NOVA Next

Melting to Keep Cool

By Phil McKenna on Tue, 10 Sep 2013

As the afternoon sun streams into a once abandoned warehouse in South Boston, the building's interior walls begin to melt. It's no design flaw; embedded within the walls is a thin layer of microencapsulated paraffin wax that turns from solid to liquid as the building warms.

"For high efficiency buildings, you need to start thinking in dynamic ways," says Jan Kosny, head of building enclosure research at the Fraunhofer Center for Sustainable Energy Systems. "Mother Nature is so generous, giving us tons of free energy. But we aren't using it. Instead we are blocking it with insulation, reflective coatings, and cool roofs. Instead of fighting with Mother Nature, we can collaborate. We can use that sun, absorbing the heat when it is warm and releasing it when it is cool."

Melting one pound of ice takes 144 times more energy than raising the temperature of one pound of water 1˚ F.

The solution, Kosny says, are phase-change materials, also known as PCMs—things that change between solid, liquid, or vapor depending on their temperature. What makes them so desirable for use in building materials is their ability to absorb or emit massive amounts of energy while maintaining a near constant temperature.

"To cool one pound of water from 33° F to 32° F takes 1 BTU of energy," says Mark MacCracken CEO of CALMAC Manufacturing Corporation, whose company sells ice-based air conditioning systems. "Taking that same one pound from 32° F water to 32° F ice takes 144 BTUs as it changes from a liquid to solid. By freezing instead of simply cooling the water, you are storing 144 times as much energy."

The incredible energy density of PCMs is a result of something known as the heat of fusion. In the case of melting ice, thermal energy is required to break hydrogen bonds between individual molecules. When water freezes, thermal energy is released as new bonds form.

"There are slightly different processes [for] different types of PCMs, but in general it is breaking and reforming of bonds between molecules as the material changes phase that requires or releases a significant amount of energy," Kosny says.

In recent years, research on PCMs has moved beyond water and ice to a vast number of new materials with a wide array of melting temperatures and applications. Some of the new materials will help keep us cool, while others will store energy at temperatures so high they would make us melt. Collectively, they will help us use existing energy supplies more efficiently, which may ultimately keep the entire planet from overheating.

Slimmer, Lighter, and Cooler

Kosny oversaw installation of the encapsulated wax at Fraunhofer's new South Boston location as part of a comprehensive energy efficiency retrofit before moving into the converted warehouse earlier this year. As the PCM melts, it absorbs energy while maintaining a near steady temperature. The change in phase, which sucks up the energy from a hot day, helps keep the building's interior cool while using significantly less air conditioning than would otherwise be required.

When the sun sets and the building cools, the wax in the walls radiates heat as it slowly solidifies, ready to absorb heat the following day. It's a concept that has been used for thousands of years in warm climates where stone or thick adobe walls absorb thermal energy during the daytime and release it at night. Using PCMs, however, allows for significantly thinner, lighter weight building materials better suited for today's glass and steel architecture. One half inch of phase-change building materials has the thermal capacity of roughly three inches of concrete, Kosny says.

"There is no one best material for all applications."

Kosny first started looking at phase-change materials as a way to store heat from the sun as a PhD student in Poland in the early 1980s. Resources in the communist country were scarce at the time, and the only material he could find to work with was beeswax. Today he is one of the world's leading experts on PCMs. His clients include leading building materials manufactures, the aerospace industry, and the U.S. Department of Defense. Working first at the U.S. Department of Energy's Oak Ridge National Lab in Tennessee and now for Fraunhofer in Boston, he has assembled a library of hundreds of different phase-change materials, each with their own unique thermal properties.

In a tour of his lab, Kosny shows me thick gels ensconced in what looks like bubble wrap—macroencapsulated PCMs, some of which are soft to the touch while others remain frozen solid at room temperature. Next to the gels are samples of drywall with tiny droplets of microencapsulated phase-change materials mixed directly into the building material. The larger gel packs can absorb more thermal energy but have to be covered by conventional drywall and are susceptible to leakage if punctured by screws or nails.

PCM pellets created in a Fraunhofer lab

In walls around the Kosny's lab, Fraunhofer uses a slightly different building material, a microencapsulated PCM surrounded by shape stabilizing polymers and sealed with aluminum foil to aide thermal conductivity. "There is no one best material for all applications," Kosny says.

The building, one of only about two dozen nationwide to incorporate PCMs into its physical structure, uses the material sparingly as part of a showcase of advanced building materials that reduce heating and cooling requirements. In rooms at the Fraunhofer facility where PCMs are used, they cut cooling needs by 10 to 15%, Kosny says.

But when liberally applied to a building's rooftop, Kosny has demonstrated that phase-change materials can reduce a roof's peak hour thermal load—the amount of heat conducted into the building during the hottest part of the day—by 95%. By absorbing heat in the middle of the day and radiating it back out later, Kosny says phase-change materials can easily reduce a building's overall cooling requirements by 25 to 30%.

Cool as Ice

When it comes to reducing peak energy demand and keeping buildings cool, there may be an even simpler solution: ice. Some of the world's largest ice cubes can be found in the basements of Manhattan skyscrapers. Inside Rockefeller Center alone, dozens of massive ice blocks, each the size of a small SUV, melt and refreeze each day. From Wall Street to Times Square, space constraints and high daytime electricity prices are pushing New Yorkers to increasingly embrace one of the oldest yet most efficient forms of air conditioning to keep cool.

"In a place like Manhattan, you need to store a lot of cooling in as little space as possible," says MacCracken, whose company has installed its IceBank system in thousands of locations around the globe. "Cold water tanks take up 10 times as much volume as ice storage."

IceBank storage tanks in the basement of a building

From the outside, an IceBank storage tank looks much like an oversized water heater. Inside, however, coolant circulating through several miles of polyethylene tubing turns the water inside the tank into an eight-ton block of ice. During the day the system runs in reverse; the ice cools warm fluid pumped through tubes in the tank that is then used to cool the building.

Running chillers at night saves money because electricity is dramatically less expensive then—roughly 70% cheaper than during peak daytime hours, MacCracken says. In effect, CALMAC's ice blocks—which belong to a class of devices industry officials call "thermal storage"—are simply a way to store energy, much like a giant battery, until it is needed.

Freezing ice the night before it's needed also allows building managers to use smaller, less expensive chillers than would normally be required of a conventional air conditioning system, which has to provide all the cooling at the time it's needed. MacCracken likens his system to buying ice prior to hosting a cocktail party, albeit on a much larger scale. "Would you ever consider making the ice cubes for a party when your guests start arriving?" he asks. "Of course you wouldn't. If it's laughable to wait to until you need ice for a cocktail party, why is it not absurd that we wait to cool an entire building?"

"Would you consider making ice cubes for a party when your guests start arriving? Of course you wouldn't."

In addition to saving money, thermal storage also offers significant savings in energy efficiency, but not where you might expect it. At the building scale, ice-based air conditioning is slightly less efficient than conventional air conditioning, which doesn't require the freezing and melting of ice. On a grid scale, however, the use of such thermal storage is significantly more efficient because electricity generated at night comes from base load power plants. These large, efficient plants operate continuously, as opposed to "peaking plants" which only operate during periods of high demand and are inherently less efficient. "By shifting to nighttime, you may use 5 to 10% more electricity, but power plants are 20 to 30% more efficient at night," MacCracken says.

As thermal storage gains traction, utility operators are taking notice. In June, the California Public Utilities Commission set a goal of developing 1.3 gigawatts of energy storage by the end of the decade. The target—equivalent to the output of a large nuclear power plant—includes incentives for technologies like ice based thermal storage that shift the energy requirements of buildings away from periods of peak demand.

Even without the incentives, thermal storage is a promising option for grid operators, according to Steven Minnihan, an analyst at Lux Research. "When you look at thermal storage, the cost is substantially less than a fuel cell or any kind of emerging battery technology," he says.

Storing the Sun

In addition to keeping buildings cool, phase-change materials may soon store excess solar power until it is needed. One form of solar power, concentrated solar, uses sunlight to generate steam that is used to produce electricity. In that way, they are similar to conventional power plants. The concentrated solar plants work well so long as the sun is shining, but they have a hard time delivering energy at night or when the clouds roll in. If excess heat not needed for immediate electricity generation could be stored, it could be tapped and used at a later time.

Researchers from the German Aerospace Center recently tested what they say is the world's largest high-temperature PCM storage module in Carboneras, Spain. At 26 feet tall and filled with 15 tons of salt, the insulated, steel reinforced tower is something akin to a giant saltshaker wrapped in a large tea cozy. It isn't hooked up to a concentrated solar plant today, but a future version could be.

The German Aerospace Center's test PCM facility in Carboneras, Spain

To charge the module, superheated steam from an adjoining coal-fired power plant is piped through a network of finned tubes that heats the sodium nitrate salt to its melting point of 581˚ F. The liquid salt can then retain its stored thermal energy for up to 24 hours. To discharge the heat, operators essentially run the system in reverse, pumping water through the finned tubes to turn it back into steam, which goes on to spin the turbines that produce electricity.

Until now, solar thermal power plants have either gone without thermal storage or relied on molten salts that remain liquid throughout their charging and discharging cycles. By keeping the salts liquid, though, the system is not taking advantage of the efficiencies inherent in phase change. “You need five times the volume with molten salt storage,” says Doerte Laing, head of thermal process technology at the German Aerospace Center’s Institute of Technical Thermodynamics. “Your storage cost would be roughly five times lower with phase-change salts.” The reduced cost could help stored solar power compete with conventional gas and coal fired power plants for reliable base load power.

The International Energy Agency predicts that concentrated solar power will become cost competitive with conventional fossil fuel power as early as 2025 and, along with photovoltaic solar power, could provide up to 25% of global electricity production by 2050.

Traditional solar thermal power plants don't use phase change to store energy, but they may soon.

Meanwhile, changes in electricity pricing could soon make ice blocks and melting walls much more commonplace. Utility companies in Texas recently began offering free electricity at night in an effort to get residential users to reduce their energy requirements during peak daytime hours.

Until now the manufacturers of ice storage and PCM building materials have focused on large commercial applications, but if the difference between nighttime and daytime residential rates continues to widen, things could change quickly. “In another decade or two we may all have a block of ice in our homes like we did in the [early] 1900s,” MacCracken says.

Name: ____ Per__

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Reading and Activity

Questions

1. In the reading it says "melting one pound of ice takes 144 times more energy than raising the temperature of one pound of water 1 °F". Why does it take more energy to melt ice then it does to raise the temperature of liquid water?

2. What are PCMs and why are they desirable for building materials?

3. How does the wax at Fraunhofer's new South Boston location work? Explain the process of what happens to this PCM.

4. What is a potential problem with the larger PCM gel packs when used in drywall?

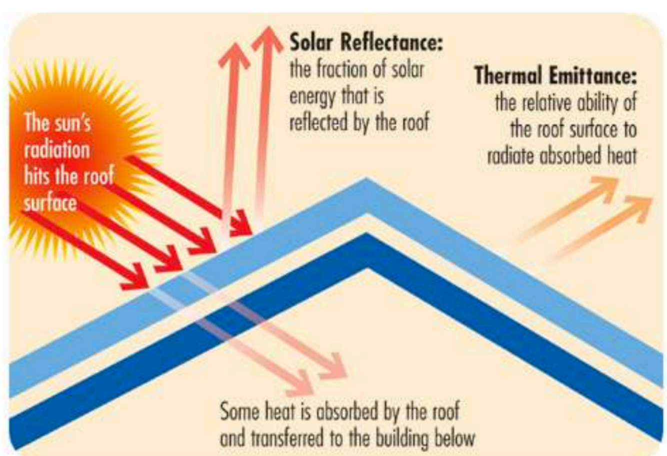
5. How much can PCMs reduce a buildings overall cooling requirements?

6. How is ICE used to cool buildings, such as the buildings in Manhattan?

7. Explain some of the benefits of thermal storage?

8. What is "concentrated solar"?

9. When does the International Agency predict that concentrated solar power will become cost competitive with conventional fossil fuel power?



10. On the back of this sheet design a home that would be the most energy efficient. Use at least two ideas that you read about in the article. Draw your home and label and explain at least five specific specific "green" elements. You can look up other "green" elements besides the ones in this article.