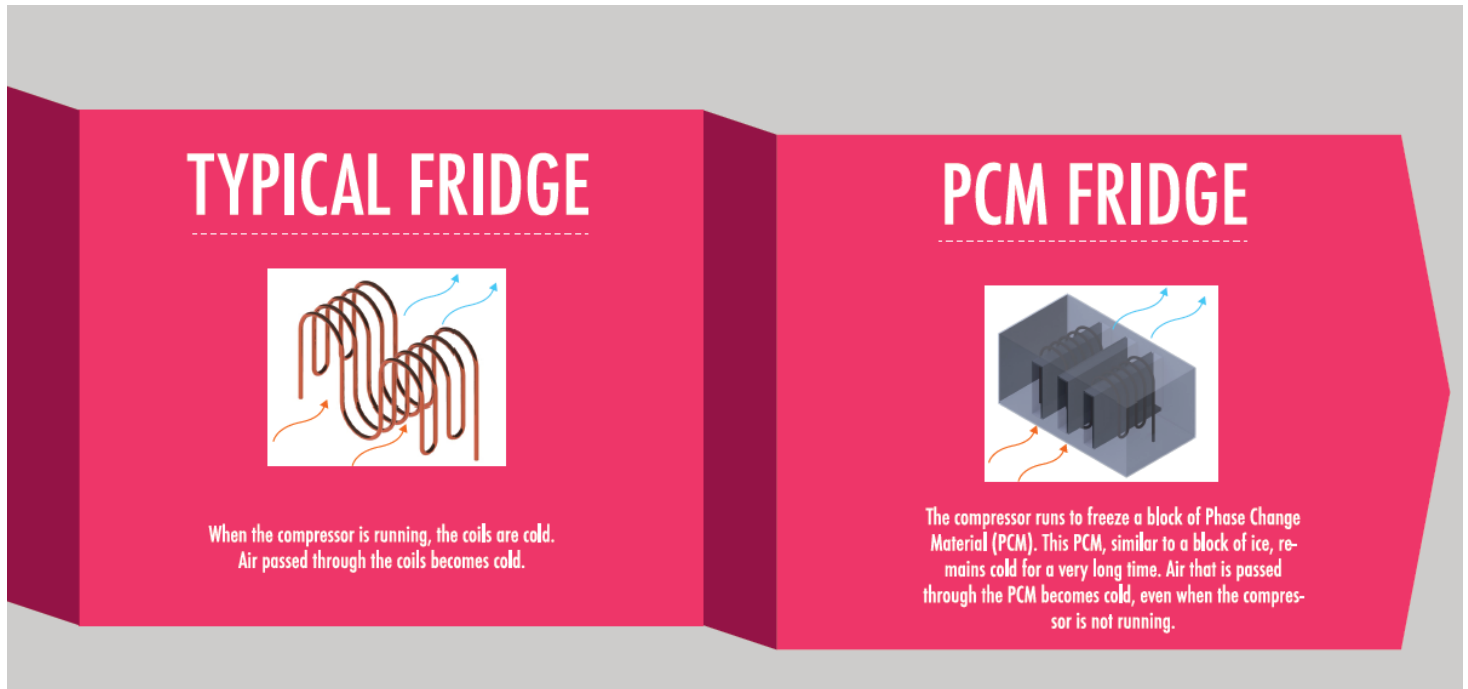


Energy Efficiency Assumptions and Calculations

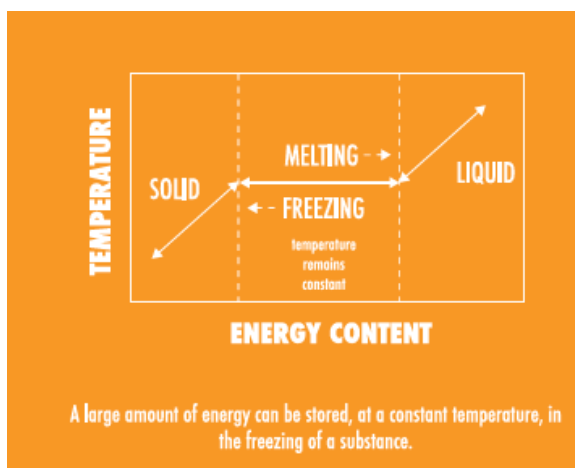
Ecofridge, UC Berkeley

Typical Refrigerators vs. Phase Change Materials:

A typical fridge operates by moving air over the evaporator coils, which are at a low temperature. In order for the coils to be cold, the vapor compression cycle must be running.



By contrast, the Ecofridge uses Phase Change Materials (PCMs) to store energy from a standard vapor compression cycle. A large amount of energy can be stored, at a constant temperature, when you freeze a substance. The cold thermal energy stored in the PCM can then keep the coils cold for a designed amount of time (1 day).



This means that the vapor compression cycle only needs to run once a day to freeze the phase change material, which will then stay cold for the remainder of the day.

Benefits of using Phase Change Materials

Running the compressor once per day provides some small advantages:

- Energy is often cheaper at night time.
- Food stays at a more constant temperature (See Talupurkar, 1).
- The refrigerator will be essentially silent during the day (the fan will still blow when cold air is needed but the compressor will never kick on).

In addition, there is one major benefit to running the compressor once per day. The compressor can be run only at night when the ambient air, especially outside, is cooler. As a result, the temperature difference across which the vapor compression cycle can be reduced dramatically, providing significant energy savings.

In order to get the biggest benefit, the fridge would need to effectively tap into the cooler outside air. The installation of the requisite vent would be very similar to the installation of a fume hood above a stove that vents to the outside, or a clothes dryer that exhausts to the outside.

The additional hardware needed is minimal (PCM reservoir and air vent), and the refrigerator operation is nearly identical to that of a traditional fridge, making adoption of this new technology easy from both a user interface and maintenance point of view.

Calculations:

Baseline energy use phase energy (per day):

The fridge, as modeled, has an interior space of about 22 cu. ft., of which about 6 cu. ft. is freezer space. The [US EPA Energy Star](#) standard for energy use for this type of refrigerator is 462 kWh/year (refrigerator/freezer with active defrost; no through-door ice maker, bottom mount freezer).

Amount of Phase Change Material Needed:

Assume a current refrigerator uses about 400 kWh of electricity a year on average and has a coefficient of performance (COP) of 1. This means that current refrigerators remove 400 kWh of thermal energy a year, or about 1.1 kWh of thermal energy a day.

Assuming that our PCM has a latent heat similar to that of water, the latent heat of melting is 334 kJ/kg. The PCMs need to store enough energy to last an entire day, so it has to have about 1.1 kWh of thermal energy stored in it. Note that 1 kWh = 3600 kJ. So, we need to store $1.1 \text{ kWh} * 3600 \text{ kJ/kWh} * 1 \text{ kg ice} / 334 \text{ kJ} = 12 \text{ kg}$ of ice.

Assuming the density of the PCM fluid is similar to that of pure water, which is about 915 kg/cubic meter, the volume of the PCM will be about $12 \text{ kg} * 1 \text{ m}^3 / 915 \text{ kg} * 1000 \text{ L/m}^3 = 13 \text{ L}$.

A 20 L is a slab about two feet wide (about the width of a fridge), 1 foot tall (fits within the height of the freezer), and 4 inches thick. So, you only lose 4 inches out of the back of your freezer.

This agrees with Azzouz (2), who used 10L of phase change material which lasted 17 hours a day, indicating about 15L would be needed to last 24 hours, but the actual amount depends on many factors (such as how often the person opens the door).

Energy Savings from Nighttime Operation:

The theoretical max COP is for current refrigerators is $COP_{theoretical} = T_{cold}/(T_{hot} - T_{cold})$.

Assuming that: $T_{cold} = 255$ K (the temperature of a freezer is about -20 C) and $T_{hot} = 293$ K (about room temperature, 20 C), $COP_{theoretical} = 6.5$.

Assuming that the condenser uses outside air at night-time through a hose, T_{hot} is decreased from 20 C to about 6 C (seasonally averaged in Mexico City - from weather data). Now, at nighttime, $COP_{theoretical} = 10.6$.

Current refrigerators achieve a COP of about 1 during the day. Assuming that the design achieves the same percentage of the theoretical maximum, the COP at nighttime is $10.6 * 1/6.5 = 1.65$.

Based on these simple assumptions, the COP achieved is 65% higher than conventional refrigerators. So the amount of energy needed per year with the PCM fridge is: $(462 \text{ kWh/year})/1.65 = 280 \text{ kWh/year}$.

As a result, the energy savings is about 40%.

$(280 \text{ kWh/year} - 462 \text{ kWh/year})/ 462 \text{ kWh/year} = 39.4 \%$

Challenge Questions:

1. Assuming that electricity costs 12 cents per Kilowatt hour, how much money would the end user save over a 15 year lifespan of the refrigerator.
2. If the refrigerator were operated in a colder climate, would it make more or less sense to use a phase-change material?
3. If the air temperature was only 5 degrees Celcius cooler at night, how much energy would you save per year by only operating the compressor at night?
4. In terms of CO₂, how long is the payback period of purchasing a new EcoFridge? In other words, assuming your fridge uses the typical amount of energy, and you replaced it with an EcoFridge, how long would it be before the CO₂ savings from reduced energy use would equal the CO₂ required to manufacture the fridge?

Works Cited

1. Talupurkar, C., et al. "Phase Change Materials for Domestic Refrigerators To Improve Food Quality and Prolong Compressor Off Time" (2010). International Refrigeration and Air conditioning Conference. Paper 1044.
2. Azzouz, K., et al. "Improving the energy efficiency of a vapor compression system using a phase change material," Second Conference on Phase Change Material and Slurry: Scientific Conference and Business Forum, 15-17 June 2005.