Phase-Change Materials Used in Post-Frame Construction

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Many *Frame Building News* articles have been written about the value of energy efficiency in buildings and the use of post-frame construction to achieve energy-efficient design. In particular, large cavity spaces and fewer thermal bridges are distinct energy-efficient advantages of post-frame construction. Energy efficiency continues to be an ever-increasing goal because energy costs change, and building owners continually attempt to reduce the overhead costs of heating and cooling the building.

The goals of energy efficiency have recently been changing. As an instructor for a green building class, I have seen my own language about energy efficiency change in the last five years. Previously, green building and energy efficiency were dominated by the Leadership in Energy and Environmental Design (LEED) program, which requires at least a 30 percent decrease in energy use. Now the discussion also includes Passivehouse, which has a typical energy reduction of 90 percent, and net-zero, where the building actually produces enough power to offset its yearly use.

Increasing energy efficiency is typically related to increasing the R-value of the structure. The R-value is a material property of the building materials and insulation, so achieving a higher R-value requires thicker insulation. Typically, materials with greater R-values tend to cost more dollars per square foot. They also tend to have less permeability, preventing the transfer of moisture through the wall section. Depending upon the design of the building envelope, this reduced permeability may be a detriment to the wall section.

How do we increase the energy efficiency of post-frame buildings? For a typical wall construction with a triple 2 x 6 post, a cavity of 5.5 inches is created. Using conventional fiberglass material creates an R-22 wall section. If a closed-cell foam product was used in the entire cavity, an R-34 wall section is created. But what if a higher R-value is needed? An exterior layer of continuous insulation, usually R-5, could be added. However, care must be taken to ensure that the metal sheathing is properly attached to the structural frame to provide adequate lateral strength for the building.

More insulation could be added on the inside of the posts, but this would reduce the usable square footage of the building. To reach higher levels of energy efficiency, another material is needed. Phase-change materials are another option to increase the energy efficiency of buildings in a thin layer. It is important to understand the background of PCMs and how PCMs function so that these materials can be used most effectively. Note that PCMs do not replace insulation but can help improve energy efficiency. Two concepts—*thermal mass and latent heat*—are important to an understanding of PCMs.

THERMAL MASS

Thermal mass is defined as the ability of a material to absorb and release heat. The amount of heat that is absorbed or released depends on the specific heat capacity of the material, the amount of mass and the change in temperature. For many heavy buildings, especially those built with concrete, thermal mass is added to the energy modeling of the building.

Typically, for metal buildings and lighter-weight buildings made of wood, thermal mass is not a consideration because of the buildings' lighter weight. A consequence of wood and metal buildings' having less mass is that these buildings also have less thermal inertia, or resistance to temperature change, than do heavier buildings.

Thermal mass can act as a "heat battery" that is able to store or release heat in response to temperature changes in the buildings. Because temperature is related to the specific heat capacity, a large temperature differential is often needed for thermal mass to be used. Most thermal mass systems use sensible heat as the storage mechanism. Sensible heat requires the temperature of the material to rise and is usually contained in a vessel or storage unit.

Figure 1 compares the relative thickness needed to achieve a set heat capacity value for various building materials with that for PCMs. This figure was adapted from Konstantinidou (2010), based upon a PCM 0.4 inches thick with a heat capacity of 70 British thermal units/lb. To achieve this same heat capacity using other building materials requires 9 inches of concrete, 13 inches of wood or 20 inches of gypsum board. By adding PCMs, any building can take advantage of thermal mass to help with temperature regulation.

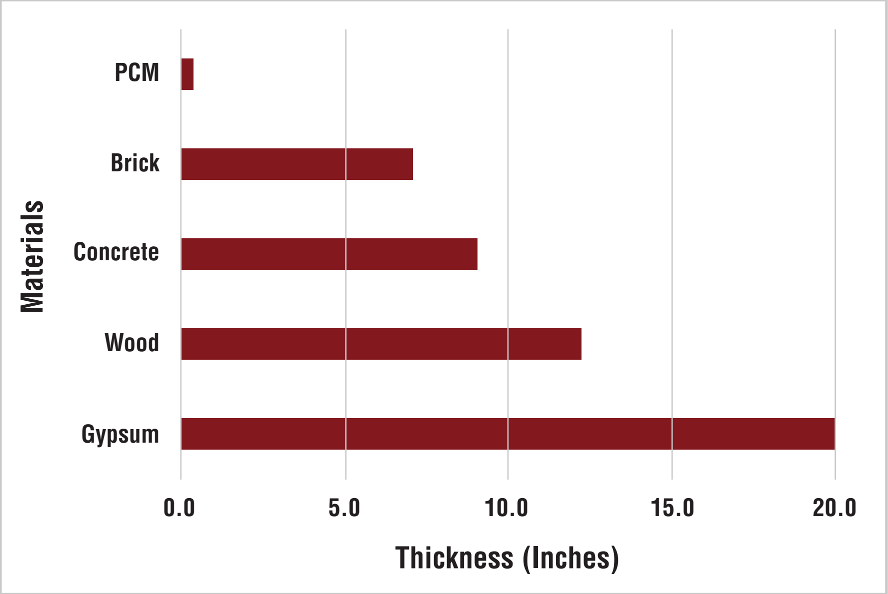

Figure 1. Relative thickness of building materials needed to provide equivalent thermal mass (figure adapted from Konstantinidou, 2010). PCM = phase-change material.

LATENT HEAT

The values for heat capacity of PCMs shown in Figure 1 seem really remarkable. The reasons for the reduction in PCM thickness compared to other materials can be explained by discussing heat transfer. Heat transfer involves two types of heat energy: sensible heat and latent heat. Sensible heat is usually what we think of as heat and is responsible for a temperature change in a material. Latent heat does not change temperature but is the heat needed to change phase (solid, liquid, gas).

For example, an ice cube at 10 degrees F has heat applied to it. The ice cube begins to warm (but not melt) until the temperature reaches 32 degrees F. The specific heat of ice is 0.5 BTU/lb-°F, which means that 0.5 BTUs are needed to raise 1 pound of ice by one degree Fahrenheit. At 32 degrees F, the phase change from solid to liquid occurs, requiring 144 BTUs per pound of ice (see **Figure 2**). Note that the addition of this heat causes no change in temperature. Adding more heat to the water causes a change in temperature due to sensible heat with a specific heat of 1 BTU/lb-°F. Note that the amount of energy needed to cause the phase change from solid to liquid is much greater than the amount of sensible heat (energy) required to raise the water or ice temperature on a unit mass basis. This example shows the potential to use latent heat for heat storage or release due to phase changes. Also, this heat storage does not require a large change in the temperature of the building to occur.

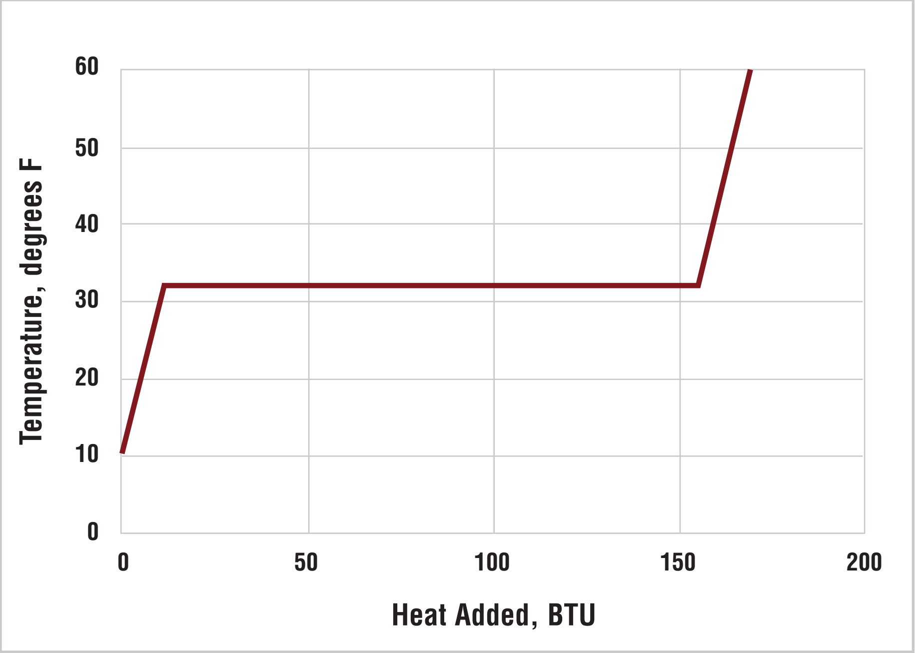

Figure 2. Amount of heat required to convert 1 lb. of ice at 10°F to water at 60°F

PHASE-CHANGE MATERIALS DEFINED

PCMs make use of thermal mass, a building's ability to store and release heat to regulate temperature, and the ability of latent heat to cause a phase change, which can "power" the thermal mass without causing a large temperature change. PCMs tend to regulate the temperature at or near the melting temperature of the PCM. Although water is a good example for explaining the latent heat aspect of PCMs, water is not considered a good PCM for use in buildings because of its low melting temperature. However, water does have important uses in many chiller applications, which will be described later.

PCMs include several groups of materials, among them, paraffin wax and other organic compounds, several inorganic salts and eutectic salts. Eutectics are mixtures of materials that have a lower melting point than either of the two materials individually. Many PCMs used in construction consist of waxes, because many of the salts tend to form crystalline structures that do not reform into liquid easily.

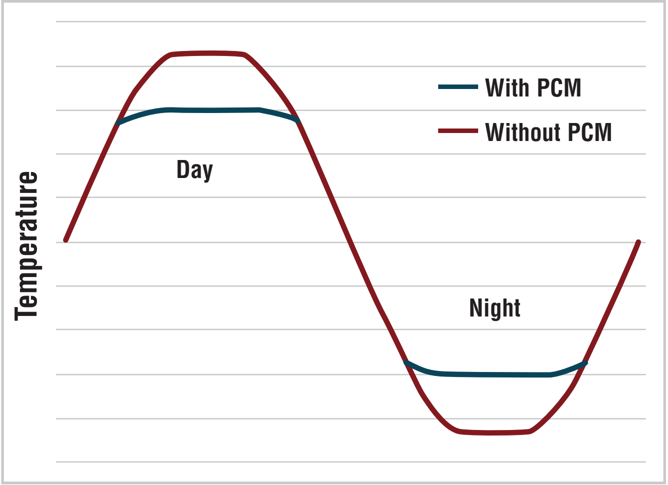

Figure 3. Example of the peak-shaving behavior of phase-change materials

HOW DOES A PHASE-CHANGE MATERIAL WORK?

Consider a solid PCM with a phase-change temperature of 70 degrees F. As the temperature inside the building rises above 70 degrees F, the PCM begins to melt. Melting requires the addition of heat, so the effect upon room temperature is to cool the room. When the room temperature drops below 70 degrees F, the PCM solidifies, which gives off heat, and warms the room.

A PCM works only when a phase change occurs. If, in the previous example, the phase-change material melts and requires heat, which cools the room, and if the temperature of the room continues to rise, the PCM would not provide any restorative effect. For this reason, PCMs must be "recharged" by having the material resolidify by means of another temperature change or by other methods such as night flushing or applying additional cooling.

PHASE-CHANGE MATERIALS AND ENERGY EFFICIENCY

It is important to note that PCMs do not replace insulation. The R-value, or resistance to heat flow, provided by insulation is vital to controlling the amount of heat entering or leaving the building. The effect of PCMs is to help regulate the temperature inside the building. PCMs can help reduce the need for use of the heating, ventilation, and air conditioning system, thereby saving energy on power and fuel bills. **Figure 3** is an example of the effect of temperature changes within a building over a day. The temperature of the building without a PCM fluctuates between hot and cold depending upon the outside temperature and the amount of insulation in the building. With the addition of PCMs to this structure, the PCM is able to reduce the change in temperature over the same time span. Anecdotal evidence in England and France has noted a 30 percent energy savings due to the use of PCMs. Peippo, Kauranen, and Lund (1991) found that a 1,290-square-foot house in Wisconsin could save up to 15 percent of total energy costs through the use of PCMs.

In Figure 3, the area between the "With PCM" and "Without PCM" curves represents the potential for energy reduction due to the use of PCMs. PCMs can help reduce the need for HVAC system use, thereby reducing energy on power and fuel bills. The effect of PCMs is to reduce the peak temperature, often called peak shaving. PCMs should be considered when the energy needs of the house are planned and incorporated into energy modeling software to optimize the placement of PCMs in different walls of the building depending upon the orientation (e.g., north, south) of the building.

FORMS OF PHASE-CHANGE MATERIALS

A number of PCM products are currently available, and new materials and methods are being studied all the time. The main forms are pouches (macroencapsulation), encapsulated beads (microencapsulation) and sandwich construction.

- Pouches—These "blister packs" of molded plastic contain squares of the PCM material (the process is known as *macroencapsulation).* These pouches are convenient to use, with tabs that can be attached by staples to other parts of the building. The pouches can also be produced with different permeability ratings and fire ratings. Pouches also allow room for the expansion and contraction of the PCM during the phase-change process. Pouches are often attached inside wall cavities, stapled to the inside of the sheathing or girts (see **Figure 4**). The

Figure 4. Pouches containing phase-change material are often attached to the inside of wall cavities, stapled to the inside of the sheathing or girts. Photo: Insulcorp.

pouches do not need to be visible or exposed in order to be effective.

- Encapsulated beads—Several products containing microscopic beads of PCM material (the process is known as *microencapsulation*) embedded within wall board materials are moving toward the market. These materials have the potential to incorporate PCM technology into the building envelope without the need to reduce the space for insulation or add to the thickness of the building envelope.
- Sandwich construction—A sandwich panel contains PCM layers on the outside and insulation in the center (this form was explored in a 2010 research paper by Diaconu and Cruceru). The outer PCM is most useful in hot seasons, and the inner PCM is most useful in colder seasons.

OTHER APPLICATIONS OF PHASE-CHANGE MATERIALS

PCMs have a wide range of uses in situations where temperature control is important:

- Satellites—As a satellite turns in space, the sides are subjected to extremes of heat when they face the sun and extremes of cold when they face away from the sun. Temperature shrinkage of electronics and mechanical parts could be catastrophic, so PCM materials are used to regulate temperatures.
- Medical supplies—Vital, lifesaving medical supplies (e.g., blood, vaccines, donor organs) are often transported in packaging containing PCMs to ensure that changes in temperature, mishandling and delays in shipping do not harm them.
- Food and drink vending—PCMs in combination with insulation can help reduce the energy costs of vending-machine cooling.
- Chiller systems—PCMs can be used as a heat battery for chiller systems in large buildings. The PCM material can be "charged" (heated or cooled) using off-peak power at lower energy costs compared to on-peak power. Then, during on-peak power times, the PCM can be used to add heat or cooling to the building system as needed, reducing the need for heating and air conditioning.

SPECIFYING PHASE-CHANGE MATERIALS FOR BUILDINGS

PCMs can be used in a variety of applications, including in new construction (**Figure 5**) and in the retrofitting of existing buildings (**Figures 6 and 7**). The following guidelines can help building designers specify the appropriate PCMs for use in their building projects. It is recommended that an energy model of the building be created and the PCM layers designed to work within this system. These recommendations are generic (they can be applied to the products of a number of manufacturers) and represent the use of macroencapsulated PCMs, which are the most common form available in the building industry.

- Choose the melting temperature.—Typically, the melting temperature chosen is 1–3 degrees greater than the set-

Figure 5. Phase-change materials can be used in new construction. Photo: Dwayne Borkholder.

Figures 6 and 7. Phase-change materials can be used in the retrofitting of existing construction. Photos: Insulcorp.

point temperature of the building. The set-point temperature is the temperature desired for the building. Different PCMs or different formulations are used to provide different set-point temperatures.

- Choose the heat capacity of the material.—The energy modeling of the building will help determine the capacity of heat storage and heat release needed from the PCM. If too little heat capacity is specified, the PCM will not provide enough heating (or cooling). If too much heat capacity is specified, the PCM may interfere with the operation of the building's HVAC system.
- Choose the fire rating.—If a fire rating is needed for a certain wall or ceiling construction, PCM products are available with fire-rated coatings.
- Choose the permeability.—The membrane containing the macroencapsulated PCMs can be perforated to adjust the permeability of the material if needed.

CONCLUSION

Phase-change materials are useful as tools to increase the energy efficiency of post-frame buildings. By using latent energy to store heat in a relatively thin thermal mass, phase-change materials can be easily installed in walls or ceilings. Manufacturers of phase-change materials and dealers in these products can provide builders with more specific product information and tools to improve energy performance.

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