Research Studies Focused on Concentrated PCM Applications in Walls and Roofs

Initial concentrated PCM testing in whole-building conditions took place about 60 years ago. One of the first documented applications of a PCM for the passive solar heating of a house was in 1948 in a house designed by Dr Maria Telkes [Dincer and Rosen - 2011]. This house in Dover, Massachusetts, contained Glauber salt PCM, placed in drums housed in spaces between the main rooms that were ventilated with fans to move the warm air into the living space in winter. In summer the same system delivered cool air to the rooms. This system alone could keep the house warm for approximately 11 sunless days.[1]

Zhang and Medina of University of Kansas developed a thermally enhanced R-11 frame wall that integrated a paraffinic PCM via macro-encapsulating [Zhang and Medina - 2005]. Results from the field testing show that the PCM wall reduced wall peak heat fluxes by as much as 38%. For a period of several days that included walls facing different directions, the average wall peak heat flux reduction was approximately 15% for a 10% concentration of PCM and approximately 9% when a 20% PCM concentration was used. The average space-cooling load was reduced by approximately 8.6% when 10% PCM was applied and 10.8% when 20% PCM was used.

In 2006, Kissock and Limas of University of Dayton investigated paraffinic PCM that can be added to the building envelope components, such as the walls or roofs, to reduce the peak diurnal cooling and heating loads transmitted through the envelope [Kissock and Limas - 2006]. This work was a combined numerical - experimental study to quantify the effectiveness of PCM in reducing thermal loads through the building envelope components and to develop a design strategy for the placement of PCM within the massive walls. The PCM studied was paraffin octadecane, with an average melting temperature of 25.6°C (78.1°F). For the climate of Dayton, OH, thermal loads through the PCM-enhanced wood frame wall were simulated using an explicit finite-difference procedure with the indoor air temperature held constant. While comparing to the conventional wall, cooling load savings were close to 16%. The simulation technique has been validated against the experimental work.

In 2009, during the Greenbuild conference, National Gypsum introduced the ThermalCORE™ gypsum panels which contain microencapsulated PCM and can store approximately 22 Btu of thermal energy per square foot (250 kJ/m^2).[2] Dynamic testing with the use of an ASTM C-518 heat flow meter apparatus was performed on ½ inch thick samples of the PCM-enhanced gypsum board. PCM with a melting point close to 79°F (26°C) was used in these experiments. Preliminary thermal performance evaluation which incorporated 300-minute temperature ramps, showed about 13.5% cooling load reduction.

A series of field test measurements were performed in Arizona for two test huts [Muruganantham et al. - 2010]. One of the test attics utilized a conventional R-30 fiberglass insulation. The other one had arrays of plastic containers with a bio-based PCM installed within all building envelope components. The structures had enclosed attic spaces with R-30 fiberglass batt between 24” o.c. ceiling framing. Half inch OSB roof sheathing was covered with 15 lb roofing felt and standard three tab fiberglass desert tan shingles. Walls were constructed with 2x4 studs 16” o.c. with R-13 fiberglass insulation, T-111 siding and ½’’ finished gypsum board. Arrays of plastic containers, holding a PCM with density of 0.56 lb/ft^3 (9 kg/m^3) inside, were installed in all walls between the fiberglass insulation and sheetrock of one of the test huts. In addition, 1 lb/ft^3 (16 kg/m^3) density PCM was installed in both the ceiling and the floor. Experimental work was carried out by Arizona Public Service (APS) in collaboration with Phase Change Energy Solutions (PCES) Inc. with a new class of organic-based PCM. The experimental setup showed maximum energy savings of about 30%, a maximum peak load shift of ~ 60 min, and a maximum cost savings of about 30%. During the entire cooling season (March through

[1] http://www.eoearth.org/article/Telkes, Maria - 2009
[2] http://www.thermalcore.info/product-info.htm

October) average energy savings for the PCM test hut reached about 16%, ranging between 12% and 14% during the June – July time period and reaching 25% during the shoulder months.

In 2006, Kissock and Limas investigated paraffinic PCMs that can be added to the steel roofs, to reduce the peak diurnal cooling and heating loads [Kissock and Limas - 2006]. This work was a combined numerical - experimental study where the simulation technique was validated against the experimental data. The PCM studied was the paraffin octadecane, with an average melting temperature of 25.6°C (78.1°F). Analyzed metal roof had two 1-inch thick layers of the polyisocyanurate foam. The bottom layer of the foam was enhanced with the paraffinic PCM. For the climate of Dayton, OH, thermal loads through the PCM-enhanced polyisocyanurate board were simulated using an explicit finite-difference procedure with the indoor air temperature held constant. When comparing to the conventional roof (no PCM), cooling load savings were close to 14%.

A prototype residential roof using a cool-roof surface, natural subventing, and PCM heat sink was designed and field tested [Kosny et al. 2007, Miller and Kosny - 2008]. A multilayer configuration of PCM-enhanced polyurethane foams, PCM-impregnated fabrics, and highly reflective aluminum foil were used. Loading of PCM was about 0.08 lb/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°C and 32°C). The total storage capacity of the PCM heat sink was about 4.8 Btu/ ft^2 (54 kJ/m^2) of the roof area. The results show that for the metal roof assembly using cool-roof pigments, reflective insulation, and subventing air channels, the summertime peak heat flow crossing the roof deck was reduced by about 70% compared with the heat flow penetrating the conventional shingle roof. Installation of the PCM heat sink generated an additional 20% reduction in the peak-hour heat flow, bringing the total reduction to 90%. A similar configuration of a roof containing metal roof panels with PV laminates and PCM heat sink was field tested during 2009−10 [Kosny et al. - 2012] in east Tennessee climatic conditions, where PCM-associated cooling energy savings were found to be about 25% comparing to the conventional shingle roof.

The capability of PCMs to reduce the peak loads is relatively well documented. For example, Zhang and coworkers found peak cooling load reductions of 35 to 40% in side-by-side testing of conditioned small houses with and without paraffinic PCM inside the walls [Zhang et al. - 2005]. Similarly, Kissock and coworkers measured peak temperature reductions of up to 10°C (18°F) in side-by-side testing of unconditioned experimental houses with and without paraffinic PCM wall board [Kissock et al. - 1998]. Kosny reported that PCM-enhanced foam insulation can reduce wall-generated peak-hour cooling loads by about 40% [Kosny - 2006]. Miller and Kosny reported over 90% of cooling peak-hour load reductions for a prototype metal roof using a cool-roof surface, natural subventing, and PCM heat sink installed over the roof deck [Miller and Kosny - 2008].

RADCOOL, a thermal building simulation program based on the finite difference approach, was used by LBNL [Feustel et al. - 1997, Feustel - 1995] to numerically evaluate the latent storage performance of treated wallboard. RADCOOL was developed in the SPARK environment in order to achieve compatibility with a new family of simulation tools under development at the Lawrence Berkeley National Laboratory. Simulation results for a living room with high internal loads and weather data in Sunnyvale, California, showed significant reduction of room air temperature when heat was stored in PCM-treated wallboards. In the case of the prototype International Energy Agency (IEA) building located in California climate zone 4, it was estimated that PCM wallboard would reduce the peak cooling load by 28%.

Table 1: Summary of the U.S. test results for concentrated PCM applications.

Authors - reference	PCM location	PCM enthalpy, kJ/kg (Btu/lb)	PCM loading, Btu/ft^2 lb/ft^2	Appr. cooling load savings, %
Zhang, Medina - 2005	Wall core - containers	123.7 (52)	~10 0.2 (10%)	9 Lawrence, KS
Zhang, Medina - 2005	Wall core - pipes	123.7 (52)	~21 0.4 (20%)	11 Lawrence, KS
Kissock, Limas - 2006	Wall – gypsum board	143 (65)	~32 0.5 (30%)	16 Dayton, OH
Willson - 2010	Wall – gypsum board	110 (50)	22 ~ 0.4	13.5 Dynamic HFMA testing
Muruganantham et al. – 2010	Wall, Celilng, Floor – PCM containers	178 (81)	Walls; 45 ~ 0.56	16 whole building – Tempe, AZ
Kissock - 2007	Metal roof– polyisocyanurate board	143 (65)	30 0.5	14 Dayton, OH
Kosny et al. - 2012	Roof deck – PCM containers	178 (81)	27 ~ 0.3	25 PCM participation - Oak Ridge, TN