An Overview on Performance Evaluation of Residential Refrigeration systems for Thermal storage using Phase Change Materials (PCM).

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Abstract

Today Due to their continual operation, household refrigerators are most energy-absorbing equipment in the home. By the end of 2026, the global market is expected to be worth 46,040 million dollars. Asia Pacific nations would contribute for about 35.0 percent of global income in 2020. Modifications to the compressor have been found to be either expensive or hard to implement in order to improve the performance of refrigerators. The necessity of the hour is to improve the performance of family refrigerators. And, along with ensuring the lowest rate of power consumption, enhancing the performance of a refrigerator is critical. It has previously been proposed and proved that incorporating PCM into refrigeration systems enhances frozen food quality while also increasing energy efficiency. This paper summarizes an over view of phase change material, analysis and experimental investigation of PCMs for use in refrigeration systems.

Keywords: *Latent heat, Phase Change Material, Thermal energy storage, Domestic Refrigerators*

1. Introduction

Household refrigerators are the most energy-intensive equipment in a household due to their continuous operation [1], implying that they require a substantial amount of energy to operate. According to Liu et al.[2], a 300-liter refrigerator in India consumes an average of 900 kWh of energy per year. Refrigerator and freezer energy use amounts approximately 15% to 20% of total household power consumption. According to Mahlia et al. [3], refrigerators and freezers utilized around 26% of household power in Malaysia. China has the largest surplus in global refrigerator and freezer commerce. In this instance, increasing the efficiency of the refrigeration equipment is crucial for reducing power use. In order to consider the elements, recent research has been undertaken.

• Creating high-efficiency compressors through design and development.

• Improving the heat transfer rates between the condenser and the evaporator

• Improving cabinet and door insulation to prevent heat loss.

• Different refrigeration cycles are being researched and developed.

Improving the effectiveness of heat exchangers has received primacy in view of the aforementioned reasons. This may be improved in a variety of ways, such as using liquid suction heat exchangers in condensers, micro-fin tubes in the evaporator and condensers, and so on. This is where the usage of phase change material (PCM) in freezers is presented as a way to increase performance. The heat energy produced by PCM is more akin to a natural phenomenon and is referred to as green energy [4]. The usage of PCM is one of the most viable sustainable energy alternatives for storing thermal energy. The use of phase change material (PCM) as a latent heat sink could be a new option for boosting the effectiveness of a residential refrigerator.

Cost-effectiveness, minimal noise production, high efficiency, high reliability, and ease of manufacture are all requirements for a suitable compressor in a domestic refrigerator; hence, hermetically sealed reciprocating ON/OFF compressors are widely used. The reason for this is that the compressor consumes over 80% of a refrigerator's total energy consumption.

A.C.Marques, et al.

Investigated the performance enhancement provided by PCM (phase change material) associated with the evaporator in a domestic refrigerator. The authors looked on PCM placement, container shape, and orientation in evaporators and condensers. In CFD software, the flow of air and temperature measurement equipment were modeled (ANSYS Fluent were undertaken to characterize). It has been discovered that when PCM is positioned vertically, the compartment temperature is higher than when it is positioned horizontally. The experimental results corroborated the CFD predictions. Combining vertical and lateral PCMs in a full-height compartment, according to the model [8].

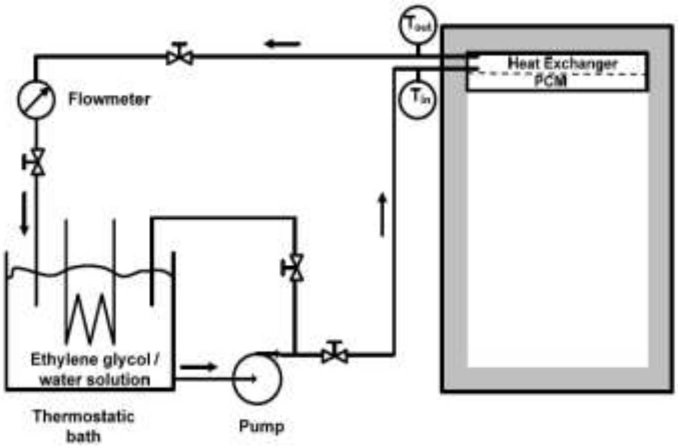

Figure 1- Schematic of the experimental test rig

K. Azzouz et al,

Conducted an experimental investigation on

1. Reduce heat loss by improving cabinet and door insulation.
2. To regulate the refrigerating capacity, Variable Speed Compressor (VSC) and Variable Capacity Compressor (VCC) are employed.
3. Improving the heat exchanger's efficiency (especially of the evaporator).

The authors employed a single-door, single-compartment refrigerator with a 0.29 m^3 internal capacity, 29 g of isobutene (R600a) as the refrigerant, and a condenser with a)hydraulic diameter of 3.3 mm b)external diameter of 5.3 mm c)length: 11.6 m d)UA value: 6.7 W/K and an evaporator with a)exchange area:

The results show that the refrigerator's response to the addition of PCM, as well as its efficiency, is largely determined by the thermal load. PCM provides for 5–9 hours of continuous running without an electrical source (as opposed to 1–3 hours without PCM) and a 10–30% increase in COP depending on the heat load. [9]

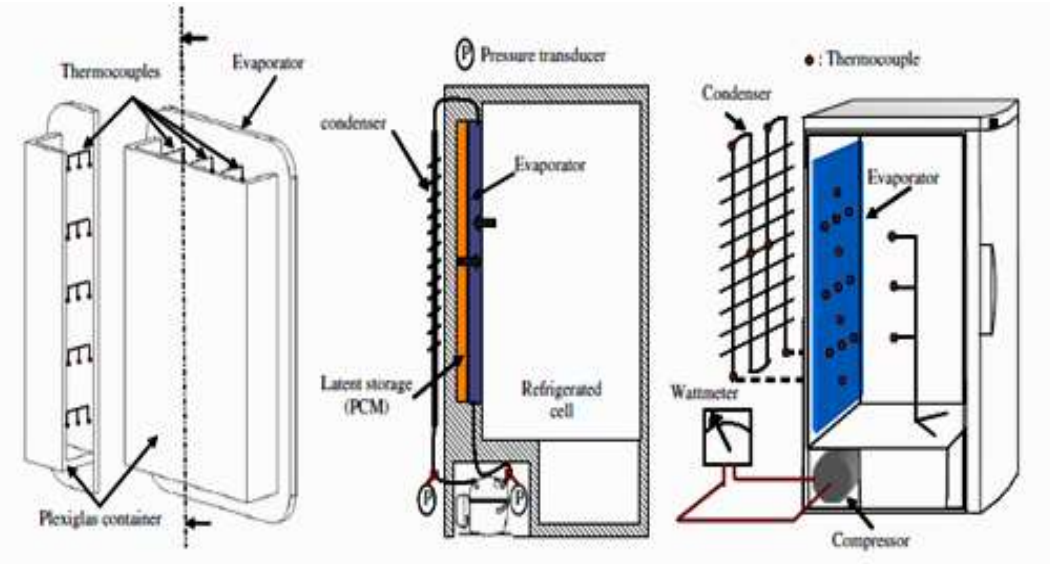

Figure 2 - Experimental set-up

Rezaur Rahman et al. investigated the performance improvement provided by a phase change material associated with the evaporator in a domestic refrigerator. Main objectives of the work being

1. Modify the refrigeration unit with a PCM-based refrigerator to create the experimental setup.
2. To see if there is a difference in the refrigerator cycle's (COP) with and without PCM.

The following experimental setup was used by the authors.

a. Internal volume: 0.015 cubic meters,

b. Evaporator: 0.015 cubic meters

- Heat transport modes are free convection and conduction.
- Coil or tube linear length = 14.5 feet = 4.4 meter
- Tube internal and exterior diameters = 5mm and 6mm • Coil or tube material - copper tube

c. Refrigerant condenser:

- Heat transmission mode = free convection
- The coil's linear length is 4.1 meters; the tube's ID and OD are 3.23 mm and 4.23 mm, respectively.
- Steel and wire tube as tube materials

d. LG MA 42LFJG 1PH 220-240V, 50HZ compressor

e. On/Off control and self-defrost

f. R-134a refrigerant

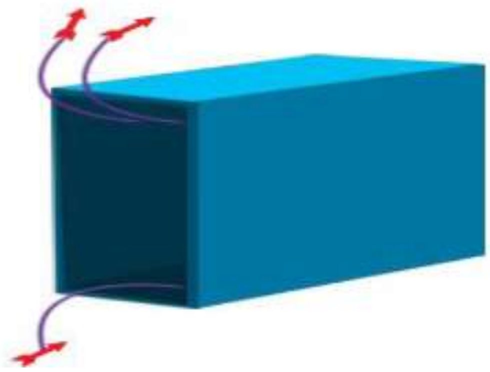

Figure 3- PCM box with PCM passage

Experiments were conducted to see if the performance of a residential refrigerator could be improved by utilizing two distinct phase change materials in varying amounts at different loads. Based on the PCM and the heat load, the PCM can yield a COP gain of 18-26 percent when compared to no PCM. [10]

R. Elarem et al

For the experiment, a ready-made vapour compression domestic refrigerator with a capacity of 136 litres was used as a prototype. Tubes of the following dimensions make up the evaporator. Each tube's linear length, internal diameter, and exterior diameter are 0.66 m, 0.007 m, and 0.008 m, respectively. A normal refrigerator, the unique PCM heat exchanger, 2 pressure gauges and 5 temperature sensors, a data collecting system, an energy logger, and a seek thermal camera are all part of the experimental setup. A thermal imaging camera was utilized to visualize the temperature distribution in the refrigerator compartments.

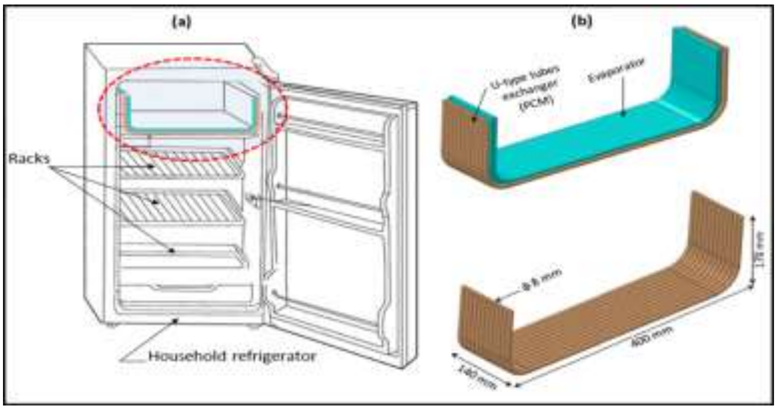

Figure 4 - (a) Refrigerator model (b) Design of the PCM heat exchanger.

The percentage of COP enhanced by employing the PCM heat exchanger under the operating parameters given in this study is 8%. In addition, electricity usage is lowered by 12%. [11]

Md.Imran H. et al

The purpose of this study is to

a. Analyze the impact of PCM on temperature fluctuations inside the cabinet of a domestic refrigerator during door opening and power outages in an experimental setting.

b. Temperature fluctuations inside a residential refrigerator cabinet have a major impact on the quality of stored food.

Authors had used following experimental set up, a standard one-door, one-chamber household refrigerator (model LG-GR-051SSF, volume: 50 liters, dimensions: width, height and depth 443 mm, 501mm and 450 mm respectively. R134 a refrigerant, polyurethane insulated cabinet, and 17 kg weight).In a stainless steel container, polyethylene glycol-400 was utilized as a PCM. A refrigerator, temperature measuring instrument a digital energy meter, and a data collecting system were used in the experiment.

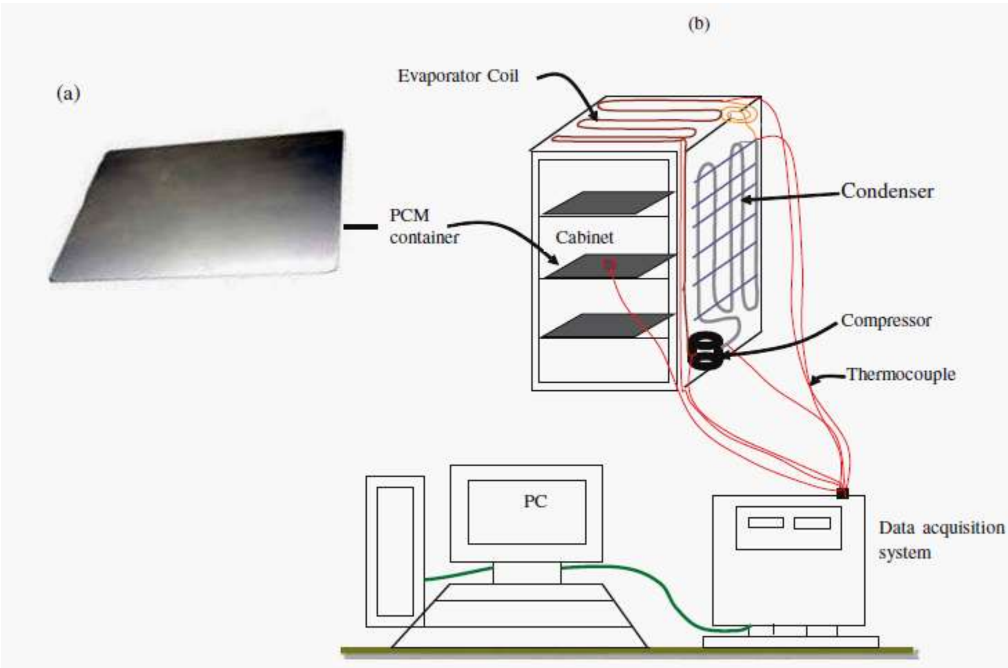

Figure 5 - (a) PCM Container (b) Schematic diagram of experimental set-up

The result shows that a significantly lower temperature fluctuation (about 2°C) was achieved using PCM. It was found that in the door opening condition cabinet, air temperature rose rapidly without PCM whereas with PCM the rise was about 3–5°C lower. During power failure time, PCM can work as a backup for up to 2 hours to maintain the lower temperature inside the chamber. [12]

Zhongbao Liu et al

The authors of this research investigated a novel air-cooled home refrigerator with PCM with fresh food, chilling chambers. The frost-free refrigerator prototype included a tube fin, and a total of 3 kg of PCM was utilized, with 332.7 kj/kg of heat capacity and 0.53 W/mK. Temperatures were monitored at three separate locations, and the experiments were carried out in a typical refrigeration laboratory.

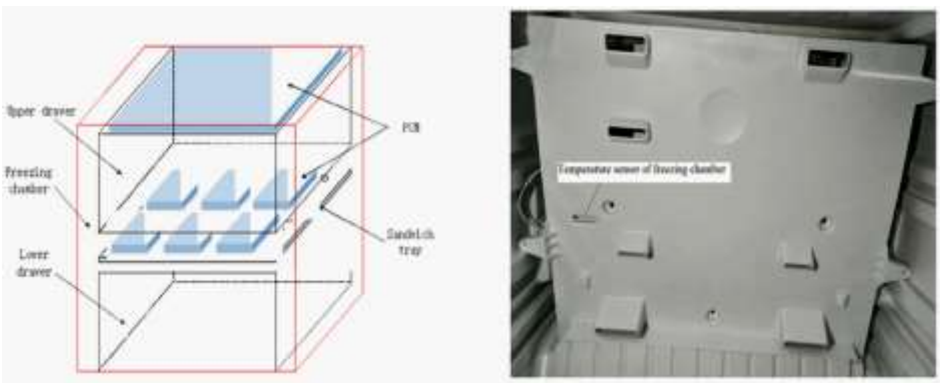

Figure 6 – Arrangement of the PCM and temperature sensor of the freezing chamber.

The author discovered that in the absence of PCM, a temperature raise of 100 ° c was seen during compressor off time, whereas with 3 kg of PCM, the temperature increase was decreased to 6 ^{0}C. The use of PCM guaranteed that the average temperature of the fresh food compartment did not exceed 8 ^{0}C. During the use of PCM, the energy consumption was lowered by 18.6%, and the compressor on time ratio was decreased by 13.6%. [13]

Y. Yusufoglu et al

The authors of this study looked at a new refrigerator that employs PCM to increase performance. Researchers used three different PCM types with different melting points, a new type of PCM packaging was introduced, and authors used a flexible PCM container for encasing it around evaporator tubes (for PCM packaging, polymer lined aluminium metallic film was used). PCM latent heat ranged from 200 kJ/kg to 250 kJ/kg, with melting temperatures ranging from -2.2^{0}C to -4.4^{0}C.

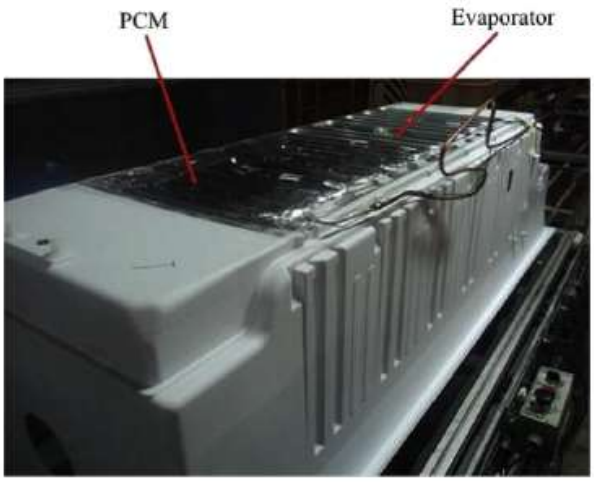

Figure 7 - PCM package assembly on evaporator tube

Using different PCMs, the performances of two types of refrigerators was tested. The compressor off time attained for refrigerator I is 8.8% and for refrigerator II is 9.4%. Increasing the condenser contact area in the refrigerator by 20% boosted the impact of PCM. It was suggested that the heat exchange area for the evaporator and condenser be redesigned. [14]

Omid G Z. et al,

In this work, the scientists employed a numerical inquiry on a PCM installed in a freezer to determine the effective volume. Different PCM thicknesses ranging from (0.5 – 6) cm were simulated using the CFD analysis. It has an evaporator with an internal volume of (28×31.5×43.5) cm^3 and a wall thickness of 37 mm of insulation. With a melting temperature of 21 °C, NaCl-H_2O was employed as the PCM. The PCM has a phase transition temperature of 252 K and a latent heat of 234 KJ/kg. 8000, 32000, 52000, and 72000 nodes were used to simulate the model. The model with 52000 nodes was chosen as the base case after all of the tests. All of meshes are made out of quad components. The analytical results were compared to the data of Marques et al. [15]

Concluding Remarks

There appears to be a correlation between the benefits and downsides of PCM incorporation on the evaporator side and PCM integration on the condenser side. PCM integration on the evaporator side has various benefits that can offset PCM's disadvantages on the condenser side, and vice versa. As a consequence, it appears that combining PCMs in the evaporator and condenser may be more advantageous.

Along with the use of PCM in the evaporator and condenser, it is critical to modify the VCR system to implement sub-cooling or super-heating to improve the COP, and more research on the use of PCM slurries can be done to reduce the amount of traditional refrigerant used in domestic refrigerators.

References

1. P.S. Raveendran, S.J. Sekhar, "*Performance studies on a domestic refrigerators retrofitted with building-integrated water-cooled condenser*", Energy Build. 134 (2017) 1–10.
2. D. Y. Liu, W. R. Change and J. Y. Lin, "*Performance comparison with effect of door opening on variable and fixed frequency refrigerators-freezers*", Appl. Therm. Eng. 24 (2004) 2281–2292.
3. T. M. I. Mahlia, H. H. Masjuki, R. Saidur, I. A. Choudhury and A. R. NoorLeha, "*Projected electricity savings from implementing minimum energy efficiency standard for household refrigerators in Malaysia*", Energy 28 (2003) 751–754.
4. B. Zalba, J.M. Marin, L.F. Cabeza, H. Mehling, "*Review on thermal energy storage with phase change: materials, heat transfer analysis and applications*", Appl. Therm. Eng. 23 (2003) 251–283
5. Subhanjan Bista, Seyed Ehsan Hosseini, Evan Owens, Garrison Phillips, "*Performance improvement and energy consumption reduction in refrigeration systems using phase change material (PCM*)", Applied Thermal Engineering 142 (2018) 723–735
6. Md. Imran H. Khan, Conventional Refrigeration Systems Using Phase Change Material: "*A Review, International Journal of Air-Conditioning and Refrigeration"*, Vol. 24, No. 3 (2016) 1630007 (16 pages).
7. Joris Jaguemont, Noshin Omar, "*Phase-change materials (PCM) for automotive applications: a review*".
8. A. C. Marques, G. F. Davies, J. A. Evans, G. G. Maidment and I. D. Wood, "*Theoretical modeling and experimental investigation of a thermal energy storage refrigerator"*, Energy 55 (2013) 457–465.
9. K. Azzouz, D. Leducq and D. Gobin, "*Enhancing the performance of household refrigerators with latent heat storage: An experimental investigation*", Int. J. Refrig. 32 (2009) 1634–1644.
10. Rezaur Rahman, Adnan hasan, Shubhra Kanti Das, Md. Arafat Hossain, "*Performance Improvement of a Domestic Refrigerator Using Phase change Material (PCM)"*, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 10, Issue 4 (Nov. - Dec. 2013), PP 08-16.
11. R. Elarem, S. Mellouli, E. Abhilash, A. Jemni, "*Performance analysis of a household refrigerator integrating a PCM heat Exchanger*" Applied Thermal Engineering 125 (2017) 1320–1333
12. Md. Imran H. Khan, Hasan M. M. Afroz & M. A. Karim, "*Effect of PCM on temperature fluctuation during the door opening of a household refrigerator*", INTERNATIONAL JOURNAL OF GREEN ENERGY 2017, VOL. 14, NO. 4, 379–384
13. Zhongbao Liu , Danfeng Zhao, Qinghua Wan, Yuanying Chi, Lingfei Zhang, "*Performance study on air-cooled household refrigerator with cold storage phase change materials*" International journal of refrigeration 79 (2017) 130–142.
14. Y. Yusufoglu, T. Apaydin, S. Yilmaz, H.O. Paksoy,"*Improving performance of household refrigerators by incorporating phase change materials*" International journal of refrigeration 57 (2015) 173-185
15. Omid Ghahramani Zarajabad, Rouhollah Ahmadi,"*Numerical investigation of different PCM volume on cold thermal energy storage system*" Journal of Energy Storage 17 (2018) 515–524