



Review Article

## A critical assessment of the implementation of phase change materials in the VCC of refrigerator

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### ABSTRACT

The ultimate heat storage system is an alternative way of improving the heat exchange in the home refrigerator. This research is a systematic analysis of the studies that are being performed with its advantages and limitations. Comments of the researcher on potential improvements in the current work to enhance efficiency are also checked. Key parameters influencing system performance and key issues related to effective system integration are discussed here. PCM integration with the standard setup is restricted by the use of low-temperature PCMs, which is why PCM analysis with Nano-particle additives can be performed. Most experiments are limited to a hot wall form only, the investigation of a PCM application for another form of the condenser is subject to further work. Besides, a combination of two thermal enhancement methods, such as LSHX and PCM, can be used to test the performance.

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### INTRODUCTION

Technology in the 21st century varies from previous technology in technological advancement. The “climate crisis” in the world has encouraged researchers to investigate other sources of energy and make better use of available resources. Household appliances are another common type

of household appliances. ACCORDING IBEF ‘s launch of the Indian refrigerator market increased by 15.70 percent from 2010-14 and is expected to expand significantly in the rural market in the coming years as the government aims to invest heavily in rural electrification. The report shows that

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the number of customers is gradually growing. Studies show that the fridge devours around 25% of the power expended at home. It also accounts for around 1/6 of the emissions of greenhouse gases. Strengthening the efficiency of the home refrigerator was therefore a basic concern. The energy efficiency of the refrigerator is affected by the efficiency of various parameters like the efficiency of its components, the surrounding temperature, heat load provided, number of times opening of the door, temperature measuring device, the capacity of the refrigerator, and movement of working medium during the compressor off-cycle [1]. Cooling energy performance can be increased by 1) The use of a high-efficiency compressor, which has a direct effect on the efficiency (COP) of the cooling system; 2) Maximization of the match and regulation of the system can be achieved by integrating advanced circulation.; 3) Increase the thermal conductivity of fridges by the intensity of the installation or by other advanced heat control measures; 4) Optimization of the heat transfer of both the heat exchanger i.e. evaporator and condenser [2].

The key load on the cabinet is the product of the heat transfer through the partitions of the unit and as a result of the use of vacuum insulated panels ideally over conventional polyurethane foam insulation, ¼ energy savings can be attained [1]. Opening doors often add heat gain in the freezer room due to the accumulation of heat to various surfaces and the movement of air and warm air outside. Fridge energy usage in the open front door fridge (one open every forty minutes in the fridge and one opening every twelve minutes in the fridge for ten hours) was found to increase by ten percent matched to the same item without opening the front door [3]. The main impact of the thermostat setup has been shown by experimentation and indicates that a drop of one degree in the temperature of the fridge will lead to a rise of 7.8 percent in energy usage.

Besides, losses arising from the transfer of refrigerant charge, e.g. due to off-cycle migration and on-cycle redistribution, were calculated at 11% (incapacity) and 9% (in energy efficiency). However, energy loss due to coolant stream displacement can be eliminated by installing a liquid line solenoid valve to avoid coolant migration from the condenser to an evaporator during off-cycle compressor operation. The compressor is responsible for nearly 80% of the overall energy consumed by the fridge. Energy savings of close to 40% is practicable by replacing the standard single-speed compressor with a variable-speed compressor (VSC) that varies the cooling power relative to the loads [1]. Both VIPs and VSCs are very promising technologies, because they're very costly, which restrict their deployment to specialized appliances only.

The last group involves attempts to increase the thermal performance of Exchangers (condensers and evaporators) in refrigeration systems that can be further divided into four main classes [4]:

- Inserting a liquid-to-suction heater (also recognized as a super-heater coil),
- Usage of the heat pipe evaporator loop,
- The use of micro-fins in both heat exchangers, also
- The use of suitable phase change materials (PCMs).

PCM has gained significant attention to the enhancement of heat transfer due to its inherent strengths. PCMs may be used in fridges with either hot or cold storage. The former needs the integration of the PCM to the condenser side, while the latter needs the integration of the evaporator or chamber [5].

### PCM Integration in the Refrigeration System

Table 1 presents the PCMs used in the system for studies and the location of the PCM application:

## PCM CAN BE INTEGRATED INTO THE REFRIGERATOR SYSTEM IN THE FOLLOWING MANNER

### PCM at Evaporator (i.e Low-Temperature Side)

The evaporator mostly in traditional refrigeration devices is based on the movement of free or imposed heat flow. If the rate of free convection heat transfer is low and leads to the consolidation of heat inside the room; while forced convection provides better thermal stability. Forced convection uses a lot of energy, spreading odor and weight loss of food due to high air circulation. The use of PCM is one of the best ways to overcome this difficulty.

Several studies have mainly focused on evaluating the efficiency of PCM based chiller systems in the evaporator (see Fig. 1) As a result of thermal storage, the compressor will have to work longer to compensate for energy storage. However, despite the longer compressor ON time for each cycle to be charged PCM, the global ON-time ratio falls due to the longer OFF time of the compressor. The key benefits of a longer OFF compressor period are lower total energy usage, improved food quality, and the avoidance of damaging effects of repeated start/stop compressors. Besides, in the event of a power loss, PCM helps to reduce the temperature increase of the refrigerator content compared to without PCM [3]. Besides, the presence of PCM in the system led to fluctuations in food temperature fluctuations that were significantly lower than the normal single-temperature refrigerator cycle [8].

A thorough study of the advantages and disadvantages of using PCM in evaporators is provided in Table 3. Other studies have stated that direct PCM interaction with a naturally cooled evaporator provides great advantages. The key explanation for this is that PCM, even if in contact with the RC evaporator, raises the evaporation temperature by enhancing the evaporator heat transfer coefficient and retains excess cooling power at secret PCM temperatures. [9] Besides, this adjustment causes high evaporator heat and pressure during PCM phase switching [10].

**Table 1.** How PCMs are used in the refrigeration system for studies

Reference	PCM	Melting point (°C)	Latent heat (kJ/kg)	Details of PCM application (PCM location)
C. Marques [1]	Distilled water	0	333	5mm thick PCM slab
Cheng [2]	Paraffin + extended graphite + HDPE	50.3	103.3	Shape stabilized PCM (SSPCM) at condenser
B. Gin et al [3,7]	19.5% Ammonium Chloride (NH <sub>4</sub> Cl) salt in water	-15.4	282	PCM panels against the wall of the refrigerator
I. Khan and Afroz [4]	Distilled water	0	333	PCM in direct contact with the evaporator coil and cabinet box
	10%(NaCl) + 90% water	-5	289	
Azzouz et al [6]	Water	0	333	5 mm thickness slab on the rear of the evaporator back of evaporator
	Eutectics	-3	280	
Tulapurkar et al [8]	Propylene glycol(C <sub>3</sub> H <sub>8</sub> O <sub>2</sub> )	20	146	PCMB
Wang et al [13]	Eutectics	8	140	PCMC
	Eutectics	21	220	PCMA, PCMB
Wang et al [14]	Eutectic solution E21	21	150	PCMA, PCMB
E. Oro et al [15]	Clim Sel C-18	-18	306	Embodied PCM mounted on the top of its evaporator pipe
Yusufoglu et al [16]	Binary aqueous mixture	-2.5	228	PCM slab at the evaporator
		-4.4	251	
		-3.6	201	
Elarem et al [17]	A4 PlusICE	4	200	U-type tubes PCM exchanger around evaporator section
Bakhshipour et al [18]	n-octadecane	30.5	244	PCMB
Liu et al [23]	18% NaCl + 5% SAP + 0.03% diatomite	-18.98	120.6	PCM trays at the bottom of drawer and PCM slab on the top of drawer
Sonnenrein et al [24]	Water	0	333	Macro-encapsulated PCM at the condenser
	Paraffin	34	251	
	Copolymer bound PCM	34	182	
Ahamed et al [25]	Ethylene glycol (C <sub>2</sub> H <sub>6</sub> O <sub>2</sub> )	-12	181	PCM panels placed against the wall of the cabin
Hoang et al [26]	Rubitherm (RT5)	5	180	PCM plates
Boban et al [27]	Water	0	333	U-shaped PCM box placed around the evaporator cabin
	Ethylene glycol	-4	181	
	Eutectic solution	-5		
Hong et al [28]	RT3	3	198	PCM filled in composite shelf
	RT4	4	182	
	RT5	5	180	

Therefore, the refrigeration capacity is high, and, as a result, the freezing capacity is increasing. Similar findings have been documented in cases where evaporator coils have been submerged in PCM. (See Fig.2) In such situations, the refrigerator absorbs room temperature by operating instead of free convection (case without PCM). For this reason, the effective temperature of the cooling coils drops dramatically to preserve the ideal temperature of the cabinet. As a result, the evaporator operates with PCM at high temperatures and pressures and raises the

temperature in the refrigerator that we put on the compressor [4].

However, if the evaporator is submerged in a PCM with even a change of phase For temperature higher than that of the storage set-point temperature, a high thermal resistance is produced from around the evaporator, that, in turn, results in a continuous start/stop of the compressor [5]. In brief, all studies are focused on the study of parameters such as phase shift temperature, PCM size, geometry and form, and the effect of thermal load.

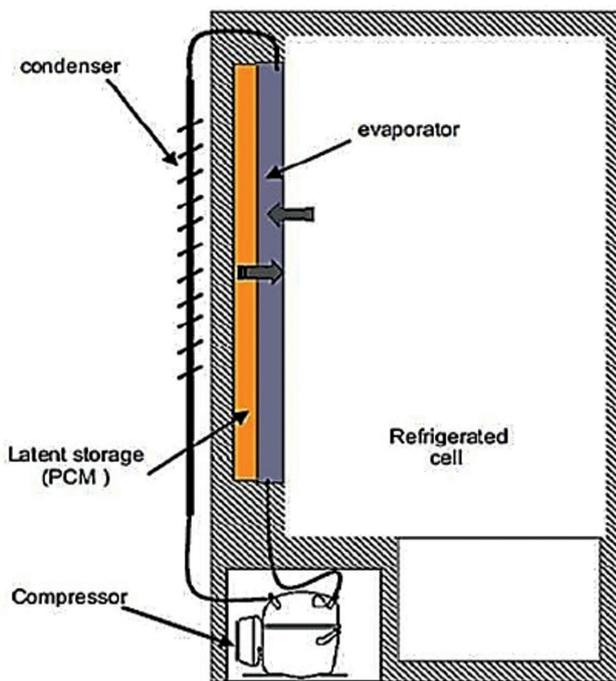


Figure 1. Experimental layout of the evaporator using.

The effect of each parameter is discussed separately in the following sections.

**PCM at the Condenser (i e High-Temperature Side)**

The condenser is indeed the heat exchanger accountable for rejecting compression heat from the refrigeration device to the atmosphere. The maximum amount of heat removal at the condenser is always better for getting the highest efficiency from the refrigeration cycle. The goal of using PCM at the condenser should always be to obtain lower temperatures throughout the condenser. Unlike the large-scale investigations of PCM in the evaporator or inside the cabin, its application to the condenser didn't even receive much focus. The reason may be the unpleasant consequences of such adjustments during the complete cycle, the usage of the PCM in the condenser resulted in the continuous heat dissipation of the new fridge, differing from the normal distribution of heat between the regular sets. Therefore, it is possible to greatly increase the overall performance of the condenser heat transfer, resulting in lower condensation rates, higher evaporation rates, and a much higher cooling rate at the generator site. The overall response time and also the time duration of a revolutionary refrigerator relative to the regular refrigerator. (An object made of solid phase-modified component (SSPCM) mounted on hot wall condenser tubes) were very small, resulting in normal compressor start but low power consumption.

Experimental studies have also shown that up-gradation of the refrigerator may improve energy efficiency by

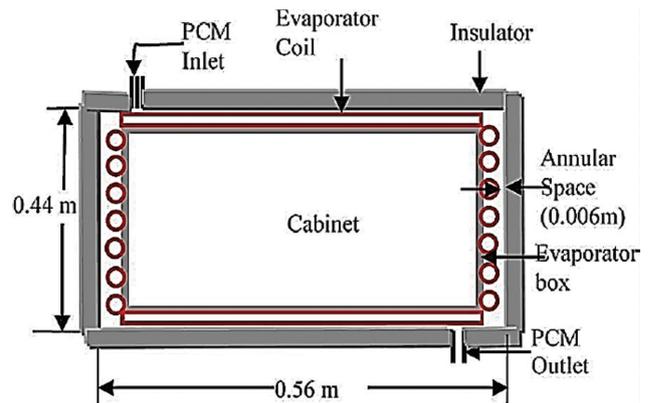


Figure 2. Front display of the evaporator panel with PCM [4].

about 12% with perhaps a minor increase in costs. The heat loss of the new refrigerator via the cabinet has been less than that of the ordinary refrigerator mostly during the on-time cycle. In contrast, the heat leaks of the new refrigerator in the off-time cycle were more severe [2]. This deficit adversely affects compressor performance in long-term use. UW. Cheng has developed a flexible version of the novel indoor refrigerator (see Fig. 3) with SSPCM (reinforced phase switching material) and With continuous heat transfer due to SSPCM secret heat storage, the efficiency ratio is improved by about 19 percent by imitation, but energy savings are 12 percent and are calculated by an increase of approximately 7 percent in heat leakage due to SSPCM inside the protective layer. To provide a theoretical basis for refrigeration optimization with SSPCM, the effects of the estimated temperature calculation, refrigeration temperature, and phase change in energy-saving temperatures were analyzed. It is concluded that growing ambient temperatures and decreasing temperatures in the refrigerator will improve energy efficiency; the second step of SSPCM 's shift in temperature at high temperatures of about 49 ° C resulted in the new refrigerator's low power consumption [Cheng. 2013]. It has been observed that when the atmospheric temperature rises or the cooling point decreases, the COP decline and energy usage increases. It has been stated that, whenever the phase temperature goes up, the energy usage shows a low temperature of 50 ° C, which is similar to the state temperature of the SSPCM. This finding confirms the significance of choosing the correct PCM melting points.

Ultimately, the latest fridge with thermal-storage condensers and a standard refrigerator with traditional hot-wall condensers are configured by the multi-purpose approach of reducing overall cost and 24-hour energy consumption. In terms of the same overall cost, the efficiency gains of the optimized new refrigerator comparable to the optimized ordinary fridge range from 19.9% to 26.1% [11].

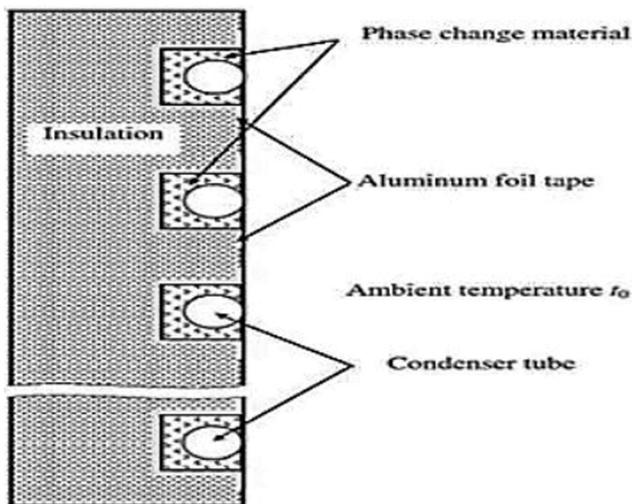


Figure 3. SSPCM heat storage condenser.

#### PCM in Between Components

1. Between the compressor to the condenser (PCMA)
2. Between the condenser and the expansion valve (PCMB)
3. Between the evaporator and the compressor (PCMC).

Such experiments were carried out using different PCMs in various parts of the refrigerator facility as can be seen in Figure 4. PCMs being inserted between the compressor and the condenser (PCMA), in between the condenser PCMs being inserted between the compressor and the condenser (PCMA), in between condenser [14]. Table 2 shows the benefits for each area and the % increase for the COP program. It also shows the limit in each area. When placed between both the compressor as well as the condenser (PCMA), the PCM was acting as an extra component at the condenser resulting in a low-pressure temperature as in condenser. In the case of PCMB, high-temperature temperatures have resulted in a high degree of low and high cooling of COP [14]. Still, the heat-resistance period was long. Extremely high temperatures deteriorate COP but it is evident that PCMB has slightly reduced COP. In PCMC, a low superheat was detected and developed by the COP, but the drop in pressure on the pull line affected the development of the COP. In general, PCMB has led to very high COP while PCMA and PCMC provide high system stability [14]. Continually; the system was also strongly modeled [14].

In the dynamic model, the system parameters were sensitive to their original conditions and this model revealed some weaknesses in superheat prediction and low cooling. This is due to the assumption of illuminated boundaries. The main problem of the model is that all the parameters calculated were intermediate parameters rather than locally distributed parameters [14]. Wang

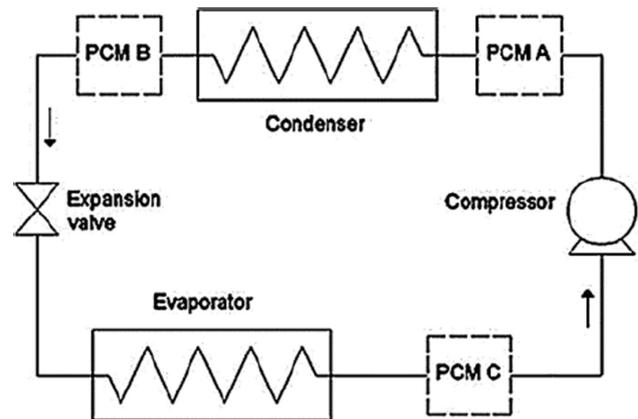


Figure 4. Interpreted PCM positions in the device under review by Wang et al.

concluded that the size as well as the max size of the PCM heat exchanger would rely on the implementation. The overall size of the PCM heat exchanger makes charging slower and more complicated. With PCMC, the removal of excessive line pressure which needs to be reduced and the positive creation of this is a matter of continuing research. It is useful to integrate the PCM specifically to the suction pipe and for installation at a specific location too [14].

#### PCM Panels/Packs Inside Compartments of the Refrigerator

E. Oro investigated the effect of PCM integration inside the refrigerator compartment. In order to evaluate the profit of introducing PCM to a low-temperature container or transfer device, a period factor (PF) was calculated as the measure of time required for indoor air or liquid temperature to reach a specified PCM temperature without it. In view of both air & frozen heat load, PF is often higher than one; i.e. the addition of PCM increases storage performance [15].

In summary, further work is necessary to optimize the form of the whole heat exchanger being designed to reduce pressure drop and enhance heat transfer [14]. There is further scope for improvement Through making improvements to the heat exchangers to enhance U value, the cycle system (to upgrade the freezer PCM melt/freeze), and the optimization of the refrigerant capillary and gas amount for a modern PCM based application, mass flow rate calculations for all recently formed cycles will lead to a far more in-depth engineering study of the new cooling systems [8]. Even more research is necessary to measure the effect of PCM mostly on the condenser because previous researches were restricted either to a hot-wall condenser or even a heating and cooling processing facility, further examination and evaluation of other installations is also required [5].

**Table 2.** Advantages based on PCM location

<b>Name</b>	<b>Location</b>	<b>Advantage</b>	<b>Limitation</b>	<b>COP change</b>
PCMA	Along with-between the compressor and the condenser	Function as an extra condenser Reducing Condenser Pressure & Temperature Enhancing Sub-Cooling.	More frequent compressor start/stop	6%
PCMB	Along with-between the condenser and the expansion valve	Increasing sub-cooling		8%
PCMC	Along with-between the evaporator and the compressor	Temperature regulation achieved by the reduction of superheat	Increased pressure drop	0%

**Table 3.** Benefits as well as drawbacks of a PCM inserted evaporator

<b>Sr. No.</b>	<b>PCM at evaporator</b>	
	<b>Advantages</b>	<b>Disadvantages</b>
1.	Higher COP [13]	Higher condensation temperature [2,14]
2.	Lesser global ON time ratio of compressor [7]	Lengthy compressor ON time of cycle [13]
3.	Longer compressor OFF time [6]	
4.	Lower compartment temperature fluctuations [3,8]	
5.	the regulated temperature at the inlet of the compressor [14]	
6.	More refrigerant density at the inlet of the compressor [4]	
7.	Quite balanced state against fluctuations in thermal load [6]	
8.	Support in the event of power loss, i.e. functioning as a backup device [7]	
9.	Enhanced quality of food [7]	
10.	Supportiveness to suppress defrost & door opening of thermal gradient [3]	
11.	Favorable to the end-users, financial systems as well as the environment at large [17]	

**Table 4.** Benefits as well as drawbacks of a PCM inserted condenser

<b>Sr. No.</b>	<b>PCM at condenser</b>	
	<b>Advantages</b>	<b>Disadvantages</b>
1.	Increase in COP [2,13]	Quite consistently on/off of the compressor [2,14]
2.	Shorter global time ratio of the compressor [7]	Temperature rise from its condenser to a container for the duration of the OFF [2]
3.	Lower energy consumption [2,18]	Higher coolant transfer loss [1,2]
4.	Additional heat transfer from the condenser, during the time of the OFF compressor cycle. [2]	
5.	A quicker balanced state of the cooling system [2,18]	
6.	Low pressures and temperatures of condensation [2,14]	
7.	The significant level of sub-cooling [2]	
8.	Higher the heat gain from the container condenser throughout ON time. [2]	
9.	Slight starting energy with the smaller time required to reach a stable status [2]	

## PARAMETERS THAT AFFECT THE PERFORMANCE OF PCM

### Refrigerant Properties

#### Effect of type of refrigerant

There is an increase of 4.78 percent using R600a instead of R134a. This is because Joule-Thomson's coefficient is R600a higher than R134a (Joule-Thomson's coefficient is 0.106 for R600a and 0.057 for R134a) [18].

#### 3.1.2 Impact of flow rate in the freezer

It is noteworthy that the increase in the flow rate of the refrigerator is increased because of the rate of heat transfer from its freezer to the PCM [18].

### PCM Features

#### Types of PCM

The choice of PCM depends largely on the type of application (hot side / cold side), the cabinet sets the temperature [15], PCM properties (LH value, HC value, the storage capacity required in cabinet) [19] and hot refrigeration load [4,6]. For example, the ultimate cooling capacity of the device is lower with even a eutectic aqueous solution than that of PCM water, however, the benefit including its eutectic solution is the ability to store fluid in the refrigerator at normal temperatures values specified for refrigeration. [19].

#### Impact of temperature on phase transition

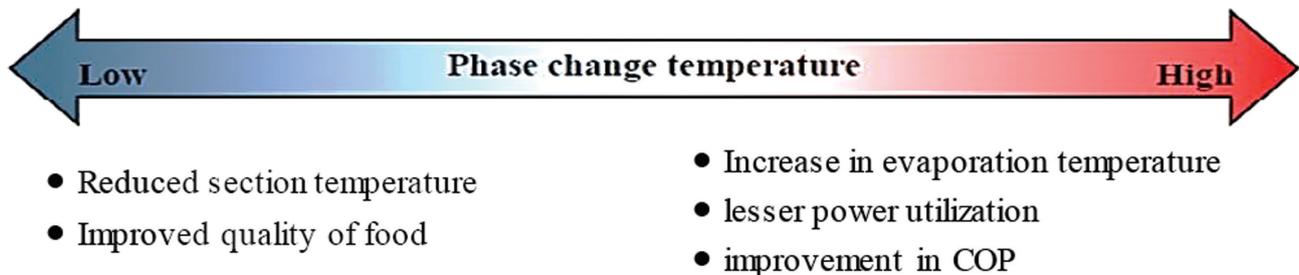


Figure 5. Benefits of high/low phase temperature adjustment on system output [Joybari 2015].

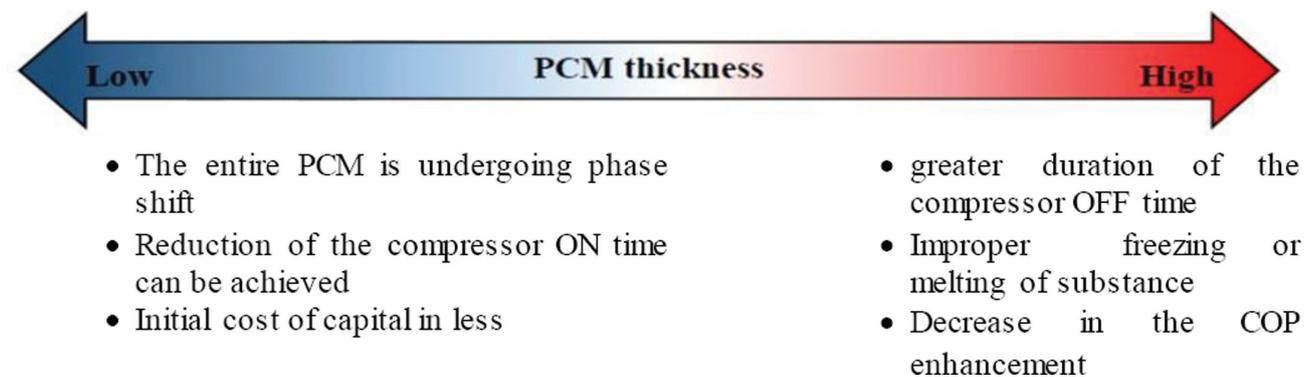


Figure 6. Benefits of high/low PCM thickness on system performance [5,18].

#### Effect of volume of PCM and depth of PCM layer

The quantity of PCM greatly affects the efficiency of the cooling system. The rise in the substantial amount of PCM is stated (about 40%) has led to a growth rate of only 6% in the COP program [22]. However, whenever it increases, The PCM amount still retains the entire PCM operating in the phase switching operation, the influence of this is quite high shortening the on-off time ratio compared to the prolonged compressor period [6]. On the other hand, the insertion of a thicker PCM is far more efficient and thus, therefore, requires higher compressor work to make the PCM more consistent; thus, the thickness of the PCM must be assessed on the basis of the load [5]. According to Onyejekwe, [22] Using the formula, the necessary capacity of the PCM to achieve the identified capacity can be calculated:

$$Q = \rho v h \quad (1)$$

Where, Q is the total amount of energy stored in the PCM,  $\rho$  &  $h$  denotes the density and heat capacity of the evaporation and  $v$  signifies the amount of the PCM (Volume). The following formula may be used to measure the total energy found in the PCM (Q)-

$$Q = UA_{\text{Cold}} (T_{\text{amb}} - T_{\text{Cold}}) \quad (2)$$

In which the amb and cold indexes are the atmospheric and cold sections, and the UA is the overall

thermal conductance. In order to achieve the desired load significantly, the energy is then stored in the PCM ought to be equivalent to the amount of energy transfer through the section walls during in the OFF time (toff) compressor; thus, the minimum volume for the PCM must be regarded

$$V_{\min} = \frac{t_{\text{off}} [UA_{\text{Cold}} (T_{\text{amb}} - T_{\text{Cold}})]}{\rho h} \quad (3)$$

**Effect of PCM position**

In order to efficiently incorporate the PCM heat exchanger throughout the fridge section, it is important to use PCM slots throughout the evaporator, walls including container racks, which enable us to quickly regulate and homogenize the temperature. This improves the compressor cut-off time and thus minimizes the energy usage of the fridge [17].

Integrating PCM with the refrigerator system is a daunting task. The use of PCM in the evaporator or condenser or inside the cabinet has shown different performance. The advantages and disadvantages of each area are presented in Tables 3 & 4. Therefore, critical studies are needed to investigate the appropriate PCM position that will improve high energy efficiency and better food quality [22].

**Effect of PCM orientation and percentage of PCM coverage**

The horizontal PCM configuration reflects lower room temperatures than vertical alignment. Considering the effects of all the simulations, combining horizontal PCMs with eutectic in a full-height room is a good option. The required functionality can also be achieved by the same volume (final volume) by dividing the room into two drawers and using a horizontal PCM per drawer, with only ice being the design method in the last home temperature refrigerator [1].

Racks with high PCM inserts have good performance to achieve a stable temperature inside the room in a short time. However, there is an additional limit that increases the installation of PCM on racks more than that 75% does not lead to a significant reduction in time to achieve the same temperature [17].

**Heat Exchanger Geometrical Properties**

**Effect of heat exchanger tube diameter**

It was found that increasing the diameter of the tube had a significant effect on reducing the temperature of that same refrigerator leading to a rise in the heat transfer region and led to an increase in COP [18].

**Effect of heat exchanger length**

It has been found that by increasing the length of the heating element, the temperature increase increases, leading to more heat transfer between the refrigerator and PCM, thereby reducing the temperature of the refrigerator and the improved COP [18].

**Operational Conditions**

**Effect of ambient temperature**

**Effect of temperature of evaporation including its pressure**

Enhancing the reliability of heat exchangers, specifically evaporators, is one of the areas most focused on boosting the effectiveness of the indoor fridge.

Azzouz found that the PCM installation immediately raised the temperature due to increased secret PCM temperatures. Note that perhaps the temperature of the vapor during the phase transition is high, which is primarily determined by its phase change as well as its pressure. But on the other hand, high evaporation pressure means greater evaporation temperatures, including the PCM process, which has led to higher performance [22]. However, poor evaporating heat requires longer consolidation of PCM due to heat transfer from PCM and lower COP [2].

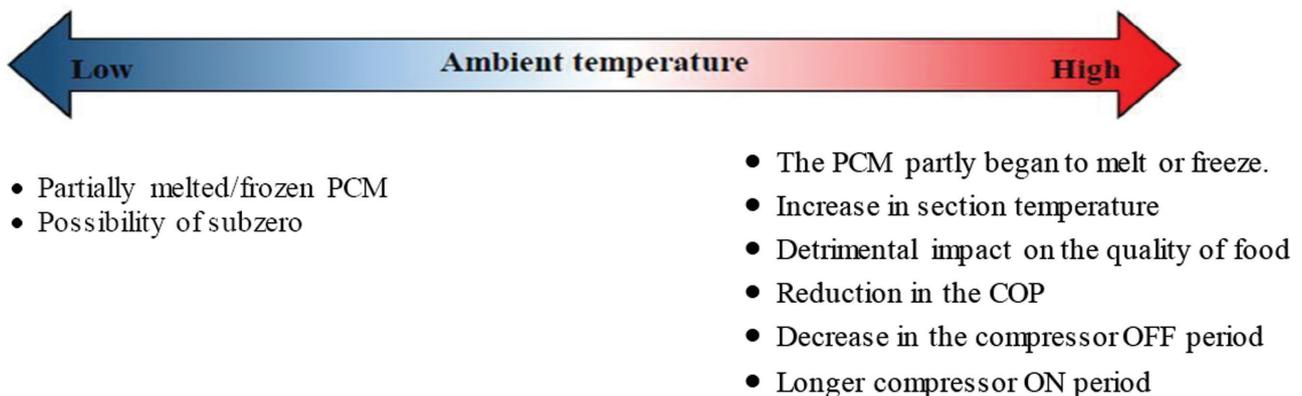


Figure 7. Adverse impacts on device efficiency of elevated/low environmental temperatures [5].

### Effect of the on-off cycle of the compressor

There could be 2- kinds of cycling losses. Being that the hot load of heat exchangers from over current cycle is higher than those of the usual operating system. This effect decreases thermodynamic efficiency due to elevated temperatures. The second one is there is a loss due to the removal of the refrigerant at the start of the compressor and the stopping process [4]. These causes lead to a 5-37% energy loss. Therefore, the reduction of on-off compressor cycling is an important function to increase the performance of the cooling system. Lowering on-off compressor cycling effectively decreases the decrease in temperature within the storage container and retains a steady temperature contributing to improved food quality [3, 4].

### Effect of thermal load

The responsiveness of the fridge to the introduction of PCM and its efficiency is highly reliant on heat conductivity [6]. Heat loads caused by open doors and shivering cycles increase refrigeration power by 11-17% and 15-21% respectively [Gin et al. 2010]. It is well known that the efficiency of the cooling system is decreasing while the hot load is increasing. From the other side, the use of such PCM in the fridge system would improve the effectiveness of the device. The highest heat loads directly impact that both charging time and also the discharge time including its PCM, as it lowers its melting time whereas rising their ice time because the compressor should obtain a greater temperature as well as the sufficient PCM [2]. Various types of PCMs can also be affected by the system for different heat loads. The refrigerator and PCM system stated whenever the heat load became low, the eutectic PCM (with such a temperature change value of  $-5^{\circ}\text{C}$ ) used to have a shorter compressor at such a time, whereas at higher loads preferred substance is water due to its high hidden temperature compared to eutectic. Therefore, the efficient effect of the PCM effect on various temperature loads is important for continuity.

### Effect of the surface area of the condenser

Increasing the size of the condenser with the fridge by 20% increased the effect of the PCM. It is suggested that the heat transfer region, including its evaporator and/or condenser, be redesigned to enhance the energy-saving capabilities of PCMs used in refrigerators [16].

### Heat gain from the refrigerator unit

The heat gain of the fridge cabinet seems to have a significant impact on the quality of PCM melting / freezing mostly during the on/off time of the compressor. Whenever the PCM is fully frozen or melts, its energy efficiency of the refrigerator may be improved. In order to further boost energy efficiency, the volume and position of the PCM on the evaporator shall be configured under the heat gain of the fridge at the normal atmospheric temperature [16].

## ISSUES FOR THE IMPLEMENTATION OF PCM TO THE REFRIGERATION METHOD

The choice of PCM container material is one of the very challenging tasks due to the oxidizing properties of most PCMs.

Aluminum has high thermal conductivity but shows pitting action on its surface that can modify the material properties of the container. SS can also be recommended for PCM containers for corrosive PCMs. Even then, SS provides low thermal conductivity that reduces the heat transfer coefficient between the PCM and thus the heat exchanger.

The PCM properties, including this phase transition, stabilization during prolonged cycling, including sub-cooling, are yet another difficulty, which restricts the integration of PCMs into the traditional method. In summary, the correct selection of PCM material (concerning the temperature change process, its corrosive properties, the optimal thickness of the PCM) and the ideal container material is subject to further examination.

## CONCLUSION

A thorough review of the application for PCM in the domestic refrigeration study was carried out and summarized in Table 1. Most of the experiments were concerned with the application of PCM mostly on the low-temperature side (i.e. evaporator). The studies indicated that the latent heat storage technology is promising. By use of PCM on the high-temperature side (i.e. condenser) provided quite promising results due to the effects on the system. In conclusion, the finding of the studies include the ones listed here:

- Much of the studies have modeled a global approach system; these can be modeled with a zone approach that has the accuracy and computational time between two extremes
- The studies are limited to less no. of PCMs; therefore more experimentation on different types of PCM is required.
- Studies are limited to hot wall condenser only, the investigation of the PCM application for a particular type of condenser is subject to the further scope of work.
- The PCM integration with traditional systems is limited due to the limited characteristics of PCMs, such as low thermal conductivity, and thus a PCM analysis with Nano-particle additives may be carried out.
- The combination of two separate heat transfer enhancement methods, such as LSHX and PCM, can be used to examine the effects.
- It seems to be the simultaneous application of PCM at high temperature and cold temperature side can enhance the system performance and reduce the power consumption.

## CONFLICT OF INTEREST

The authors confirm that there is no conflict of interest to declare for this publication.

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