Field Testing of Second-Generation Residential Attic Using Inorganic PCM Thermal Storage

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Background

The DOE Building Technologies (BT) Program has targeted the strategic goal of developing the next generation of building envelope systems, with the ultimate objective of reducing the space conditioning requirements attributable to attics by 50% compared to Building America (BA) regional baseline new construction. During 2005/06 computer modeling and dynamic lab and field experiments lead to a new paradigm for designing thermally active building envelopes. To meet BT's goal, Oak Ridge National Lab's Building Envelope Program (BEP) has worked with several industries, universities, and collaborated with a sister national laboratory to merge key technologies into prototype components for building envelopes.

Since residential attics are subjected to greater temperature extremes than any other component of the building envelope, the first field experiments were conducted on new and unique attic material configurations containing, PCM storage, reflective insulations, cool-roof surfaces, and air channels. Increasing the thermal capacitance of the attic can reduce diurnal temperature swings, and, in turn, reduce both the total energy use and peak demand in moderate and some cooling-dominant climates.

One of the first experimental modules tested during 2006/07 eliminated almost 90% of conventional attic heat gains and losses crossing the roof deck. Infrared reflective roof products, above-sheathing ventilation, thermal mass, thermal capacitance using phase change materials (PCMs) and radiant barriers were field tested to quantify attic performance. During the week of July 16th 2007, a new test roof was constructed. This roof contains increased amount of inorganic PCM (12 times higher storage capacity from the previous test roof) and improved configuration of the above-sheathing ventilation channels.

Configuration Improvements in the Second Generation of the ORNL Roof Assembly (2007)

First attic test module tested during 2006/07 had PCM thermal storage installed just above the sheathing. The ORNL team used a multilayer configuration of PCM-enhanced polyurethane foams, PCM-impregnated fabrics, and highly reflective aluminum foil. Loading of organic PCM was about 0.08 lb per ft^2 of the surface area (0.39 kg/m^2). Two types of PCMs were used. Their melting temperatures were around 78 and 90°F (26 and 32°C). The total storage capacity of the PCM was about 4.8 Btu per ft^2 (54 kJ/m^2) of the roof area. The first PCM roof used 4 in. (10-cm.) air channels to exhaust excess heat during peak irradiance (subventing). Two low-emittance membranes were placed above the roof sheathing with the low-emittance surfaces facing each other across the 4 in. air gap (description is greatly simplified). PCM storage was placed above the roof deck but below the reflective foil. Standing seam cool-painted metal roofing was used for this test assembly. Thus the thermal performance of this roof assembly represents the combined effects of reduced thermal bridging, reflective insulation, cool-roof pigments, PCM, and an attic subventing strategy.

In July 2007, a new roof assembly containing PCM thermal storage, reflective insulations, cool-roof surfaces, and air channels was installed. In the second generation of the PCM roof, the ORNL team used a multilayer configuration of bubble reflective insulation, 2-in. (5-cm) air cavity, 3/8-in. thick foil-faced foam supporting PCM storage, inorganic PCM storage, 2-in. (5-cm) air cavity, and infrared reflective painted metal roof (SR28E81). The air space adjacent the roof deck has two radiant barriers facing each other to negate almost all of the radiation heat transfer crossing the air space. The phase change material (calcium chloride hydrate) is placed in the upper air space and is contained in sealed aluminum pouches.

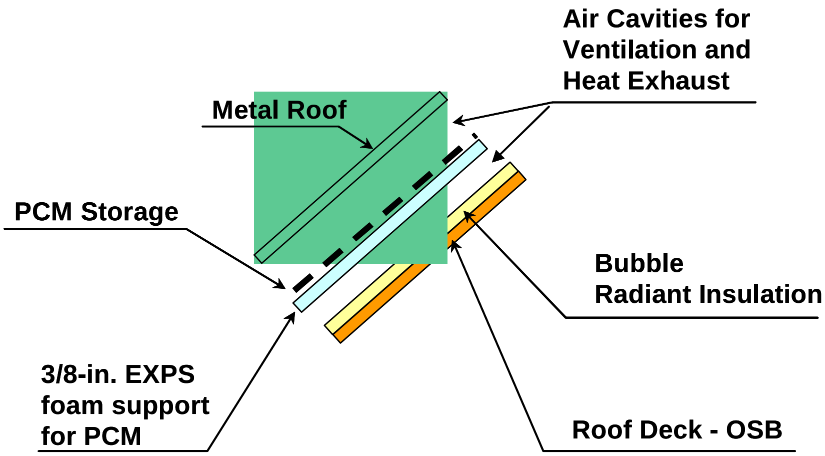

FIGURE 1. Cross-section of the second generation of the residential attic containing dynamic reflective insulation and sub-venting air channels.

PCM loading for installed in 2007 roof assembly was 12 times higher as in the roof installed in 2006. According to the manufactures information, approximate cost of the PCM packages was about $5.00 per square foot. The PCM loading was about 0.65 lb per ft^2 of the surface area (~4.5 kg/m2). The melting temperature of the PCM was around 82°F (28°C). The total storage capacity of the PCM was about 58 Btu per ft^2 (652 kJ/m2) of the roof area.

Figure 2 shows installation of the bottom reflective insulation, PCM storage, and custom spacers for installation of PCM in the roof deck.

Figure 3 shows the completed 2007 PCM roof

Preliminary Test Results for August 2007

As stated above, during the week of July 16th 2007, second generation of the PCM test roof was constructed. This roof contains 12 times more PCM storage capacity than the previous test roof built in summer 2006. The new roof assembly also contains an improved configuration of the above-sheathing ventilation channels. At this time, two separate air channels are utilized to remove heat from the PCM storage.

As presented in Figure 4, the summertime heat transfer penetrating the roof deck of the asphalt shingle conventional roof (SR093E89) reaches a peak of about 28 Btu per hr per square foot of roof deck. A conventional shingle (SR11E89) with radiant barrier attached to the underside of the sheathing (facing into attic) was used for comparison of how effective a radiant barrier facing into the attic would be as compared to the conventional roof and the roof with above-sheathing ventilation. The roof wit radiant barrier facing the attic plenum, dropped deck heat flow by about 20% - of the heat penetrating through the asphalt shingle roof (with solar reflectance 0.093). For comparison, the second generation ORNL PCM roof dropped the heat flux to less than 5 Btu per hr per square foot of roof deck for field testing at ORNL when outdoor temperatures were exceeding 95°F.

FIGURE 2. Installation of the second generation PCM attic containing dynamic reflective insulation and sub-venting air channels.

FIGURE 3. Top view of the second generation of the ORNL PCM roof. An infrared reflective painted metal roof (SR28E81) was used.

Temperature profiles for the same three roofs are depicted in Figure 5. The solid lines represent roof top surface temperatures. The dashed lines represent roof sheathing temperatures (facing attic). Roof surface temperatures were almost the same for all three roofs, with their maximums reaching 170°F, and night minimums being close to 60°F. However, temperatures of the roof sheathing (facing attic) were very different and reveal the thermal effectiveness of the roof and attic assemblies.

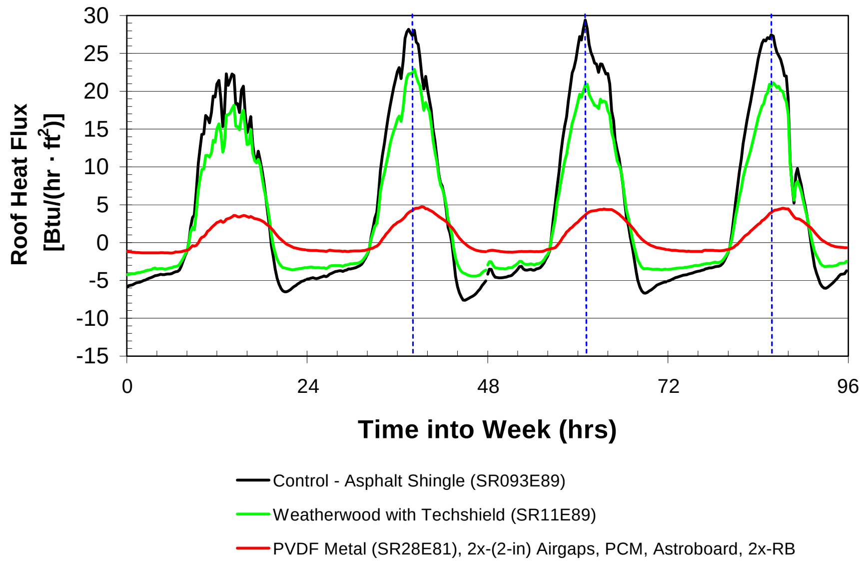

FIGURE 4. Roof heat fluxes recorded during field testing conducted in August 2007 on adjacent shed-type attic assemblies on ORNL's Envelope Systems Research Apparatus.

The maximum sheathing temperature for PCM roof was only close to 100°F, which is about 65°F lower than the maximum temperature recorded on the roof surface. The outdoor temperature was close to 95°F. Therefore, the PCM roof significantly reduced solar peak loads, making bottom temperature of the roof sheathing very close to the ambient air. The result was achieved by utilizing reflective insulation, cool roof surface, above sheathing ventilation, and PCM thermal storage.

The phase change materials caused a slight shift in peak heat flow (about 2 to 3 hours later in the afternoon) as compared to the more conventional roof and attic assemblies (Figure 5. view vertical blue dashed lines). The data also shows that the PCM is able to charge and discharging heat over the diurnal cycle even when outdoor air temperature reached highs of 100°F. It is also very important to note that the PCMs release heat back to the sky at night. The asphalt shingle roofs have the greatest night sky radiation losses, and the painted metal systems (cool roof coating) show night time heat losses that are less than that of the shingle roofs especially because of the phase change materials release of stored energy. This finding may be very useful for commercial cool roofs (for example in Northern California).

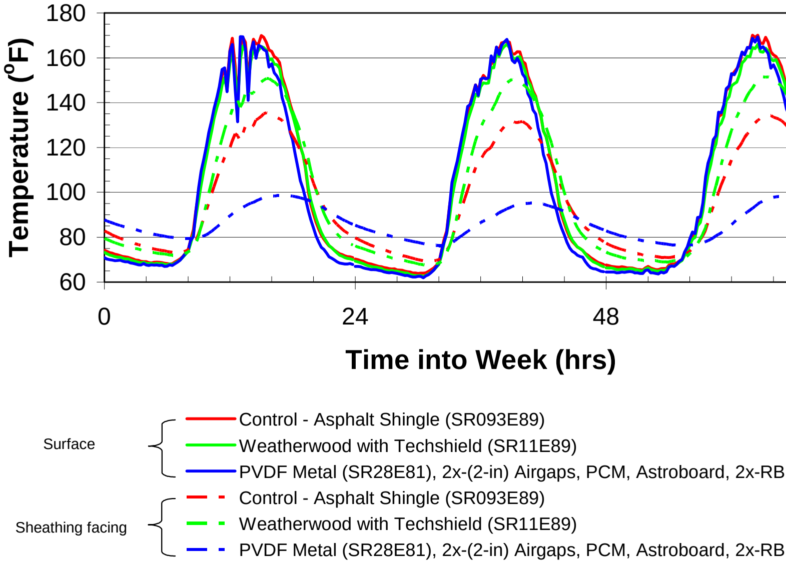

FIGURE 5. Temperature profiles recorded during field testing conducted in August 2007 on adjacent shed-type attic assemblies on ORNL's Envelope Systems Research Apparatus.

As a 2007 upgrade, the second generation prototype roof used above sheathing ventilation in two separate 2-in air spaces[1] above the sheathing providing improved heat removal from the PCM storage. During the winter season, these two air cavities will be sealed. These two cavities together with the PCM storage will work, at that time, as a solar collector. Solar energy stored during the day will be transferred to the interior of the building reducing roof-generated heating loads. During September 2007, a similar material will be installed and field-tested on the ORNL experimental wall.

Research Plans for the Second Generation ORNL PCM Roof

1. During October 2007 roof will be opened and PCM storage will be inspected for leaking.
2. In October 2007 air cavities in the PCM roof will be blocked to stop free air ventilation.
3. In April 2008 air cavities in the PCM roof will be opened again to allow natural air ventilation
4. After 122 months field testing is completed, selected PCM pouches will be sent to producer for further analysis

SUMMARY

The DOE Building Technologies (BT) Program through the Building Integration program of Building America (BA) is working to develop affordable, energy efficient and environmentally compliant Zero Energy Buildings (ZEB) by 2025. The roof tested on the ESRA (cool painted metal with two 2-in air

[1] Renegade Roof Systems, Inc. patented metal batten for ventilation above the sheathing.

spaces shows excellent performance and helps curtail building envelope energy consumption. Testing will be continued for the full twelve months period.