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Innovation Abounds

Sustainable Retrofit of Residential Roofs
Using Metal Roofing Panels, Thin-Film Photovoltaic Laminates and PCM Heat Sink Technology

By Jan Kosny, Kaushik Biswas, William Miller, Phillip Childs and Scott Kriner

DURING 2009-2010, RESEARCH TEAMS REPRESENTING THE Metal Construction Association, the largest North American trade association representing metal building manufacturers, builders and material suppliers; CertainTeed, one of the largest U.S. manufacturers of thermal insulation and building envelope materials; Unisolar, the largest U.S. producer of amorphous silicone photovoltaic (PV) laminates; Phase Change Energy, a manufacturer of bio-based phase change materials (PCMs); Oak Ridge National Laboratory (ORNL); and the Fraunhofer Center for Sustainable Energy Systems (CSE), which joined the team in 2010, analyzed three experimental attics utilizing different roof retrofit strategies. The attics were located in the climatic conditions of east Tennessee.

The main goal of this project was the experimental evaluation of PV-PCM roofs, a newly-developed sustainable re-roofing technology that consists of metal panels integrated with amorphous silicone PV laminates and PCM heat sink. Collected experimental results indicate that PV-PCM roofs acted as a passive solar collector during the winter, with the PCM storing solar heat throughout the day and increasing the overall attic air temperature at night. This could reduce technology heating loads.

INTRODUCTION

According to the National Association of Home Builders (NAHB), asphalt shingles are the most common type of roofing material used in the United States, both in new home construction and re-roofing, accounting for over 60 percent of the residential roofing market. Asphalt roofs generally last from 12 to 20 years and then they are either replaced or old shingles are covered with new ones. Re-roofing generates an estimated 6.8 million tons of waste asphalt shingles each year, equivalent to nearly 3 percent of municipal solid waste (www.smartgrowth.org/library/waste_mngmt_update_2.html).

One of the biggest environmental drawbacks to re-roofing is that old shingles require large disposal areas that pollute the environment over time (Townsend et al., 2007; Sengoz and Topal, 2005). Recycling and processing waste asphalt shingles into other materials, such as asphalt pavements (Decker, 2002; Sengoz and Topal, 2005), has been gaining momentum in recent years. However, other practices need to be explored to further conserve landfill space. The experimental re-roofing techniques presented here are intended to be installed directly on top of the existing asphalt shingles, precluding the need for recycling or disposal to landfills.

During the summer of 2009, three test attics were built at the ORNL Field Exposure Testing Facility in order to evaluate a new sustainable method of re-roofing utilizing metal panels, PV laminates and PCM heat sinks. The first test attic represented the traditional retrofit, where the old roofing materials were totally removed and replaced with a new cover (FIGURE 1). Next, the project team constructed two additional test attics utilizing roof-over-the-roof retrofit technologies.

Figure 1. Cleaning the old shingle roof.

In the first case, metal roofing panels were installed directly on top of the existing roof shingles without removal of the old materials. The new metal roof, utilizing cool roof coating technology, will be referred to in this paper as infrared-reflective roofs (IRR). The two radiative properties that characterize cool roofs are solar reflectance and thermal emittance. A cool roof minimizes the solar heat gain of a building by first reflecting a large part of the incoming radiation and then by quickly emitting the absorbed portion. As a result, during the summer months, cool roofs show lower temperatures than traditional roofs of similar construction, reducing overall building cooling energy loads.

In the second case, which will be referred to as PV-PCM, metal roof panels with pre-installed amorphous silicone PV laminates were mounted directly on top of the old shingles (FIGURE 2).

Figure 2. Installation of PCM cells topped with reflective foil-faced fiberglass and roofing panels.

In order to minimize the thermal stresses generated during sunny days by the PV laminate, internal heat sinks with air ventilation channels were used. A bio-based phase change material (PCM) of melting point 84.2°F (29°C) and total enthalpy between 180 and 190 Joules/gram was utilized for this roof assembly. FIGURE 3 shows the results of the differential scanning calorimeter

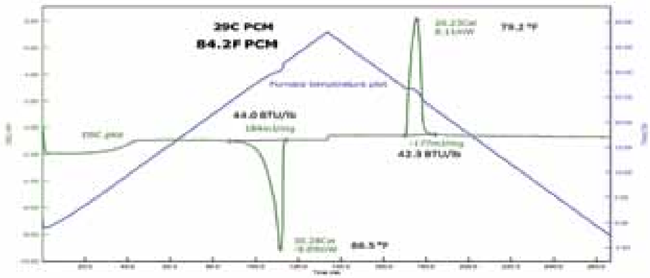

Figure 3. Differential scanning calorimeter (DSC) test data.

(DSC) tests for this material. The PCM was macro-packaged in between two layers of heavy-duty plastic foil forming arrays of PCM cells **(FIGURE 2)**.

In PV laminates sunlight is converted into electricity and heat simultaneously (Van Helden and Zondag, 2002). In building integrated applications, the relatively high solar absorption of amorphous silicone laminates can be utilized during the winter for solar heating purposes with PCM providing heat storage capacity. This could decrease heating loads in the southern U.S. because roof temperatures in this region can easily exceed 86°F (30°C) during winter months (Miller and Kosny, 2007; Kosny et al., 2007). By the same token, PV laminates may also increase building cooling loads during summer. To lessen this effect, the PCM cells were covered with a .78 inch (2 cm) thick layer of high-density fiberglass insulation that had a reflective surface on top. Moreover, air channels were included between the PCM cells and above the fiberglass insulation to promote natural air ventilation over the roof deck, which could help reduce the attic-generated cooling loads **(FIGURE 4)**.

Figure 4. The location of the PCM heat sink directly on top of the old roofing material with air channels between the PCM cells and above the fiberglass insulation.

WINTER TEST RESULTS

The thermal performance of the three test attics were simultaneously monitored during four winter months between 2009 and 2010. Tests were continued during the summer of 2010.

The left-hand side of **FIGURE 5** shows a photograph of three test attics. The right-hand side contains a diagram showing the locations of measure sensors and basic heat fluxes for the IRR test attic. All three test attics had the same configurations of measure sensors.

FIGURE 6 shows roof temperature profiles for each of the tested assemblies. From the roof energy performance stand-point, internal attic air temperature and attic floor heat flow are the most important performance control factors. The higher the average attic air temperature during the winter time, the lower the attic heat losses.

Figure 5. Three test attics, from the left: shingle roof, IRR roof and PV roof followed with the test diagram of the IRR test attic.

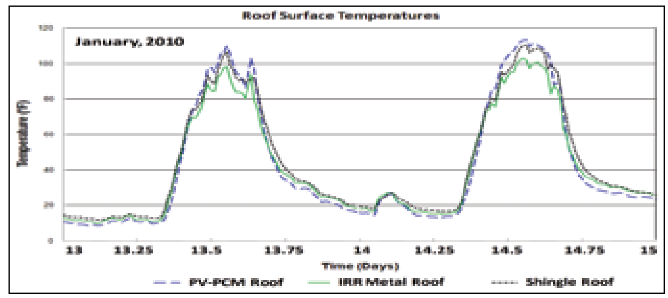

Figure 6. Roof surface temperatures recorded during two sunny days of January 2010.

Initially, it was expected that the increased R-value of the PV-PCM roof (due to the combined thermal resistance of the fiberglass with reflective surface, PCM and two air cavities) would dominate its energy performance during the winter because the PCM was designed to work primarily during the summer and mid-season months. However, the measured roof surface temperatures shown in **FIGURE 6** demonstrate that PCM, with a melting point of 84.2°F (29°C) and installed just under the metal roof panel, can easily go through phase transition during winter sunny days.

FIGURE 7 shows daily fluctuations of the attic floor heat fluxes recorded during two sunny days in November 2009 and January 2010. Significant solar gains can be observed in cases of the conventional shingle and IRR attics during the day. However, during the night these two assemblies showed about 50 to 80 percent higher heat loss compared to the PV-PCM attic. This is due to the combined effect of extra insulation and PCM latent heat released during the night. The approximately three-hour lag time observed

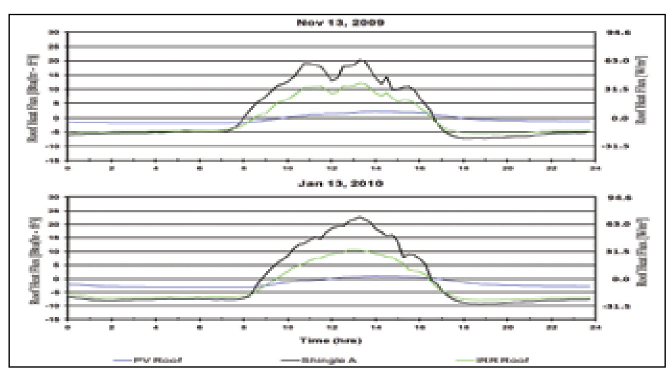

Figure 7. Attic floor heat flux profiles recorded during late fall and winter sunny days.

in the PV-PCM attic is evidence that the phase change material worked as intended. FIGURE 8 confirms these findings.

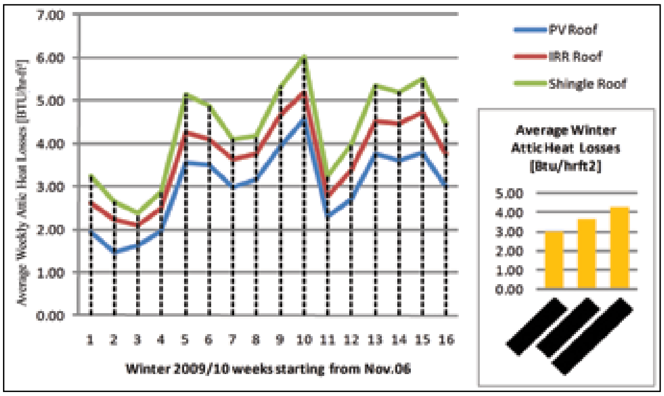

Figure 8. Average weekly attic floor heat losses recorded during the winter season 2009-2010.

In the IRR and PV-PCM roofs, the new metal panels were installed directly on top of the existing structures; therefore, the old shingles enhanced thermal as well as moisture protection. In addition, the materials added to the underside of the metal panels (for example, fiberglass insulation, air cavities and PCM) provided extra thermal insulation and heat capacity to the PV-PCM roof. As a result, the IRR and PV-PCM roofs had average weekly attic heat losses that were about 18 and 30 percent lower than those from the conventional attic with shingles, respectively (FIGURE 8). Due to the lower heat losses, the average weekly attic air temperatures of the IRR and PV-PCM assemblies were higher than in the attic covered with shingles by about 3.5°F and 8°F (2°C and 4°C), respectively (FIGURE 9).

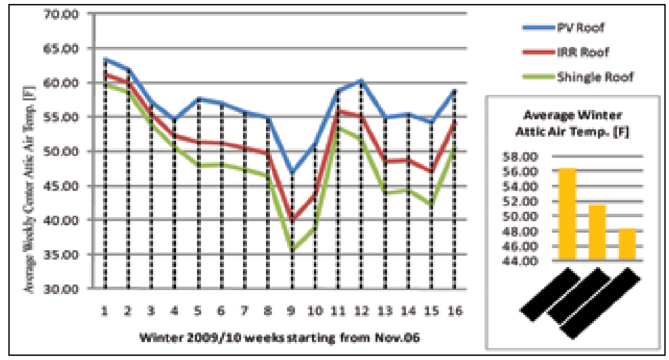

Figure 9. Average weekly attic air temperatures recorded during the winter season 2009-2010.

SUMMARY

The first test attic represented the traditional way of roof retrofitting, where the old roofing materials are totally removed, disposed of and replaced with new roof shingles. The two other attics utilized roof-over-the-roof technologies. In both cases, metal panels were installed directly over the existing roofs without a need for removal of the old materials. In the case of the third test attic, roof-integrated PV laminate and PCM heat sink were utilized as well. The test data demonstrated that roof-over-the-roof re-roofing

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can be a very effective way of not only refurbishing the old roofing surface but also improving the energy performance of existing roofs. PV-PCM attics had average winter heat losses that were 30 percent lower than those from conventional attics covered with shingles. Moreover, traditional shingle roofs showed heat losses that were 80 percent higher than those from PVC-PCM roofs at night.

The presented test results show that re-roofing using metal panels with PV technology and PCM heat sink can be a very effective way of repairing existing roofs without generating solid waste in the future. This new sustainable way of re-roofing not only improves the overall performance of existing roofs, it will generate inexpensive solar electricity. ■

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A full list of references for this article is available upon request. Please email ssavory@matrixgroupinc.net.

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to great upcoming presentations in the future.

New this year, we are broadcasting live video of our presentations over the internet. Our meetings are held on the first Tuesday of each month from 12:00 pm to 1:30 pm (Pacific Time). We invite everyone to join in via the web during our meetings at http://pdx.uoregon.edu.

ST. LOUIS

By Michael Zensen, Cannon Design

BEC-St. Louis offered a program on envelope testing in October 2010, which was hosted by the Masonry Institute of St. Louis. The program was presented in three parts: an introduction to testing methodologies, a case study project and a panel discussion about the challenges of testing. Many thanks go to Tod Huddleston of Edward Jones for bringing an owner's perspective on the cost/value of testing, Gary Atkins of McCarthy Construction and John Emert of Arcturis for their willingness to present the *Edward Jones Case Study*.

This program uniquely touched every one of our membership constituencies, including designers, engineers, owners, product representatives, contractors and subcontractors.

The focus for 2011 is on *Integrated Mechanical, Envelope and Energy Analysis.* A calendar of programs is posted at our website, www.bec-stl.org. We have also created a region-wide continuing education calendar in an effort to fulfill our exchange and connection mission. We are in the post-production of webinars of our programs and some are already available on our website. ■