TECH SOLUTIONS 512.0
Thermal Advantages of Ballasted Assemblies vs. White Membrane Cool Roofs

Summary

This document describes the research results from Oak Ridge National Laboratory (ORNL) on "Evaluating the Energy Performance of Ballasted Roof Systems." This ORNL research addressed whether ballasted roof systems offer similar energy-efficiency benefits as cool roofs sponsored by the Single Ply Roofing Industry (SPRI). Different weights of ballasted roofs were compared to a paver system and black and white membranes. These systems were constructed and installed on the Roof Thermal Research Apparatus (RTRA) at ORNL near Knoxville, Tenn., and monitored for thermal performance for a three-year period.

The research results show that a white single-ply membrane performed better than a black single-ply membrane and ballasted roof for the first seven months. But as time goes on and the white membrane ages, high density ballasted roof assemblies (17 lb/ft^2 and 24 lb/ft^2 [83 kg/m^2 and 117 kg/m^2]) and the paver system (24 lb/ft^2 [117 kg/m^2]) have lower surface temperatures than both white and black single-ply membrane roof systems. The black EPDM membrane roof had the highest roof surface temperature and cooling load throughout the research period.

Cool Roofs

Cool roofs consist of materials that very effectively reflect the sun's energy from the roof surface. Cool materials for low slope roofs are mainly bright white in color, although non-white colors are becoming available for sloped roof applications. Cool roofs must have high emissivity, allowing them to emit infrared energy. Cool roofs also have high reflectivity. Unfortunately, bare metals and metallic coatings tend to have low emissivity and are not considered cool materials.

It is well known that the mass of a ballasted roof can reduce peak roof temperatures and delay the heat flow into the building. However, a ballasted roof does not meet the traditional requirements of high solar reflectance and high thermal emittance set out by the U.S. Environmental Protection Agency (EPA) and other organizations regarding a cool roof. Table 1 lists current cool roof requirements of different organizations.

The Cool Roof Rating Council (CRRC) was created in 1998 to develop accurate and credible methods for evaluating and labeling the solar reflectance and thermal emittance (radiative properties) of roofing products and to disseminate the information to all interested parties. CRRC measures and labels the products tested with initial and aged radiative properties (reflectance and emittance), but CRRC does NOT determine whether a particular product is a cool roof product.[1]

CRRC conducts all radiative property testing by accredited testing laboratories. (See CRRC Accredited Testing Laboratories for a list.) Solar reflectance can be measured in accordance with ASTM test methods C1549, E1918 and E903, and CRRC-1 Method #1: Test Method for Certain Variegated Products. Thermal emittance is measured in accordance with ASTM C1371. For aged ratings, product samples are exposed for three years at the CRRC Approved Test Farm. Product ratings are verified periodically through the CRRC Random Testing Program. For specific product listings, visit http://www.coolroofs.org.

ORNL Research Results

The ORNL research "Evaluating the Energy Performance of Ballasted Roof Systems" addresses whether ballasted roof systems offer similar energy-efficiency benefits as cool roofs. The study began March 12, 2004, with the start of data collection that continued uninterrupted for 161 weeks through April 2007 in east Tennessee.[2]

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The following roof types were included in the research study:

- EPDM black membrane
- TPO white membrane
- 10 lb/ft² (49 kg/m²) stone ballast with black EPDM membrane
- 17 lb/ft² (83 kg/m²) stone ballast with black EPDM membrane
- 24 lb/ft² (117 kg/m²) stone ballast with black EPDM membrane
- 24 lb/ft² (117 kg/m²) uncoated paver

The temperature of the conditioned space inside the building was maintained at 70ºF to 80ºF (21ºC to 26ºC) by an electric resistance heater and a small through-the-wall air conditioner. Wood fiberboard insulation 1.5" (38 mm) thick was used to maximize sensitivity to differences among the test sections.

1. *One month after data collection started (April 5, 2004)*

   The black membrane showed the surface temperature peaked at approximately 146ºF (63ºC). The white membrane showed the lowest surface peak temperature at 86ºF (30ºC). Ballasted systems and the paver system were in between the two extremes – the black membrane and the white membrane. The three ballasted systems peaked at 103ºF (39ºC) (10 lb/ft² [49 kg/m²]), 95ºF (35ºC) (17 lb/ft² [83 kg/m²]) and 90ºF (32ºC) (24 lb/ft² [117 kg/m²]) respectively – the higher the ballast density, the lower the peak surface temperature. The paver system had comparable peak surface temperature to the 24 lb/ft² (117 kg/m²) ballasted system. The ballasted systems showed a delay of peak temperature ranges from 30 minutes to 2 hours depending on density – the higher the density, the longer the delay.

   The trend of the heat flux data is consistent with the temperature data described above. Peak heat fluxes are arranged in the identical order as the peak surface temperatures.

2. *Seven months after data collection started (October 4, 2004)*

   The black membrane continued to be the warmest membrane with peak temperature at 150ºF (66ºC). However, the white membrane was no longer the coolest membrane. After seven months in service, the paver system and the 24 lb/ft² (117 kg/m²) ballasted system were cooler than the white membrane. The 17 lb/ft² (83 kg/m²) ballasted system had almost the same surface temperature as the white membrane. The heat flux trends duplicated the temperature trends. The ballasted system and paver system delayed the peak temperature from 1 to 3 hours, depending on the ballast density.

   It is notable that the paver system and the 24 lb/ft² (117 kg/m²) ballasted system have similar density but very different solar reflectance. The solar reflectance for the paver and ballast are 0.55 and 0.22, respectively. This strongly suggests that the controlling factor is mass instead of solar reflectance.

Table 1: Cool Roof Requirements

Code	Minimum Initial Value	
	Solar Reflectance	Thermal Emittance
California Title 24/ASHRAE 90.1[1]	0.7	0.75
ENERGY STAR[2]	Initial solar reflectance: >0.25 for steep slope (>2:12) and >0.65 for low slope (2:12 or less) Weathered solar reflectance: >0.15 for steep slope and >0.50 for low slope, after three years of normal exposure A comparable warranty to non-reflective roof products	N/A
U.S. Green Building Council, LEED program[3]	A combination of reflectance and emittance called Solar Reflectance Index (SRI), which needs to be calculated. SRI is required to be greater than 78 for low slope roof and 29 for steep slope roof for 75 percent of the roof area for new construction. To qualify as cool, LEED requires roofs to meet U.S. EPA ENERGY STAR requirements for solar reflectance as well as a requirement for an emittance of 0.90.	

(1) Whole Building Design Guide, http://www.wbdg.org/resources/coolmetalroofing.php
(2) ENERGY STAR website, http://www.energystar.org
(3) USGBC LEED for New Construction and Major Renovations Reference Guide Version 2.2

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3. *Twelve and 37 months after data collection started (March 21, 2005 and April 22, 2007)*

Consistent with the trend at seven months, the black membrane was still the warmest membrane with peak temperature at 146ºF (63ºC). The paver system and the 24 lb/ft² (117 kg/m²) ballasted system continued to be 9ºF (-13ºC) cooler than the white membrane. The 17 lb/ft² (83 kg/m²) ballasted system now had a cooler temperature than the white membrane (1ºF [-17ºC] cooler). The heat flux trends and peak delay duplicated the temperature trends.

At 37 months, the conclusions drawn from one year were still true. As the white membrane aged, its solar reflectance continued to drop, while little change was anticipated for the ballasted systems. Since these roofing systems are expected to have a service life in excess of 10 years, the performance for the ballasted roof systems is expected to continue to exceed that of the white membrane system for over 90 percent of their service lives. See Figure 1 for more details.

Building Energy Code Compliance

Based on this study, ASHRAE 90.1-2007 Addendum recognized a ballasted roof as a type of cool roof in addition to the traditional types of cool roofs defined by reflectivity and Solar Reflectance Index. The ASHRAE 90.1-2007 Addendum wording in Section 5.5.3.1.2 Cool Roof is as follows:

"Exceptions to 5.5.3.1.2:

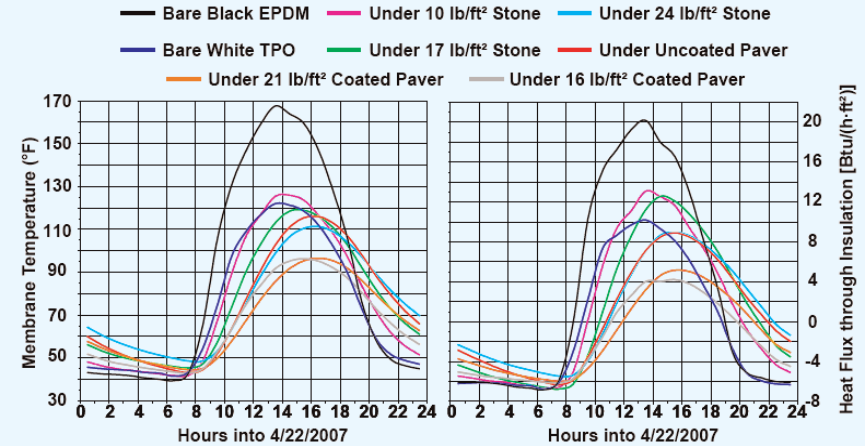
1. Ballasted Roofs with a minimum stone ballast of 17 lb/ft² (83 kg/m²) or 23 lb/ft² (117 kg/m²) pavers …"

Additional code bodies are being asked to consider adding this provision in the roofing section.

Conclusions

- The cooling loads for the heavy (24 lb/ft² [117 kg/m²]) and medium (17 lb/ft² [83 kg/m²]) stone ballasted and uncoated-paver ballasted system (24 lb/ft² [117 kg/m²]) were approximately the same for the white membrane system.
- Cooling loads for the lightweight stone (10 lb/ft² [49 kg/m²]) system were slightly larger than for the white membrane system but significantly less than for the black membrane system.
- The white membrane system showed significant effects of weathering. Maintenance and cleaning to keep the white membrane at its initial reflectivity is key to long-term performance of the white membrane system.

Figure 1



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- The membrane temperature for the 24 lb/ft^2 (117 kg/m^2) ballasted roof system as well as the same density paver system was lower than the white TPO membrane starting from seven months after installation.
- The membrane temperature for the 17 lb/ft^2 (83 kg/m^2) ballasted roof system was lower than the white TPO membrane starting from 12 months after installation.
- The black membrane had the highest temperature among all the roof types throughout the entire research period.
- Ballasted systems have the additional benefit of further reducing energy demand requirements due to thermal mass effects. The thermal mass effects also delayed peak temperature.
- ASHRAE 90.1-2007 Addendum recognizes a ballasted roof as a type of cool roof.

Overall, the research study results indicate that the ballasted systems performed at the same or better level of thermal performance compared to the rated ENERGY STAR cool roof products such as the white TPO membrane used in the study. If a typical service life of a roof is 10 years, the ballast/paver roof systems with a minimum density of 17 lb/ft^2 (83 kg/m^2) is expected to perform better than the white membrane for 90 percent of the roof's service life.

References

1. Cool Roof Rating Council, http://www.coolroofs.org
2. "Evaluating the Energy Performance of Ballasted Roof Systems," ORNL Report Number UF-04-396, prepared for Single Ply Roofing Industry (SPRI), by Andre Desjarlais, Thomas Petrie and Jerald Atchley from Building Envelope Program, Oak Ridge National Laboratory, Richard Gillenwater, Carlisle Syntec, Inc. and David Roodvoets, SPRI, Inc., April 2008

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THE DOW CHEMICAL COMPANY . Dow Building Solutions . 200 Larkin . Midland, MI 48674
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