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Analysis of COP in Thermal Battery Equipped Refrigerator

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Abstract: Economic growth is the dominant factor for the surging use of household apparatus namely Refrigerators & Air conditioners to achieve desired comfort and better style of living. Which has inevitably caused a considerable increment in household energy consumption. As Energy is one of the crucial elements for the continuous economic growth of the nation. At the same time developing countries are facing an acute Energy crisis, it becomes prominent to re-design and develop equipment to achieve better efficiency in such a way that loss of energy is minimized. Refrigerators and Air conditioners plays a leading role in domestic power consumption. One of the solutions to this problem is developing energy storage device like thermal energy storage system. Having capability of high latent heat of fusion, This Device which store heat during peak power operation and release the same during reduced power operation. Phase change material is one of the thermal storage devices. Efforts have been made on commercially available VCRS system of M/S Samsung is used along with Phase Changing Material (PCM) as thermal energy storage device. The method calculation and result of the trials leads to successful application which are detailed in this report.

Keywords: Household refrigerator, Air conditioner, Phase change material, Compressor running time, Coefficient of performance

I. INTRODUCTION

One of the most revolutionary and influential invention in the history of science was that of “electricity”. This single invention is the base for the vast and unimaginable growth in scientific and technological field that we see today. At the same time when this became an inseparable part of our lives, world now is facing an acute “energy crisis”. A situation dealing with definite difference between power supply and power demand is termed as energy crisis. Around 41% of total electricity generation across the globe relies on coal fired power plants. Despite severe environmental threats leading to global warming via greenhouse gas effect. According to Thar Coal and Energy Board, these blocks can carry proven reserves of 39 billion tons, however percentage of electricity generation from coal is only limited to 0.1% with heavy reliance on imported furnace oil. For every kilogram of coal that gets burned, a total of 2.312 × 107 Joules of energy gets released, meaning we need to burn a total of 24 billion tonnes of coal in order to meet Earth's energy needs. As it is, coal is responsible for about one-third of our world's current energy production, which means that 8 billion tonnes of highly-polluting coal gets burned every single year.Way is to use the available amount of energy in a better way, wisely. Increasing the efficiency of equipment’s is the solution. Focusing on the increment of efficiency of the instruments which consume a large amount of energy like Refrigerators, Air conditioners, Home Cleaning Instruments etc.Refrigeration and air conditioning systems are directly and indirectly responsible of present energy crisis problem as their use in household, commercial and transportation sector is increasing rapidly.Using air conditioners and electric fans to stay cool already accounts for about a fifth of the total electricity used in buildings around the world – or 10% of all global electricity consumption today.

II. PROBLEM STATEMENT

In normal refrigerator there is presence of thermostat which maintains the prescribe temperature inside the cabinet by actuating the power supply of compressor. If the temperature increases by the set limits than compressor would start and the refrigeration cycle would start to bring down the temperature.

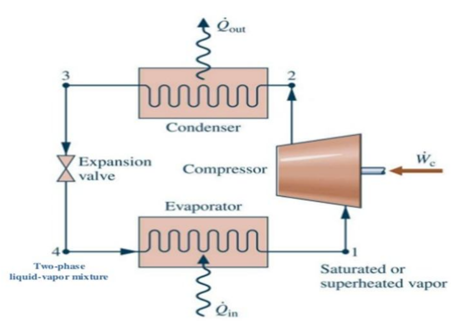

Fig. 1 Schematic diagram of VCRS

Whenever there will be a temperature difference the compressor has to nullify the difference. This difference is majorly created when the large amount of heat load is applied in the cabinet. This occurs whenever the door of the room is opened. Refrigerator compressors mostly feature input power in the range of 1000-1300 W for 1 ton. The steady state current is then in the range of 5 to 7 Amp for a 220-240 V mains voltage. The highest current appears at start-up and can reach up to 4 times the steady state current. Whenever heat load increases inside the room the compressor has to start. As frequently the compressor starts it consumes large amount of power in comparison to continuous operation. Cumulative this extra power is happening frequently in a day.

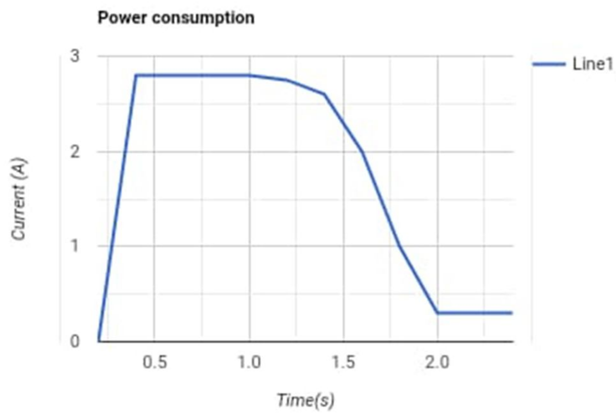

Fig. 2 initial power consumption

The Portland General electric utility did a study on wasteful air conditioner use. "It turns that if you never opened the door, they would use about half the annual projected energy consumption”. The Institute of Food & Agricultural Sciences at the University of Florida says poor open/close habits waste 50 to 120kWh a year!

III.PROBLEM SOLUTION

This frequently on/off of compressor due to reduction in prescribe temperature is the main reason of excessive power consumption. This can be eliminated by using thermal batteries or Phase Changing Material. Latent heat storage using phase change materials (PCMs) is one of the most efficient methods to solve this day to day problem. As shown in fig, PCM bed will applied to outer side of evaporator coil. PCM has characteristic that absorb high amount of heat while changing its phase from solid to liquid. Now, whenever the heat load is applied to the cabinet temperature of refrigerator starts to increase. Says above 5℃. To maintain temperature to 5℃ compressor has to start. But here PCM will play its role. It will help evaporator to absorb this extra heat load even without running compressor. PCM will continuously absorb this load until it completely converts into liquid. Then compressor will start and VCRS cycle run normally.

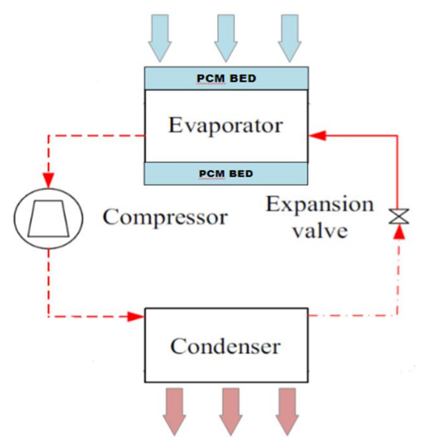

Fig. 3 PCM equipped VCRS

Here, heat energy is not conserved but as there is reduction in frequency of starting of compressor. hence electrical energy is conserved.

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IV. COMPONENT AND ITS SPECIFICATION

The list of Components which were being used in the final experimental Setup are

A. *Vapour Compression Refrigeration System*

The vapor-compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere.

Fig. 4 VCRS

1) *Company:* Samsung
2) *Power of Fridge:* 220V/66 Watt/60Hz
3) *Refrigerant:* R-12
4) *Quantity:* 47 Liters
5) *Compressor:* Hermetically Sealed Compressor

B. *Energy meter*

The meter which is used for measuring the energy utilizes by the electric load. The energy is the total power consumed and utilized by the load at a particular interval of time.

Fig. 5 energy meter

1) *Phase:* Single Phase
2) *Voltage:* 220V/60Hz

C. *Clip-on Meter*

Digital clip-on meter is designed for short-term measurement of the strength of AC sinusoidal frequency of 50 Hz without breaking the circuit with a nominal voltage of 650 V.

Fig. 6 clip-on meter

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D. Temperature Sensors

The temperature sensors are used to measure the working range of the refrigerators and the walls of the refrigerator and the ambient temperatures.

Fig.7 thermometer

1) *Accuracy:* 0.1˚C
2) *Range:* -50˚C to 99˚C
3) *No. Of Quantity:* 4

E. Phase Changing Material

The Phase Change Material is the key component of the project which would save the power, Due to the high latent heat of fusion.

Fig. 8 PCM

PCM	Contents	Operating Range (*C)	Latent Heat (KJ/kg*K)
PCM 22	Inorganic Salts	17 to 27	185
PCM HS-01	Inorganic Salts	16 to 26	190
PCM FMS-65	Organic material	16 to 26	235

Table 1: types of PCM

V. EXPERIMENTAL SETUP

Fig. 9 experimental setup

A. Line Diagram of Setup

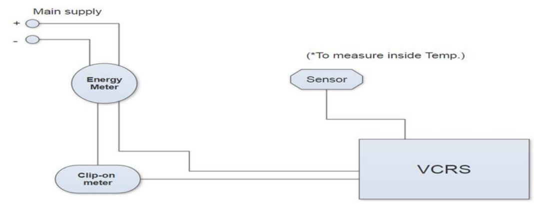

Fig. 10 line diagram of setup

VI. RESULTS AND CALCULATION

We would take the duration of compressor on time from the reading with that we would also note the amount of time during which the refrigerators would remain off and the with both the duration we would calculate the percentage of compressor on period from the following formula:

R (Compressor ON %) = [Compressor ON time/Total time period (Compressor On time + Compressor Off Time)] x100

A. Readings and Calculations are Being Conducted on Various Conditions

1) *Without PCM: Here there won't be any PCM readings are taken on the refrigerator with certain amount of artificial heat load.*
2) *Considering for the optimal Quantity: Which is the best quantity of PCM which is to be kept on the evaporator coil readings are taken on different quantity and selecting the optimum from the available results.*
3) *Calculating the readings of optimal quantity for PCM 22: After having an optimum amount of quantity PCM22 is kept and readings for the power conservation is being taken.*
4) *Calculating the readings of optimal quantity for PCM HS-01: After having an optimum amount of quantity PCM HS-01 is kept and readings for the power conservation is being taken.*
5) *Calculating the readings of optimal quantity for PCM FMS-65: After having an optimum amount of quantity PCM FMS-65 is kept and readings for the power conservation is being taken.*
6) *Comparing the Results Obtained: From the obtained results of Without PCM, With PCM22 (optimal Quantity) with PCM HS-1 (optimal Quantity) and with PCM FMS-65(optimum quantity). All the results are being compared with each of them.*
7) *Selecting the ideal PCM for the Refrigerator: After the comparisons it would be known the ideal PCM for the VCRS.*

B. Without PCM condition

TIME	TEMPERATURE(˚C)			CURRENT(Amp)		COMPRESSOR ON
	Cut off	Cut on	Outside	Initial	Running	
04:34	16.1	-	33.2	-	-	
04:39	-	22.5	33.9	2.4	0.4	8
04:47	15.8	-	33.6	-	-	
05:00	Artificial Heat load applied for (3min) 5:00-5:03					
05:00	-	22.1	33.7	2.5	0.4	9
05:09	16.0	-	32.8	-	-	
05:22	-	21.9	32.6	2.4	0.4	5
05:27	15.8		32.6			
05:30	Artificial Heat load applied for (3min) 5:30-5:33					
05:31	-	21.8	32.8	-	-	9
05:40	16.2	-	32.5	2.4	0.4	
05:53	-	22.4	32.8	-	-	7
06:00	15.9		32.4			
06:00	Artificial Heat load for (3min) 6:00-6:03					
06:02	-	21.9	32.4	2.4	0.4	10
06:12	16.2	-	32.6	-	-	
06:23	-	22.2	32.5	2.5	0.4	6
06:29	16.1		32.5			
06:30	Artificial Heat load for (3min) 6:30-6:33					
06:33	-	21.8	32.3	2.4	0.4	8
06:41	16.2	-	32.4			

Table 2: calculation without PCM

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1) Initial Peak Current

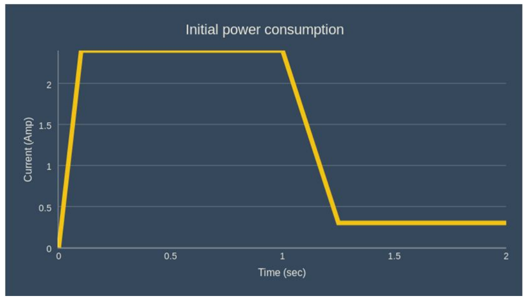

Fig. 11 initial peak current

As Shown in table initially compressor takes power between 2.4-2.5 Amp for 1.8-2 Sec.While its normally running power is just 0.3-0.4 Amp

Means, 2.4/0.4= 6

Which means initially Compressor takes 6 times more current than its normally running condition!

2) Calculating R_0 (Compressor On %) for NO PCM

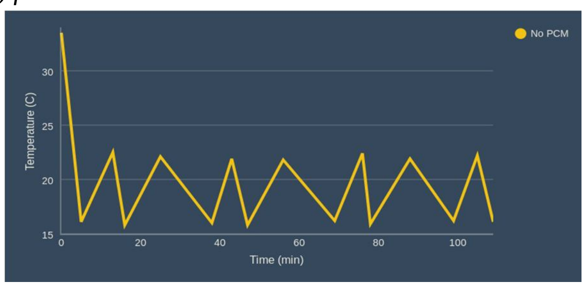

Fig. 12 calculation of R_0

Compressor On %(R_0) = Compressor ON time/Total time period x100

Compressor On time=8+9+7+9+7+10+6+8=64 min

Total time =127 min

R_0= (64/127) x100 =51.61%

3) Meter Reading

Initial meter Reading=2.35 kwh

Final Meter Reading=2.6 kwh

Total Unit consumed by Compressor: 2.60-2.35 = 0.25 Kwh

C. Selection of Optimal Quantity of PCM

Selecting the optimal quantity of PCM is necessary through which the maximum power could be saved. It was noted that after increasing the amount of PCM from the set limit the power conservation reduced. Thus, the misconception of adding more PCM resulting more power conservation was wrong. For optimal Quantity following amount of PCM on which observation was carried out were 250ml,500ml,750ml,1000ml. For Readings only 2 Working cycle is being considered and the Phase Change Material is being Pre-Charged and Kept on the evaporator Coil.

1) Readings for 250ml PCM

TIME	TEMPERATURE (*C)		COMPRESSOR ON TIME(min)
	CUT OFF	CUT ON	
11:56	16.2	-	
12:06	-	21.5	7
12:13	15.7	-	
12:20	-	22.1	6
12:26	16.0	-	

Table 3:reading of 250 ml PCM

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a) Calculating R_{250} (Compressor On %)

Compressor On %(R250) = Compressor ON time/Total time period x100

Compressor On time= 7+6 =13mins

Total time =28mins

R_{250}= (13/28) x100 =46.42%

2) Readings for 500ml PCM

TIME	TEMPERATURE (*C)		COMPRESSOR ON TIME(min)
	CUT OFF	CUT ON	
12:30	15.9	-	
12:39	-	22.3	6
12:45	16.5	-	
12:55	-	22.1	5
01:00	16.1	-	

Table 4: reading of 500ml PCM

a) Calculating R_{500}(Compressor On %)

Compressor On %(R500) = Compressor ON time/Total time period x100

Compressor On time=6+5=11mins

Total time =30mins

R_{500}= (11/30) x100 =36.66%

3) Readings for 750ml PCM

TIME	TEMPERATURE (*C)		COMPRESSOR ON TIME(min)
	CUT OFF	CUT ON	
01:16	15.7	-	
01:29	-	21.9	6
01:35	16.0	-	
01:47	-	22.3	5
01:52	16.2	-	

Table 5: reading of 750ml PCM

a) Calculating R_{750}(Compressor On %)

Compressor On %(R_{750}) = Compressor ON time/Total time period x100

Compressor On time=6+5 =11mins

Total time =37mins

R_{500}= (11/37) x100 =28.72%

4) Readings for 1000ml PCM

TIME	TEMPERATURE (*C)		COMPRESSOR ON TIME(min)
	CUT OFF	CUT ON	
02:30	15.7	-	
02:48	-	22.4	9
02:57	16.3	-	
03:17	-	22.3	10
03:27	16.1	-	

Table 6: reading of 1000ml PCM

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a) Calculating R_{1000}(Compressor On %)

Compressor On %(R_{1000}) = Compressor ON time/Total time period x100

Compressor On time=10+9=19mins

Total time =57mins

R_{1000}= (19/57) x100 =33.33%

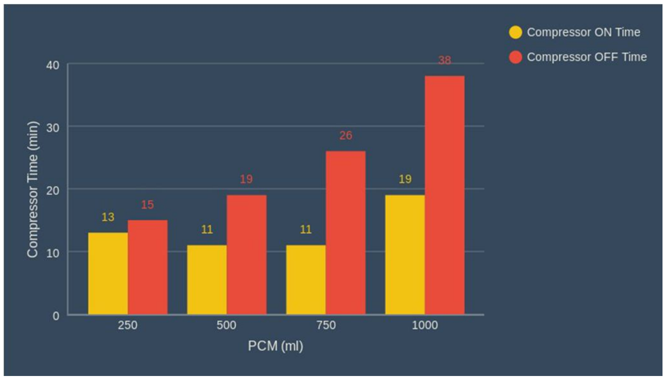

Fig. 13 comparison of with and without PCM

Sr. No.	Quantity Of PCM(ml)	Compressor On time (min)	Compressor Off time (min)	Compressor On Percentage(R)
1.	250	13	15	46.62
2.	500	11	19	36.66
3.	750	11	26	29.72
4.	1000	19	38	33.33

Table 7 comparison of different PCM quantity

Fig. 14 optimum quantity

From the Graph it is clearly seen that as adding PCM quantity the compressor on percentage is gradually reducing up to 750 ml of PCM. But after 750 ml further increment in amount of PCM leads to the increase in the compressor on percentage (R). So, the optimal Quantity of PCM is of 750ml. Further the observations will be taken on the optimal (750ml) quantity for all the PCMs.

D. Reading with Optimal Quantity of PCM

Efforts have been made on both the PCMs with the optimal 750ml quantity to find out the amount of power which is being saved. The both PCM have different working temperature operating range with different latent heat. Finding the compressor On (%) for both the PCM and then comparing it with the compressor on (%) with No PCM. Which would eventually tell us the conservation of power. The three PCMs are;

PCM 22 (17*C to 27*C) Latent Heat- 185kJ/kg*k

PCM HS-01 (16*C to 26*C) Latent Heat- 190kJ/kg*k

PCM FMS 65 (16*C to 26*C) Latent Heat- 235kJ/kg*k

1) Readings for Optimum Quantity of PCM22:

TIME	TEMPERATURE(˚C)			CURRENT(Amp)		COMPRESSOR ON TIME(min)
	CUTOFF	CUTON	OUTSIDE	INITIAL	RUNNING	
08:00	16.1	-	34.2	-	-	
08:11	-	22.2	34.3	2.4	0.4	3
08:14	15.8	-	34.9	-	-	
08:29		22.1	34.4	2.4	0.4	
08:30	Artificial Heat load applied for (2min) 08:30-08:33					
08:36	15.9	-	34.5			7
08:52	-	21.9	34.7	2.5	0.4	4
08:56	16.3	-	34.9	-	-	
09:00	Artificial Heat load applied for (3min) 09:00-09:03					
09:03	-	22.5	35.1	2.4	0.4	6
09:09	15.6	-	35.3	-	-	
09:23		21.9	35.1	2.5	0.3	5
09:28	16.0	-	35.2			
09:30	Artificial Heat load for (3min) 09:30-09:33					
09:33	-	22.7	35.1	2.4	0.4	5
09:38	15.9	-	35.1	-	-	
09:56	-	22.1	35.1	2.3	0.3	7
09:57	Artificial Heat load for (3min) 09:57-10:00					
10:03	16.4		35.2			

Table 8 calculation of PCM22

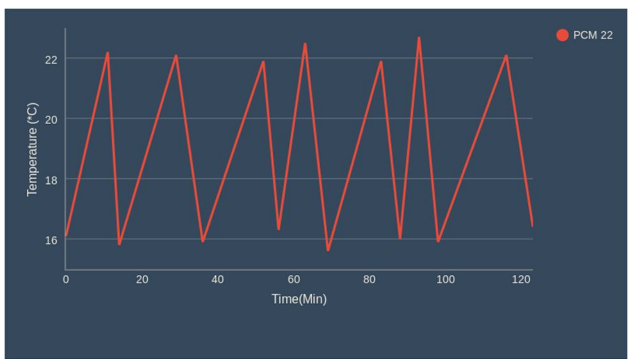

Fig.15 frequency of PCM 22

a) Calculating R_{22} (Compressor On %)

Compressor On %(R_{22}) = Compressor ON time/Total time period x100

Compressor On time=3+7+4+6+5+5+7=37mins

Total time =123mins

R_{22}= (37/123) x100 =30.081%

b) Meter Reading

Initial meter Reading=2.9 kwh

Final Meter Reading=3.06kwh

Total Unit consumed by Compressor: 3.06-2.9 = 0.16 Kwh

2) *Readings for Optimum Quantity of PCM HS-01*

TIME	TEMPERATURE(˚C)			CURRENT(Amp)		COMPRESSOR ON TIME(min)
	CUTOFF	CUTON	OUTSIDE	INITIAL	RUNNING	
09:09	16.6	-	34.4	-	-	
09:29	-	21.9	33.8	2.5	0.4	5
09:34	15.5	-	34.4	-	-	
09:34	Artificial Heat load applied for (3min) 9:34-9:37					
09:38	-	21.9	34.2	2.4	0.4	5
09:43	15.8	-	34.3	-	-	
09:59	-	22.0	33.5	2.4	0.4	8
10:00	Artificial Heat load applied for (3min) 10:00-10:03					
10:07	16.5	-	32.9	-	-	
10:24	-	21.8	32.4	2.5	0.4	4
10:28	15.6	-	32.9	-	-	
10:30	Artificial Heat load applied for (3min) 10:30-10:33					
10:34	-	22.2	32.9	2.3	0.3	6
10:40	15.9	-	32.7	-	-	
10:56	-	22.0	31.8	2.4	0.4	4
11:00	16.2	-	32.1	-	-	

Table 9 calculation of PCM HS01

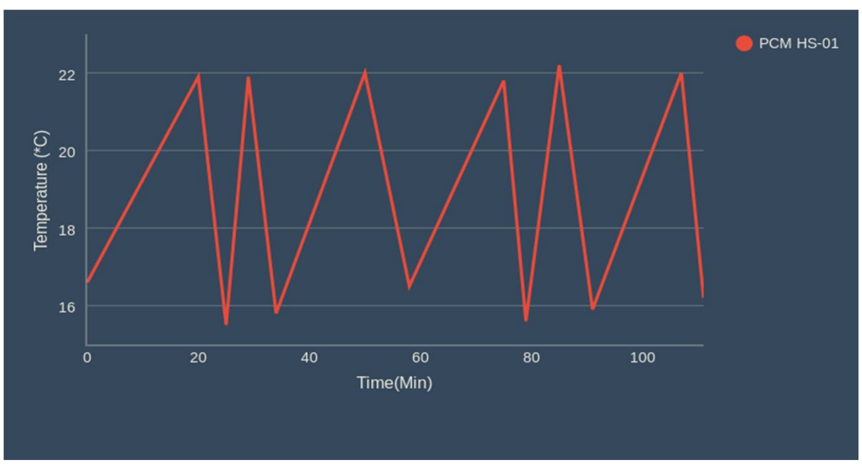

Fig.16 frequency of PCM HS01

a) *Calculating R_{01} (Compressor On %)*

Compressor On %(R_{01}) = Compressor ON time/Total time period x100

Compressor On time=5+5+8+4+6+4=32mins

Total time =111mins

R_{01}= (32/111) x100 =28.82%

b) *Meter Reading*

Initial meter Reading=3.06 kwh

Final Meter Reading=3.2kwh

Total Unit consumed by Compressor:3.2-3.06 = 0.14 Kwh

3) Readings for Optimum Quantity of PCM FMS 65

TIME	TEMPERATURE(˚C)			CURRENT(Amp)		COMPRESSOR ON TIME(min)
	CUTOFF	CUTON	OUTSIDE	INITIAL	RUNNING	
01:15	15.8	-	34.4	-	-	
01:25	-	21.9	33.8	2.5	0.4	4
01:29	16.1	-	34.4	-	-	
01:44	-	22.1				7
01:45	Artificial Heat load applied for (3min) 01:45-01:48					
01:51	15.6	-	34.2	2.4	0.4	
02:06	-	22.3	34.3	-	-	4
02:10	16.3	-	33.5	2.4	0.4	
02:15	Artificial Heat load applied for (3min) 02:15-02:18					
02:16	-	21.9	32.9	-	-	8
02:24	15.9	-	32.4	2.5	0.4	
02:37	-	22.1	32.9	-	-	6
02:43	16.4	-				
02:45	Artificial Heat load applied for (3min) 02:45-02:48					
02:48	-	22.2	32.9	2.3	0.3	5
02:53	15.7	-	32.7	-	-	
03:11	-	21.8	31.8	2.4	0.4	7
03:12	Artificial Heat load applied for (3min) 3:12-3:15					
03:18	16.1	-				

Table 10 calculation of PCM FMS 65

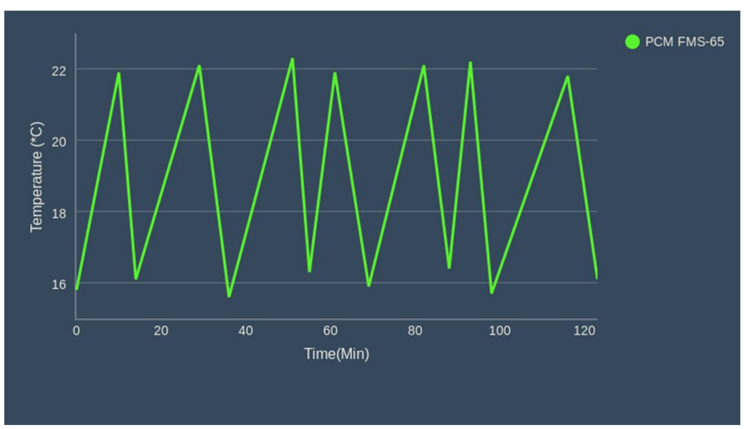

Fig.17 frequency of PCM FMS65

a) Compressor On %(R_{65}) =
Compressor ON time/Total time period x100
Compressor On time=4+7+4+8+6+5+7=41mins
Total time =123mins
R_{65}= (41/123) x100 =33.33%

b) Meter Reading
Initial meter Reading=3.3 kwh
Final Meter Reading=3.5kwh
Total Unit consumed by Compressor:3.5-3.3 = 0.20 Kwh

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E. Selection of PCM

For Selecting the best PCM the parameters considered are:

Compressor On Percentage(R)

Power Consumption

Compressor On-Off Frequency

1) Compressor On Percentage(R)

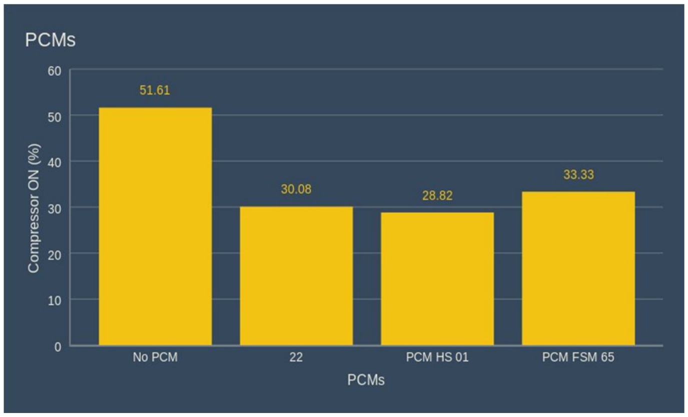

Fig.18 compressor on percentage

The compressor On percentage is compared with the No PCM condition and with two PCM.Here it is seen that PCM HS-01 has the lowest Compressor ON Percentage(R). Thus, in reference to this PCM HS-01 is ideal choice.

2) Compressor ON/Off frequency

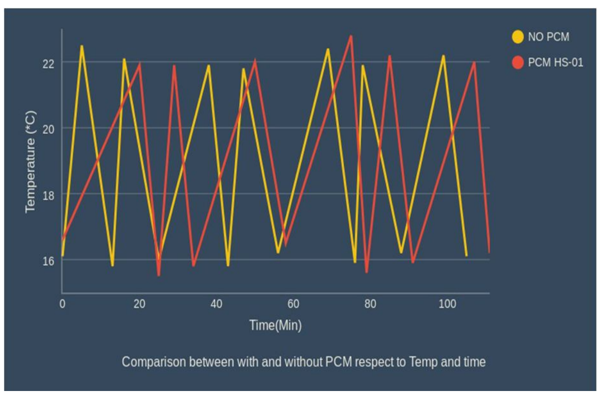

Fig.19 compressor on/off frequency

Here it is seen that the compressor frequency with no PCM is far more than with addition of ideal PCM HS-01. Thus, another parameter of the selection of best PCM goes to the HS-01.

3) Power Consumption:

Sr No.	PCM	Initial Meter Reading	Final Meter Reading	Total Meter Reading
1.	No PCM	2.36	2.6	0.25
2.	PCM 22	2.9	3.06	0.16
3.	PCM HS-01	3.06	3.2	0.14
4.	PCM FMS 65	3.3	3.5	0.20

Table 11 reading of power consumption

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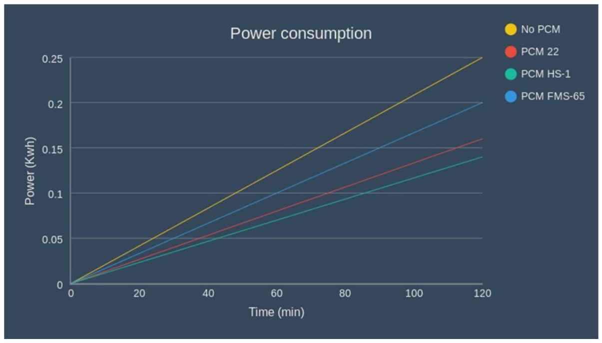

Fig.20 power consumption

As seen from the Graph the power consumption is least with PCM HS-01 from other three condition.

VII. TOTAL POWER SAVED

It is being observed that the power consumption of the refrigerator with No PCM is far more than the power consumption in ideal PCM HS-01.

Efforts has been made to calculate to power consumed in a day by the readings obtained above.

Power Consumed without PCM=0.25 kwh

Power Consumed with ideal PCM=0.14 kwh

Total power saved=0.25-0.14=0.11 for 2 hours

Considering for 24 Hrs =0.11x12=1.32 kwh

Cost of 1kwh power =7 Rs.

Amount of money that can be saved in 1 day=7x1.32 =9.24 Rs.

Calculating the money saved in a year=9.24 x 365=3,372 Rs.

This is the power saving done in one day if we consider this for the mass population of India this would result in massive power saving!

VIII. CONCLUSION

After conducting several experiment on phase changing material equipped refrigerator, we have analyzed that we can reduce power consumption of domestic refrigerator significantly. The total power consumption without PCM was 0.25 kwh. After applying ideal PCM power consumption reduced to 0.14 kwh which is around 44%. It is way more efficient than regular refrigerator.

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