A Study of the Thermophysical Properties and Mathematical Modeling Techniques for Encapsulated Phase Change Materials for Use in Building Envelopes

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With rising energy costs, many owners and designers have searched for ways to cut overall costs of constructing and operating their buildings. A majority of the capital costs when a building is built is focused on the systems within the building, while the operating costs of a building are highly correlated to the building systems. With the majority of capital being spent on conditioning the building, it is important to study how the building itself can be improved to inherently create better system performance.

The advent of heating, ventilating, and air-conditioning (HVAC) control systems has led to better building efficiency and a more adaptive system, but, today, there is an added push to move toward a more "active" building. The idea is that the building will react to the surroundings, and if it is correctly harnessed, will drastically lower energy costs. A new technology that has been developed mainly in Europe and Asia over the past fifteen years is the use of phase-change material (PCM) as a building insulation.

While there are many ways to implement PCM insulation, the concept is all the same. As the PCM gains energy and, in turn, heats up, it acts as a normal material that energy conducts through. When the PCM reaches its melting point, it begins to change phase. During its melting process, it stores a high amount of energy while still conducting some energy through to the other side. This creates a thermal mass which slows the passage of heat. Once the amount of energy stored reaches the prescribed latent heat of fusion, the PCM will once again act as a normal material conducting energy. In theory, an "active" building in the summer will be more resistant to conduction through the walls at peak cooling hours than it would normally.

While there have been many attempts to test and model the PCM, most of the work has been conducted in government laboratories. This high scholarly work has produced accurate simulations and tests, but to the average consumer and HVAC engineer, this work is often complicated and inaccessible. Interest in the field of phase change materials in the research world has been growing over recent years, but few companies in the United States produce a PCM insulation. This has created a stagnation in the integration of PCM insulation in the construction field. The goal of this project was to accurately test the encapsulated InfiniteR PCM insulation to determine the thermophysical properties and to mathematically model the PCM in a cost effective way that current design engineers can replicate.

The thermophysical properties that are necessary to model the phase change insulation, InfiniteR, were found through a variety of experiments based on ASTM standards. The melting point of the InfiniteR insulation was determined to be 27 °C through the use of a TA Q20 Differential Scanning Calorimeter. Standard Differential Scanning Calorimetry was chosen as the best way to determine the latent heat of fusion and the heat capacity of the phase change insulation. The latent heat of fusion was determined to be 142800 J/kg. The heat capacity was determined as a function of temperature of the PCM using the TA Specialty Library and sapphire as a reference. The heat capacity for the solid, melting, and liquid regions of the PCM were determined to be

2100, 3200, and 1900 J/kg-°K, respectively. The graph of the heat capacity of the PCM as a function of temperature is shown below in Figure 1.

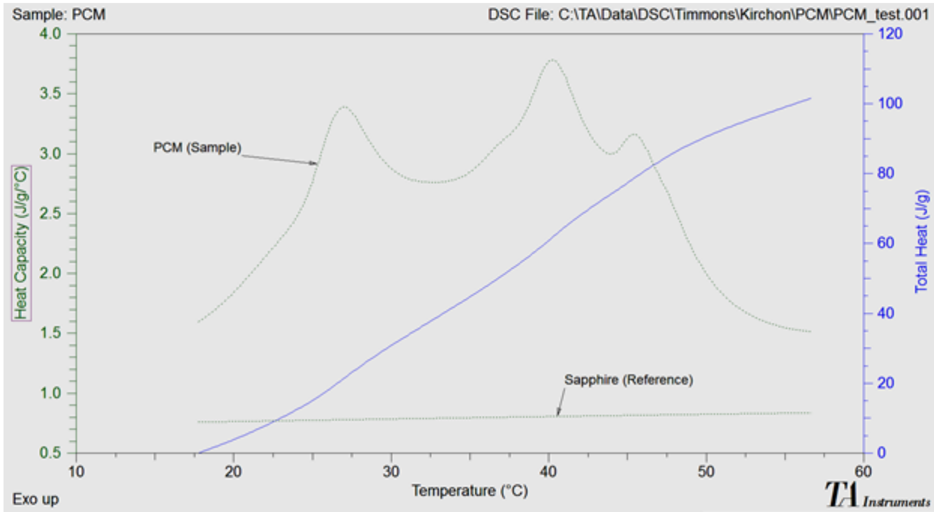

Figure 1: Heat Capacity (J/gm-℃) as a function of temperature (℃).

The thermal conductivity was determined based on a designed heat flow meter apparatus, and the properties were once again broken into three temperature regions. The thermal conductivity for the solid, melting, and liquid regions was 0.39, 0.35, and 0.43 W/m-°K, respectively. These three properties were used in an explicit lumped capacitance model that stepped through time to map the temperature of a composite wall using InfiniteR insulation. The results of this model are shown below in Figure 2 in a zoomed in view.

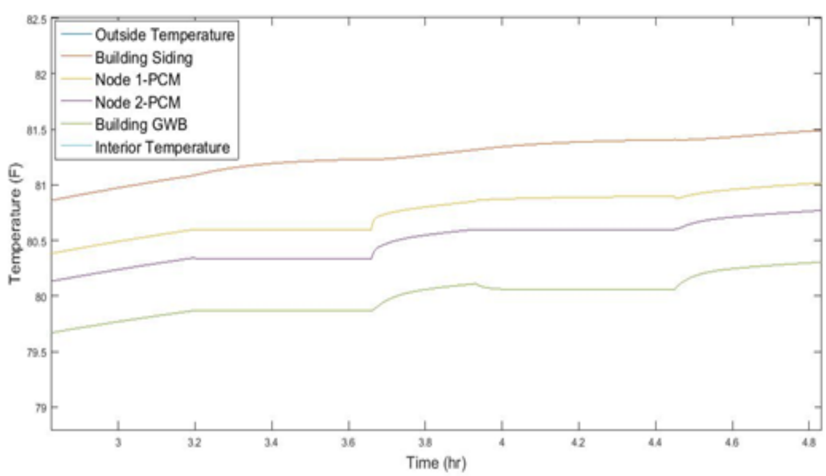

Figure 2: Temperature (℃) of PCM as a function of time (hr).

This model used multiple nodes to model the PCM so that conduction could be modeled in a lumped capacitance environment. This model gave insight into the use of PCM in a wall system in future building construction due to its reduction in the temperature of the interior node of gypsum wallboard over the time in which the PCM was melting.