USE OF PHASE CHANGE MATERIALS IN RETAIL DISPLAY CABINETS TO REDUCE THE EFFECT OF DEFROSTS

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ABSTRACT

Phase change materials (PCMs) have the potential to reduce temperature fluctuations in retail display cabinets. There are several areas where reducing temperature fluctuations may be beneficial, e.g. minimising effects of defrosts and to damp the day/night variation in refrigeration duty.

PCMs were placed below the shelves in a closed door multi-deck cabinet with the aim of reducing temperature fluctuations during defrosts. The cabinet was tested in a test room conforming to the EN23953 test standard (climate class 3). The cabinet was tested with and without the PCMs. No measurable effect for the PCMs was found.

A finite difference model was used to explain the results and suggest improvements. Predictions showed the problem was due to the limited heat transfer coefficient, surface area and low thermal conductivity of the PCM.

1. INTRODUCTION

The refrigeration load on a retail cabinet is not steady, it changes with time. Regular defrosts, door opening, unloading and loading of product and day/night variation will all effect refrigeration load. There will be peak hours of shopping, where there is a higher frequency of usage/door opening, loading and unloading of product. During the night, ambient temperature in the store may be reduced, lights may be turned off or dimmed and night covers pulled down on open fronted cabinets. Peaks in refrigeration load mean that refrigeration capacity needs to be higher than if the load was stable. If the cabinet cannot extract the heat added, product temperatures can rise. This is especially the case during off-cycle (passive) defrosts, where there is no refrigeration for a time, resulting in particularly high heat loads for short periods of time directly after the defrost.

Increase in product temperature during defrost will reduce the quality and shelf life of the products. To maintain quality and shelf life, refrigeration systems need to run at a lower average temperature to provide a thermal buffer for the period immediately after defrosts. This results in the refrigeration system using more energy than if there was a constant load.

Alzuwaid *et al*. (2015) added water-gel based PCM ‘radiators’ (−2.0°C phase change temperature) placed just after the evaporator coil of a refrigerated display cabinet and showed that they could save energy (5%) and reduce the cabinet air temperature.

Gin *et al*. (2010) investigated the effects of PCM systems on domestic freezers. They used a low temperature PCM (−15.4°C phase change temperature) for storage of frozen foods in a domestic freezer. They showed beneficial effects in minimising temperature variations inside the freezer. They also showed decreased energy consumption during a defrost cycle by 8%, and by 7% during door openings, when using PCMs.

Marques et al (2014) showed a slab of 5 mm thick PCM allowed a larger more efficient compressor to be used in a domestic refrigerator by reducing stop/start events.

The recent energy saving trend in supermarkets is to fit doors on chilled cabinets (Evans, 2014). This allows maximum temperatures to be maintained whilst raising minimum temperatures. A water based PCM is therefore not adequate for these types of cabinets as the air temperature will rarely be at 0ºC or below. Another advantage of using a PCM above 0ºC is that it will not need defrosting.

High temperature (>0ºC) PCMs are available in two main groups; organic and inorganic. Inorganic PCMs can either be metallic or salt hydrates. Metallic PCMs have very low latent heat per mass. Salt hydrates often have incongruent melting and poor nucleating properties. Organic PCMs can be classified as paraffin and non-paraffin. Paraffin wax is safe, reliable, predictable, less expensive and non-corrosive and can be selected at many different melting temperatures (Sharmaa *et al*, (2009).

Evans *et al* (2007) analysed a number of refrigerated cabinets and showed that warmest temperatures occurred at the front of 94% of the chilled full door cabinets. Therefore reducing temperature deviation at the front of the cabinet is of more benefit than elsewhere.

In this study paraffin wax PCMs were placed at the front of the shelves in a closed door multi-deck cabinet and tested to the EN23953:2005 standard. These results were compared to the same test without the PCMs. A numerical model was used to explain the results and investigate potential improvements.

2. METHOD

2.1. PCM

Two types of paraffin based PCM were used, RT6 and RT6HC. The enthalpies at different temperatures for the two PCMs are shown in Figure 1 (RT6) and Figure 2 (RT6HC). The thermal conductivity of both phases for both RT6 and RT6HC was 0.2 $W.m^{-1}.K^{-1}$.

The PCM needed to be contained. It was important that the container was adequately sealed whilst minimising air gaps that would reduce heat transfer. The PCM was packaged into plastic boxes using the following method. PCM was poured into plastic vacuum sealed bags. The bags were placed in a freezer until the PCM had frozen. The bags were vacuum sealed and the PCM was allowed to thaw. The bags were then placed into the boxes and the lids sealed onto the top of the boxes using tape.

It was important to keep the PCMs thin to maximise surface area and increase their effect, therefore thin boxes were chosen. Two sizes of boxes were used; 210 x 100 x 30 mm and 100 x 100 x 35 mm (with 1.5 mm wall thickness). The larger box contained 350 g of PCM, the smaller box contained 175 g.

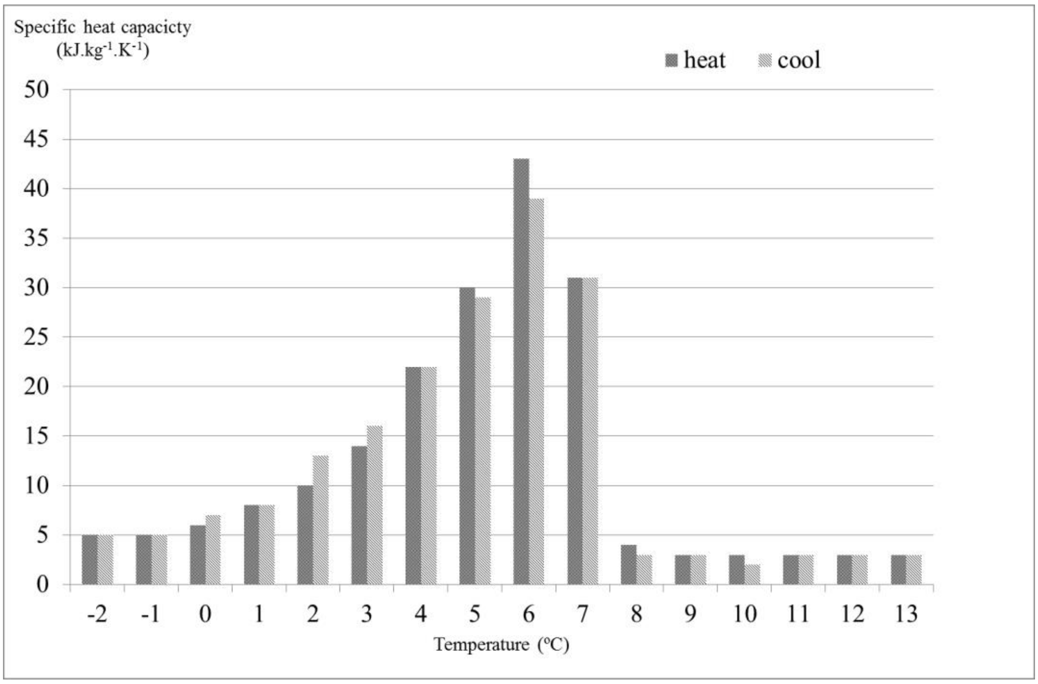

Figure 1. RT6 enthalpy data.

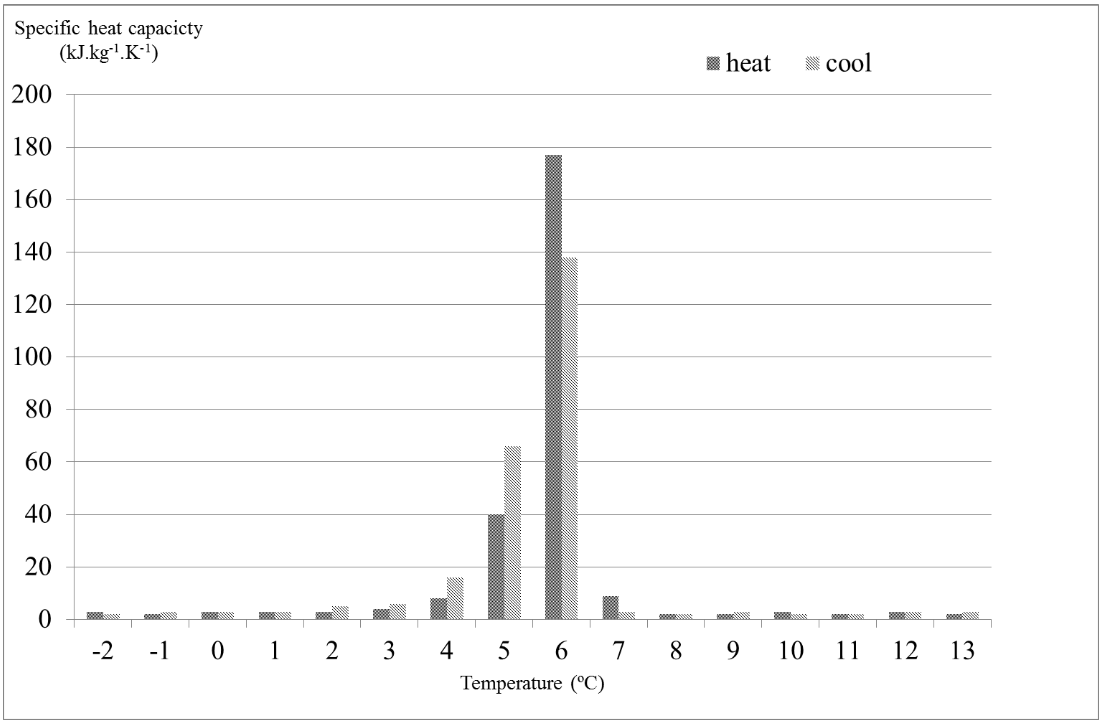

Figure 2. RT6HC enthalpy data.

2.2. Test method

The cabinet used for the test was an Epta full glass door remote cabinet which was connected to an R404A refrigeration system. The cabinet had an off-cycle (passive) defrost with 10 hours between defrost. Ten of the large boxes and two of the small boxes were attached to the front underside of each of the 4 shelves as shown in Figure 3. The RT6 was put on the left side shelves and the RT6HC on the right side shelves. There was a total of 30.8 kg of PCM (50/50 split of RT6 and RT6HC) in the cabinet.

The cabinet was loaded with Tylose test packs (as specified in EN23953:2005) at the edges and centre of the cabinet (regions of temperature measurement) and polyurethane foam elsewhere. The test packs and polyurethane foam were in rows of 200 mm width. The reason for not loading the cabinet completely with

Tylose test packs was to reduce the thermal load on the cabinet to better see the effect of the PCMs. The total mass of Tylose test packs was 158.125 kg.

The cabinet was tested in a test room conforming to the EN23953:2005 test standard at climate class 3 (25ºC and 60% RH). Temperatures were measured by t-type thermocouples inserted in Tylose tests packs (‘m’ packs) at the extremes of the cabinets. The cabinet was tested over a 12 hour period with the lights switched on and the doors closed.

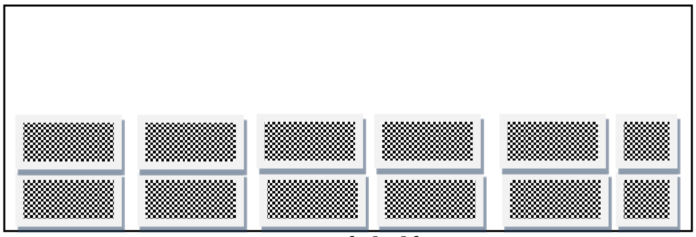

Figure 3. Layout of PCMs on the underside of a shelf.

2.2. Numerical model

A finite difference model as described in Evans *et al* (1996) was used to predict the transient temperature profile of the PCM and also of the Tylose packs. The thermal properties (specific heat capacity and conductivity) of the PCM (RT6HC) were taken from the manufacturer’s datasheet. For the Tylose, specific heat capacity was taken from the EN23953 test standard and the thermal conductivity was that of lean beef. The model assumed that the PCM was an infinite slab of 25 mm thickness, one side of the slab had a heat transfer coefficient of 10 $W.m^{-2}.K$ (air velocity of approximately 1 $m.s^{-1}$) and was exposed to the air temperature and the other side was insulated. The model was divided into 12 nodes of equal thickness except for the outer nodes which were half thickness.

3. RESULTS

3.1. Test results

Figure 4 shows maximum, minimum and mean ‘m’ pack temperatures with and without PCMs. The PCMs were not found to damp the transient fluctuation in temperatures as was expected even though the maximum temperature packs were within the phase change temperature of the PCMs.

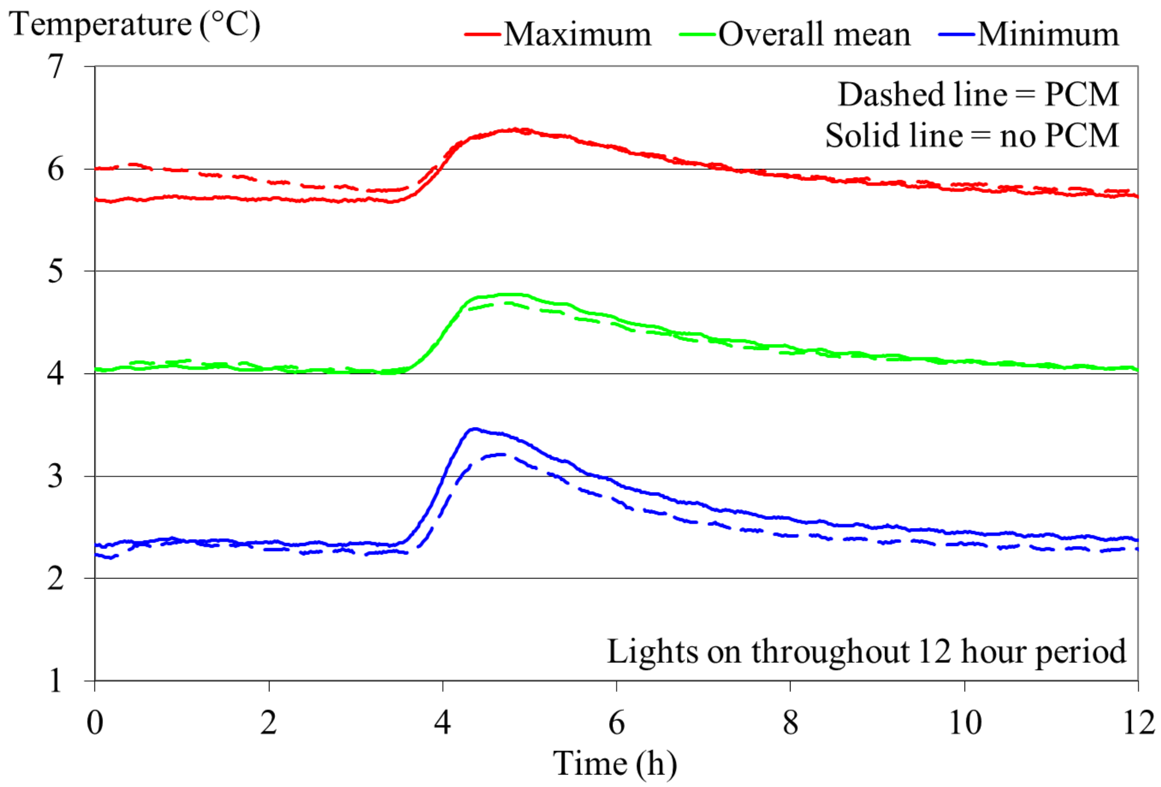

Figure 4. Maximum, minimum and mean 'm' pack temperatures for the first 12 hours of the test with PCMs and without PCMs.

3.1. Finite difference results

A finite difference model was used to predict the change in temperature of the Tylose packs and PCMs during defrosts. An approximation of the air temperature profile (not including the fluctuations outside of the defrost) to be used in the model was taken from the measured data of one of the air return probes during a defrost (Figure 5).

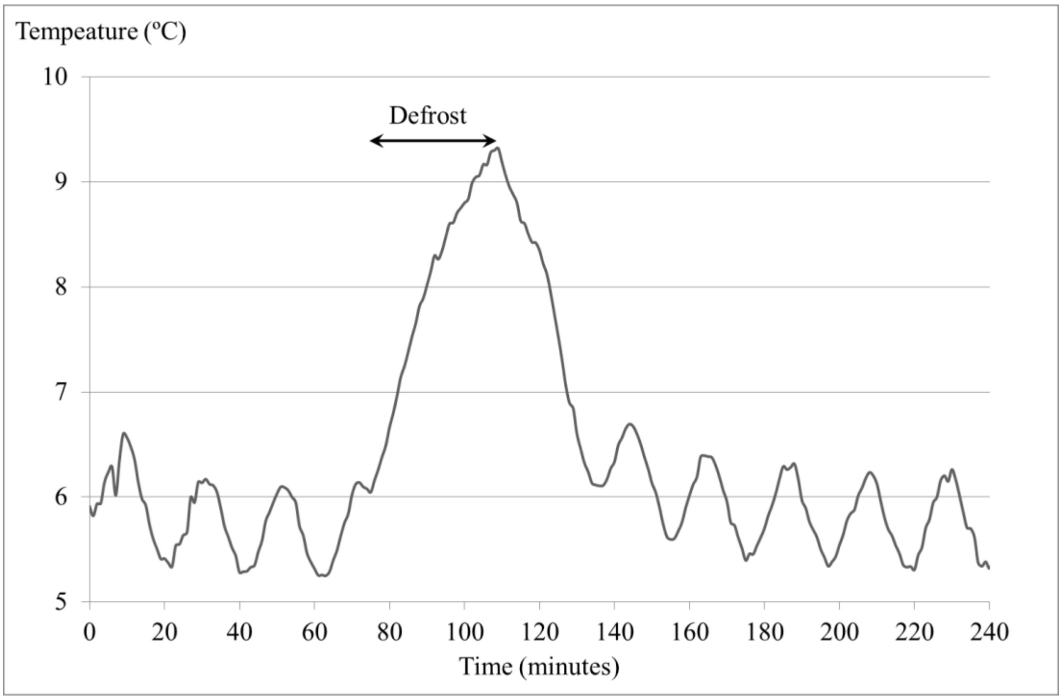

Figure 5. Measured air temp before, during and after defrost

Figure 6 shows predicted temperature during a defrost and afterwards for the Tylose packs. T1 refers to the node closest to the surface exposed to the air, T2 is the next node etc. The predicted surface temperature of the Tylose rose by 0.85ºC. The predicted centre of the Tylose rose by 0.6ºC, which is similar to that measured, 0.7 ºC (Figure 4).

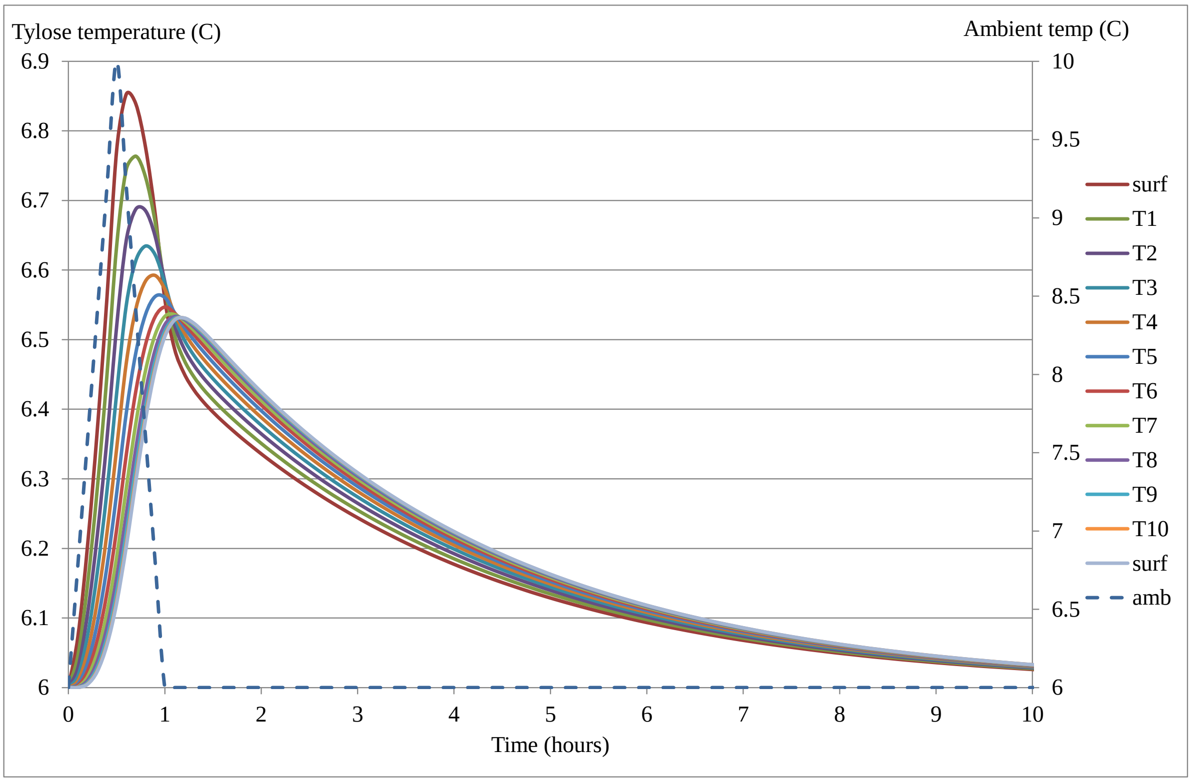

Figure 6. Predicted Tylose temperature during a defrost. Ambient temperature is plotted according to scale on the right.

Figure 7 shows the same predictions for the RT6HC PCM. It can be seen that the surface of the PCM only rose by 0.24ºC. The reduced temperature rise of the PCM compared to the Tylose pack is due to its latent heat.

The model predicted that the PCM absorbed 3.47 $kJ.kg^{-1}$ during the defrost compared to the Tylose which absorbed 1.98 $kJ.kg^{-1}$. Therefore the PCM absorbed 75% more energy than the Tylose in the same conditions. As RT6HC has a melting specific heat capacity of 177 $kJ.kg^{-1}.K^{-1}$ at 6ºC, this shows that only a small amount of the PCM is melting during the defrost.

Based on the predicted energy absorbed by the PCM during a defrost (3.47 $kJ.kg^{-1}$), if we wished to absorb all of the heat load during a defrost which the refrigeration system cannot do, because it is off (2 kW x 40 minutes x 60 seconds = 4.8 MJ), we would require 1383 kg of PCM. As the cabinet would only take approximately 1160 kg of Tylose when fully loaded (this is a much higher load than when in a store), this loading is not feasible. As the specific heat capacity of RT6 was much lower at 6ºC than RT6HC, the amount of heat absorbed by this PCM would clearly be even lower, requiring even more PCM to damp the defrost.

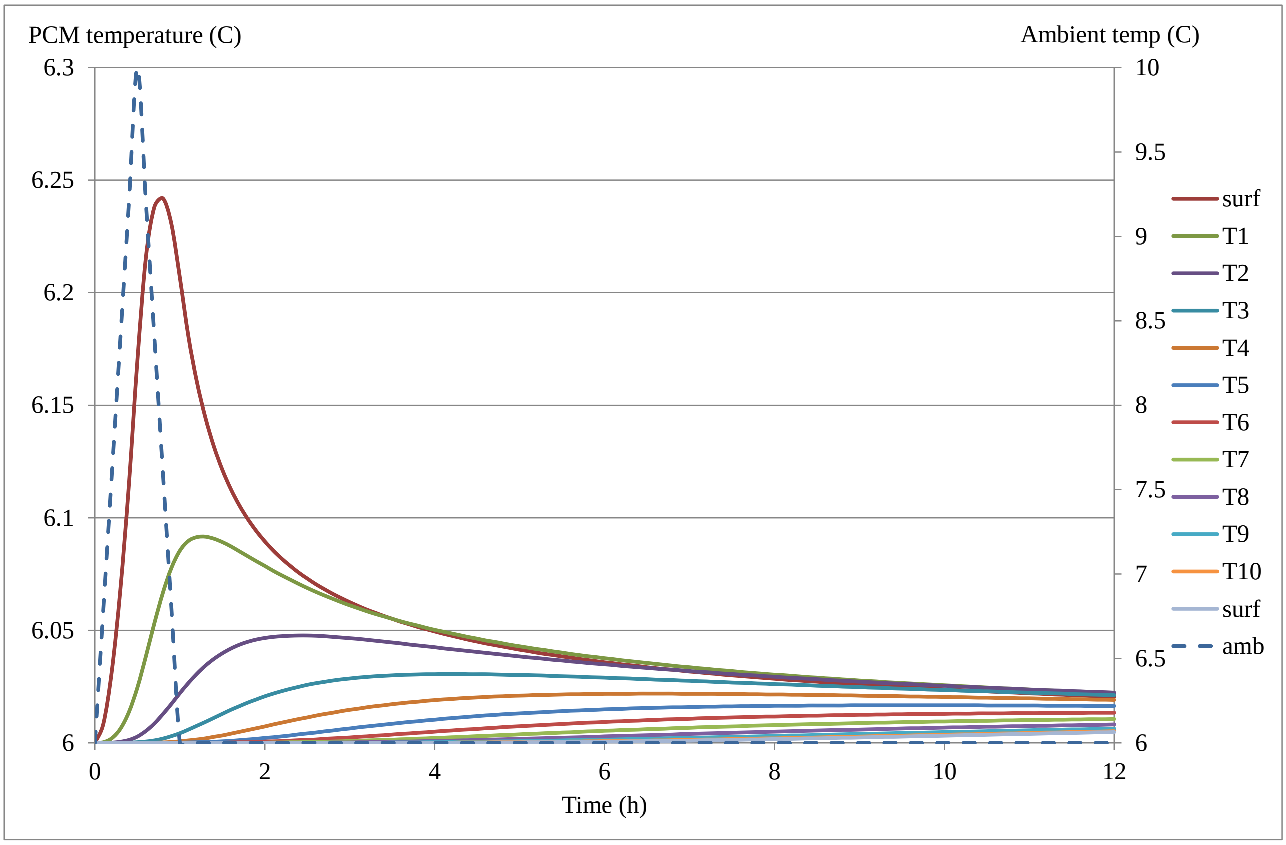

Figure 7. Predicted PCM temperature during a defrost. Ambient temperature is plotted according to scale on the right.

Ji *et al* (2014) showed that it was possible to increase the conductivity of a PCM by 18 times by embedding continuous ultrathin-graphite foams. The finite difference model was used to see the effect of increasing the conductivity from 0.2 to 3.6 $W.m^{-1}.K^{-1}$. At the end of the defrost, the energy absorbed is only 3.7% higher than the RT6HC PCM (3.60 $kJ.kg^{-1}$). The reason for this is that the surface temperature of the PCM rises a very small amount for both the low and high conductivity PCM. Therefore the temperature difference between PCM surface and air is very similar for both cases. As the amount of heat absorbed is proportional to the temperature difference between air and surface, there is consequently very little difference in the amount of heat absorbed.

Another way to increase the effectiveness of the PCM would be to increase its surface area, by making the PCM thinner. To absorb the energy of the defrost would require the surface area exposed to the air to increase by 8.7 times by using PCMs of thickness 3 mm. This extra surface would take up more than the interior surface area of the cabinet (shelves, side walls, back panel), therefore the extra surfaces would need to be in layers, with air blowing through the layers.

Another option would be to embed high conductivity fins into the PCM. If we added fins to one surface of the PCM (1 fin per 5 mm, 10 mm high) and assumed a fin efficiency of 1, we could increase the surface area by 3. This has the same effect as increasing the heat transfer coefficient by a factor of 3. The finite difference model was used to predict the effect of this. At the end of the defrost, the energy absorbed was predicted to be 8.97 $kJ.kg^{-1}$. This is 2.5 times higher than RT6HC without fins. The benefits of a high conductivity PCM would be greater when used in conjunction with the finned PCM.

Placing the PCMs in an area of higher heat transfer coefficient, e.g. higher air velocity, would have a similar effect than adding fins. The highest air velocity region would be within the duct. However, care would need to be made to not detrimentally affect the air flow exiting the duct.

4. CONCLUSIONS

Paraffin PCMs placed on the front of shelves of a glass doored refrigerated cabinet were shown to have no measurable effect in damping air temperature rise during defrost. The limited surface area and heat transfer coefficient of the PCMs meant that the PCM was not effectively used.

It is possible to get more effective use of the PCMs by the following methods.

- Increase the surface area of the PCMs by having it in layers, with the air blowing through the layers.
- Add finning to the PCM.
- Increase the thermal conductivity of the PCM. This is only required if the surface heat transfer is also increased.
- Increase the heat transfer coefficient. This could be done for example by putting the PCMs in a region of higher air velocities, e.g. in the rear duct of the cabinet.
- Eutectic PCM. A eutectic PCM will change phase at a constant temperature releasing all of its latent heat before it changes temperature. Eutectics were not found to be available for this temperature range, but it may be possible to source PCMs which release more latent heat over a smaller temperature range.

Increasing the surface area, adding finning and increasing the effectiveness of the PCM by increasing its thermal conductivity or reducing the range in temperature at which melting occurs would be required to effectively damp the temperature fluctuation during a defrost.

5. ACKNOWLEDGEMENTS

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