Fat and Vegetable Oil Based Phase Change Materials

Renewable Alternatives has developed a range of phase change material (PCM) chemicals from bio-based fats and oils during a Phase 1 and II SBIR Program and made these PCM chemicals available for use in consumer products. PCMs are increasingly being used in heating, ventilation and air conditioning applications (HVAC) to reduce energy demands. Unfortunately, most PCM chemicals are currently derived from petroleum products. Our innovative, bio-based PCM chemicals are an environmentally friendly and renewable alternative to petroleum and salt-derived PCM products.

The term “phase change material” (PCM) is used to describe materials that use phase changes (e.g., melting) to absorb or release relatively large amounts of latent heat at relatively constant temperature. The most commonly used PCM is water/ice. Because ice takes in a LARGE quantity of heat when it melts, ice is very effective when used in a cooler to keep food or beverages at temperatures near water’s freezing point of 0 ºC. PCMs also find utility during pizza delivery where materials undergoing a latent heat transformation at ~65 ºC can be used to keep pizza warm. A few other applications of these materials include reducing the increased tendencies of bridges to freeze over during winter and socks that keep your toes warm longer.

The research on PCM is fairly widespread throughout the world, but only a modest number of peer-reviewed journal papers have been published. Most of the research to date has focused on the use of PCMs in small-scale applications, such as electronics enclosures.[i] Room-temperature PCMs (i.e., those with melting temperatures at 73-77°F) are increasingly being used in the construction and renovation of new state-of-the-art buildings in lieu of conventional insulation and wallboard. This latter, residential application is referred to as climate control. Because of the large amount of heat required to melt or freeze the PCM, interior spaces can be maintained at comfortable temperatures with far less energy.

Applications and Benefits of Phase Change Materials - Fats, oils and their commonly marketed derivatives are observed to melt near ambient temperatures. They have inherent properties that make them ideal for phase change materials between 0 and 110°C. Below 0°C, water and a vast number of water-salt and water-organic eutectics exhibit sharp latent heat transitions with high latent heats. Because of the increased potential for thermal degradation, applications above 110°C are less than ideal for fatty acid derivatives. Our research has a focus on development of PCM chemicals from fats and oils at temperatures between 0 and 110°C.

PCM chemicals are being incorporated into clothing to keep patrons warm,[ii,iii,iv] on computer chips to stop overheating[v] and in hot plates/containers to keep food/beverages warm. But by far the biggest applications are in heating,[vi,vii] ventilation and air conditioning (HVAC).

As indicated by Table 1, the amount of energy consumed in HVAC is about the same as the amount of energy burned in gasoline engines in the U.S. The HVAC industry represents a market potential in excess of 10 billion pounds of PCM chemicals per year.

Table 1. Summary of largest energy applications in U.S. Numbers are Energy in Quadrillion BTU

Amount of Gasoline Consumed	15
Electricity Produced	12
Approximate Energy Expended on Producing Electricity	34
Energy Consumed for HVAC (including hot water heaters)	14

For air conditioning applications, a 7-20°C PCM chemical[1] can be frozen during the night using a) cool nighttime air, b) evaporative coolers that are more efficient during the night, or c) air conditioners using less expensive off-peak electricity (The air conditioners also operate more efficiently at night time). During the day, rather than running the air conditioner, house air can be circulated next to the encapsulated phase change material to keep the house cool. Electrical costs are largely eliminated if you are able to use the evaporative cooler. Commercial buildings and some residences are able to get reduced electrical rates during the night. The Northern States Power Company Standard (residential) rate code A04 charges 3.27 cents/kWhr for off-peak (night time) electricity and 13.95 cents/kWhr for daytime electricity. In China, minimum off-peak electricity rates are widely available at one fifth the price of peak demand electricity.

For peak load shifting of electricity from day to night time, the A04 rate code of the Northern States Power Company provides a savings of 10.68 cents/kWhr or 0.002966 cents/Joule. For a 200 kJ/kg PCM chemical, this translates to 0.5933 cents/kg per cycle of use. A material that costs $0.50/lb ($1.10 per kg) would require 185 cycles to pay for itself. For an air conditioner application at 90 cycles per year, this represents a 2-year payback. Many commercial buildings (low surface area to volume ratio keeps in generated heat) use air conditioners for more than 250 days per year; *here the payback period is less than one year*. Payback periods double if encapsulation and installation doubles the PCM system costs. A demonstration project in Los Angeles used PCM storage to reduce air conditioning costs form $19,941 to $14,943 per month just though load shifting of air conditioner use.[viii] Equally excellent opportunities exist for heating applications. Our approach to commercializing PCM chemicals is to both produce better alternatives from fats and oils and to reduce the cost of placing the PCM chemicals in useful devices.

For commercial buildings, an optimal implementation strategy includes the following components:

1) Size (identified tonnage) the air conditioner based on the hottest day of the year but at a tonnage rating 30% to 50% lower than is necessary without PCM storage. Since the PCM chemicals allow the air conditioner to run at full capacity for 24 hours rather than full capacity for 8 hours plus about half capacity for the remainder of the day/night energy storage allows smaller air conditioners to be used.

[1] Here, high latent heat capacities between 7-20°C are preferred—lower temperatures decrease AC efficiency and higher temperatures increase heat exchange and air circulation costs. Chilled water is a great and proven alternative for campus/network applications, but for commercial or residential buildings, use of PCM devices is preferred (lower maintenance)!

2) Use the energy storage potential of the PCM device to its full potential for peak load shifting for most of the commercial building air conditioning season. and
3) Avoid air conditioner costs during part of the commercial air conditioning season when the nighttime outside air is sufficiently cold to freeze the PCM without air conditioner operation.

For many large commercial buildings, low surface area to volume ratios combined with the generation of heat from electronics and people in the building mandate the use of air conditioning even during some winter months—during many Fall, Winter, and Spring months the nighttime coolness is sufficient to charge/freeze the PCM chemical for use during daytime hours. For these commercial applications, PCM-assisted air conditioning has the following advantages: 1) reduced air conditioner tonnage requirements with associated reduced capital and maintenance costs, 2) substantial peak load shifting resulting in use of more efficient base load electrical power, 3) more efficient air conditioner operation during the cooler night temperatures, and 4) elimination of air conditioning when nighttime temperatures are sufficient to freeze the PCM chemical (without air conditioner operation). Furthermore, PCM energy storage can extend the utility of evaporative coolers to meet cooling requirements and of heat pumps to meet heating requirements.

HVAC applications have far-reaching benefits. If the 700,000 MW of electrical power generating capacity in the U.S. were operated at full load continuously, it would produce 6.1 billion MWhr of power every year. Instead, the U.S. generates only 3.4 billion MWhr each year because of the cyclic nature of electrical power demand. Nevertheless, during past summers the U.S. experienced shortages of electricity across the nation from San Diego to New York. Even though we have nearly twice as much capacity as required by total annual power consumption, we are unable to meet peak power consumption during the summer. Furthermore, the most inefficient of the peak demand electrical power systems are only about 50% to 70% as efficient as the base load systems—unnecessarily producing vast quantities of carbon dioxide and burning large quantities of natural gas or petroleum. The use of PCM devices is the best solution for reducing electrical power costs and reducing greenhouse gas emissions.

When all's said and done, HVAC applications of PCM chemicals can achieve the following goals: 1) save consumers money, 2) substantially reduce carbon dioxide emissions,[ix] 3) reduce reliance on imported crude oil (heating oil), and 4) stabilize fat and oil prices at more than $0.30 per pound. The use of PCM chemicals for load-shifting of electricity is debatably the best method to reduce greenhouse gas emissions in the U.S. to levels lower than those of 1990.[x] Load shifting using thermal energy storage (such as PCM devices or chilled water) is the predominant (if not only) means of load shifting that has a load-shifting *efficiency that approaches 100%*.

[i] Marongiu, M.J., and Clarksean, R., "Thermal Management Of Electronics Enclosures Under Unsteady Heating/Cooling Conditions Using Phase Change Materials (PCM)," to be presented at 32nd Intersociety Energy Conversion Engineering Conference, Honolulu, HI, July 27-Aug.1, 1997.

[ii] See http://www.pcm-solutions.com/coolinggloves.html.

[iii] See http://www.outlast.com.

[iv] See http://www.conserval.com.

[v] Marongiu, M.J., and R. Clarksean. "Thermal Management Of Electronics Enclosures Under Unsteady Heating/Cooling Conditions Using Phase Change Materials (PCM)," to be presented at 32nd Intersociety Energy Conversion Engineering Conference, Honolulu, HI, July 27-Aug.1, 1997.

[vi] Abhat, A. "Low Temperature Latent Heat Thermal Energy Storage: Heat Storage Materials," Solar Energy, Vol. 30, No. 4, 313-332, 1983.

[vii] Silvetti, B., and M. MacCracken. "Thermal Storage and Deregulation," ASHRAE Journal, April, 1998.

[viii] *Energy-Wise News*, Sept. 1998.

[ix] Suppes, G. J., S. Lopes, and M. Goff. "Phase Change Materials from Fats and Oils," Bioenergy'2002 Proceedings, Paper 2062, Published by Pacific Regional Biomass Energy Program, Boise, Idaho, 1-5, September, 2002.

[x] Suppes, G. J., M. J. Goff, and S. Lopes. "Use of Renewable Phase Change Materials to Reduce Carbon Dioxide Emissions," Proceedings of The 6th Annual Green Chemistry and Engineering Conference, An American Chemical Society Publication, Washington, D.C., 1-4, 2002. Available online at http://www.missouri.edu/~suppesg/CO2.htm.