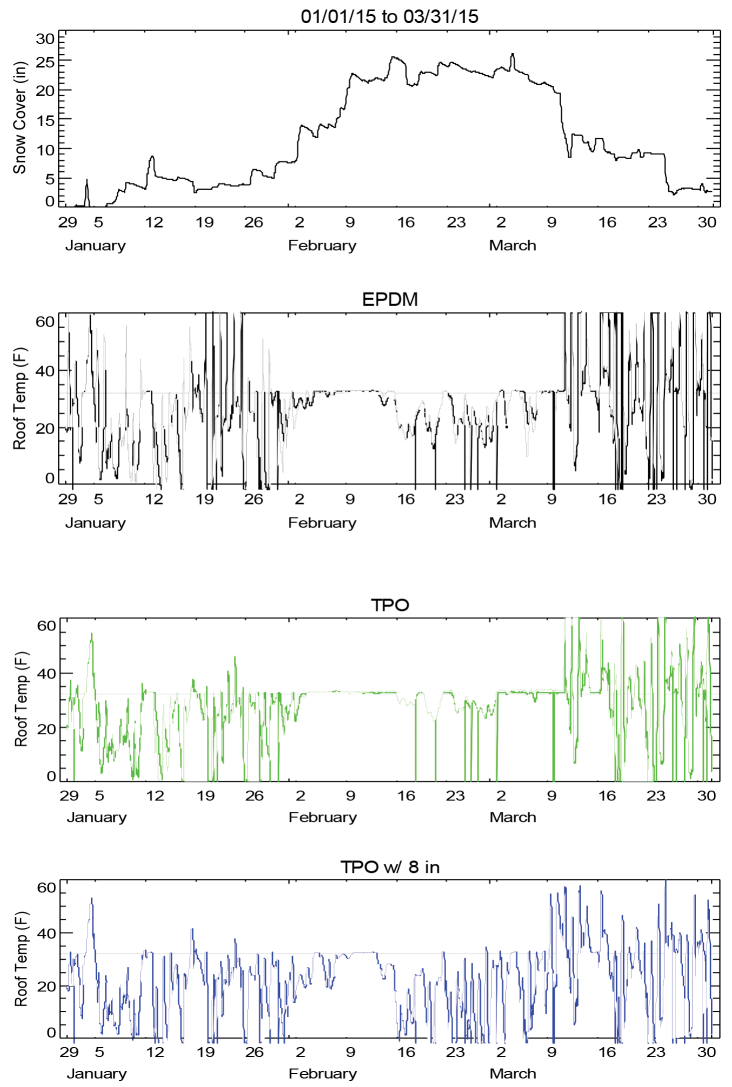


Figure 18 – Comparing snow cover and roof temperatures (TRO) for three roof types, winter 2015.

initial findings (summarized in the October 2011 report) continued over the long term:

- The EPDM surface did result in roof temperatures that were as much as 60°F higher than the other surfaces. This surface had higher temperatures in the summer, as well as in the winter.
- The TPO membrane significantly reduced the surface temperatures in the summer, but also resulted in a greater heating penalty in the heating season (since beneficial solar gains are reduced).
- The vegetative roof adds thermal mass to the roof assembly that dampens the temperature swings. Evaporation at the surface also provides cooling in the summer and swing seasons. The vegetative roof

also retained more snow cover more often and had lower heat losses in the winter.

Over the long term, the TPO membrane with 4 inches of insulation had 30% to 45% higher thermal losses over the heating season, as measured at the roof surface.¹ This higher heat loss increases heating costs by \$23 per year per each 1000 sq. ft. of roof area. However, the reduced summertime

heat gains equate to about \$16 per year per 1000 sq. ft. in cooling energy savings. Overall, heating losses and cooling savings resulted in a net annual cost penalty of \$8 per 1000 sq. ft. for the 4-inch TPO roof.

Using different assumptions for internal gains and cooling system arrangement (corresponding to a small office with a packaged cooling system that uses economizer cooling in the swing season) changes the resulting impact on heating and cooling

| Roof Assembly | R-squared | Coefficient of Variation (CV) |
|-------------------|-----------|-------------------------------|
| EPDM | 0.885 | 1.09 |
| TPO with 4 inches | 0.960 | 0.18 |
| TPO with 8 inches | 0.964 | 0.14 |

Note: CV indicates the average variation of the data from the linear model.

Table 9 – Linear regression statistics for different roof assemblies (in Figure 21).

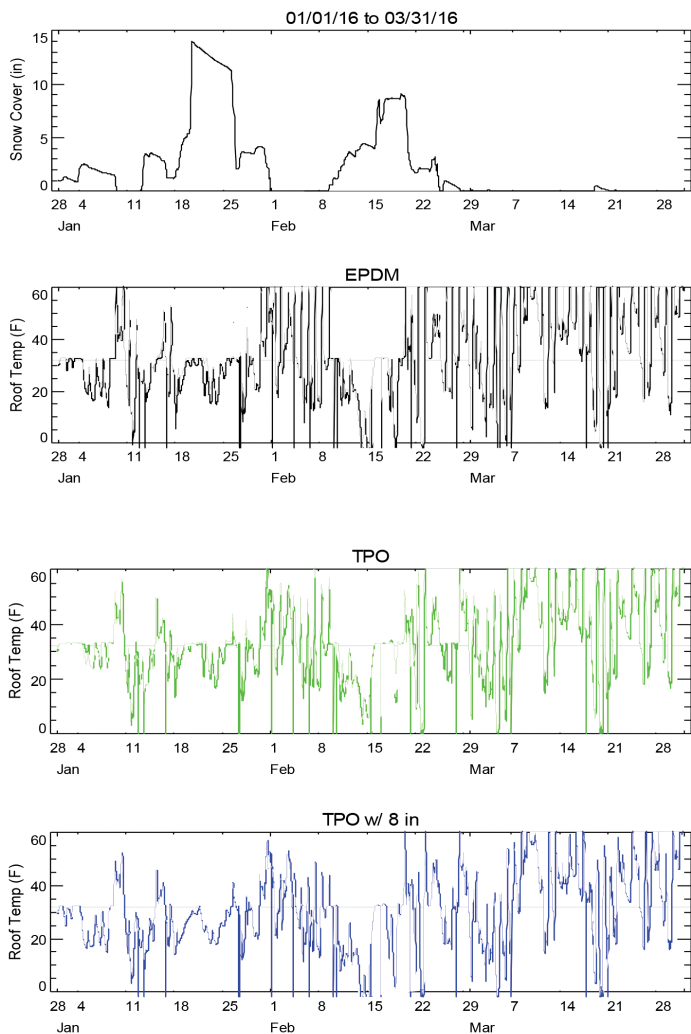


Figure 19 – Comparing snow cover and roof temperatures (TRO) for three roof types, winter 2016.

loads and energy use. The heating penalty of the 4-inch TPO over a shorter heating season (caused by internal gains) drops to \$16 per 1000 sq. ft., and the cooling benefit becomes \$9 per 1000 sq. ft. The net annual cost penalty of the 4-inch TPO roof compared to the EPDM roof is still around \$7 per 1000 sq. ft.

The results from Hossieni (2014) and Hosseini and Akbari (2015) showed similar trends of heating penalties from reflective roofs and summertime savings, with a slightly smaller net annual penalty of \$1 to \$2 per 1000 sq. ft. for nearby Toronto (using our assumptions). Details of building application (office, retail, institutional, etc.) and HVAC arrangement (economizer, cooling efficiency), as well as utility costs have a significant impact on whether cooling roofs provide net cost increases or savings in each climate.

Hosseini and Akbari (2015) included roof snow in the analysis whenever ground

in the model codes. In this research project, we sought to determine the relationship between ground snow cover and the presence of snow on the roof.

To predict hourly ground snow cover for the Jamesville, NY, site over the monitoring period, we used snow cover data from a monitoring station three miles from the Jamesville facility provided by the NOHRSC in Chanhassen, MN. We found that periods with ground snow cover generally have roof surface temperatures that remain very close to freezing, regardless of outdoor

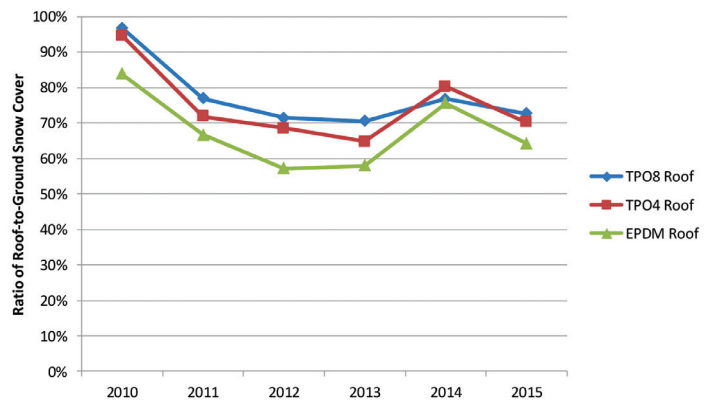


Figure 20 – Percentage of days with snow cover on each rooftop relative to ground cover.

snow was present; however, this assumption does not reflect known snow-fall behavior. The cited analysis thus overestimates the effect of roof snow cover in reducing heat gain of highly absorptive roof coverings during winter months. Live-load calculations for roof snow loads include reductions for sliding snow; other variables permit adjustments to the structural requirements

temperatures. By combining the snow cover and roof temperature data, we were able to show that the roofs are generally covered with snow less often than snow is on the ground; the ratio of roof-to-ground snow cover ranged between 60 and 80%. The EPDM roof clears snow faster than the other roof types (as evidenced by temperature excursions above freezing). The TPO roof with extra insulation retained snow longer, since the lower heat loss results in less melting at the roof surface.

When we look at the days that are snow-free, the trend of heat loss with ambient temperature becomes highly linear for the EPDM and TPO roofs. The highly-insulated TPO roof has the lowest degree of scatter from the linear trend, since the impact of solar gains is minimal in this case. The vegetative roof shows a nonlinear trend, even with snowy days excluded, since it retains water and ice even if there is no snow on the ground.

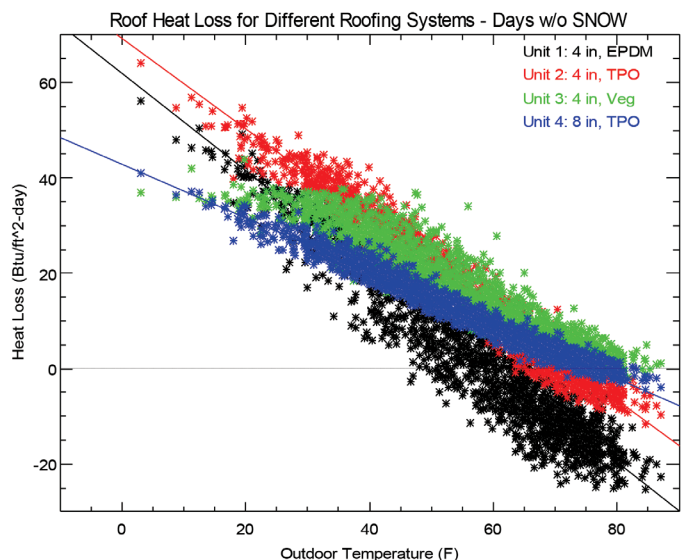



Figure 21 – Daily heat loss vs. outdoor temperature on snow-free days.

We found that the temperature difference between the similarly-insulated EPDM and TPO roofs was as high as 60°F on summer days when the roofs were first installed. Over the first two or three years, the temperature difference dropped by 10°F to 15°F. Generally, the peak temperature of the EPDM roof stayed about the same over the long term, while the peak surface temperature of the TPO roof increased by 10°F to 15°F—perhaps due to soiling or aging. This long-term temperature increase of the white reflective roof is less than what was observed in earlier studies using the first cool roof membrane products (Miller et al. 2004), but seems to be consistent with the published rating numbers for this TPO membrane (initial and three-year reflectance ratings per Energy Star CRRC are 0.79 and 0.70, respectively).

These findings support a whole-building approach to roof system selection and design, with appropriate consideration given to occupancy, internal loads, site, and orientation. Design for insulation levels and roofing reflectance and absorptance values should be optimized on a project-specific basis using energy modeling. Future research might look at refining the assumptions and variables in energy modeling for roof snow cover. Note that there were no measurements of relative humidity or moisture content within the roof assemblies; additional consideration for condensation management of the various roof assemblies is another possible research topic. 

FOOTNOTE

1. We applied a correction for thermal mass of the roof deck, developed from an analysis using EnergyPlus that resulted in a similar heat loss rate at the ceiling over the long term.

ACKNOWLEDGEMENTS

The authors wish to thank Scott Perry and his team at Ashley McGraw Architects for providing the detailed specifications for this roofing project, as well as their insights on its design and construction. Thanks also to Lee Klosowski, Director of Energy at Onondaga County, and to Daniel Loguidice and George Manolis in Onondaga County Correctional Department, who graciously

arranged for access to this secure facility.

Technical Oversight Committee: Michael Fischer, Kellen Company, Coalition Chair, ARMA; Marcin Pazera, PIMA; Jerry Phelan, Covestro, PIMA; Ellen Thorp, ERA; Rick Gustin, Johns-Manville, ERA.

REFERENCES

CDH Energy. Comparative Roof Testing at Onondaga County Correctional Facility. Final Report. Submitted to Onondaga County with Ashley McGraw Architects. October 2011.

CDH Energy. “Long-term Performance Monitoring of Various Roof Assemblies – A Side-by-Side Comparison.” Final Report. Submitted to the Asphalt Roofing Manufacturers Association. February 2017.

M. Hosseini and H. Akbari. “Heating Energy Penalties of Cool Roofs: the Effect of Snow Accumulation

on Roofs.” *Advances in Building Energy Research*. DOI: 10.1080/17512549.2014.890541. 2014.

M. Hosseini. “Cool Roofs Savings and Penalties in Cold Climates: the Effect of Snow Accumulation on Roofs.” Master’s thesis. Concordia University, Montreal, Quebec, Canada. 2014.

M. Hosseini and H. Akbari. “Effect of Cool Roofs on Commercial Buildings’ Energy Use in Cold Climates.” *Energy and Buildings*. DOI:10.1016/j.enbuild.2015.05.050. 2015.

W. Miller, A. Desjarlais, and D. Roodvoets. “Long Term Reflective Performance of Roof Membranes.” Oak Ridge National Laboratory and DLR Consultants. 237680034. www.researchgate.net. January 2004.

GLOSSARY OF TERMS

| | |
|------------|---|
| ARMA | Asphalt Roofing Manufacturers Association |
| CRRC | Cool Roof Rating Council. Part of Energy Star cool roofs program. |
| Economizer | An optional HVAC arrangement where outdoor air is used to provide “free cooling” when outdoor conditions are favorable. |
| EnergyPlus | A building simulation software tool from the U.S. Department of Energy. Used to determine theoretical heat transfer through the roof assembly to verify calculations in this study. |
| EPDM | Ethylene propylene diene monomer single-ply rubber roof membrane. Also a conventional or dark roof membrane. |
| ERA | EPDM Roofing Association |
| HVAC | Heating ventilation and air conditioning. System that provides heating and cooling for a building. |
| PIMA | Polyisocyanurate Insulation Manufacturers Association |
| TPO | Thermoplastic polyolefin roof membrane. Also a white, reflective, or cool roofing membrane. |
| TRI | Temperature roof inside. Temperature under the insulation layer. |
| TRO | Temperature roof outside. Temperature at the roof surface (but under the deck board). |