BENJAMIN BENSCHNEIDER

The University of Washington Molecular Engineering and Sciences building in Seattle was the first ZGF Architects project that used phase change material as a zonal strategy.

AMERICAN SOLAR ENERGY SOCIETY

PHASING OUT MASS

During graduate school, a green building sage introduced my cohort group to a proven low-energy building strategy by simply stating, “Mass matters.” Through a series of case studies and relatively simple calculations, the concept was reinforced and proven, again and again. Cooling peaks were offset or shifted. The cool of the night could recharge the system, making it ready for the loads of the following day. The captured solar resource was stored and distributed throughout the day and into the evening. Energy was saved and people were comfortable. All accomplished through the appropriate choice of material, a little bit of math and sensible design.

By the end of the course, there was no question that mass matters, but aesthetic and functional challenges associated with the incorporation of mass into today’s building stock limited application in practice. The general public, and more importantly, clients, do not always appreciate the aesthetic of exposed concrete — not even board formed — and there is limited opportunity for thick stone or adobe walls in the current architectural fashion. Instead, carpets and drop ceilings are used for acoustic treatments and to create a feeling of sophistication and to illustrate stature associated with specific programmatic uses. These refined finishes often “hide” mass, if present, and prevent thermal interaction with people, the space they inhabit and the larger environment. The question then becomes: How can we incorporate the thermal benefit of massive construction in today’s building paradigm, which has little appetite for exposed mass?

Phase change materials (PCMs) have been reintroduced to the building industry, some in improved form, to provide the qualities of thermal mass in innovative ways that can be readily applied to new construction as well as retrofit applications. The required thickness of common building materials to match the thermal capacity of 1-inch-thick PCM material (enthalpy of approximately 150 kilojoules per kilogram) is compared in figure 1, facing page (Konstantinidou, 2010).

PCM gained popularity during the energy crisis of the 1970s and was used to capture and store both solar energy and the “coolth” of the night. It fell out of favor as energy became less expensive. Additionally, early PCM often lost effectiveness over time and the packaging commonly failed, creating an underperforming mess for the building owner. The post-9/11 desire for the United States to become energy independent, as well as the understood anthropogenic impact on world climate, has driven a new era of conservation and an elevated desire to make

SOLAR TODAY
JANUARY/FEBRUARY 2014
VOL. 28, NO. 1

Phase change materials provide the benefits of thermal mass without the structural and aesthetic costs of thick concrete.

By **ED CLARK**

our buildings more energy efficient. This trend has been reinforced by the call to arms from the American Institute of Architects with the 2030 Commitment, the U.S. Green Building Council and the LEED certification system, and the International Living Future Institute's Living Building Challenge. "Net-zero energy" is no longer viewed as impossible but as a realistic goal. With this renewed ethos of conservation, a new age of PCM application is afoot.

Harnessing the Change of State

Sensible heat storage relies on the heat capacity and the temperature change of a material. The storage capacity depends upon the specific heat of a material as well as the amount of material. Increasing the quantity of the material increases the storage capacity in a linear relationship. Sensible heat strategies are typically applied through the use of massive construction materials or through the use of large volumes of water integrated into conditioning systems.

PCMs leverage the latent or thermochemical capacity of a material's change of state, absorbing heat while changing from a solid to a liquid and releasing that heat when returning to a solid. Latent heat storage uses the energy absorbed or released when the material changes from a solid to a liquid or a liquid to a gas and vice versa without a chemical change and relies on the latent heat of the specific material. Thermochemical reactions rely on the energy absorbed and released in breaking and reforming molecular bonds. The heat stored depends on the amount of storage material, the endothermic heat of reaction and the extent of conversion.

Figure 2, right, illustrates the heat capacity of a PCMs' latent or thermochemical change of state compared to sensible heat storage capacity of stone or water as applied to solar energy storage systems (Sharma, 2009). The vertical line at approximately 27°C (81°F) illustrates the very steady nature of heat absorption and release at a discrete temperature. For a solid liquid PCM product, once the ambient temperature rises to the melting point, the PCM absorbs the heat and maintains a constant temperature until fully liquefied. The absorbed energy is stored until the temperature falls below the melting point and the material solidifies. The melt temperature can be tuned to suit specific applications. For instance, temperature can be set around the comfort range of 72°F (22°C) for use within a specific space, or 55°F (13°C) if used as thermal storage for a mechanical system.

Typically the change of state is completely reversible, but there are challenges associated with some PCMs. Salts become less effective when super cooled, or cooled at a temperature well below the freezing point, interfering with proper heat exchange. When salts liquefy the solution becomes super saturated and the denser unmelted crystals sink and become unavailable for the recombination when the salts solidify, decreasing capacity over time. Paraffins and fatty acids have a low thermal conductivity with fatty acids having a higher cost than paraffins.

Often a single material may not satisfy all the criteria to be used as a homogenous application, and mixtures are created using one material to complement another. Systems can also be designed to recognize the limitations of a given material. For instance, metallic fins can be used to increase thermal conductivity and effective heat exchange.

Eutectics attempt to solve some of these concerns and are a combination of two or more materials that melt and freeze at or near the same temperature. The benefit of a mixture over a homogenous material is that multiple materials create a well-mixed solution that when melted does not segregate into its constituent parts, and freezes into an intimately mixed solid (Sharma, 2009). ➢

Ed Clark, LEED AP BD&C, is a passionate green professional with broad experience in applying building science solutions. At ZGF Architects he works to reduce resource consumption through efficient building systems, envelope optimization and occupant engagement without comprising comfort or aesthetic. He holds a bachelor's in environmental and resource science from the University of California-Davis and a master's in architecture from the University of Oregon.

FIGURE 1. **Relative Material Thickness for Similar Thermal Capacities**

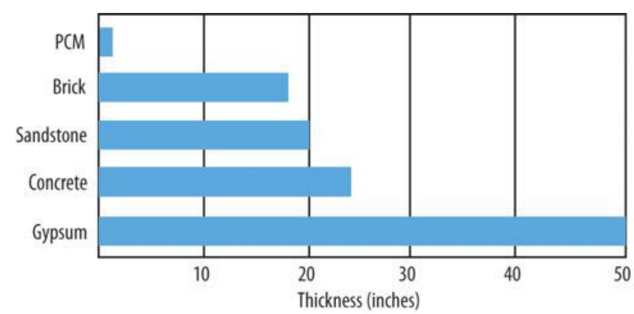
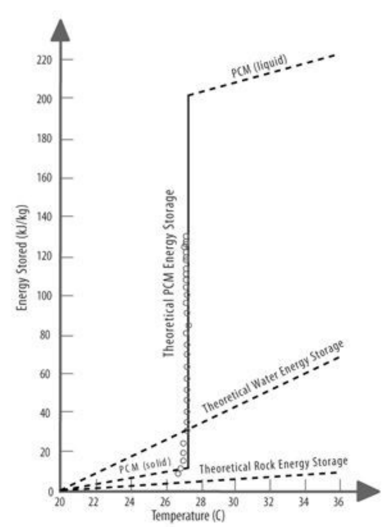
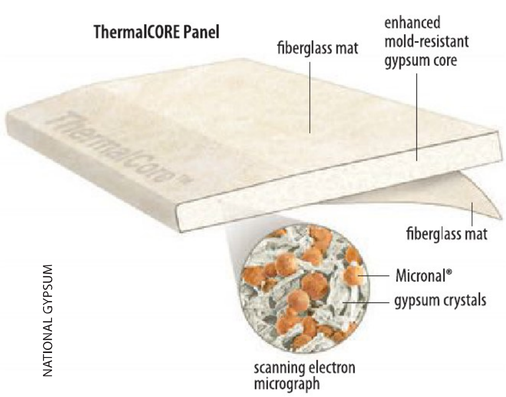


FIGURE 2. **Thermal Energy Storage Comparison of PCM, Water and Rock**



PCM Applications in Buildings

PCMs are commonly applied to buildings in two basic strategies: zonal (integrated within the space where temperature control is needed) or whole building (incorporated into building systems as thermal storage). PCMs in zonal applications are typically incorporated into walls, ceilings, floors or other interior surfaces, increasing the heat exchange capacity of a given space. One method of application is micro-encapsulation. Very small discretely packaged particles are incorporated in gypsum board, acoustic ceiling tiles, raised floor tiles, partitions and even furniture. Micro-encapsulated PCM can also be used as an admixture in concrete to increase thermal capacity, with a slight decrease of structural integrity (Hunger, 2009).



NATIONAL GYPSUM

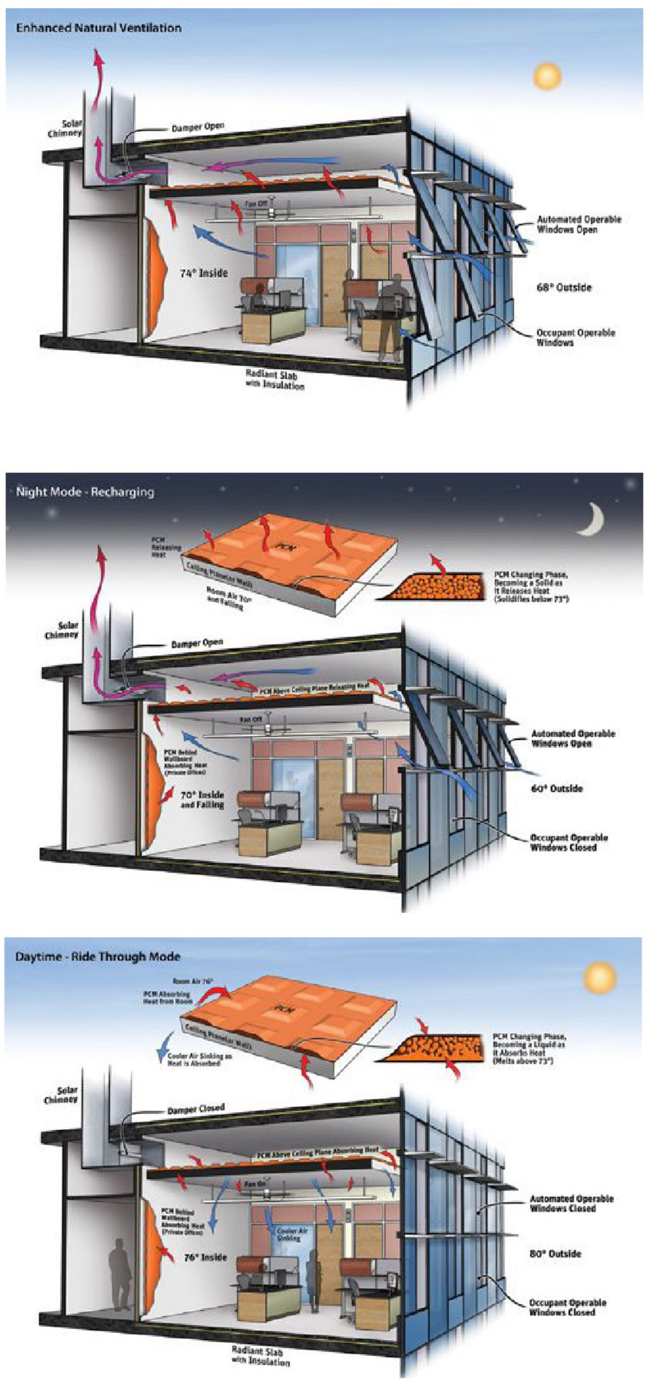
Micro-encapsulated PCM in a gypsum wall panel.

Macro-encapsulated PCMs are larger packages of PCM with a greater capacity. One product is sold as a sheet that can be likened to a large sheet of ravioli, to be placed within interior and exterior wall cavities or laid above standard acoustic ceiling tile systems.

Another example of macro-encapsulation is used as a thermal storage system applied to whole buildings. One product uses PCMs in stackable brick shaped containers, stored in tanks, and integrated into the HVAC system. This application is most commonly tied to hydronic heating and cooling systems. A PCM tank is analogous to a ground-source energy-storage strategy, with a daily rather than seasonal storage cycle.

A common misconception is that including PCMs will yield energy savings. Energy savings are had only if one side of the process, melting or freezing, is accomplished with less energy than was input or withdrawn from the system. For example a locally applied PCM strategy will absorb gains throughout the day. If the PCM is then cooled via a night-flush natural-ventilation strategy, the stored heat will be released to the cool of the night without an energy penalty. In a whole-building scenario, a PCM tank may be drawn upon to harvest heat for a morning warm-up, and then the deposited "coolth" can be used later in the day to offset cooling demand. When only cooling is needed, heat can be rejected into the PCM tank throughout the day, and recharged during the cooler nighttime hours. If the local utility has a peak rate billing structure the nighttime recharge will have an even greater benefit. Energy-saving benefits ripple beyond the discrete space and beyond the building itself (Pavlov, 2011).

FIGURE 3. **Ventilation Modes**



COURTESY OF AFFILIATED ENGINEERS INC

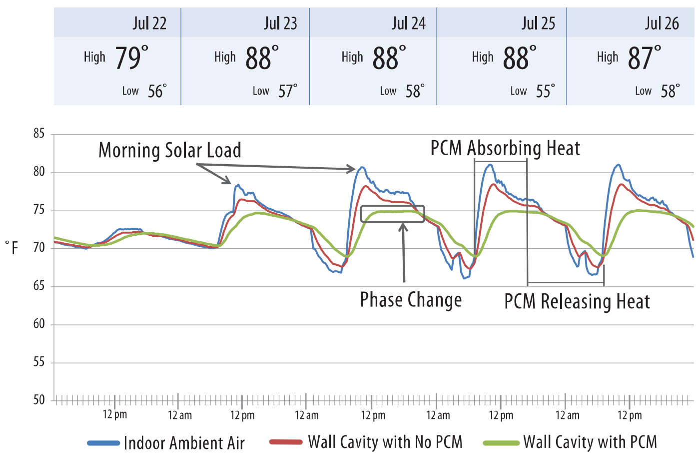
Zonal PCM Application Case Study

The University of Washington Molecular Engineering and Sciences (UW MolES) building, located in Seattle, is a cutting-edge research facility housing laboratories and support spaces on floors one through four, with instrumentation rooms on the partially subgrade ground floor.

Space-conditioning strategies are tailored to the specific programmatic conditioning demands. The laboratories are conditioned with an overhead VAV system and are located on the west side of the building to help dissipate western solar gains with ventilation rates that are much greater than required in the support spaces. The instrumentation rooms use active chilled beams, due to vibration requirements and the high sensible loads. The office and write-up area is conditioned with a hybrid strategy, with natural ventilation as the predominant strategy for comfort cooling, supplemented with a minimal amount of conditioned supply air. Supply air is needed to pressurize the space and prevent contamination from the adjacent labs, and to provide ventilation air when outdoor temperatures prevent the opening of windows.

The multifaceted natural-ventilation/cooling strategy for the office/support space was designed to minimize hours outside of the comfort zone (see the ventilation modes in figure 3, facing page). Operable windows, within arms reach of occupants and cued by a “red light/green light” system, feed a stack enhanced by a solar chimney and capped by a turbine ventilator. Automated windows above the standard operable windows can be triggered if occupants are unresponsive, and at night to recharge the PCM. Bio-based PCM sheets, with a melting point at 73°F (23°C), are installed above the drop ceiling and within the interior wall cavities of offices. The stack inlets are positioned at the rear of the room at occupant level to encourage ample air changes within the breathing zone. Dampers close during night flush mode and open an alternate path to draw cool night air across the PCM sheets above the ceiling. Ceiling fans can be used as needed, and a small set of fans within the stack provide the last line of defense against a rogue Seattle heat wave.

FIGURE 4. **PCM Monitoring Data from the Office Installation for July 22-26**



UW MolES was the first ZGF Architects LLP project that used PCM material as a zonal strategy. The structure and floor plates are concrete, but the client desired a more refined interior finish, and in the process thermal capacity was reduced. PCM was incorporated into the natural-ventilation strategy to add thermal capacity to the space, expanding the range of natural ventilation and night flush effectiveness, while reducing the risk of occupant discomfort. Data loggers were placed in the ceiling and the office wall cavities to understand how the PCM was performing.

In the office, the data loggers were placed in a pair of adjacent wall cavities, one with PCM and one without. A similar monitoring strategy was undertaken at the drop ceiling, with data loggers measuring adjacent sections with and without PCM. From a purely scientific perspective, it would have been advantageous to have true control and experimental conditions, with full rooms or even floors with and without PCM material, but the comfort of our clients trumped our scientific curiosity.

Figure 4, above, illustrates data from the office during a four-day Seattle heat wave with daytime highs of nearly 90°F (32°C). These outside temperatures are outside of natural ventilation ranges.

This data set was taken from the enclosed office July 22-26. The blue line indicates ambient interior temperature, spiking from morning solar gains. The red line indicates the temperature within the wall cavity without PCM, and shows a similar trend as the indoor ambient temperature. The green line represents the temperature within the wall cavity with PCM. The flattening-out of the green line shows the transition from a solid to a liquid state. The lack of temperature increase after the flattening of the line indicates that the latent capacity of the PCM was not exceeded. The decrease in ambient temperature and the temperature in the control cavity, blue and red lines respectively, correlate with the change of phase indicated by the flattening of the green line. The night flush strategy can also be seen in the decrease of temperature in all three conditions, with the nighttime low well below melting/fusion temperature of the PCM.

Night flush controls were designed to solidify the PCM material without overcooling the space. One benefit of PCM is the ability to cool or recharge in far less time and at a much higher temperature than would be required to recharge mass of an equal thermal capacity. The night flush temperature is based upon the maximum indoor temperature of the previous day. A higher indoor temperature triggers a lower night flush set point. This strategy not only makes up for additional sensible storage after melt has completed, but also adds additional sensible capacity prior to melting for the following day.

The Future Is Now

PCM has the potential to greatly reduce energy consumption in new and existing buildings and can complement low-energy cooling strategies without compromising comfort. A recent study by Southern California Edison illustrated that within their service territory, the potential market for PCM is 1.06 billion square feet, corresponding to 3,351 gigawatt-hours per year of cooling-related energy consumption, with potential savings being estimated to be 67 to 469 gigawatt-hours per year (Southern California Edison, 2012).

Although the impact of PCM is potentially immense, one must apply this strategy appropriately. The right type of material, with the proper melt temperature and form factor must be carefully chosen to yield maximum benefit and fit into the desired design aesthetic. Charging and discharging of the PCM must be carefully designed. Climatic synergies must be recognized to maximize savings through low energy charging or discharging (solar gain or night flush). Carefully consider program and associated internals gains, ventilation rates and control sequences to ensure that maximum value is received. PCMs alone will not lead us to an energy-independent future, but thoughtful design that considers robust passive strategies can be applied in new and exciting ways. **ST**

REFERENCES

Hunger, M., A.G. Entrop, I. Mandilaras, H.J.H. Brouwers and M. Founti. “The Behavior of Self-Compacting Concrete Containing Micro-Encapsulated Phase Change Materials.” *Cement and Concrete Composites* 31, no. 10 (November 2009): 731–743. doi:10.1016/j.cemconcomp.2009.08.002.

Konstantinidou, Christina. “Integration of Thermal Energy Systems in Buildings.” Masters Thesis. Austin, Texas: University of Texas. 2010.

Pavlov, Georgi, and Bjarne W. Olesen. “Building Thermal Energy Storage - Concepts and Applications” (2011). http://tapironline.no/fil/vis/774.

Sharma, Atul, V.V. Tyagi, C.R. Chen and D. Buddhi. “Review on Thermal Energy Storage with Phase Change Materials and Applications.” *Renewable and Sustainable Energy Reviews* 13, no. 2 (February 2009): 318–345. doi:10.1016/j.rser.2007.10.005.

Southern California Edison. “Phase Change Materials for Building Cooling Applications.” ET11SCE1260/HT11.SCE.022 Report. 2012.