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

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ABSTRACT

During September-October 2009, research teams representing 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 (largest U.S. producer of amorphous silicone photo-voltaic (PV) laminates), Phase Change Energy (manufacturer of bio-based PCM), and Oak Ridge National Laboratory (ORNL) installed three experimental attics utilizing different roof retrofit strategies in the ORNL campus. The main goal of this project was experimental evaluation of a newly-developed sustainable re-roofing technology utilizing amorphous silicone PV laminates integrated with metal roof and PCM heat sink. The experimental attic with PV laminate was expected to work during the winter time as a passive solar collector with PCM storing solar heat, absorbed during the day, and increasing overall attic air temperature during the night.

INTRODUCTION

According to the National Home Builders Association (NAHB) in the U.S. the asphalt shingles are the most common type of roofing material used in both new home construction and reroofing, accounting for over 60% of the residential roofing market. Asphalt roofs generally last from 12 to 20 years and then require replacement or recovery. In the U.S., reroofing generates an estimated 6.8 million tons of waste asphalt shingles each year- equivalent to nearly 3% of municipal solid waste.

One of the biggest environmental drawbacks to re-shingling a roof is disposing of the old materials. The old shingles require large disposal areas and pollute the environment in time (Townsend et.al 2007, Sengoz and Topal, 2005). The practice of recycling waste asphalt shingles has gained momentum in recent years. Cited benefits of recycling asphalt shingles include the marketability of materials that can use processed asphalt shingles as a component and the conservation of landfill airspace. The role of recycled roofing shingle as an ingredient in hot mix asphalt pavements has been considered as well (Decker, 2002; Sengoz and Topal, 2005). The experimental attics presented here are designed for installation directly on top of the existing asphalt shingles, precluding the need for recycling or disposal to landfills.

Three test attics were constructed in order to evaluate a new sustainable method of re-roofing utilizing PV laminates, metal roofing panels, and PCM heat sink. The first test attic represented traditional roof retrofit, where the old roofing materials are totally removed and replaced with a new cover – see Figure 1. Next, the project team constructed two additional test attics utilizing roof-over-the-roof retrofit technologies.

Figure 1. Cleaning of the old shingle roof and removal of old roofing materials.

In the first case, metal roofing panels were installed directly on top of the existing shingle roof without removal of old materials. The new metal roof utilized cool-roof coating technology. 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 incoming radiation and then by quickly re-emitting the remaining absorbed portion. As a result, during the summer months, the cool roof stays cooler than a traditional roof of similar construction, reducing overall building cooling energy loads. That is why, in the following thermal performance charts this roof is marked as infrared-reflective (IRR) roof.

In the second case, metal roof panels with pre-installed amorphous silicone PV laminates were installed directly on top of the old roof - see Figure 2. In order to minimize thermal stress generated during sunny days by the PV laminate, internal heat sink combined with air ventilation channels were used. The bio-based phase change material (PCM) of melting point 29°C (84.2°F) and total enthalpy between 180 and 190 J/g was utilized for this roof assembly. As shown in Figure 2, the PCM was macro-packaged in between two layers of heavy-duty plastic foil forming arrays of PCM cells.

Figure 2. Installation of the PCM heat sink with reflective fiberglass insulation followed by metal roofing panels containing pre-installed PV laminates.

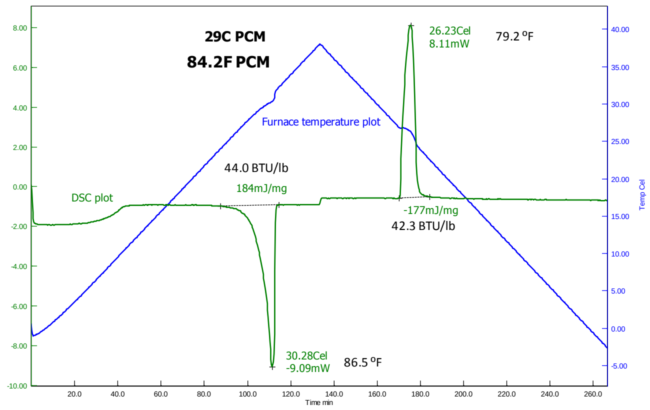

Figure 3. DSC test data for PCM used in attic experiments.

In PV laminates sunlight is converted into electricity and heat simultaneous [Van Helden W.G.J. & Zondag H.A. 2002]. In case of building integrated applications, a relatively high solar absorption of amorphous silicone laminates can be utilized during the winter for solar heating purposes with PCM providing necessary heat storage capacity. However, PV laminates may also generate increased building cooling loads during the cooling season. That is why in this project the PCM heat sink was designed in a special way in order to minimize summer heat gains as well.

Figure 3 shows results of the differential scanning calorimeter (DSC) tests for this material. As shown in Figure 4, from the top, the PCM was covered by about 2-cm. thick layer of high-density fiberglass insulation with a reflective surface on top. Two air cavities, between PCM cells and above the fiberglass insulation, helped the over-the-deck natural air ventilation. It is anticipated that during summer months, this extra ventilation capability will help in reducing the attic-generated cooling loads.

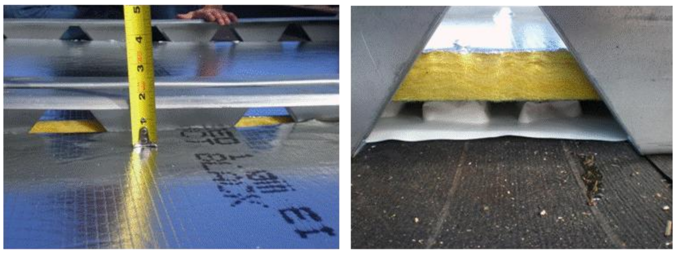

Figure 4. Location of the PCM heat sink directly on top of the old roofing material with air channels above and below the fiber glass insulation.

During winter months of 2009/2010, all three test attics were field tested at the ORNL Field Exposure Testing Facility and their thermal performances were compared. Since in southern U.S, roof surface temperatures can easily exceed 30°C (86°F) during winter months [Miller & Kośny 2007, Kośny et al. 2007], it was expected that the PCM heat sink may be at least partly useful during the heating season.

WINTER FIELD TESTING RESULTS -2009/10

During summer 2009, three experimental attics utilizing roof retrofit technologies were installed at the ORNL Field Exposure Testing Facility. Thermal performances of three test attics were monitored during four months of winter 2009/2010. Thermal performances of these test attics were monitored and experimental data for each of the test assemblies were compared. Attic tests will be continued during the summer of 2010.

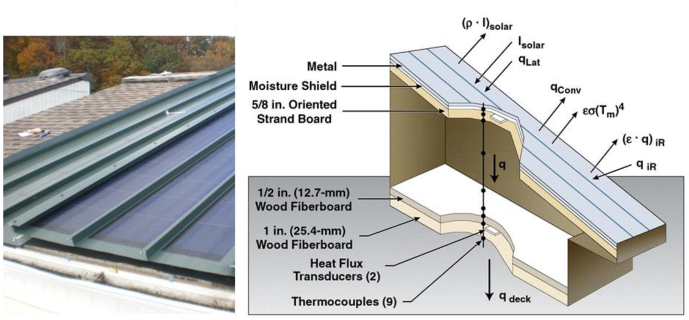

Figure 5. Three test attics – from the left; shingle roof, IRR roof, and PV roof followed with the test diagram of the IRR roof attic

As shown on Figure 5, for each of the test attics detailed temperature profiles were recorded and heat flux measurements took place. 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 winter time, the lower the attic heat losses.

Initially it was expected that the major winter energy performance improvement in case of the solar roof using PCM heat sink would come from the increased R-value of the top of the roof (due to combined thermal resistance of the fibreglass with reflective surface, PCM, and two air cavities). PCM was designed to work mostly during the summer and mid-season months. However, the temperature measurements demonstrated that PCM with 29°C melting point, installed just under the roof surface, can easily go through the phase transitions during the winter sunny days – see Figure 6.

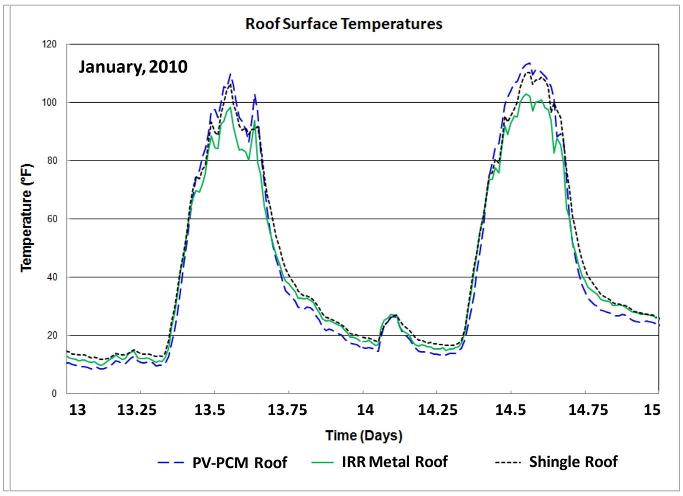

Figure 6. Roof surface temperatures recorded during two sunny days of January 2010.

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. However, during the night time these two attics show about 50% to 80% higher heat losses compared to the PV attic with the PCM-heat sink. It is a combined effect of extra insulation and PCM latent heat release during the night. About 3 hour lag time in case of the PV attic is evidence that PCM really worked during these days.

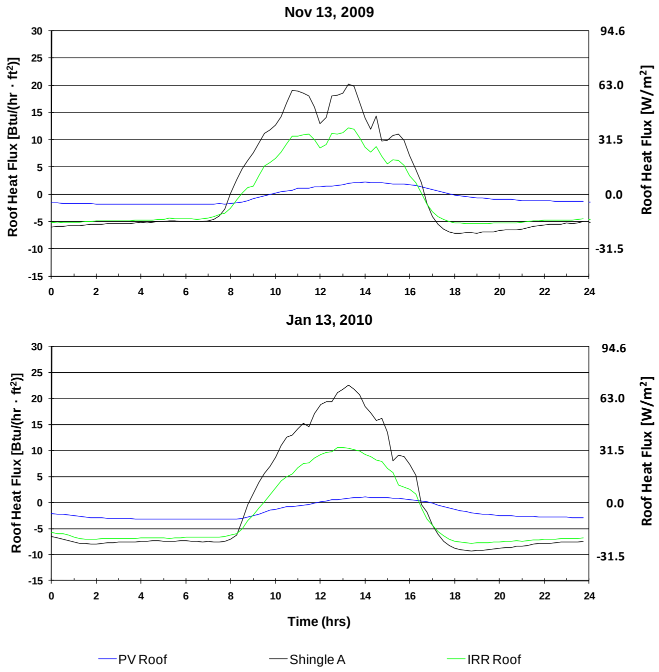

Figure 7. Attic floor heat flux profiles recorded during late fall and winter sunny days.

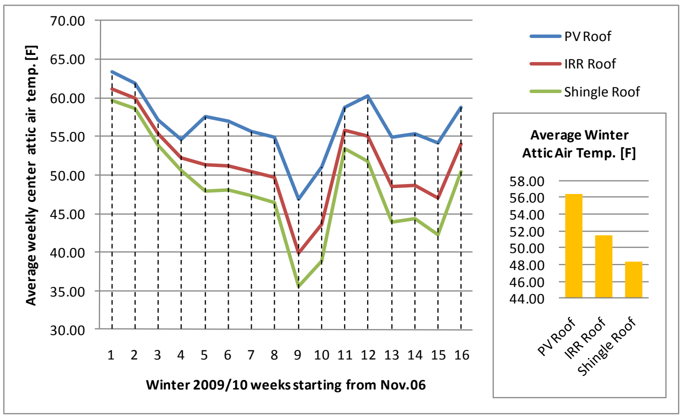

Figure 8. Average weekly attic air temperatures recorded during the winter season 2009/10.

Figure 8 confirms the above findings. It depicts recorded average weekly attic air temperatures. In both test attics where new metal roofs were installed directly on top of the existing structures, the old materials were utilized as free (since already existing) enhancement of moisture and thermal protection. In addition, in case of the PV attic with the PCM heat sink, 2-cm thick layer of fiber glass insulation, reflective surface, and two air cavities were utilized as extra thermal insulation. As a result, average winter attic air temperatures of the IRR and PV attics were higher than the shingle attic air by about 3.5°F and 8°F, respectively.

Figure 9 depicts recorded average weekly attic heat losses. It can be observed that an average winter 2010 IRR attic and PV attic heat losses are about 18% and 30% lower, respectively - compared to the conventional shingle attic.

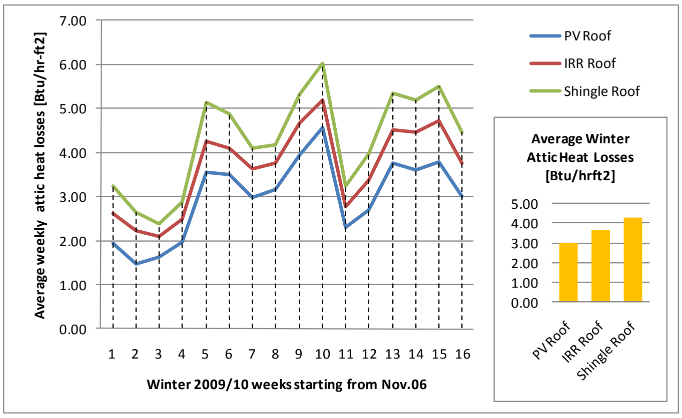

Figure 9. Average weekly attic floor heat losses recorded during the winter season 2009/10.

SUMMARY

During early fall 2009 three experimental attics utilizing different roof retrofit technologies were constructed at the ORNL Field Exposure Testing Facility. In this paper only initial winter experimental results are presented. Attic tests will be continued during the summer 2010 in order to fully investigate PCM energy performance.

The first test attic represented the traditional way of roof retrofit, where the old roofing materials are totally removed, disposed at the land fields, and replaced with a new roof cover. The two other attics utilized roof-over-the-roof technologies. In both cases metal roofs were installed directly over the existing roofs without a need for removal of the old materials. In 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 reroofing can be a very effective way of not only refurbishing of the old aged roofing surface, but also improving energy performance of existing roofs. In case of the PV attic with the PCM heat sink, about 30% reduction of average winter heat losses were recorded comparing to the conventional shingle attic. During the winter nights the same heat losses were reduced up to 80%.

Presented test results show that reroofing using metal roof and PV technology with the PCM heat sink can be a very effective way of repairing of the existing roofs without generating solid waste in the future. This new sustainable way of reroofing not only improves overall performance of existing roofs but in addition will generate inexpensive solar electricity.

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REFERENCES

T. Townsend, J. Powell, X. Chad 2007 "Environmental Issues Associated With Asphalt Shingle Recycling" – report prepared for Construction Materials Recycling Association Asphalt Shingle Recycling Project, US EPA Innovations Workgroup by Innovative Waste Consulting Services, LLC Gainesville, Florida - October 19, 2007.

B. Sengoz, A. Topal, 2005, "Use of Asphalt Roofing Shingle Waste in HMA," Construction and Building Materials, vol. 19, no. 5, p 337-346.

D. S. Decker, 2002, "The Road to Shingle Recycling," Recycling Today, vol. 40, no. 9, p 28-32.

W.G.J. Van Helden, H.A., Zondag 2002. "Photovoltaic Thermal Panels: On the Brick of Demonstration"- Proceedings of PV in Europe – From PV Technology to Energy Solutions, Conference and Exhibition, October 2002, Rome, Italy.

W. A. Miller and J. Kośny, 2007. "Next-Generation Roofs and Attics for Residential Homes," in Proceedings of the 2007 ACEEE Summer Studies on Energy Efficiency, August 2007.

J. Kośny, D. Yarbrough, W. A. Miller, T. W. Petrie, P. W. Childs, and A. Syed 2007. "Thermal Performance of PCM-Enhanced Building Envelope Systems," presented at Thermal Envelopes X Conference, December 2007.