Contents list available at: https://journals.ekb.eg/
Sohag Journal of junior Scientific Researchers
journal homepage: https://sjyr.journals.ekb.eg/
ISSN 2735-5543

Review Article

Improving the performance of a domestic refrigerator using phase change materials: a short review study

Mahmoud Salem, Sami Samir*, Ahmed Askalany, Ahmed Said

Mechanical Department, Faculty of Technology and Education, Sohag University, Sohag, 82524, Egypt
*****Corresponding author: Samii_samir@techedu.sohag.edu.eg; Tel.:+201064613404

Article info.
Citation: Salem, Mahmoud, Samir, sami, Askalany. Ahmed, & Said, Ahmed. (2022). Improving the performance of a domestic refrigerator using phase change materials: a short review study. *Sohag Journal of junior Scientific Researchers*, *2*(2), 12-22. https://doi.org/10.21608/sjyr.2022.227417

Received: 28/01/2022
Accepted: 27/02/2022
Published: 28/03/2022

Abstract

Electricity generated from diverse energy sources is being studied closely by scientists to reduce its consumption rates in the systems that utilize it. Home refrigerators are one of the products that should be looked into to see if they can be made to consume less electricity. Phase Change Materials (PCMs) are an example of a solution that can store energy in a household refrigerator, lowering electricity use. PCMs are being utilized to improve the efficiency of household refrigerators. PCM materials absorb a significant amount of heat energy when they transition from liquid to solid and release it when they solidify. According to the previous study, using PCMs in household refrigerators resulted in a 72 percent increase in refrigerator performance and a 30 percent reduction in energy use. The present paper sheds light on the published research on the use of the PCMs to improve the performance of the home refrigerator and thus reduce electricity consumption.

Keywords
PCM, COP, Evaporator, condenser

1. Introduction

Refrigeration systems are used in household appliances, including refrigerators in homes, industrial freezers, and air conditioning. A compressor consumes the most energy. (Pirvaram et al., 2019) Domestic refrigerators are the most used household appliances. These appliances consume more residential electricity throughout the year. The primary issue is to enhance the energy efficiency of the domestic refrigerator. We can overcome this issue by improving the coefficient of performance(COP) of a domestic refrigeration system. (Prashanth et al., 2019) Improving the efficiency of household refrigerators, which includes compressor refrigerators broadly, thermal load, ambient temperature, and the refrigerant used. (Karthikeyan et al., 2020), has a substantial impact on rating power consumption. The refrigeration cycle can be enhanced by using a high-performance compressor that can directly impact the COP of the cooling system or using other advanced thermal insulation techniques. Much research has been conducted using various approaches to shorten compressor working time. A few investigations have been done with PCM in the evaporator section and PCM in the condensing coil. (Karthikeyan et al., 2020; Wagh et al., 2018; Azzouz et al., 2008) Thermal energy storage in phase change materials is a new field of study that has piqued the curiosity of scientists. Energy storage reduces the mismatch between supply and demand, improves energy systems' performance and reliability, and plays an essential role in conserving energy.(Geete et al., 2018) Using Phase change material (PCM) for latent heat storage in household refrigerators is one of the upcoming technologies in the refrigeration field. Many researchers investigated the dynamic model for vapor compression refrigeration systems by using Phase change material as latent heat storage. Thermal inertia globally Phase change with latent heat storage enhances evaporator heat transfer and allows high evaporating temperature. Thus, it increases the energy efficiency of the system. Energy stored in the PCM is yielded to the refrigerator cell during off-cycle and allows several hours of continuous operation without a power supply. (Azzouz et al., 2008; Geete et al., 2018).

These PCM melts and solidifies at a specific temperature. During phase change time, the material can store and release large amounts of heat energy. There is no artificial energy associated with thermal energy storage using PCM. PCM could be an excellent option for enhancing the refrigerator's performance by reducing temperature fluctuation inside the evaporator cabinet. (Geete et al., 2018)

2. Materials and Methods

Phase-change materials (PCMs) can store large amounts of energy in small volumes, resulting in some of the lowest storage medium costs of any storage notion.

PCM is a type of thermal energy storage that can store and release enormous amounts of energy. The system relies on the material's phase change to retain and release energy.

Melting, solidifying, and evaporation, for example, all require energy. When a material transforms from solid to liquid or vice versa, heat is absorbed or released. As a result, PCMs may quickly and predictably change their phase in response to specific energy input and then release that energy later. As a result, a slight temperature change can store and release energy.

An analytical study of phase-changing material was conducted in a domestic refrigerator condenser under the influence of thermal loads using two phase-changing materials (polyethylene glycol-1000 and polyethylene glycol-600). They have arranged them on the upper side of the condenser for maximum temperature and the lower side for the lower temperature. At a freezing temperature of -5°C, a heat load for food in the upper portion of the refrigerator is packaged with a chemical makeup comparable to frozen meat. The specifications of the refrigerator used in the tests were a home refrigerator with a capacity of 285 liters operating with R134a refrigerant.

Experiments were conducted on four cases: one without PCM and no heat load, another without PCM and using convection, a third case using thermal load and one PCM material in the capacitor, and a fourth case using thermal load and two PCM materials in the capacitor, with a total heat load of 10 kg in each case.

The results showed the effect of using the two PCM materials in successive order, as the percentage of compressor work during the 24-hour test decreased from 32 .7% to 27.6%. At the same time, the refrigerator contained one substance of PCM decreased the operating coefficient to 29.6%.

In addition, using two PCM substances in a sequential order improved condenser performance. It reduced condensing temperature as the temperature of the bottom side in the condenser decreased from 37.5°C to 36.5°C for one material. When two materials were used, the temperature dropped to 34.5°C, increasing the refrigerator's performance coefficient (COP). The measurements showed a decrease in energy consumption in the fridge with two PCM materials from 0.7578 kilowatt-hours per hour to 0.6564 kilowatt-hours per hour. In contrast, the consumption rate decreased equipped with one PCM material to 0.6917 kilowatt-hours. (Pirvaram et al., 2019)

Experiments were conducted using a 16-foot household refrigerator consisting of a top freezer and lower heatsink powered by 149 W. It used water as a phase changer. Using PCM by placing plates on the backside of the evaporator and other plates placed at the bottom of the evaporator inside the cabin**.** The experiments were performed in two parts**:**

The first experiment's purpose was to determine the refrigerator's usual running rate and compare it to the performance of a refrigerator without PCM.

The second experiment was conducted after placing the PCM inside the refrigerator.

It took 135 minutes to freeze without the PCM after the first cycle completely, but just 52 minutes with the PCM at the end of the second cycle. (Prashanth et al.,2019)

Four PCM materials (OM32, OM29, OM03, and HS3N) were included to raise the refrigerator's efficiency.

HS3N in the freezer at -3°C, OM03 in the refrigerator cabinet as rectangular plates with dimensions of (400 mm x 200 mm x 20 mm) that hold 1.1 liters of liquid, and OM32, OM29 in the condenser as bundles enclosed by aluminum foil at 5°C, with materials of high melting temperature on the upper side of the condenser and fabric with low melting temperature on the more downside. The experiments were carried out on a 185-liter household refrigerator using R134a. Table 1 shows the thermophysical properties of PCM used.

Table 1.Thermophysical properties of PCM (Karthikeyan et al., 2020)

Properties	P.C.T (˚C)	L. heat (KJ/Kg)	Densit (Kg/m3)	K (W/m.K)
Om32	32	157	876	0.145
Om29	29	194	876	0.172
Om03	5	229	855	0.146
Hs3n	-3	247	1060	0.35

The use of PCM in all refrigerator sites reduced the condensing coil's maximum temperature from 43.8°C to 39°C in the lower portion and from 46°C to 40°C in the top section. The temperature in the refrigerator area dropped from 4.4°C to 3.9°C, while the temperature in the freezer part dropped from -18.6°C to -18.3°C.

Therefore, it can be concluded that refrigerator temperature fluctuations can be effectively reduced by using PCM arrangements in all locations, such as refrigerator, freezer, and condensing coil. Low-temperature fluctuation helps maintain food quality and reduces energy consumption. (Karthikeyan et al., 2020)

Wagh et al (2018) studied and tested the cooling system using eutectic phase change materials with a melting point from 0 to -5°C for three-phase changing materials on the COP of the system. The properties of materials are shown in table 2.

Table 2. Thermophysical properties of PCM. (Wagh et al., 2018)

PCM	Percentage by weight	Melting point (˚C)	Latent heat (kJ/kg)
KNO3	9.7	-2.8	296
Na2So4	12.7	-3.6	285
NaCl	8	-5	289

The tests were performed on a refrigerator with a 0.3TR sealed compressor, R134a refrigerant, and a casing-type evaporator and coil inside an exterior container. The PCM materials are inserted between the inner and outer receptacles in the gap between them.

The inner container diameter was 150 mm, and the outer container diameter was 20 cm, in which glass wool is used for insulation.

The results of the experiments on the coefficient of performance were as shown in figure (1).

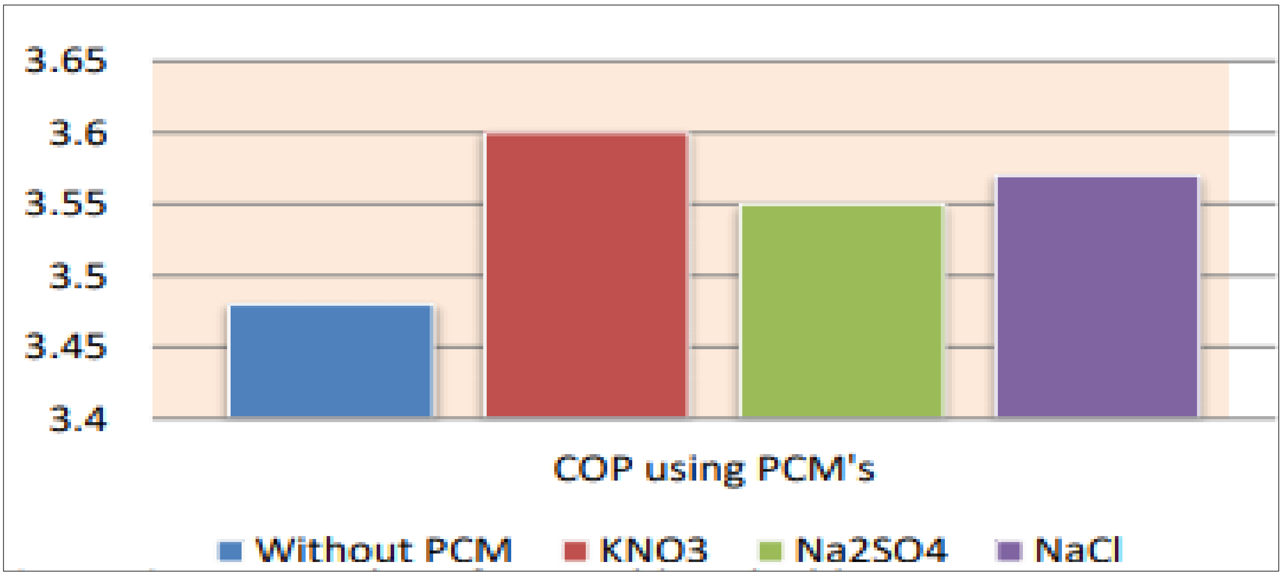

Figure 1. Compression of COP with and without PCM(Wagh et al., 2018)

The findings also revealed that using the PCM results in a long time to turn off the compressor, which improves the system's stability and improves the system's performance while also reducing fluctuations inside the cabin. (Wagh et al., 2018)

Azzouz et al. (2008) presented a dynamic vapor pressure cycle model with a PCM on the outside refrigerator evaporator and investigated operating conditions and their impact on system performance and energy efficiency.

The phase change material is a eutectic aqueous solution in the shape of a plate (surface area of 0.48m2) put on the rear side of the evaporator between the insulation and the evaporator, with a phase change degree ranging from -9°C to 0°C.

The model used for a single-door refrigerator with an internal volume of 0.29m3, energy consumption of 0.44 kWh/day, an R600a refrigerant of 29g, an evaporator, a hermetically sealed reciprocating compressor, and a convection condenser free and hermetically sealed reciprocating compressor.

Azzouz et al. (2008) studied the effect of adding a layer of phase change material (PCM) on the outside of the refrigerator evaporator, as shown in Figure 1. They used a phase change material to operate a dynamic model of the vapor compression cycle and validated it in experimental work. Model dynamics aims not only to study various designs but also to study the energy efficiency of refrigerators under operating conditions. Simulation results with PCM in mind show that thermal inertia increases the overall heat transfer from the evaporator, allowing for higher evaporation temperatures. This improves the energy efficiency of the system. The energy stored in the PCM is transferred to the refrigerator cell during the off-cycle, allowing several hours of continuous operation without a power source. (Azzouz et al., 2008)

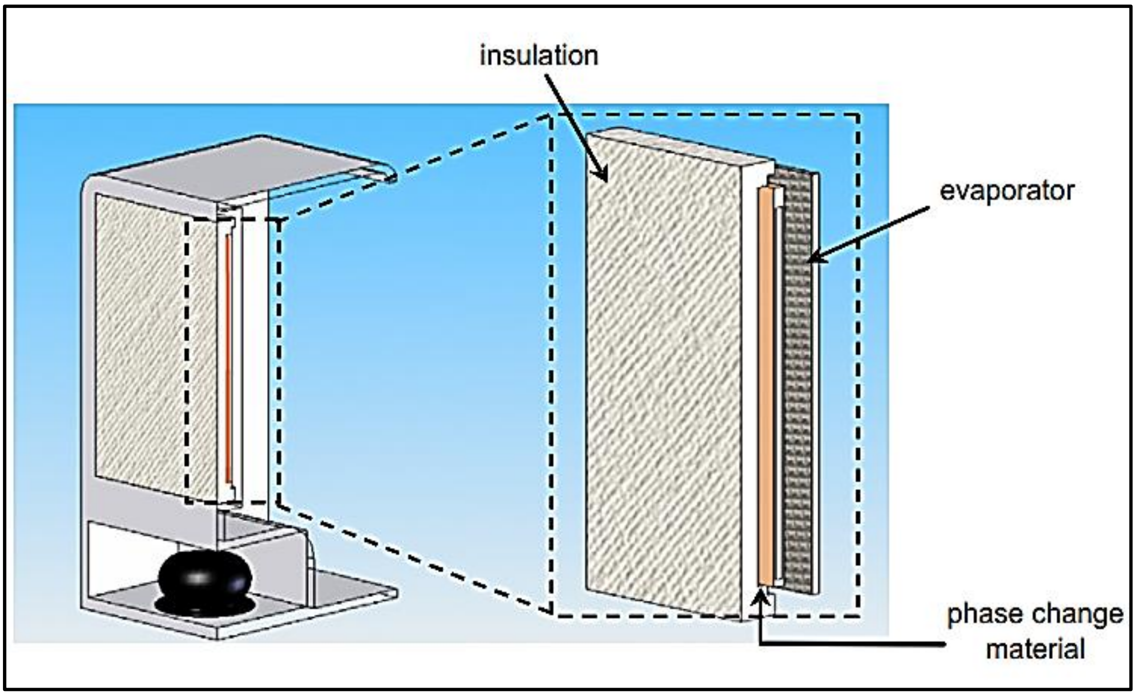

Figure 2. Construction of the PCM along with evaporator side. (Azzouz et al., 2008)

Geete et al (2018) designed a refrigerator to run experiments in a separate freezer using the refrigerant R134a. Power consumption was 650Wh per dayat an internal temperature of 4 ° C and an external temperature of 22 °C. Ethylene glycol was used as the PCM to create a slice with dimensions (0.03 m x 0.5 m x 0.45 m). The PCM is located on one side of the evaporator. Experiments were performed at different loads of 0.25, 0.5 to 3 kg, and improved efficiency was found. The phase change material keeps the evaporator temperature constant for 6 to 8 hours. However, the temperature of the evaporator is almost endless because it can drop by 1 to 2 degrees per hour depending on the heat load of the substance. This was found to significantly reduce the average compressor operating time per cycle, about 17% to 30%, compared to materials with no phase change. (Geete et al., 2018).

Theoretical studies were carried out by Azzouz et al. (2005) in a household refrigerator without a freezer to improve energy efficiency and COP. For this purpose, a mathematical refrigerator model was created and simulated with and without PCM (eutectic salt solution, its properties are shown in Table 3). The material was placed on one side of the evaporator in the form of a slide with dimensions of 0.03 m * 0.5 m * 0.5 m and a phase change temperature of 6 to 0. The test conditions for the model were an air temperature of 20°C and an internal temperature of 4°C. The test conditions for the model were an air temperature of 20°C and an internal temperature of 4°C. The model study results show that the COP increases by 72%, and the operating time of the global compressor are reduced by 25% (Azzouz et al., 2005).

Table 3. Thermophysical properties of PCM. (Azzouz et al., 2005)

Saymbol	Value	Unit
L	280	kJ / kg
ʎs	1,8	W / m K
ʎl	0,6	W / m K
Ps	1042	kg /m³
Pl	1115	kg /m³
Cps	2592	kJ / kg K

Azzouz et al. (2009) used the phase change material placed on the back of the evaporator to analyze the performance of the home refrigerator, increase the storage capacity, improve the efficiency of the refrigerator, and operate for several hours without a power supply. Water is used as the phase change material and tested using a eutectic mixture with a phase change temperature of 0 ° C, thicknesses of 5 mm and 10 mm, and a freezing point of 3 ° C and thickness of 5 mm. The performance of the home refrigerator showed a reduction in temperature fluctuations and an increase in coefficient performance by 10- 30%. The results show that latent heat can be stored in 5-9 hours of operation without power, compared to PCM, which only works for 1-3 hours (Azzouz et al., 2009).

Gin et al. (2010) studied the effect of adding a phase-changing material in the form of a panel to the inner wall of a 153-liter vertical freezer to maintain a constant temperature.

The effects of heat loads such as defrosting in the event of energy loss (30-minute defrosting cycle and door openings) and an 11-hour door opening system consisting of 13 door openings are performed. An aqueous solution of NH_4Cl was used as a phase change material with a temperature of 15.4°C as its temperature close to the storage temperature in the freezer 18°C. The composition of the phase change material was an easy aqueous solution Melting (19.5% of the salt of NH_4Cl in water). The test was performed at room temperature 10-50 ° C and relative humidity 40% -80%. Test results show how effective PCM is in the freezer, reducing temperature changes and fluctuations reducing freezer energy consumption by 8% during the defrosting cycle and 7% when the door is opened. Tests show that without PCM, the heat load increases energy consumption by 1117%, and the defrosting cycle results are 1521%, demonstrating the effect of using phase change materials on reducing energy consumption. It has been (Gin at al., 2010).

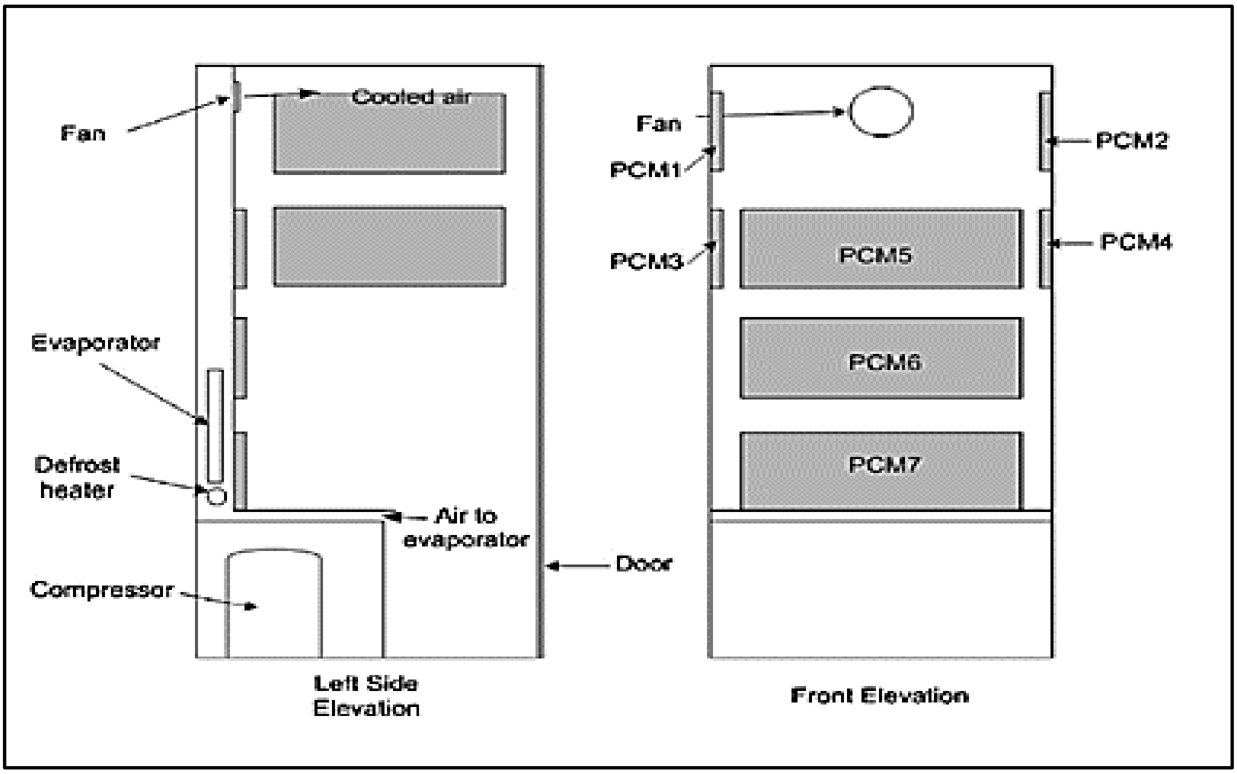

Figure 3. Schematic of the freezer showing positions of the evaporator, defrost heater, and placement of the panels (Gin et al., 2010).

Cheng et al. (2011) uses the phase change material as a condenser to store the heat generated by the condenser in the refrigerator and release it to the environment during the shutdown of the home refrigerator. The experiment was conducted on a 2-door 3-star model with a capacity of 220 liters, refrigerant R600a, and a freezer freezing temperature of 18°C, using HCESS PCM materials made of paraffin foamed graphite and polyethylene. It was manufactured and manipulated to density. As a result, it was found that the average temperature of the condenser decreased by

2.3°C, and the temperature of the outlet of the condenser decreased by 6.5°C. This is a stable system efficiency in addition to the short time it takes to reach temperature. As a result, it was found that the average temperature of the condenser decreased by 2.3°C, and the temperature of the outlet of the condenser decreased by 6.5°C. This is a stable system efficiency in addition to the short time it takes to reach temperature. Since the energy consumption of an average refrigerator with HCESS PCM ranges from 0.51kWh to 0.45kWh, the results show a 12% reduction in energy consumption (Cheng et al., 2011)

Khan et al. (2011) experimented by placing PCM on the five sides of the evaporator to improve the coefficient of performance of the household refrigerator. Refrigerators have been tested with three-phase change materials. Table 3.4 shows the properties of the materials used Eutectic solutuins-1 (90% H2O + 10% NACL)(E.S.1), Eutectic solutuins-2 (80 % H2O + 20% KCL), (% Wt.)(E.S.2) and Distilled water (D.w). Using a single-door refrigerator with R134a refrigerant, the evaporator cabin was changed to a zinc-plated iron box with a thickness of 1 mm and dimensions (width 0.56 mm, height 0.44 mm, depth 0.47 mm). With an internal volume of 0.11 cubic meters and an external volume of the evaporator cabin of 0.04 cubic meters, supply and store extras and connect the top two pipes to the phase change material box to connect another pipe. In addition, the bottom surface for unloading the phase change material as needed. Figure 4. Shows arrangement of the PCM-based evaporator (Khan et al., 2011).

Table 4. Thermophysical properties of PCM (Khan et al., 2011)

Properties	D.w	E.S.1	E.S.2
Melting/freezing temperature(°C)	0	-5	-10
Latent heat (kJ/kg)	333	289	284

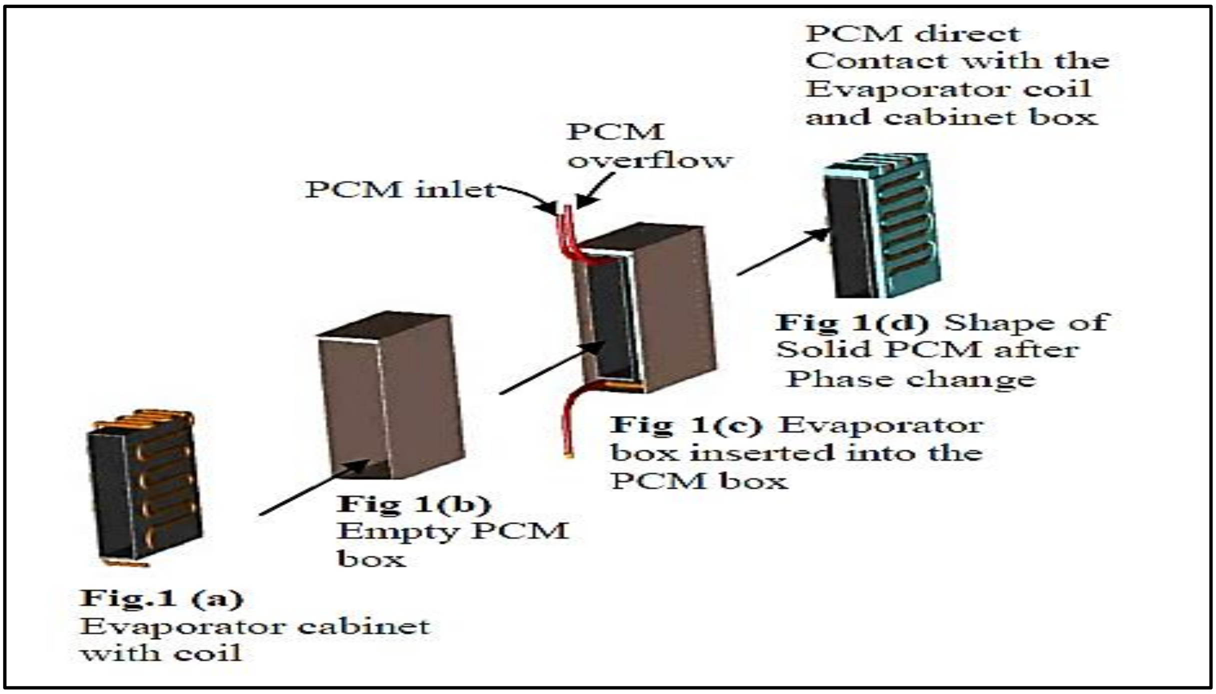

Figure 4. The arrangement of the PCM based evaporator. (Khan et al., 2011)

Rahman et al. (2013) used water as the PCM and incorporated the water into the evaporator through a coil or path surrounding the vaporizer. The PCM loses heat when the compressor runs and solidifies due to its solid state. An experiment was conducted in two stages, the first without PCM and the second using PCM.

In the first test without PCM, COP = 5.78, and PCM COP = 10.25, with improvement rate = 77.33%, and in the second test, without PCM, COP = 5.55, and PCM COP = 9.42, with improvement rate = 69.7%. The two stages improved the coefficient of performance of refrigerators with PCM by 55:60%.

In addition, the use of PCM reduces temperature fluctuations in the refrigerator. In the absence of PCM or PCM, the coefficient performance improves as the heat load decreases, and the coefficient performance decreases as the heat load increases. (Rahman et al., 2013)

Table 5 displays the results of using various PCM materials and their impact on electricity consumption reduction

Table 5. Summary Previous studies

PCM	Refrigerant	Phase change ˚c	Increase	Improving in electrical	position	Ref.
polyethylene glycol-1000 and polyethylene glycol-600	R134a	Non	Non	13%	condenser	(Pirvaram et al., 2019)
kNO_3	R134a	-2.8 ˚c	Non	17:30%	Evaporator	(Wagh et al., 2018)
Na_2So_4		-3.6 ˚c				
NaCl		-5 ˚c				
Eutectic aqueous solution	R600a	-9˚C to 0˚C	5:15%	Non	Evaporator	(Azzouz et al. 2008)
ethylene glycol	R134a	Non	Non	17:30%	Evaporator	(Geete et al. 2018)
Eutectic salt solutions		-6 to 0	72%	25%	Evaporator	(Azzouz et al. 2005)
Water	R600a	0°C	10:30%	Non	Evaporator	(Azzouz et al. 2009)
Eutectic mixture		-3°C				
HCE-SSPCM	R600a	Non	Non	12%	Sides	(Cheng et al. 2011)
H_2O		0 ˚c				
90% H_2O + 10% NaCl	R-134a	-5 ˚c	21: 34%	Non	Evaporator	(Khan et al. 2011)
80 % H_2O + 20% KCl		-10 ˚c				
Water	Non	0 ˚c	55:60%	Non	Evaporator	(Rahman et al.2013)

3. Conclusions

The following conclusions can be drawn from the literature review:

It reduced electricity consumption and temperature fluctuations, as well as the compressor's on/off time.

Its usage was also extended to include maintaining a cooling effect after a power outage.

Compared to a conventional regulator, PCM extends the period of a compressor shutdown while preserving the cooling effect.

It could be incorporated into the refrigerator's evaporator or condenser.

It reduces electrical consumption and improves the coefficient of performance of the system.

These materials also do not definitively harm food products while maintaining their quality.

Finally, PCMs in household refrigerators are ecologically friendly and energy-efficient.

References

Azzouz, K., Leducq, D., & Gobin, D. (2007). Performance enhancement of a household re-frigerator by addition of latent heat storage. Int. J. Refrig., 31, 892–901.

Azzouz, K., Leducq, D., & Gobin, D. (2009). Enhancing the performance of household refriger-ators with latent heat storage: An experimental investigation. Int. J. Refrig., 32, 1634–1644.

Azzouz, K., Leducq, D., Guilpart, J., & Gobin, D. (2005). Improving the energy efficiency of a vapor compression system using a phase change material. Second Conference on Phase Change Material & Slurry, pp. 1–11.

Cheng , W. L., Mei , B. J., Liu , Y. N., Huang , Y. H., & Yuan, X. D. (2011) . A novel house-holdrefrigerator with shape-stabilized PCM (Phase Change Material) heat storage con-densers: An experimental investigation . Energy, 36, 5797–5804 .

Geet, P., Singh ,H. P., & Somani ,S. K. (2018). Performance analysis by Implementation of Micro-encapsulated PCM in Domestic Refrigerator : A novel Approach. International Jour-nal of Applied Engineering Research , 13, 14365–14371.

Gin ,B., Farid , M. M., & Bansal ,P. K. (2010). Effect of door opening and defrost cycle on

Karthikeyan, A., Sivan ,V. A., Khaliq ,A. M., & Anderson ,A. (2020). Performance improvement of vapor compression refrigeration system using different phase changing materials. Ma-terials Today: Proceedings, 3–6.

Khan , M. I. H. & Afroz , H. M. M.(2011). An experimental investigation of the effects of Phase Change Material on Coefficient of performance (COP) of a household refrigerator. Proc. Int. Conf. Mech. Eng. Renew. Energy.

Pirvaram, A., Sadrameli, S. M., & Abdolmaleki, L. (2019). Energy management of a household refrigerator using eutectic environmental friendly PCMs in a cascaded condi-tion. Energy, 181, 321–330.

Prashanth, B.,& Madaria,Y. (2019). Experimental investigation for performance enhancnement of household refrigerator using phase change material. Journal of Engineering, Computing and Architecture, 9, 29–36.

Rahman, R., Hossain, M.A., Das, S., & Hasan, A. (2013). Performance Improvement of a Domestic Refrigerator Using Phase change Material (PCM). IOSR J. Mech. Civ. Eng., 10, 08–16 .

Wagh, A., & Gawali, B. S. (2018). Performance Improvement of Vapour Compression Refriger ation System with Phase Change Material. Journal of advancement in engineer-Ing and technology, 6, 6–10.

الملخص العربي

تحسين أداء الثلاجة المنزلية باستخدام مواد تغيير الطور: دراسة مراجعة قصيرة

محمود سالم، سامي سمير، أحمد عسقلاني، أحمد سعيد

قسم الميكانيكا، كلية التكنولوجيا والتعليم، جامعة سوهاج، سوهاج، مصر

الباحث المسؤول: Samii_samir@techedu.sohag.edu.eg

تتم دراسة الكهرباء المولدة من مصادر الطاقة المتنوعة عن كثب من قبل العلماء لتقليل معدلات استهلاكها في الأنظمة التي تستخدمها. تعتبر الثلاجات المنزلية أحد المنتجات التي يجب النظر فيها لمعرفة ما إذا كان يمكن تصنيعها لاستهلاك قدر أقل من الكهرباء. تعد مواد تغيير الطور (PCMs) مثالاً على الحل الذي يمكنه تخزين الطاقة في ثلاجة منزلية ، مما يقلل من استخدام الكهرباء. يتم استخدام مواد تغيير الطور لتحسين كفاءة الثلاجات المنزلية. تمتص هذه المواد كمية كبيرة من الطاقة الحرارية عندما تنتقل من الحالة السائلة إلى الحالة الصلبة وتطلقها عندما تتصلب. وفقًا للدراسة السابقة ، أدى استخدام مواد (PCMs)في الثلاجات المنزلية إلى زيادة بنسبة 72% في أداء الثلاجة وانخفاض بنسبة 30 % في استخدام الطاقة. يلقي هذا البحث الضوء على الأبحاث المنشوره حول استخدام أجهزة PCM لتحسين أداء الثلاجة المنزلية وبالتالي تقليل استهلاك الكهرباء.