PERFORMANCE IMPROVEMENT OF A HOUSEHOLD REFRIGERATOR USING PHASE CHANGE MATERIAL

*Pradeep N and Somesh Subramanian S

Department of Mechanical Engineering, Government College of Engineering, Tirunelveli, Tamil Nadu- 627007, India

.

ABSTRACT

Thermal energy storage through phase change material has been used for wide applications in the field of air conditioning and refrigeration. The specific use of this thermal storage has been for energy storage during low demand and release of this energy during peak loads with potential to provide energy savings due to this. The principle of latent heat storage using phase change materials (PCMs) can be incorporated into a thermal storage system suitable for using deep freezers. The evaporator is covered with another box which has storage capacity or passage through phase change material. The results revealed that the performance is increased from 3.2 to 3.5 by using PCM (($Na_2HPO_4.12H_2O$) & (Zn ($No_3)_2.6H_2O$)).

Keywords: PCM, Temperature and COP

1. Introduction

As a demand for refrigeration and air conditioning increased during the last decade, large demands of electric power and limited reserves of fossil fuels have led to a surge of interest with efficient energy application. Electrical energy consumption varies significantly during the day and night according to the demand by the industrial, commercial and residential activities. This variation leads to a differential pricing system for peak and off-peak periods of energy use. Efficient and economical technology that can be used to store large amounts of heat or cold in a definite volume is the subject of research for a long time. A refrigerator is a common household appliance that consists of a thermally insulated compartment. The domestic refrigerator is one found in almost all the homes for storing food, vegetables, fruits, beverages, and much more. There has been reasonable demand now-a-days for the development of greener refrigeration technologies. Rising and fluctuating prices of fuel ultimately give a higher electricity cost.

A growing global environmental awareness and the rising costs of energy are driving the demand for the development of sustainable cooling technologies. In INDIA itself cold appliances are responsible for 17% of average domestic electricity use. Worldwide it has been estimated that there are approximately 1 billion domestic refrigerators in use, although the emissions out from the refrigerators have been greatly reduced by using various environmentally friendly refrigerants the real grave problem is the emissions let out during generation of electricity. Various eco-friendly refrigerants like R134a have been already replaced but still developing a sustainable refrigeration system is the rising need for hour. The compressor among the components is the largest electricity consuming device. Approximations suggest that nearly 40% of energy is being consumed by the compressor. Various researches are especially oriented with a view to reduce the electrical consumption of the compressor and at the same time also get the desired refrigeration effect.

2. Literature Review

Refrigeration systems form to be one of the essential subjects in the field of mechanical engineering. Conserving energy and at the same time obtain the desired refrigeration effect is the challenging part and need of the hour. These use of phase change materials to improve the Performance in Direct Cool Refrigerators materials have great potential to reduce the work load acting upon the compressors and save a considerable amount of energy.

Arun Kappen et al. [1] have completed the experiment and gives the conclusion that the Performance results and cold storage capacity measurements have been obtained and compared with the original system without storage. The results indicate that the response of the refrigerator to the addition of PCM and its efficiency are strongly dependent on the thermal load. A significant decrease in the number of starts and stops of the compressor and consequently of the temperature fluctuations inside the refrigerated cell was

*Corresponding Author - E- mail: pradeyy@gmail.com

observed due to the use of PCM. Also, an increase in COP of the system in the range of 10-30% was observed

Akshadnya et al. [2] concluded that the theoretical and experimental data which is being available analytically, experimentally and by preferring science journals, it is being concluded that the use of PCM. Energy storage device in the field of refrigeration and air conditioning can make the significant impact on the problem of energy consumption and has the capability to save the energy in large amount by increasing the efficiency and performance. Hence, optimization in the use of phase change material can lead to greater results in the field of energy saving and can turn the thinking of the common people into renewable energy sources.

Akshata et al. [3] concluded that the use of phase changing materials is indeed useful and will significantly contribute to society in saving energy. Due to its appreciable Thermal physical properties it has various uses. Use of phase change materials will indeed save electricity and also improve the quality of food in terms of hygiene by reducing the fluctuations of temperatures in the evaporator section. It was observed that there is no significant change in COP value but the performance has improved in terms of saving in electricity by using 125 ml PCM material for the refrigerator we have used in our experiment. Bottom-line we can conclude that phase changing materials are indeed useful serving elements in the refrigeration industry.

Azzouz et al. [4] found that the addition of the phase change material results in an enhanced heat transfer from the evaporator by conduction to the PCM that replaces the previously natural convective heat transfer to the air. This model yields a 72% increase in the coefficient of performance and a 25% decrease in the global working time of the compressor. These first results show a clearly positive impact of this technology on the energy efficiency. Nevertheless, let us underline that most assumptions (particularly the hypothesis related to the thermal resistance of the evaporator) contribute to over predict the performance.

Reddy et al. [5] investigated the performance improvement of a house hold refrigerator using phase change material and tested with and without PCM. The results showed that cooling effect is maintained inside the chamber without PCM is increased 5 hours 21 minutes to 7 hours 10 minutes during power of periods and increased COP from 3.29 to 3.5 at full load. After switching of the system, the time to reach the temperature inside the evaporator from 32 °c to -16.9°c is noted 7 hours 10 minutes. This is the time required to store the product without spoiling inside the freezer at power off conditions.

Rahman et al. [6] investigated the performance improvement of a household refrigerator using two different phase change materials of different quantities at different loads. This improvement by sub cooling can be done for single evaporator refrigeration system. Because of prolonging of the compressor off time by using the latent heat of energy of the PCM capsulated ice, used as the thermal energy storage material, has been investigated numerically. We can have better food quality due to lower hysteresis cycles of on/off for a given period of operation In case of without PCM and with PCM the COP Is higher at low thermal load while it decreases with it decreases with the increase of thermal load Depending on the PCM and the thermal load around 55-60% COP improvement has been achieved by the PCM in respect to without PCM. Use of PCM decreases the fluctuation of the cabinet temperature. At higher load this effect is not so significant.

Hence by various such reviews and analysis of the researchers we can conclude that the use of phase changing materials although is challenging yet they are worth useful. Use of such materials is a rising need of the hour. One cannot always depend and believe that energy is available in plenty. There always has to be an alternative for sustaining life and sustaining energy.

3. Types of Phase Change Materials

The melting point and heat of fusion details for different phase change materials are presented in Table 1.

Table 1 Salt Hydrate Pcm Properties

S. No.	Phase Change Material	Melting Point ($\degree$C)	Heat of Fusion (Kj/KgK)
1.	$Na_2HPO_4.12H_2O$ (Zinc nitrate hexahydrate)	36.2	246.5
2.	Zn $(No_3)_2.6H_2O$ (sodium orthophosphate dodecahydrate)	35.5	265

4. Method for Selecting PCM Materials

According to thermo- physical properties. The melting point of a PCM must be lying in a practical range of operation. The latent heat should be as high as possible to minimize the physical size of the heat storage. According to the physical properties, it must have limited changes in density to avoid problems with storage vessel, low vapour pressure, favorable phase equilibrium.

According to chemical properties, a suitable material should be non-toxic, on flammable, non-corrosive.

5. Experimental Procedure

5.1. Experimental set-up

The original experimental device is a single-door refrigerator with the following characteristics:

5.2 Refrigerator

The refrigerator is of Videocon Company with the following specification.
  i.   Compressor Model – THK1330
  ii.   Refrigerator Gross Capacity – 47 L.
  iii. Power Input – 80w
  iv.   Current – 0.7A
  v.   Refrigerant Type – R134a
  vi.   Voltage Limit – 220v

5.3. Refrigerant Used

Refrigerant used in the process is R-134a with the following specification.
  i.   It is halo alkane refrigerant with thermodynamic properties similar to R-12 but with less ozone depletion potential.
  ii.   Its Chemical formula is CFH2CF3.-Tetraflurethane
  iii. No chlorine

5.4. Measuring Devices

As the measurement of variables affect the test results, care is taken to choose the best instrument at our premises.

5.5. Thermocouple

The temperature at various points of the system is measured using thermocouples. The thermocouples used are Chromel-Alumel (known as K type thermocouples). The thermocouple tip is attached on various points of the copper refrigerant lines to note down the respective temperature.

5.6. Thermocouple Indicator

The temperature at various points of the system which is measured using thermocouples connected with thermocouple thermometers with knobs correspondingly positive and negative. Thermocouple shows the temperature at the point of contact. The prepared experimental setup and the used measuring unit are presented in Figure 1 and 2 respectively.

Fig. 1 Experimental set up

Fig. 2 Measuring Unit

The evaporator setup and the PCM box used in the experimental setup are shown in Figures 3 and 4 respectively.

Fig 3. Evaporator section

Fig 4. PCM box

6. Procedure

The performance of the refrigerator under no load and without PCM is noted first. Then the performance characteristics of the refrigerator without PCM and at a load of 40 W is tested then. Temperature limits are set between -15 ^{0}C and 3 ^{0}C of the freezer (evaporator). This is the usual temperature limit as this ensures the preservation of perishables inside freezer. After completing these tests, keeping those readings as the basis the refrigerator is tested with PCM at different conditions (varying loads, varying PCM type used etc.) Since our prime aim was not to modify the existing refrigerator, PCM was inserted inside the evaporator chamber. Here, we are assuming that the conduction losses through evaporator walls is negligible. We go for the simple method of introducing the PCM material inside the evaporator in a galvanized box separately.

First of all, we selected Zinc nitrate hexahydrate (Na_2HPO$_4$.12H_2O) as the PCM and conducted tests at no-load and then with sodium Orthophosphate dodecahydrate (Zn (No_3)$_2$.6H_2O) similar testing is taken. Then, rest of the calculations were done on readings taken when this optimum value of PCM of about 250 grams was used. Similar test was carried with load of about 40 watts. At the end of the section, the best option available for using as PCM in refrigerator.

7. Results and Discussion

The experiments were conducted on the above-mentioned refrigerator in the following order.
  i.   At No Load and Load condition (40 W) without PCM.
  ii. At No Load and Load condition (40 W) with two different PCM.

Temperatures at different points were noted for each case. Thus, we will be able to calculate COP's at different points. Required graphs were plotted for comparison purposes. At the end of the section, the best option available for using as PCM in refrigerator were found out, from among the available options. Tests were conducted on the refrigerator without any load and without using the PCM. The readings were noted down at different points for temperatures the results obtained for testing the refrigerator with no PCM and the same procedures with load condition also. Usual energy consumption of a refrigerator per day is approximately 1 kWh. So, a load of 60 W is selected. This 60 W is given with the line of freezer by lighting a bulb of 60 W. Now, since the load is finalized all the above steps done for no load was repeated with load also. The test was carried out for a period of about 2hrs.

7.1. Effect on Coefficient of Performance (COP)

One of the parameters that most frequently used to compare performances of refrigerators is the Coefficient of Performance or COP. COP of the system is calculated using the formula

Coefficient of performance, COP = Q / W
Where,
Heat removed by evaporator, $Q_e = (h_1 - h_4)$ kJ/kg
Work done by the compressor, W= $(h_2 - h_1)$ kJ/kg

The COP values will be higher in the cases of system with PCM.

7.2. Variation in Evaporator Temperature

Variation in evaporator temperature as time progresses is shown graphically, as this is the value that we are controlling for compressor cut off and on. We will be now taking into consideration the graph showing evaporator temperature v/s time for no load condition, loaded condition, with and without PCM usage and then comparing them.

7.3. Variation in Compressor Temperature

Variation in compressor temperature inlet and outlet temperature as time progresses is shown graphically plotted. We will be now taking into

consideration the graph showing compressor temperature v/s time for no load condition, loaded condition, with and without PCM usage and then comparing them.

7.4. Variation in Coefficient of Performance

Graph showing the COP values for no load condition, loaded condition, with and without PCM usage is plotted. The graph is plotted with cop v/s time.

7.5. Comparison of variation in Evaporator Temperature

The graph for variation in evaporator temperature v/s time for load condition is almost in the similar pattern as in the case of no-load condition but it shows a great change when PCM is placed. Graph showing the Evaporator temperature v/s time for no load condition, loaded condition, with and without PCM usage s. Graph gives an idea about the effect of PCM and without PCM conditions on the evaporator temperature. Figure 5 presents the graph plotted to depict the variation of evaporator temperature with respect to time.

7.6. Comparison of variation in Compressor Temperature

The graph for variation in compressor inlet and outlet temperature v/s time for load condition is almost in the similar pattern as in the case of no load condition but it shows a great change when PCMs (Zinc nitrate hexa-hydrate and sodium orthophosphate dodecahydrate) is placed. Graph is plotted with the compressor inlet and outlet temperature v/s time for no load condition, loaded condition, with and without PCM usages.

It was observed that the temperature curves of compressor with and without load condition of the system without PCM is found to be higher curve than the temperature curve of with and without load condition of the system with both PCM. Figure 6 shows the graph plotted to depict the variation of compressor inlet temperature with respect to time.
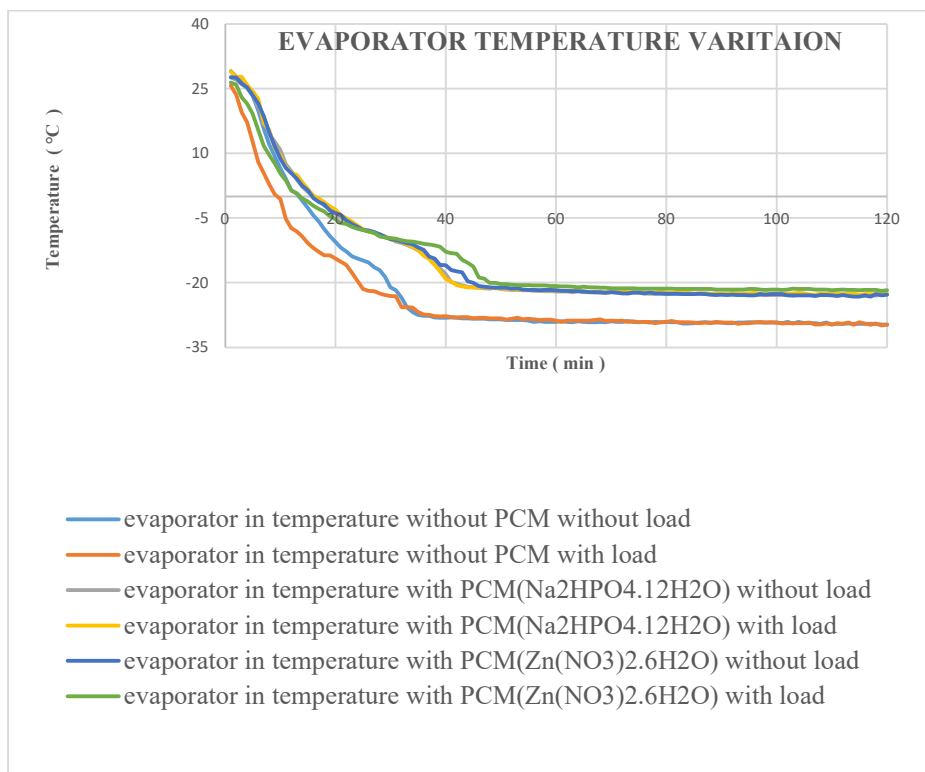

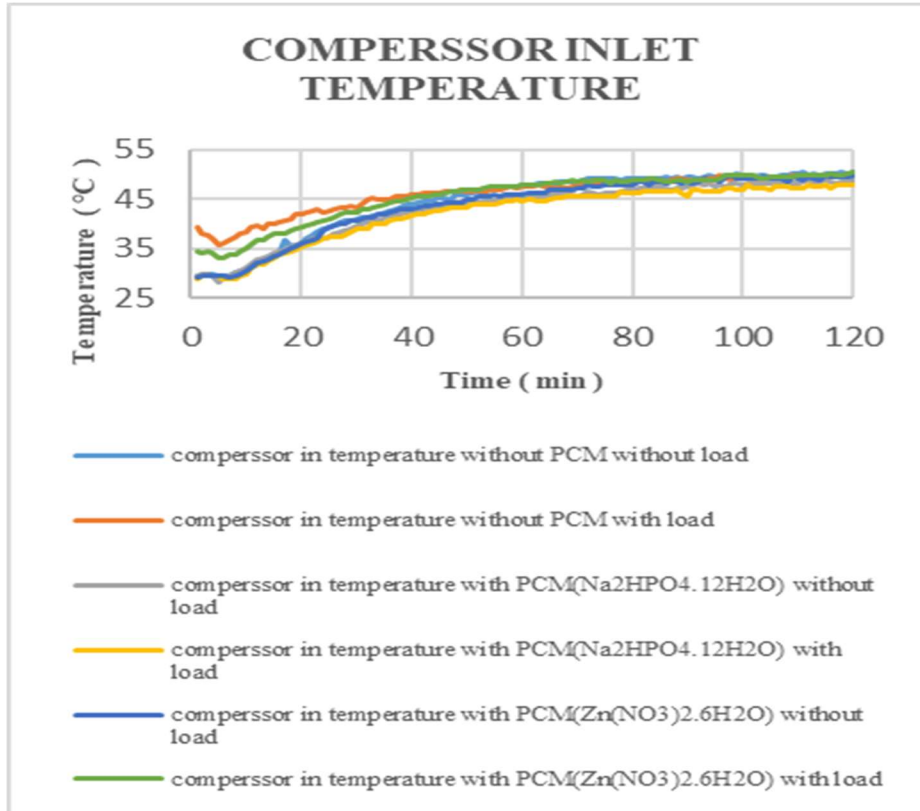**Fig 5. Evaporator Temperature (°c) Vs. Time (min)**

Fig 6. Compressor inlet Temperature (°c) Vs. Time (min)

7.7. Comparison of Variation in COP

Graph showing the COP values for no-load condition without PCM and load condition is plotted. The graph is plotted with cop v/s time. Here an average COP value for no load condition was 4.57 and for loaded condition 3.99 was obtained. Here an average COP value of 5.04 was obtained for Zinc nitrate hexahydrate and 4.9 for sodium orthophosphate dodecahydrate in no load condition whereas for loaded condition it is of 4.29 and 4.34 for sodium orthophosphate dodecahydrate, Zinc nitrate hexahydrate respectively. Figure 7 presents the graph plotted to depict the variation of compressor outlet temperature with respect to time.

Figure 8 presents the graph plotted to depict the variation of COP with respect to time.

7.8. Comparison of variation in PCM Temperature

The graph for variation in PCMs (Zinc nitrate hexa-hydrate and sodium orthophosphate dodecahydrate) temperature v/s time is almost in the similar pattern as in the case of both PCM for no load condition and loaded condition. The temperature varies from range of 30 to -30 °c. Figure 9 presents the graph plotted to depict the variation of PCM temperature with respect to time.
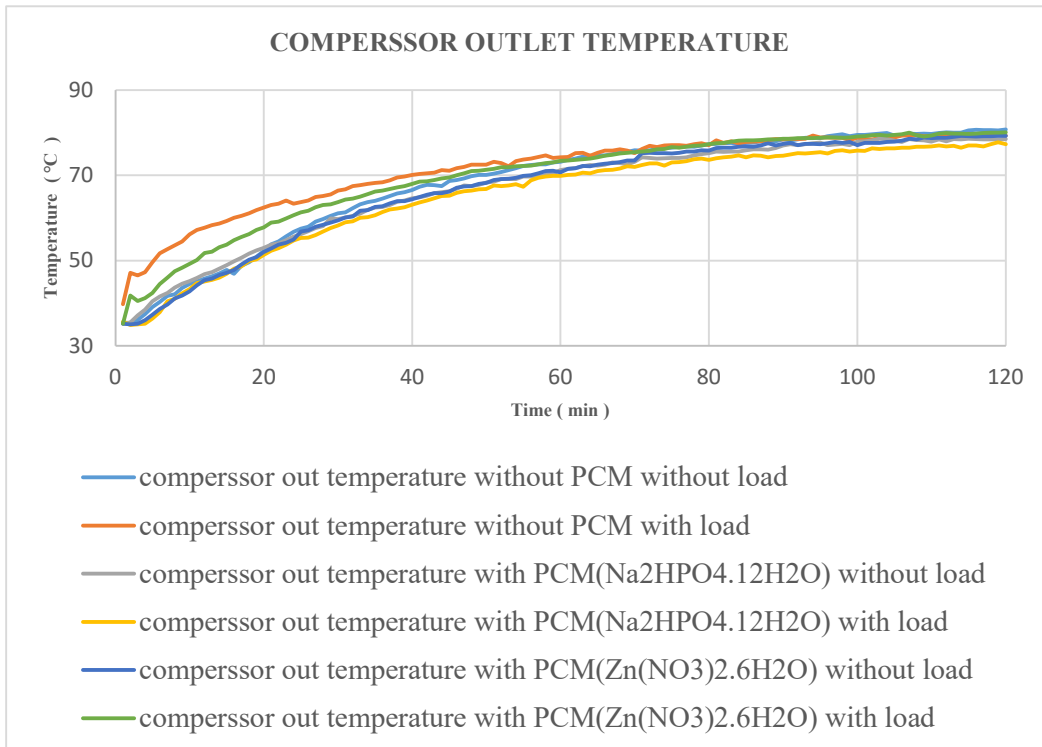
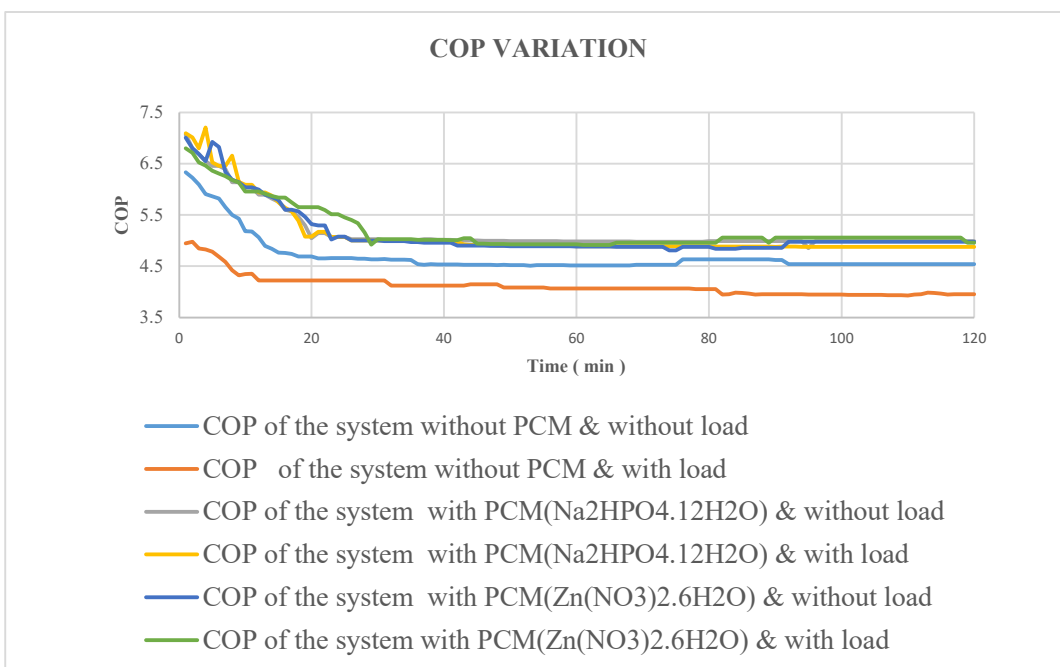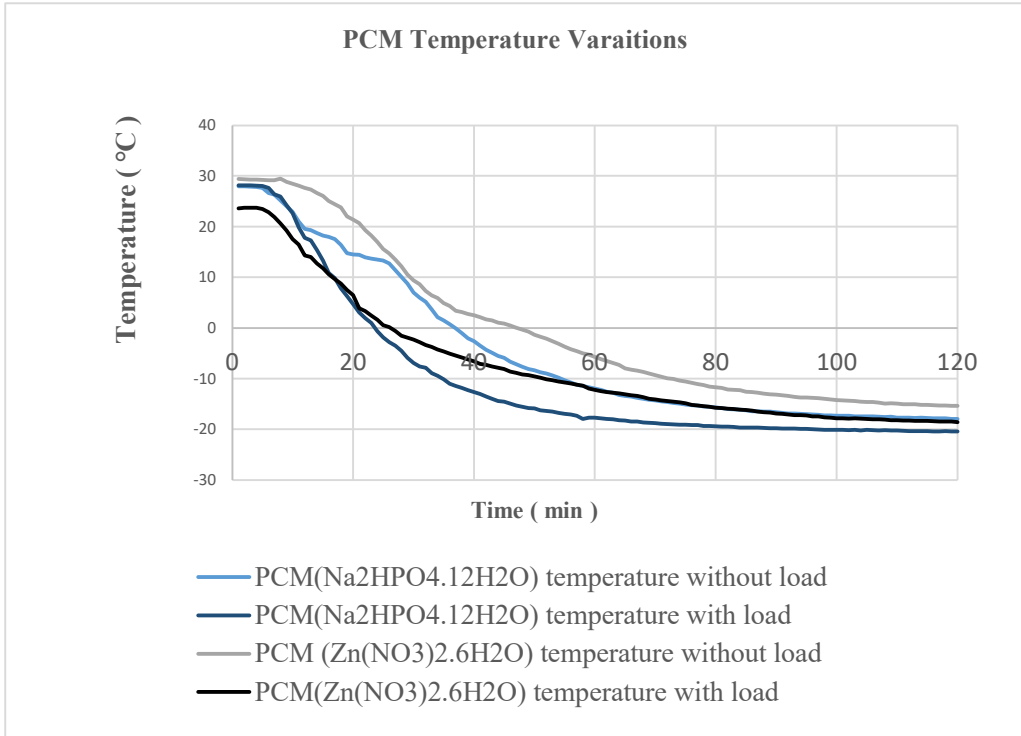**Fig 7. Compressor outlet Temperature (°c) Vs. Time (min)**

Fig 8. COP Vs. Time (min)

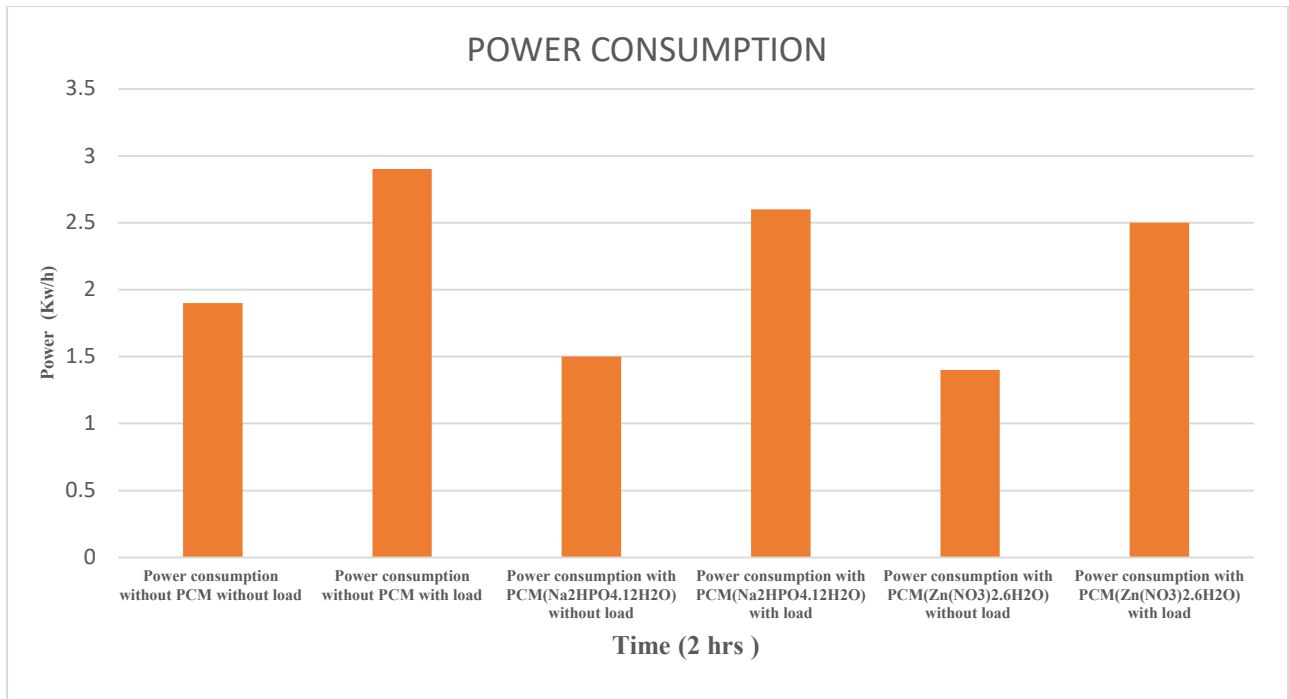**Fig 9. PCM Temperature (°c) Vs. Time (min)**

Fig 10. Power (Kwh) Vs Time (min)

7.9. Comparison of variation in Electrical energy consumption

Next step in the study will be to find out the advantages of using PCM in saving electrical energy. As the compressor cut-off time is increased considerably, there should be a clear saving in the electrical energy consumption too. In order to find this out, we have attached a digital wattmeter in the circuit. Bar chart shows the electrical energy consumption for all the cases (Zinc nitrate hexahydrate and for sodium orthophosphate dodecahydrate and with no PCM condition). This is report for about time period of 2 hours' time interval.

The figure 10 clearly shows the advantages of using PCM in saving electrical energy. It can be noted that for Zinc nitrate hexahydrate is the minimum consumption of electrical energy is obtained as about 2.5kw

for 2 hrs in loaded condition and 1.4kw in no loaded condition. Whereas the sodium orthophosphate dodecahydrate has about 2.6kw and 1.5kw in loaded and no-load condition for about 2 hrs run.

8. Conclusions

Experiment tests have been carried out to investigate the performance improvement of a house hold refrigerator using phase change material and tested with and without PCM. It is observed that the power consumption of the refrigerator is reduced when the PCM is used in the system and also the coefficient of performance is increased respectively. The coefficient of performance and power consumption of the refrigerator nit with and without using PCM are compared and presented in Table 2.

Table 2 Coefficient of performance and Power consumption

Performance parameters	Without PCM	With PCM ($Na_2HPO_4.12H_2O$)	With PCM (Zn $(No_3)_2.6H_2O$)
Refrigerant effect without load KJ / kg	212.3931	215.8014	216.7739
Work of compression without load KJ/kg	46.4011	43.9023	43.01025
COP of the system without load	4.577328986	4.915491899	5.040052081
Power consumption without load	1.8	1.5	1.4
Refrigerant effect with load KJ / kg	215.43912	218.2326	218.9209
Work of compression with load KJ/kg	53.88215	50.92235	50.4247
COP of the system with load	3.998339339	4.299112276	4.341540951
Power consumption with load	2.9	2.6	2.5

References

1. *Arun Kappen, Titto John George,Vinay Vn, march (2016), Performance Improvement Of A Household Refrigerator By Use of a Phase Change Material, International Journal Of Scientific & Engineering Research, Vol. 7: 58 -68*

2. *Akshadnya D. Ukey, Mohd. Irfan Khan, Prashant U. Bokade, V. P. Katekar (2017), A Reassess on Phase Change Material Application in Refrigeration and Air Conditioning, International Journal of Mechanical Engineering Research, Vol. 7: 119-128*

3. *Akshata Namjoshi,Yash Gokhale, Kavita Dhanawade , august (2016), Use Of Phase Change Materials To Improve The Performance In Direct Cool Refrigerators, International Journal of Advanced Engineering And Innovative Technology, Vol. 3: 507-514*

4. *K. Azzouz, D. Leducq, J. Guilpart, D. Gobin, (2005), Improving the Energy Efficiency of a Vapor Compression System Using a Phase Change Material, Second conference on phase change material & slurry: scientific conference & business forum Yverdon-les-Bains, Switzerland, 15 – 17*

5. *M.Surendra Reddy, G.Venkatesh, K.Jayasimha Reddy, B.Suresh, (2016), Performance Improvement of a Domestic Refrigerator by Using Phase Change Material, International Journal of Advance Research In Science and Engineering, Vol. 5: 166-173.*

6. *Rezaur Rahman, Md. Arafat Hossain, ShubhraKanti Das & Adnan Hasan (2013), Performance Improvement of a Domestic Refrigerator by using PCM (Phase Change Material), Global Journal of Research in Engineering (GJRE): (A) Mechanical and Mechanics Engineering, Vol 13, No 10-A*

Nomenclature

Symbol	Meaning	Unit
a	Ampere	a
W	Watts	W
L	Litters	L
KJ	Kilojoule	KJ
Kg	Kilogram	KG