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Experimental Investigation of Performance Improvement of a Domestic Refrigerator Using Phase Change Material

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Abstract : This study aims to investigate the performance improvement provided by a Phase Change Material (PCM) associated with the evaporator in a domestic refrigerator. The heat release and storage rate of a refrigerator depends upon the characteristics of refrigerant and its properties. The usage of PCM as thermal storage will help to improve the coefficient of performance(COP) of new refrigeration cycle by introducing a new PCM heat exchanger. The experimental results showed that the usage of PCM exemplifies the improvement of the system coefficient of performance considerably. Using PlusICE A4 as PCM, reduced the number of compressor on-off cycles within a certain period significantly compared to without PCM. It is indicated that the novel refrigerator could save energy by 18% approximately and the coefficient of performance of the conventional refrigerator increased by 8%.

keywords :**phase change material , domestic refrigerator**

1. Introduction :

Thermal energy storage (TES) is defined as the temporary holding of thermal energy in the form of hot or cold substances for later utilization [1]. Energy demands vary on daily, weekly and seasonal bases. These demands can be matched with the help of TES systems that operate synergistically, and deals with the storage of energy by cooling, heating, melting, solidifying or vaporizing a material and the thermal energy becomes available when the process is reversed. TES is a significant technology in systems involving renewable energies as well as other energy resources as it can make their operation more efficient, particularly by bridging the period between periods when energy is harvested and periods when it is needed. That is, TES is helpful for balancing between the supply and demand of energy [1,2]. TES systems have the potential for increasing the effective use of thermal energy equipment and for facilitating large-scale fuel commutating [2]. The selection of a TES system for a particular application depends on many factors, including storage duration, economics, supply and utilization temperature requirements, storage capacity, heat losses and available space [3]. PCMs are either packaged in specialized containers such as: tubes, shallow panels, plastic bags; or contained in conventional building elements such as: wall board and ceiling; or encapsulated as self-contained elements [1,3]. The aim of this chapter is to provide a compilation of practical information on different PCMs and systems developed for thermal management in residential and commercial establishments based on TES technology in building integrated energy system.

1.1. Using PCM as heat exchanger to release heat from evaporator

In conventional system the heat releasing environment for evaporator is usually air but using a Phase Change Material (PCM) surrounding the evaporator coil ,,,,[4,5]work as a liquid or solid medium to release the heat. PCM is touched with the evaporator coil the stored heat energy of PCM will be extracted by the refrigerant through conduction method during compressor on mode. The conduction heat transfer is faster than the natural convection heat transfer [6]. In the conventional refrigerator the cabinet heat is extracted by the refrigerant through natural convection. So the PCM will improve the heat transfer performance of the evaporator as we see in figure 1.

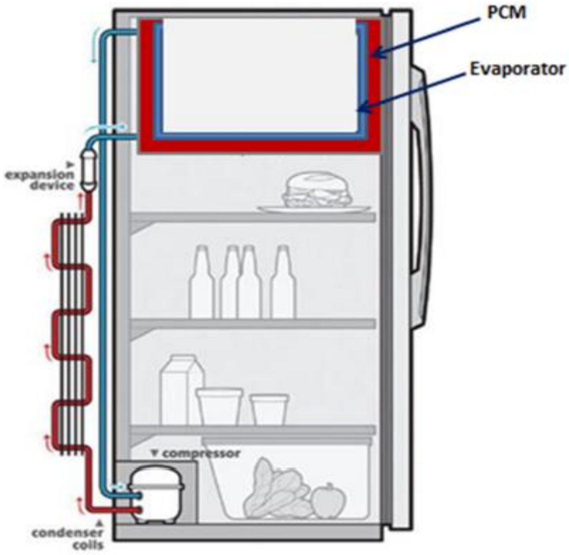

Figure 1. Refrigerator integrated a PCM as heat exchanger

A PlusICE with a phase change temperature of 4°C was used as the PCM because this temperature is close to the food storage temperature of 4°C.The used PCM is Organic material tend to be polymers with long chain molecules composed primarily of carbon and hydrogen[7]. They tend to exhibit high orders of crystallinity when freezing and mostly change phase above 0°C. Examples of materials used as positive temperature organic PCMs include waxes, oils, fatty acids and polyglycols[8 ;9 ;10]. The Table 1 depicts the thermo-physical properties of the used PCM.

Material	Name	Type	Form	Melting Temperature°C	Latent heat of fusion (kj/kg)	Density (kg/m^3)	Thermal Conductivity (W/mK)	Specific heat (kj/kg.K)
A4	PlusICE	Organic	Bulk	4	200	766	0.21	2.18

Tab1. Thermo-physical proprieties of the PCM[11]

1.1.1. Experimental Methodology

A conventional household refrigerator is used in the modified form with the PCM heat exchanger located behind the evaporator cabinet as shown in Figures 3.1 and 3.2 . The experimental set up involves a refrigerator, two pressure gauges, five thermocouples, a PCM heat exchanger, and a data acquisition system. The PCM box is made by copper tubes sheet having 6 mm radius, which is 0.4 m width, 0.14 m height, and 0.26 m depth. The evaporator cabinet box of outer volume 0.01456 m3 with cooling coil is inserted into the empty PCM box of internal volume 0.014 m3. The detailed design of the PCM heat exchanger is shown in Figure 3.4. The novel heat exchanger consists of twelve adjacent U-type tubes. Linear length of each tube: 0.54 m. Internal and external diameter of each tube: 0.00635 m and 0.007 m, respectively; Material of the tubes: Copper tube. The placement of the PCM heat exchanger can be seen in Figure 3.4 . Figure 3.3 shows the detailed circuitry of the setup. The modified PCM-based refrigerator has a single evaporator cabinet with a single door.
The following are the major technical specifications of the refrigerator:

- *Cabinet: Internal volume, 0.01456 m3*
- *Evaporator: Mode of heat transfer-natural convection;*
- *Condenser: Mode of heat transfer-natural convection;*
- *Compressor: Hermetic reciprocating compressor, HITACHI FL 1052- SK, 13 FL 220–*

230 V, 60 Hz

- *Expansion device: Capillary tube (internal diameter 1 mm)*
- *On/off control and self-defrost*
- *Refrigerant: Tetrafluoroethane (R-134a)*
- *Voltage: 220V/60Hz.*
- *Dimensions (mm) H1060 x W550 x D540*

1.1.1.2 Experimental results

1.1.1.3 Evaporator temperature

Figure 2 shows the comparison of the evaporator midpoint temperatures. For the ordinary refrigerator, the evaporator midpoint temperature ranged from -16 ^{o}C to -3.5 ^{o}C and the average evaporator midpoint temperature was -10 ^{o}C over a whole cycle. For the novel refrigerator, the evaporator midpoint temperature was from -12.5 ^{o}C to -3.5 ^{o}C and the average evaporator midpoint temperature was -8 ^{o}C. Obviously, the evaporator midpoint temperature of the novel refrigerator varied in a smaller range. It indicated that the lowest evaporator midpoint temperature and the average evaporator midpoint temperature of the novel refrigerator were higher than that of the ordinary refrigerator by about 3.5 ^{o}C and 2 ^{o}C, respectively.

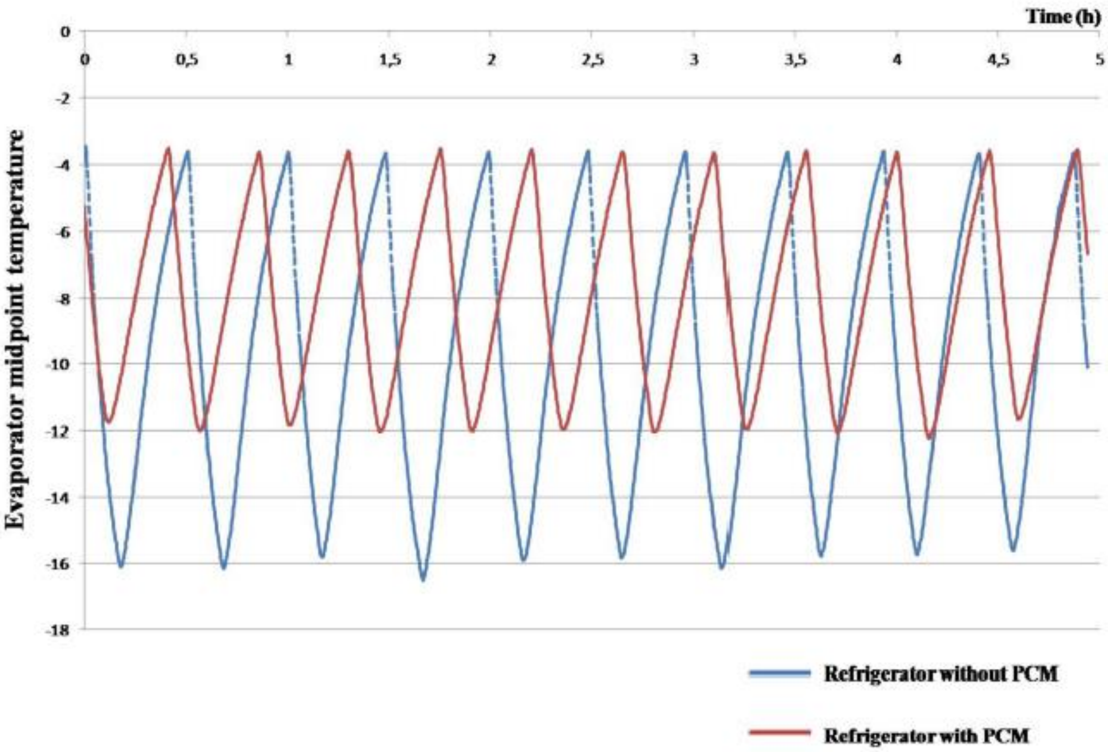

Figure2: Curves of the evaporator midpoint temperatures.

Considering the close relationship between the evaporator midpoint temperature and the evaporating temperature, the higher evaporator midpoint temperature may correspond to a higher evaporating temperature. Thus, the COP of the cooling system of the refrigerator may be improved by the increase of the evaporating temperature

1.1.1.4 Condenser temperature

Figure 3 illustrates the comparison between the condenser outlet temperatures. For the ordinary refrigerator, the condenser outlet temperature increased gradually after the compressor was switched on, then reached the highest outlet temperature (about 32.2 ^{o}C) and kept the temperature until the compressor stopped.

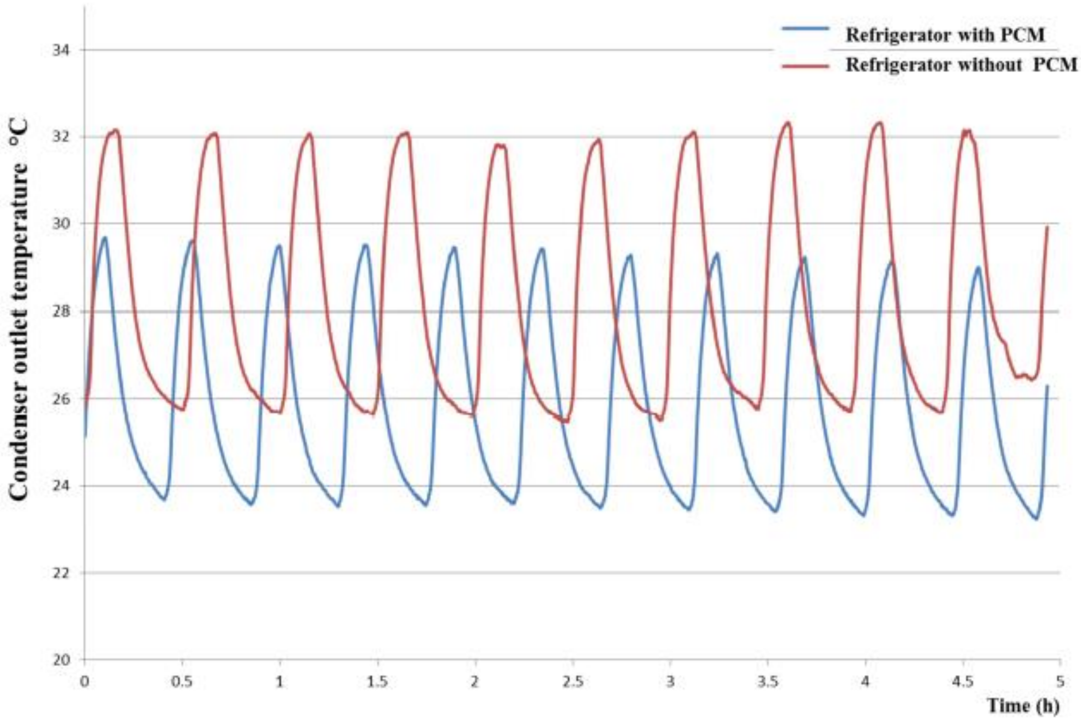

Figure 3: Comparison of the condenser outlet temperatures

Conclusion

In this experimental study, a ready-made vapor compression refrigerator was equipped with a PCM exchanger as sensible and latent heat storage unit and their impact on power consumption was compared to the traditional one. The results showed a significant impact of heat storage unit on the evaporator temperature and consequently on power consumption. For the novel refrigerator, the condensation temperature was higher before the compressor started, however, the condensation temperature was lower when the refrigerator worked in the stable status. Therefore, it needed smaller starting power and shorter time to achieve the stable status. The novel refrigerator was working under a lower condensation temperature and a higher evaporation temperature. Consequently, the novel refrigerator had a greater COP. By integrating a PCM heat exchanger, power consumption was reduced by up to 18 % and thecoefficient of performance of the novel refrigerator increased by 8%.

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