Performance Evaluation of an Energy-Efficient Re-roofing Technology

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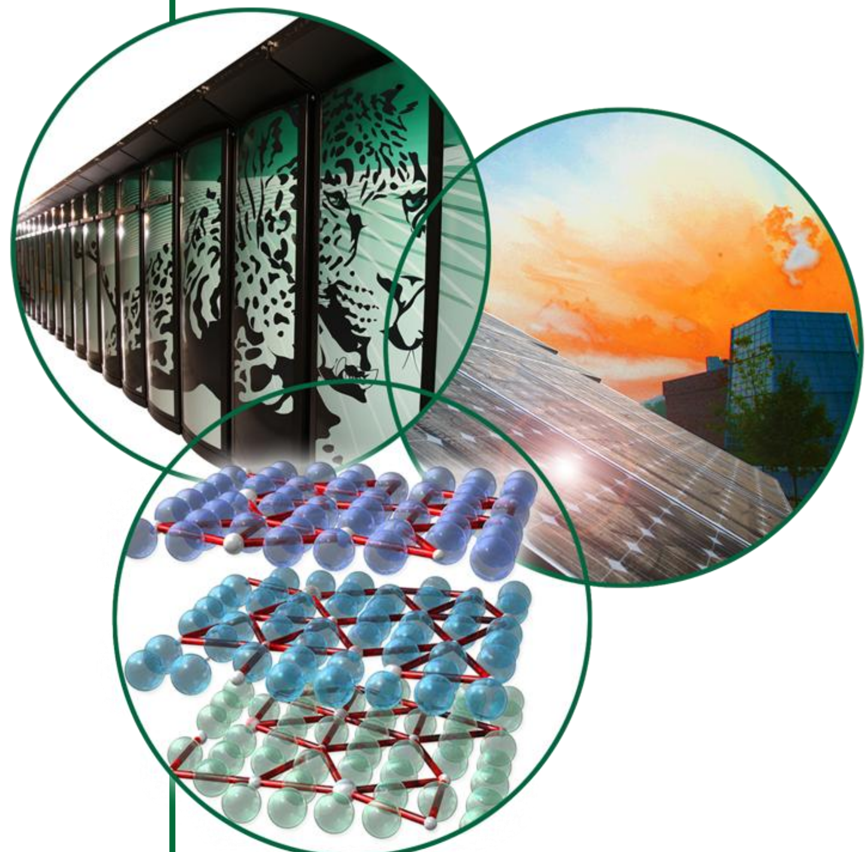
Sept 8, 2011

Washington, D.C.



U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

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Introduction: Advanced Roof System

- During Sept-Oct, 2009, an experimental roof was installed by a research team of
  - Metal Construction Association,
  - CertainTeed,
  - Uni-Solar,
  - Phase Change Energy Solutions, and
  - Oak Ridge National Laboratory (ORNL).
- Objective: Evaluate a roof system with photovoltaic (PV) laminates integrated with metal panels and phase change material (PCM).
- Field test data from Nov, 2009 to Sept, 2010 are presented.

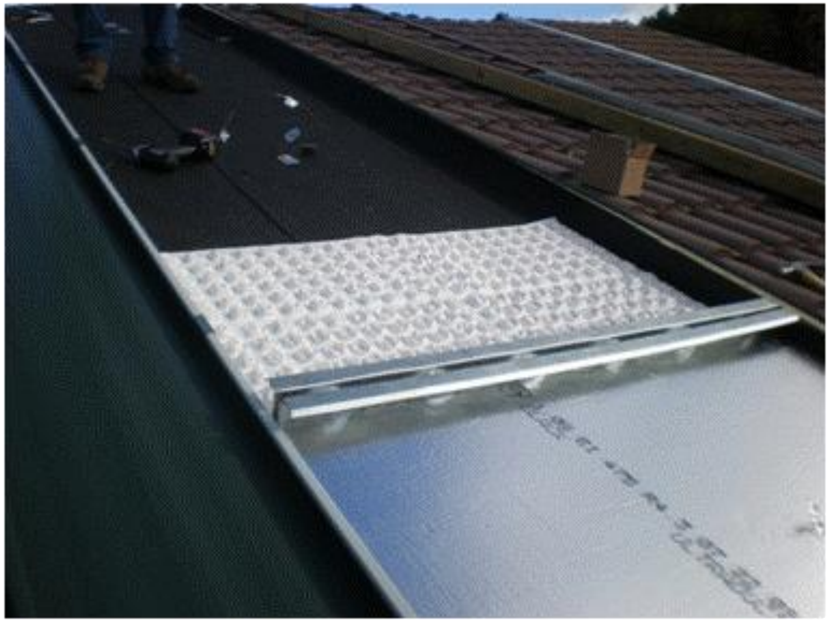
Energy-Efficient Re-roofing System

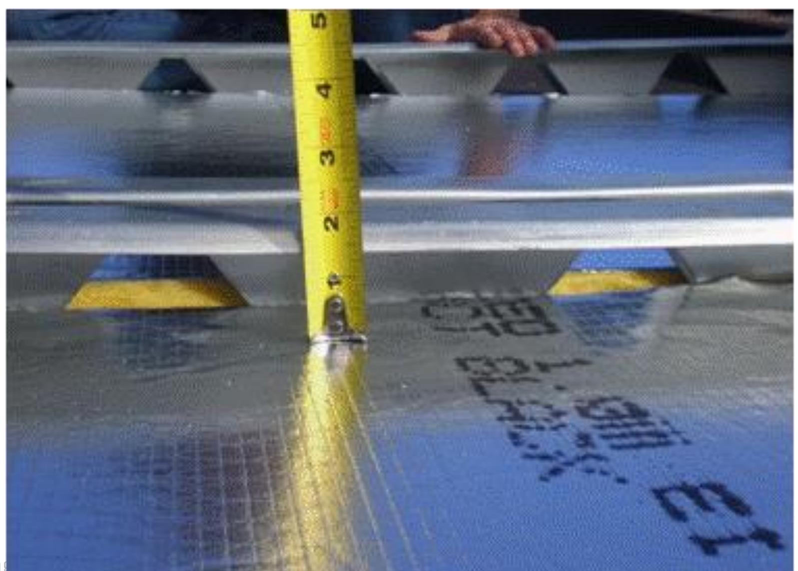
- Reduction in attic generated heating and cooling loads.
- Reduction in asphalt shingle waste generation:
  - Asphalt shingles account for over 60 percent of the residential roofing market in the U.S.
  - Reroofing generates an estimated 6.8 million tons of waste asphalt shingles each year.
  - Experimental roof designed for installation directly on top of existing shingles, precluding the need for recycling or disposal to landfills.

ORNL Envelope Systems Research Apparatus (ESRA)

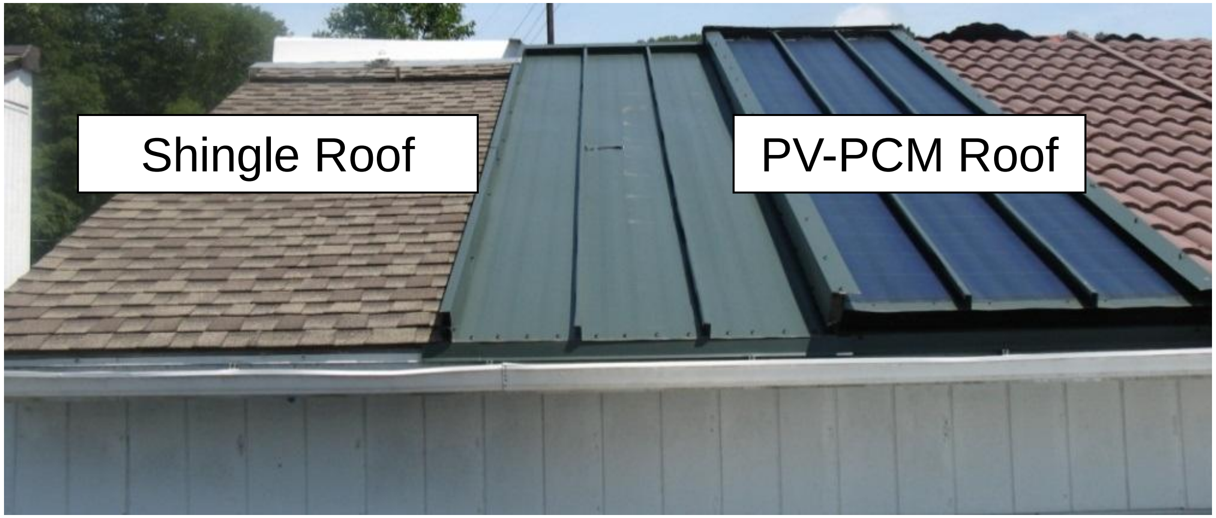
- Test attics with 18-ft by 4-ft roof modules; Built over a conditioned basement.
- Thermally isolated attics – separated by 4-in of foam insulation walls.

PV-PCM Roof Construction





PV-PCM Roof

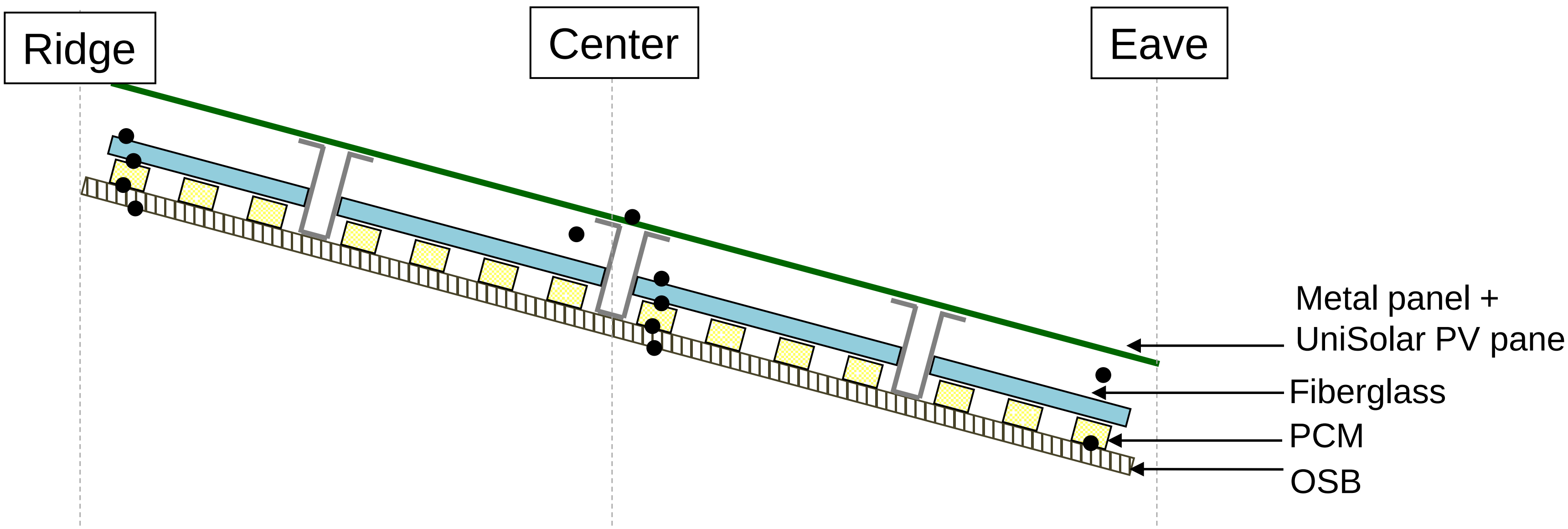


- Macro-encapsulated bio-based PCM on roof deck,
- 2-cm thick dense fiberglass insulation with foil facing,
- Metal panels with pre-installed PV laminates on top,
- Metal sub-purlins provided a 2-in air gap above fiberglass insulation for above-sheathing-ventilation (ASV), vented at both ridge and eave.
- Shingle roof used as control for comparison and evaluation of the PV-PCM roof.

Material Properties

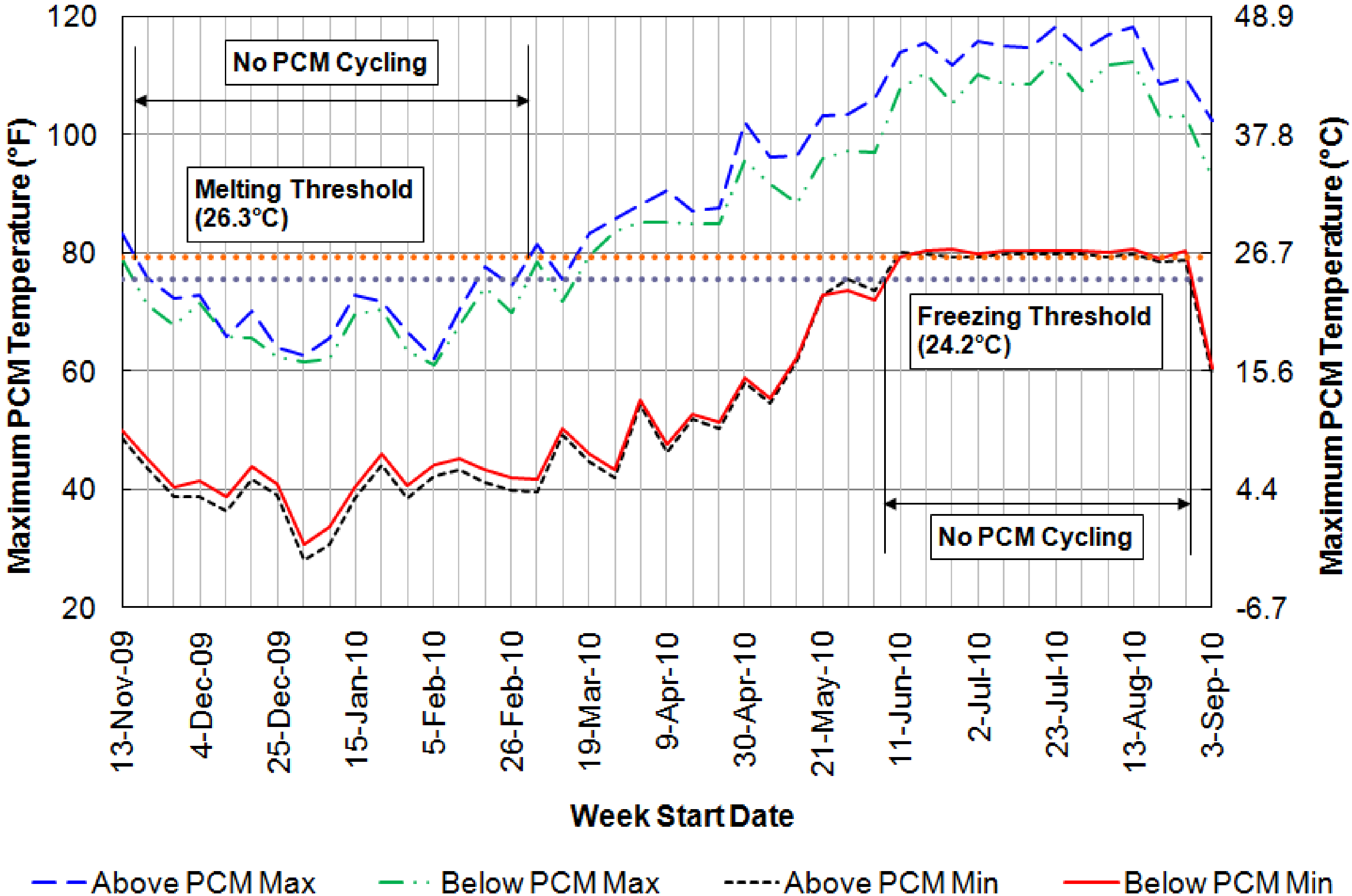
- PCM nominal phase change temperature - 29°C (84°F).
  - Threshold initiate melting - 26°C (79°F); Freezing - 24°C (76°F).
- Fiberglass R-value - 0.76 $m^2 \cdot K/W$ (4.3 $ft^2 \cdot hr. \cdot °F/Btu$).
- PVL-144 models;144 Watts (W) rated max. power; 33 V operating voltage and 4.36 A current.
- PV solar absorptance – 0.82
  - High solar heat gain advantageous in winter.
  - Higher cooling load during summer.

Data Acquisition System



- Thermocouples and heat flux transducers (HFT) located in the roof, attic and attic floor.
- On-site weather station to measure incident solar flux, ambient temperature, ambient air relative humidity, etc.

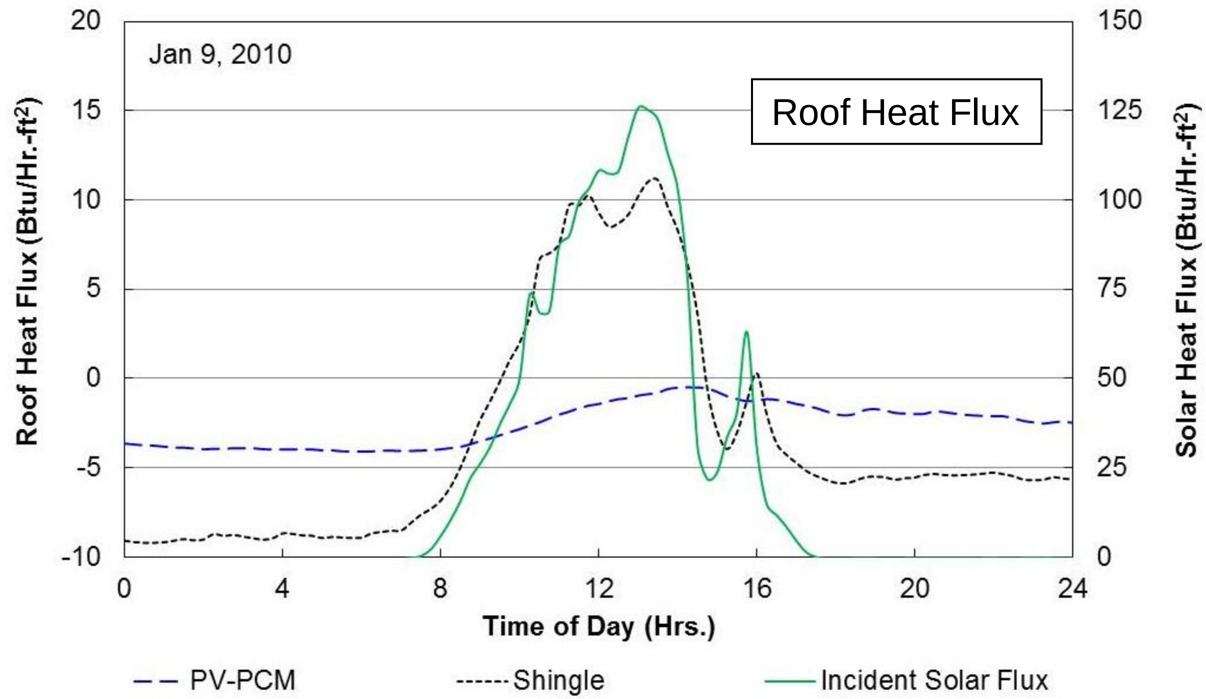
PCM Behavior

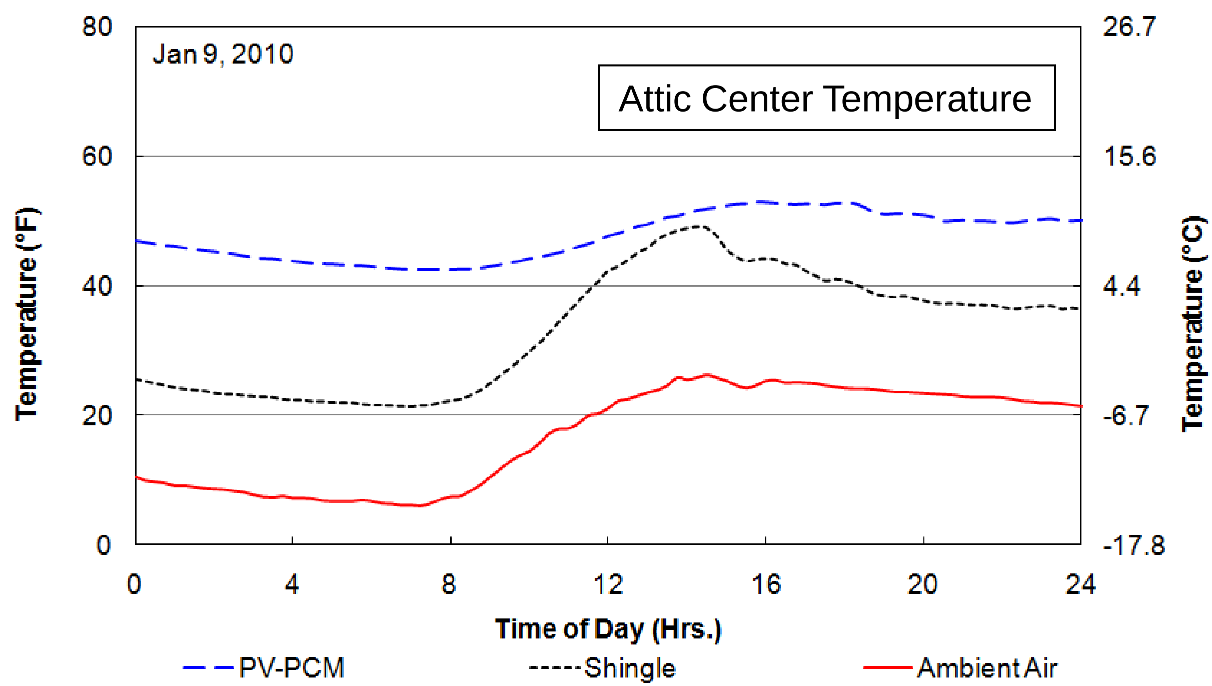


- No phase change during peak winter and peak summer.

Winter Data

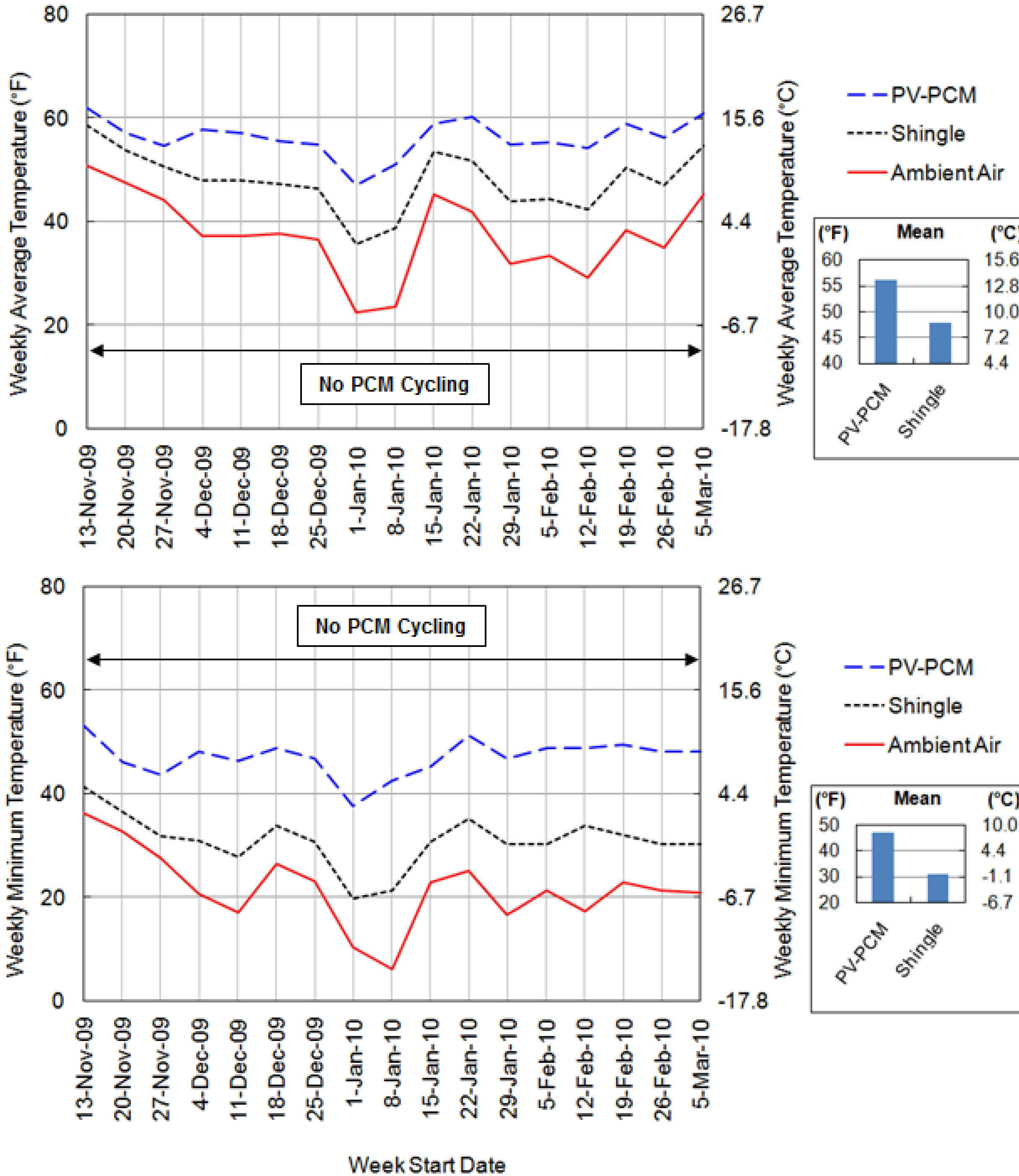
- Heat flow into the attic is positive, and vice-versa.
- Substantially lower heat flow through PV-PCM roof, and warmer attic.
- Mid-day heat addition increases the shingle attic temperature; possible heating penalty in PV-PCM.





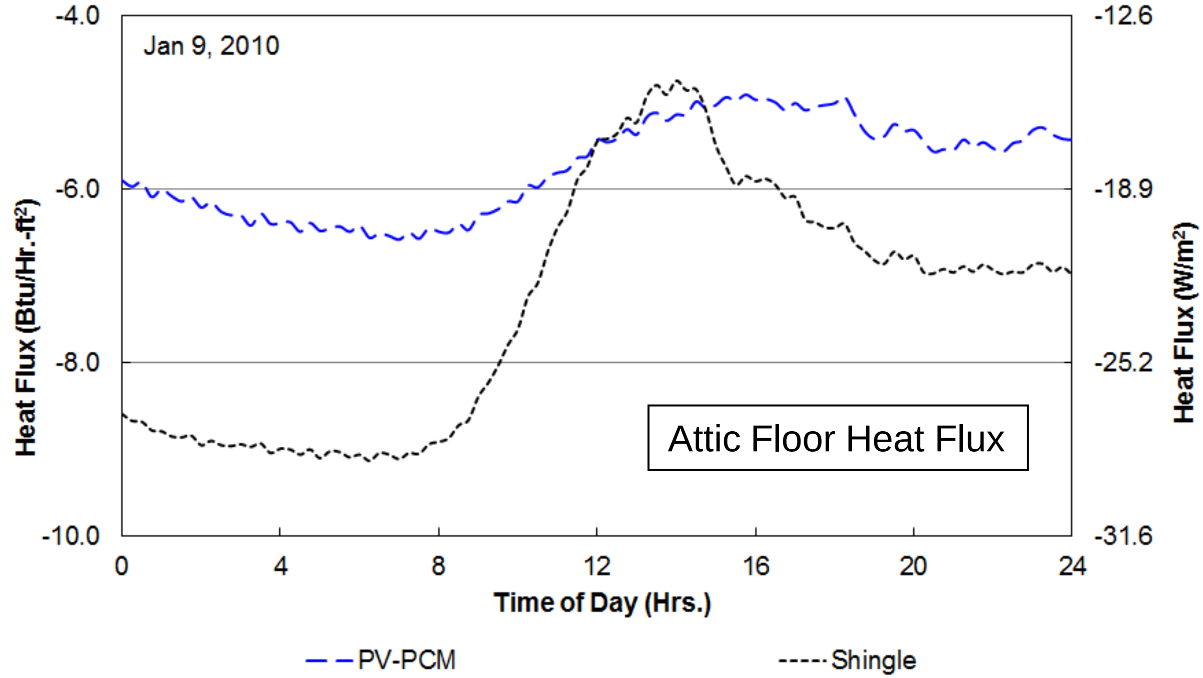
Winter Data

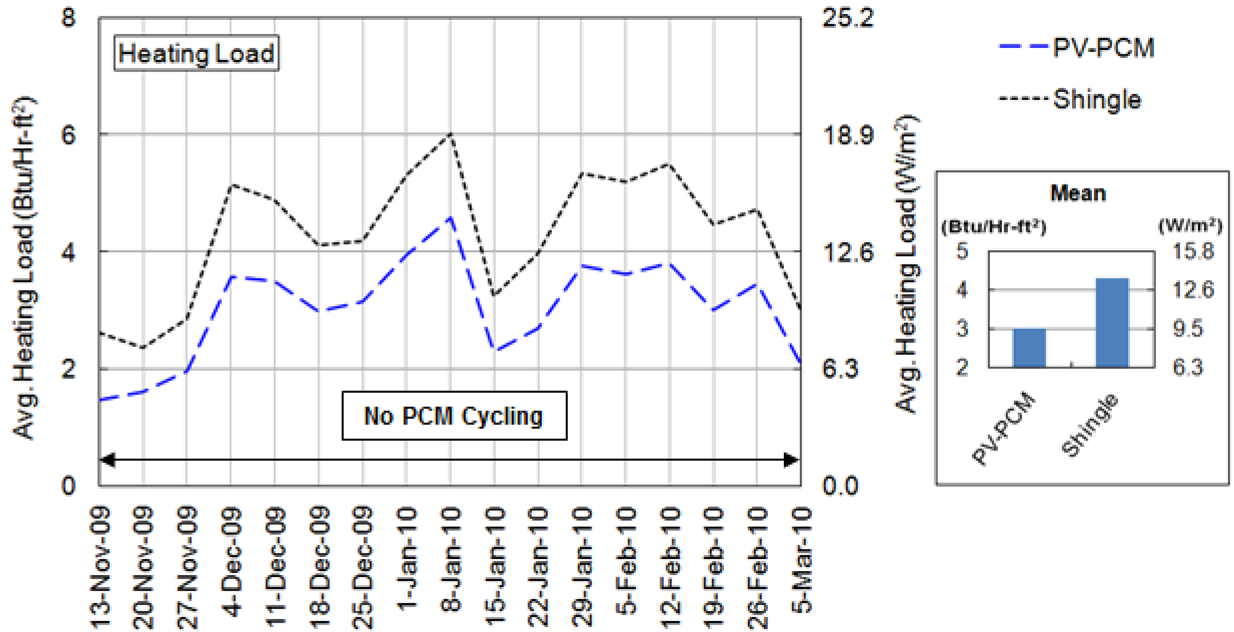
- Weekly average and minimum attic temperatures.
- Both average and minimum PV-PCM attic temperatures are higher (~ 8 & 16 ºF).



Winter Data

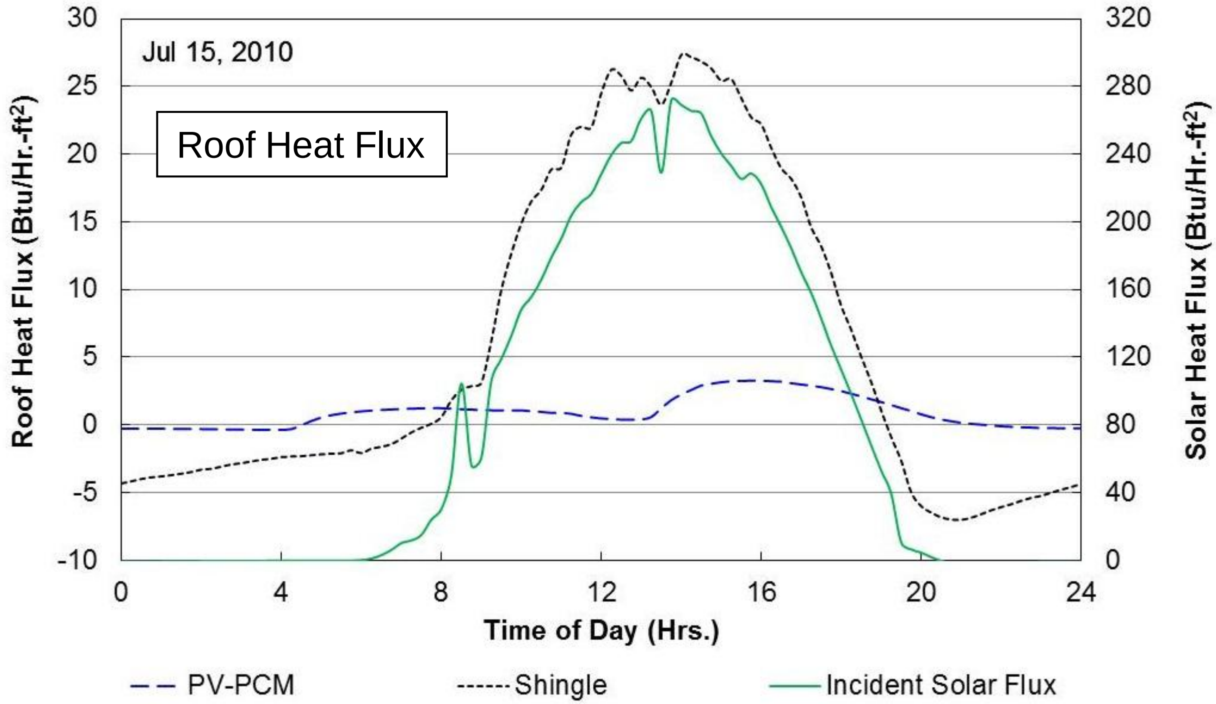
- Heat loss from conditioned basement is negative (heating load).
- Approx. R-5 thermal resistance of the attic floor.
- 30% lower average weekly heating load with PV-PCM roof.
- Insignificant cooling loads during winter.

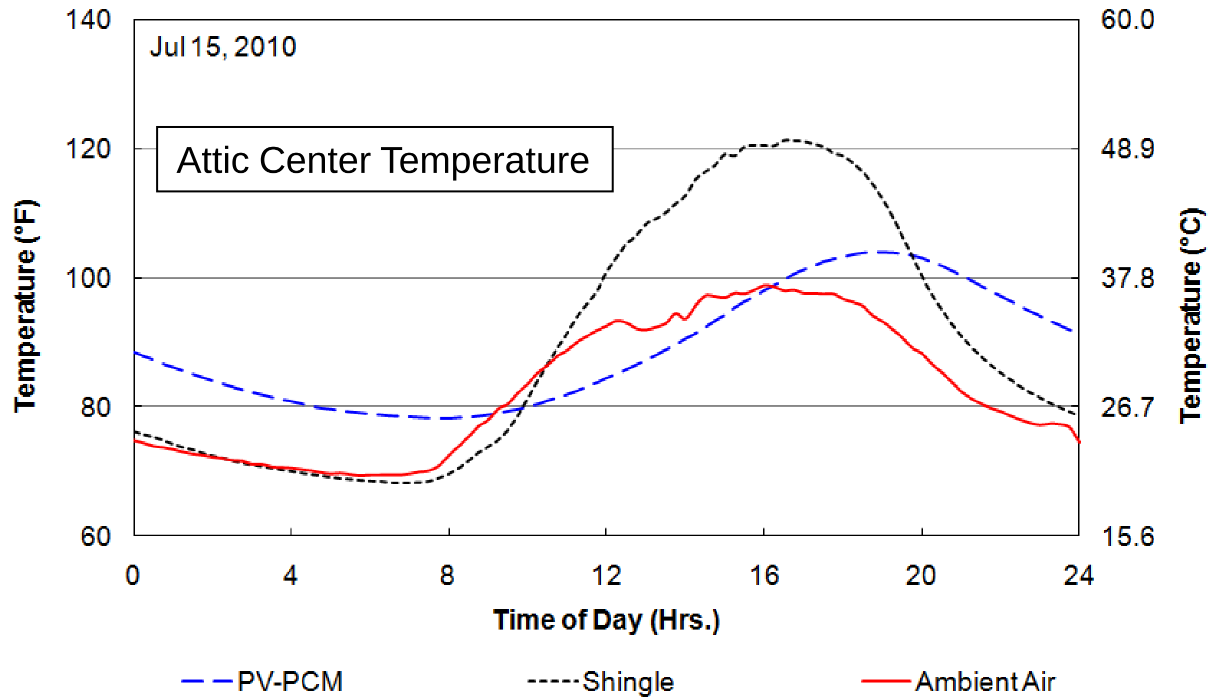




Summer Data

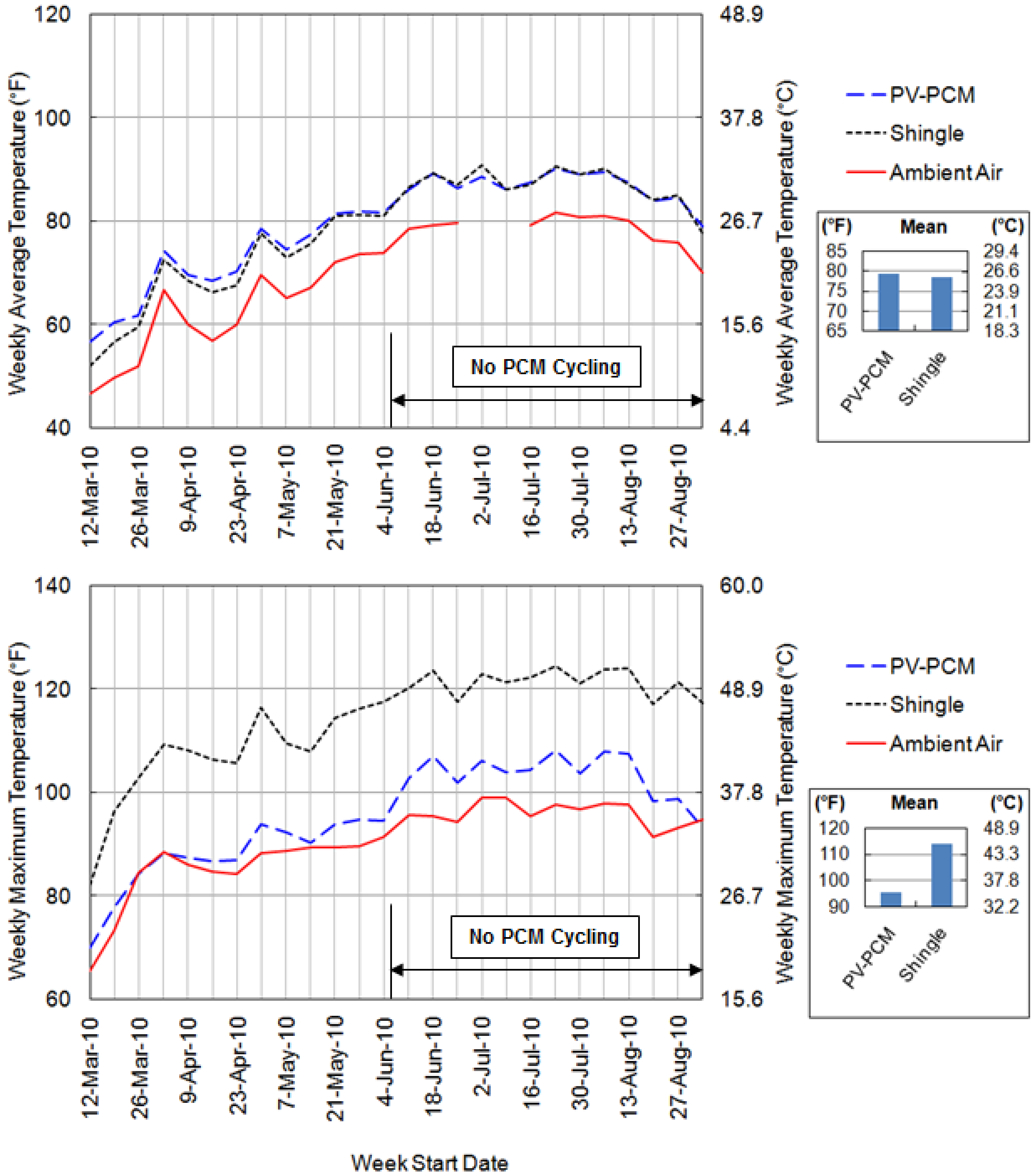
- Substantial lower peak daytime heat addition through PV-PCM roof.
- PV-PCM attic temperatures show lower fluctuations; Also evident is a ~2 hr. peak shift.





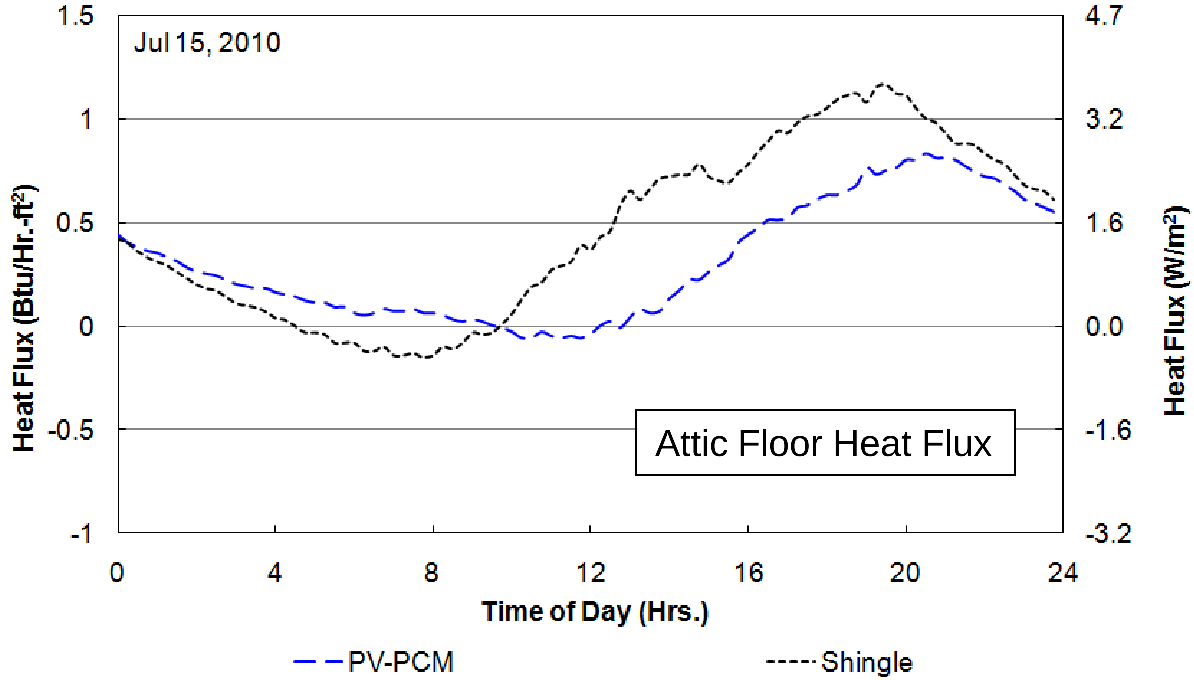
Summer Data

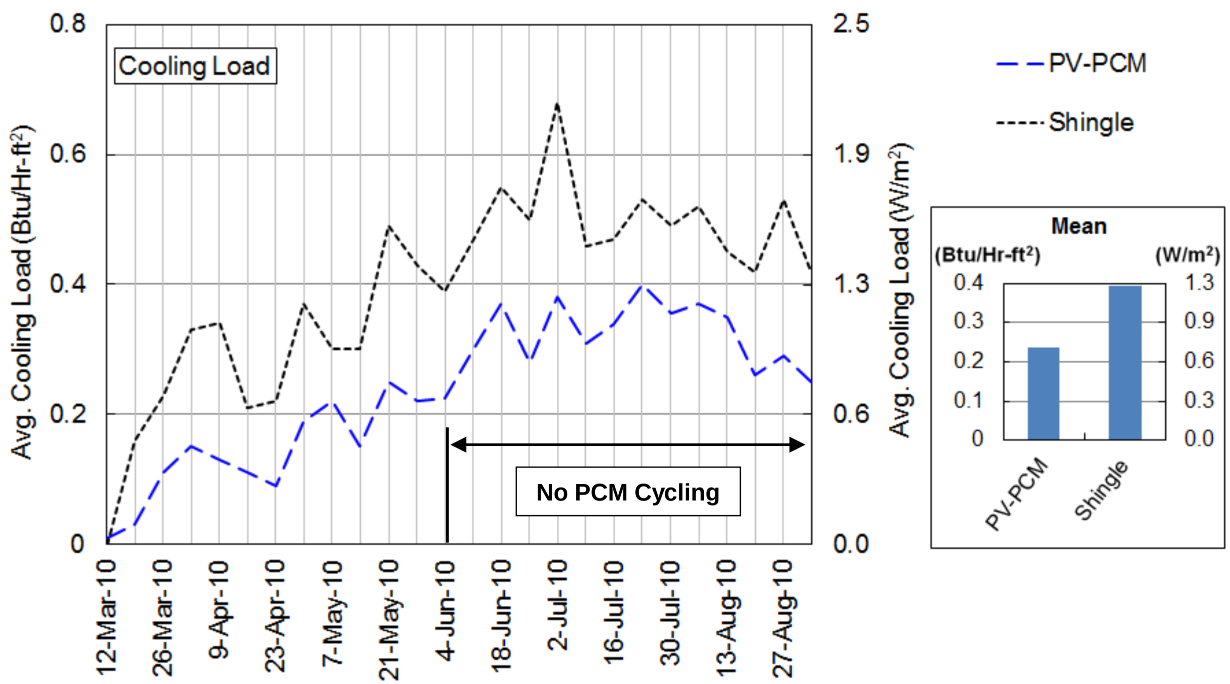
- Weekly average and maximum attic temperatures.
- Similar average temperatures.
- Weekly maximum PV-PCM attic temperature was about 19 ºF lower.
- No PCM cycling during peak summer.



Summer Data

- R-38 insulation added to attics on Mar 9, 2010; Floor thermal resistance ~ R-43.
- Comparable cooling and heating loads.
- 40% reduction in both heating and cooling loads with PV-PCM roof.





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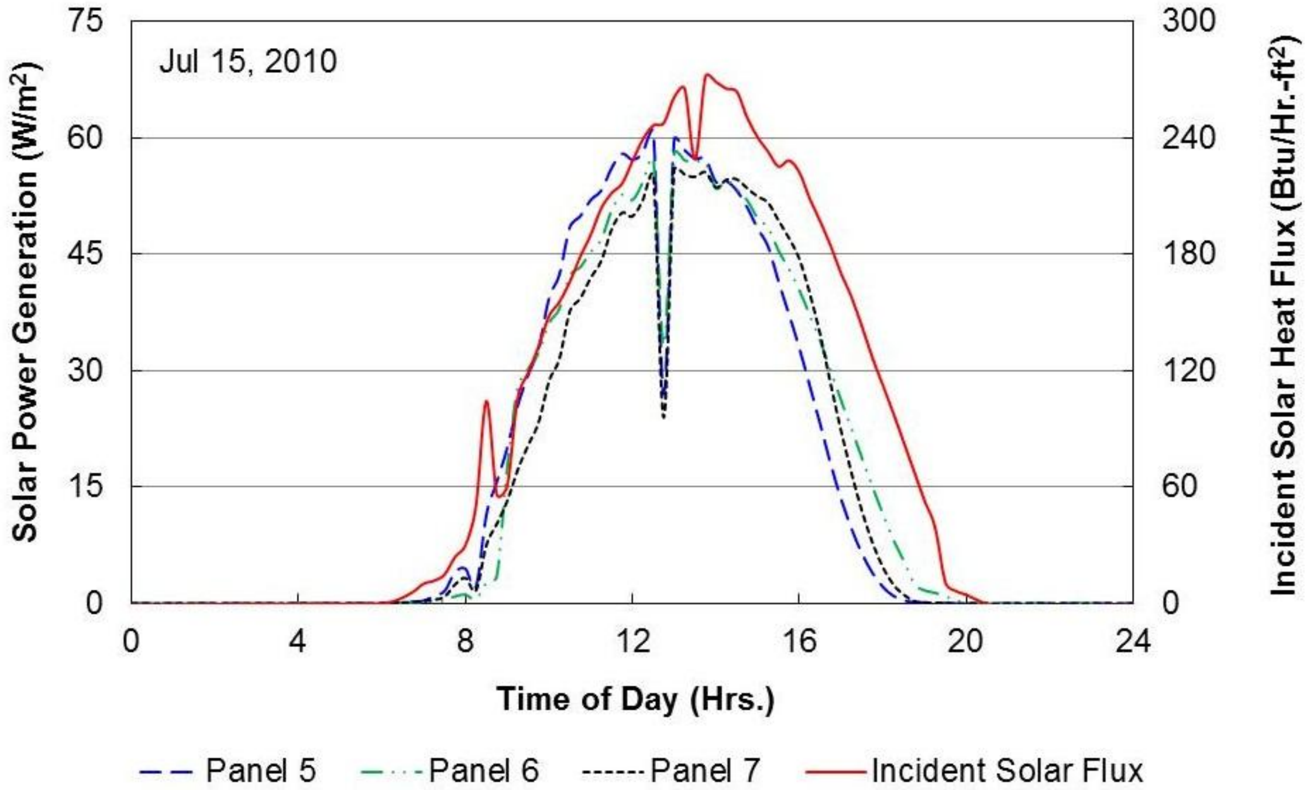
PV Generation Data

- PVL-144 amorphous silicon laminates; Rated max. power – 144 W; Operating voltage & current – 33 V & 4.36 A.
- Two panels (5 & 7) loaded with fixed 8.2 ohm resistor.
- Panel 6 had a electronic load that locked the voltage at 22 V and allowed the current to rise.
- Solar power generation followed the evolution of incident solar flux.



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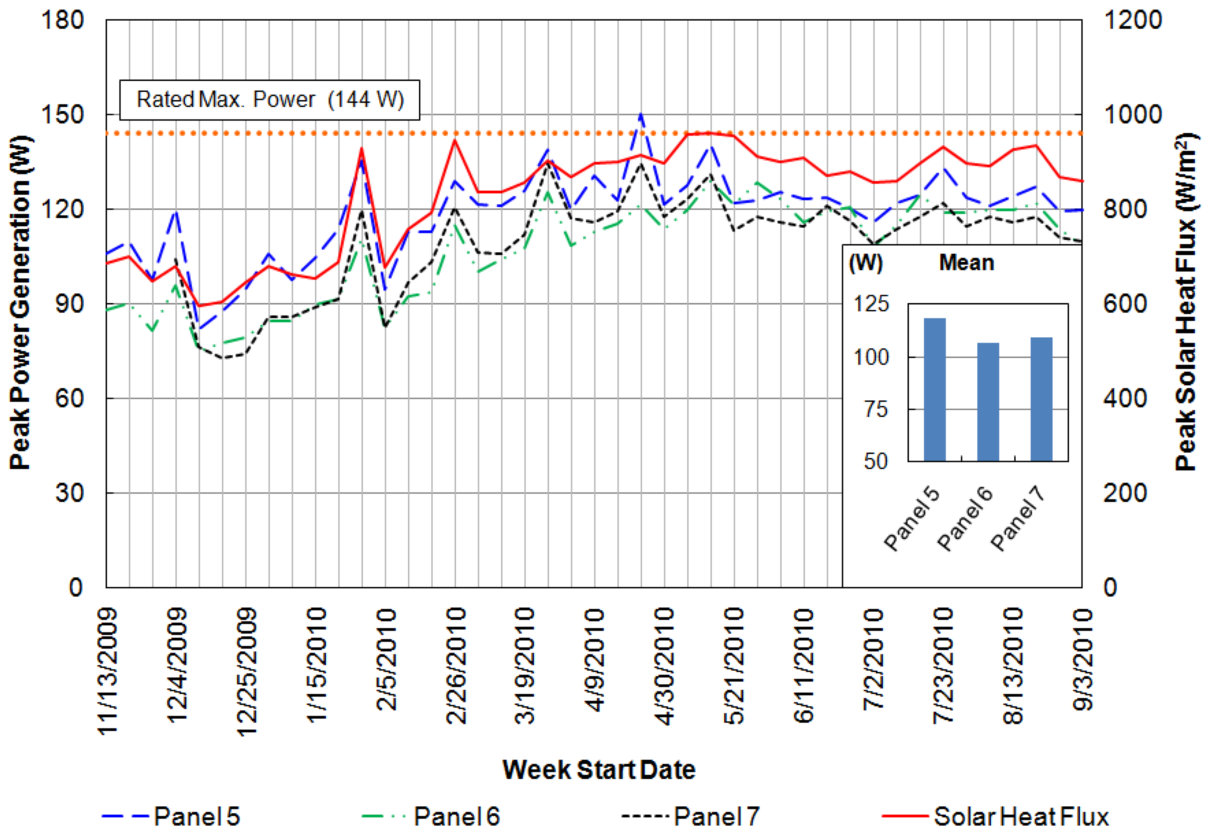
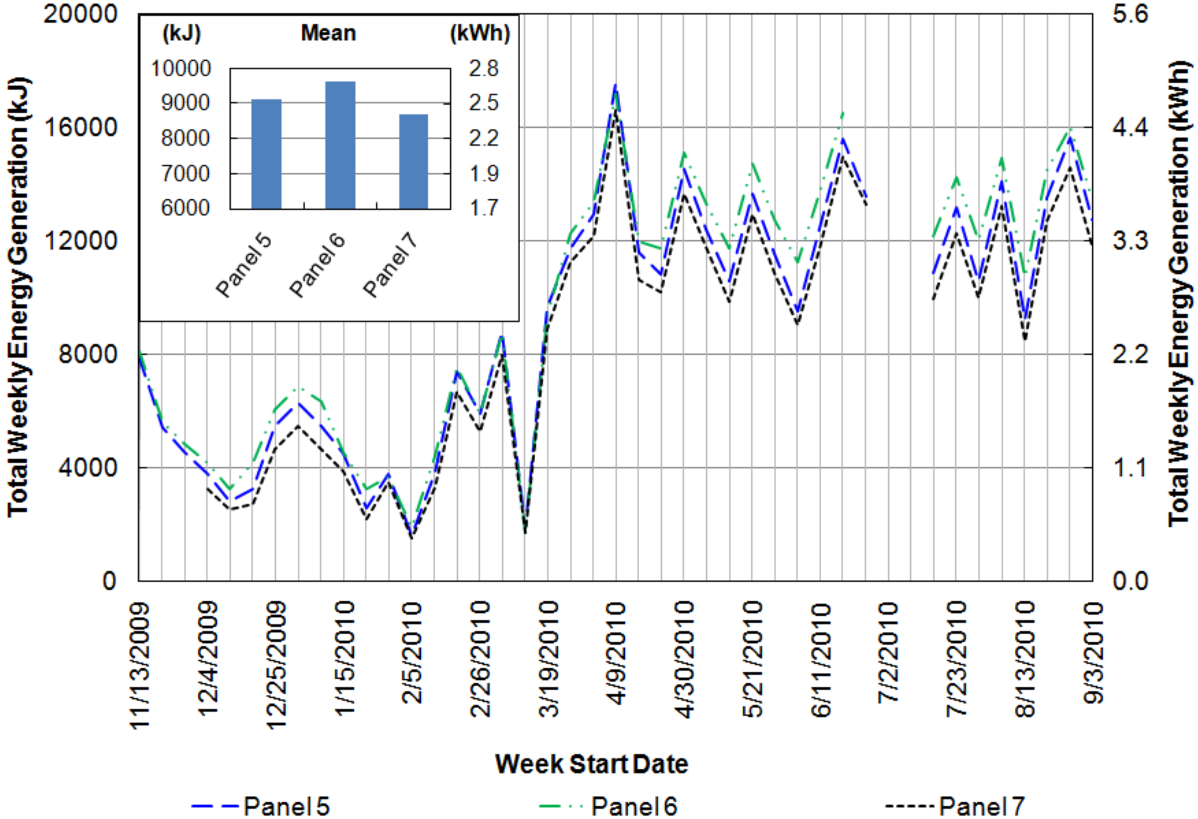
PV Generation Data



- Weekly peak power generation.
- Laminates with fixed resistance load yielded higher peak powers.

PV Generation Data



- Weekly total energy generation.
- PV laminate with variable load generated more energy.
  - Current evaluation using maximum power point tracking (MPPT) dynamic load to maximize the power production.

Summary and Conclusions

- During 2009-10, an experimental attic using a roof retrofit technology was installed and monitored at ORNL.
- Test data demonstrated that this retrofit technology can be very effective in improving energy performance of existing roofs, even with code-level attic insulation.
- The PCM did not undergo any phase change for a major portion of the evaluation, but the combination of fiberglass insulation with radiant barrier and above-sheathing-ventilation enabled reduced attic loads.
- Roofs and attics are attractive locations for PCM application due to their large temperature fluctuations. PCM, or combination of PCMs, better tuned to the local weather extremes can yield higher energy savings.

References

- Townsend, T.; Powell, J.; Chad, X.; 2007. “Environmental Issues Associated with Asphalt Shingle Recycling,” Report, US EPA Innovations Workgroup by Innovative Waste Consulting Services, LLC - Oct, 2007.
- Sengoz, B.; Topal, A.; 2005. “Use of Asphalt Roofing Shingle Waste in HMA,” *Construction and Building Materials*, v 19, n 5, p 337-346.
- Decker, D. S.; 2002. “The Road to Shingle Recycling,” *Recycling Today*, v 40, n 9, 28-32.
- Kosny J., Biswas K., Miller W., Childs P., and Kriner S. “Sustainable Retrofit of Residential Roofs Using Metal Roofing Panels, Thin-Film Photovoltaic Laminates and PCM Heat Sink Technology,” *Journal of Building Enclosure Design*, BETEC, Winter 2011/3.
- Miller, W. A., P. Wilson, and A. Karagiozis. 2006. “The Impact of Above-Sheathing Ventilation on the Thermal and Moisture Performance of Steep-Slope Residential Roofs and Attics.” 15th Symposium on Hot and Humid Climates, Orlando, Fla., July.
- van Helden, W. G. J.; van Zolingen, R. J. Ch.; Zondag, H. A.; 2004. “PV Thermal Systems: PV Panels Supplying Renewable Electricity and Heat”, *Progress in Photovoltaics: Research and Applications*, v 12, n 6, 415-26.

Thank you!

Questions?

Winter Cooling and Summer Heating Load