

# Sustainable Passive Cooling Strategy for Automobile using Phase change material

Srinivasa Rao Gampala<sup>1</sup>, Sunil Ambadipudi<sup>2</sup>, S.Venkateswarlu<sup>3</sup>

Assistant Professor, Department of Mechanical Engineering, Swarna Bharathi Institute of Science & Technology,  
Khammam, Telangana, India.

Assistant Professor, Department of Mechanical Engineering, Swarna Bharathi Institute of Science & Technology,  
Khammam, Telangana, India.

Associate Professor, Department of Mechanical Engineering, Swarna Bharathi Institute of Science & Technology,  
Khammam, Telangana, India.

**ABSTRACT:** In the sunny days especially in the summer, when the cars are parked in the parking facing the sun or even during the driving, the drivers feel severe thermal discomfort just after entering an automobile's cabin. Therefore a huge amount of cooling energy from the AC must be used to lower down the temperature to the comfort condition, In order to maintain comfort condition by using the phase change material. This is an innovative system for the temperature control in the interior compartment of a stationary automobile facing the sun. The number of PCM pouches lining placed in the top inner side of the car in which the heating energy is absorbed and release with melting and solidification of phase change materials. As a result the temperature of the car interior is maintained in the comfort condition. The amount of required PCM has been calculated to be theoretically 1000 g and practically 5000g.

**KEYWORDS:** Phase change materials, Energy storage methods, Conceptual design, latent heat

## I. INTRODUCTION

A phase change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage (LHS) units. Different types of phase change materials (PCM) are summarized along with their advantages and disadvantages. An overview is provided of research on the thermo-physical properties of PCM. The fundamentals of modelling solid-liquid phase changes are reported together with major applications of PCMs. Initially, solid-liquid PCMs behave like sensible heat storage (SHS) materials; their temperature rises as they absorb heat. Unlike conventional SHS materials, however, when PCMs reach the temperature at which they change phase (their melting temperature) they absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase. When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat. A large number of PCMs are available in any required temperature range from  $-5$  up to  $190$  °C.<sup>1</sup> Within the human comfort range between  $20$ – $30$  °C, some PCMs are very effective. They store 5 to 14 times more heat per unit volume than conventional storage materials such as water, masonry or rock.<sup>2</sup> The time course of cabin temperature in an automobile parked in the sunshine in MARCH in Khammam. The cabin temperature began to increase at sunrise and peaked at  $50$  °C at 01:00 pm. Since the maximum cabin temperature ranging from  $41$ – $76$  °C, a  $76/50 = 1.52$  factor multiplied by the cabin temperature measured by SBIT STUDENTS. The PCM-temperature control system is designed to maintain the cabin temperature at

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

about 35 °C. Since the cabin temperature is designed to maintain at around 35°C, the PCM OM32, which has the melting temperature of 32 °C is chosen. The OM32 belongs to the paraffin type.

## ***A.I BACKGROUND OF THE INVENTION***

During the summer months, the temperature inside an automotive passenger compartment can rise substantially; especially, when the car is parked outside and the sun's heat radiation penetrates steadily through the windows. In order to stabilize the interior temperature while driving the car, many car models are equipped with air-conditioning systems. But providing a sufficient cooling capacity requires high energy expenditure. On the other side, during the winter months, the driver and the passengers are often confronted with very low temperatures in the passenger compartment at departure. After turning on the heating system, it usually takes a few minutes before a significant temperature increase occurs. In order to solve the problem, some car models have extra heating systems installed in their seats. The energy necessary for running the seat heating system is provided by the car's battery. Due to addition of new auxiliary systems for monitoring and controlling functions in the cars over the past years, the power supply needed for their operation has steadily increased. In order to prevent demands for further increases in the battery's capacity, energy savings are necessary.

Phase change material possesses the ability to change its physical state within a certain temperature range. When the melting temperature of a phase change material in a heating process is obtained, the phase change from the solid state to the liquid state occurs. During this melting process, the phase change material absorbs and stores a large amount of latent heat. The temperature of the phase change material remains nearly constant during the entire process. In a cooling process, the heat stored by the phase change material is released into the environment in a certain temperature range and a reverse phase change from the liquid state to the solid state takes place. In order to contrast the amount of latent heat absorbed by a phase change material during the actual phase change with the amount of sensible heat in an ordinary heating process, the ice- water phase change process will be used. When ice melts, it absorbs an amount of latent heat of about 335 J/g. When the water is further heated, it absorbs a sensible heat of only 4 J/g while its temperature rises by one degree C. Therefore, the latent heat absorption during the phase change from ice into water is nearly 100 times higher than the sensible heat absorption during the heating process of water outside the phase change temperature range.

In addition to ice (water), more than 500 natural and synthetic phase change materials are known, including salt hydrates, metals, alloys, poly-alcohols, eutectics and paraffin. These materials differ from one another in their phase change temperature ranges and their heat storage capacities.

## ***B.II PHASE CHANGE MECHANISM***

On application of heat, the internal energy of a solid is increased to a specific melting point at which it becomes a liquid. In pure materials liquefaction/solidification occurs at the distinct temperature  $T_m$ , which is known as equilibrium temperature of melting/freezing. This temperature depends solely on pressure and is constant if melting/solidification proceeds at a slow rate. In this case no curvature of the solid liquid interface is present and no significant difference in specific heats between phases exists. For phase transformation occurring at the equilibrium temperature, the latent heat of melting corresponds to difference of the products of solid and liquid phase densities and specific enthalpies at the temperature  $T_m$  (Banaszek et al., 2005). Phase change materials (PCM) absorb or releases large amount of heat at constant phase transition temperature when they undergo phase change as shown in Figure 1. Theoretical phase change diagram of solid-liquid phase change materials.

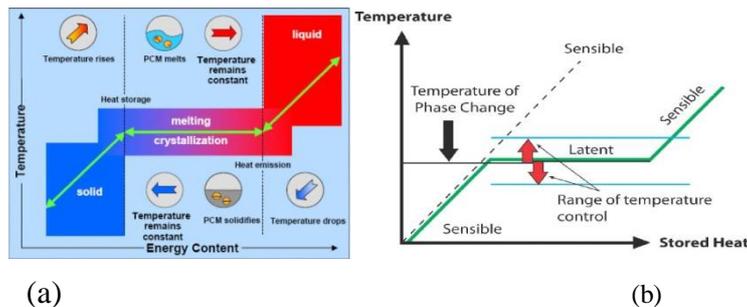


Fig: 1. (a) Phase diagram of Phase Change material (b) Temperature Control image

Absorption of a large amount of heat at constant temperature during phase change is one of the main advantages of PCM. The isothermal nature of heat absorption and release shown in figure 1(b) renders PCM a suitable candidate for thermal energy storage and temperature control applications. Phase change materials are classified as organic, inorganic and eutectic mixtures. Organic PCM consist of paraffin wax and fatty acids, inorganic PCM consist of salt hydrates and eutectic PCM consist of both organic and inorganic materials

### B.III THERMO-PHYSICAL PROPERTIES OF PHASE CHANGE MATERIALS

Fatty acids, myristic acid, palmitic acid and stearic acid having melting temperature ranges of 50 °C-70 °C have been investigated for thermal energy storage (Hassan and Sayigh, 1994). Their densities and dilation volumes were measured using dilatometry techniques and thermal cycling properties were measured using differential scanning calorimetry. It was found that fatty acids were stable to thermal cycling showing little change in melting points and heat of fusion. Thermal properties of binary and ternary mixtures of palmitic acid, stearic acid and oleic acid have also been measured. It has been reported that a reversible solid-solid phase change in oleic acid occurs before melting and a liquid-liquid phase change before solidification (Cedeno et al., 2001). The thermal properties of capric acid, lauric acid and pentadecane mixtures have been measured and their use was evaluated for cooling applications (Dimaano and Watanabe, 2002). An improvement in the melting characteristics of capric-lauric acid mixture was observed by addition of 10 % pentadecane to the mixture (Dimaano and Watanabe, 2002).

## II. CONCEPTUAL DESIGN

The key component of the temperature control system is the PCM pouch which is shown in blue colour in Fig. 1. When the car interior temperature is above the PCM melting point the heating energy is transferred to the PCM for melting and causing the decrease in car temperature.

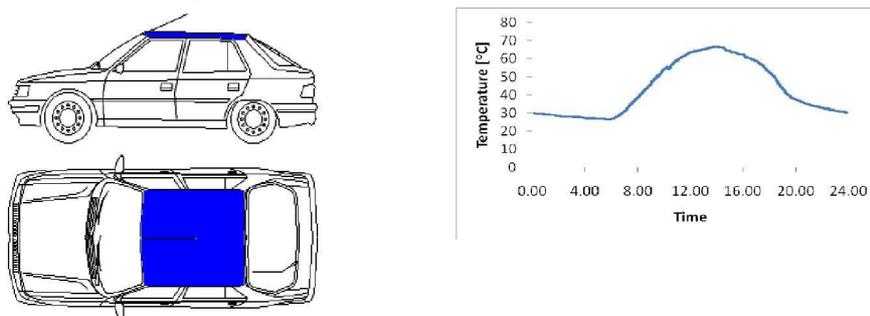


Fig: 2. Configuration of a PCM layer installed in the ceiling part of the automobile.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

On the other hand, when the car temperature is lower than the PCM melting point, the thermal energy is released from the PCM by solidification. Application of Phase Change Materials (PCMs) in Maintaining Comfort Temperature inside an Automobile

In this work we were considered paraffin material and made it into pouches. They are applied to an automobile cabin and laptop cooling purpose, compared to other phase change materials, the paraffin. OM32 possess very high heat storage capacities. Furthermore, paraffin can be mixed in order to realize desired temperature ranges in which the phase change will take place. Paraffin is nontoxic, noncorrosive and no hygroscopic. The technique of the present invention for thermal control of automotive interior includes the utilization of a first phase change material in the headliner. A second phase change material in the car seats and a third phase change material in the instrument panel. The first phase change material might be embedded in a thin polymeric or elastomeric compound structure which is attached to the headliner for the purpose of absorbing excess heat generated in the passenger compartment mainly by heat penetration through the windows



Fig: 3. (a) PCM lined on top side of car at first stage, (b) PCM lined bottom side of car at second stage

The technique of the present invention for thermal control of automotive interior includes the utilization of a first phase change material in the headliner as shown fig 3(a), (b). A second phase change material in the car seats and a third phase change material in the instrument panel. The first phase change material might be embedded in a thin polymeric or elastomeric compound structure which is attached to the headliner for the purpose of absorbing excess heat generated in the passenger compartment mainly by heat penetration through the windows.

The second phase change material is located on the back side of the car seat cover and is separated from the seat cover by a spacer fabric or a lofted batting. The structure which contains the phase change material may be a polymeric compound structure, an elastomeric compound structure, or foam. In one embodiment of the technique of the present invention, the containment structure for the phase change material also includes the seat heater system. The second phase change material shall absorb surplus body heat, if necessary, to enhance the thermal seating comfort. Furthermore, in correspondence with a seat heater system, the phase change material shall prevent overheating and contribute to energy savings by extending the time between the heating cycles.

The third phase change material is embedded in a polymeric compound structure, an elastomeric compound structure or foam and is located underneath the cover layer of the instrument panel. In the instrument panel application, the phase change material absorbs excess heat generated in the passenger compartment mainly by heat penetration through the wind shield. In a preferred embodiment of the technique of the present invention, The melting temperature of the first phase change material is in a range between 30 °C and 34 °C; the melting temperature of the second phase change material is in a range between 34 °C and 38 °C; and the melting temperature of the third phase change material is in a range between 38 °C and 43 °C. Preliminary studies were carried out in order to select the appropriate phase change material, the necessary amount of phase change material, and a suitable location for the phase change material in the headliner. The headliner composite used in these studies consists of an outside

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

## II. THE HEADLINER COMPOSITE USED IN THESE STUDIES CONSISTS OF AN OUTSIDE

An intermediate foam insulation layer, an inside leather layer, for the example headliner configuration the following technical data have been determined:

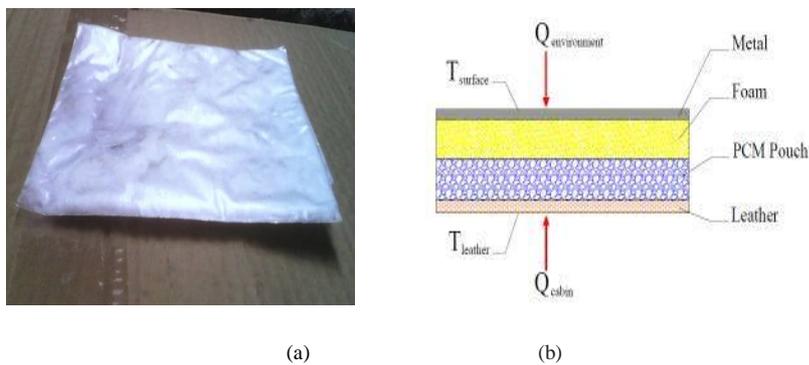


Fig: 4. (a) Headliner Packet, (b) Cross-section of the automobile's headliner using PCM-temperature control system

In the tests, a temperature increase of 30-60<sup>0</sup>c over a period of two hours has occurred which indicates that the headliner has absorbed about 54 kJ of heat energy. This leads to heat absorption of about 27 kJ per hour by the selected headliner during high heat incidences observed in this test. In order to avoid such a temperature increase in the headliner, most of this heat needs to be absorbed by the phase change material. Most preferably, the layer of the compound structure with the directly incorporated phase change material is arranged between the inside (fabric or leather) layer facing the passenger compartment and the intermediate (foam) insulation layer of the headliner configuration in order to obtain a sufficient heat absorption arising from the passenger compartment. On the other side, the insulation effect of the intermediate (foam) insulation layer and the outside (nonwoven) layer (1) avoids a substantial absorption of the heat penetrating from outside through the roof. The headliner configuration, equipped with a layer of a compound structure with directly incorporated phase change material.

## III. PROJECT WORK ANALYSIS DATA

### Calculation part: PCM CAR LINING

Car cabin volume:

$$\text{Length} = 136\text{cm} = 1.36\text{m}$$

$$\text{Width} = 92\text{cm} = 0.92\text{m}$$

$$\text{Height} = 106\text{cm} = 1.06\text{m}$$

$$\text{Volume} = 1.326\text{m}^3$$

$$\text{Inside temperature } T_1 = 45^{\circ}\text{C}$$

$$\text{Atmospheric temperature } T_2 = 30^{\circ}\text{C}$$

$$\Delta T = 15^{\circ}\text{C}$$

1. Heat transfer from top steel surface.

$$U_{\text{steel}} = 1.2 \text{ w/m}^2$$

$$Q = U \cdot A \cdot dt$$

$$\text{Area} = L \cdot B = 1.36 \times 0.92 = 1.25 \text{ m}^2,$$

$$dt = 15^{\circ}\text{C}$$

$$Q = 22.5 \text{ kW}$$

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

2. Heat transfer from right left sides glasses.  
 $U_{\text{glass}}=1.22 \text{ w/m}^2\text{k}$   
 Height=50cm=0.5m  
 Length=136cm=1.36m  
 Area =  $0.5 \times 1.36 = 0.68 \text{ m}^2$   
 $Q=1.22 \times 0.68 \times 15 = 24.88 \text{ kW}$
3. Heat transfer from front and back side glasses.  
 Length =66cm=0.66m  
 Width =92cm=0.92m  
 Area= $0.66 \times 0.92 = 0.607 \text{ m}^2$   
 $Q = 1.22 \times 0.607 \times 15 = 22.216 \text{ kW}$
4. Heat transfer from left & right steel walls.  
 $L=221 \text{ cm}=2.21 \text{ m}$   
 $H=56 \text{ cm}=0.56 \text{ m}$   
 $A=1.237 \text{ m}^2$   
 $Q=44.53 \text{ kW}$
5. Heat transfer from front & back steel walls.  
 $L=0.92 \text{ m}$   
 $B=0.56 \text{ m}$   
 $A=0.515 \text{ m}^2$   
 $Q=18.848 \text{ kW}$
6. Heat transfer from bottom steel floor.  
 $L=2.21 \text{ m}$   
 $B=0.92 \text{ m}$   
 $A=2.21 \times 0.92 = 2.033 \text{ m}^2$   
 $U=1.2 \text{ w/m}^2$   
 $Q=2.033 \times 1.2 \times 15 = 36.594 \text{ kW}$
7. Total heat transfer=  $Q_a$   
 $Q_a = 22.5 + 24.88 + 22.216 + 44.53 + 18.848 + 36.59$   
 $= 169.564 \text{ kW}$

$$C_p = 1.005$$

$$M = \text{density} \times V = 3.67 \text{ kg/m}^3 \times 1.326 \text{ m}^3 = 4.866 \text{ kg}$$

$$Q_b = m C_p \Delta t$$

$$m = \text{mass of air} = 4.866 \text{ kgs}$$

$$Q_b = 4.866 \times 1.005 \times 15 = 73.355 \text{ kW}$$

TOTAL HEAT LOAD:

$$Q_a + Q_b = Q_t$$

$$Q_t = 169.564 + 73.355 = 242.919 \text{ kW}$$

MASS OF PCM =  $Q_t / \text{latent heat}$

$$= 242.919 / 235 = 1.0337 \text{ kg}$$

$$\text{Area of top surface} = L \times B = 1.36 \times 0.92 \text{ m}^2$$

$$A = 12.512 \text{ m}^2 = 12,512 \text{ cm}^2$$

$$\text{Pcm pouch area} = 16 \times 12 = 192 \text{ cm}^2$$

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

Area occupied by sticker layers = 4440 cm<sup>2</sup>  
Remaining area for pouches = 192 \* 42 = 8064 cm<sup>2</sup>

No of PCM pouches = Remaining area for pouches /pouch area  
= 8108/192 = 42.

We take PCM for Car liner = 3 kgs & 5 kgs.

The sources of heat to the PCM in the pouch come from the cabin and the ambient air around the automobile. Assuming the air in the cabin as system and writing an energy balance around it, leads us to the following equation

$$Q_{Total} = m c_p dT/dt \text{-----1}$$

$$Q_{Total} = Q_{cabin} + Q_{Environment} \text{-----2}$$

In the Eq. (1), m is the mass of the air in the cabin that for a mid-size car [4] and at 40 °C is equal to 3670 g [5]. The air in the cabin and is equal to  $Q_{Total} = 167.6$  kJ, The amount of PCM,  $m_{PCM}$ , required for absorption of that heat is Determined by the following equation:

$$Q_{Total} = m_{pcm} \lambda_{pcm} \Rightarrow m_{pcm} = 5000g$$

### Tabular Data: Car lining without PCM:

TIME	Driver seat T1	Driver back T2	Driver left T3	Driver back left T4	SURFACE T5	ATM T6
12:00	60	60	40	50	45	38
12:15	55	55	42	50	45	41
12:30	56	55	44	48	44	44
12:42	55	49	44	45	44	52
01:00	54	48	44	43	50	55
01:15	53	48	45	46	53	60
01:30	52	47	45	47	55	63
01:45	49	47	45	47	60	65
02:00	49	48	45	48	63	65
02:15	47	47	45	47	63	65
02:30	47	47	45	45	63	65

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

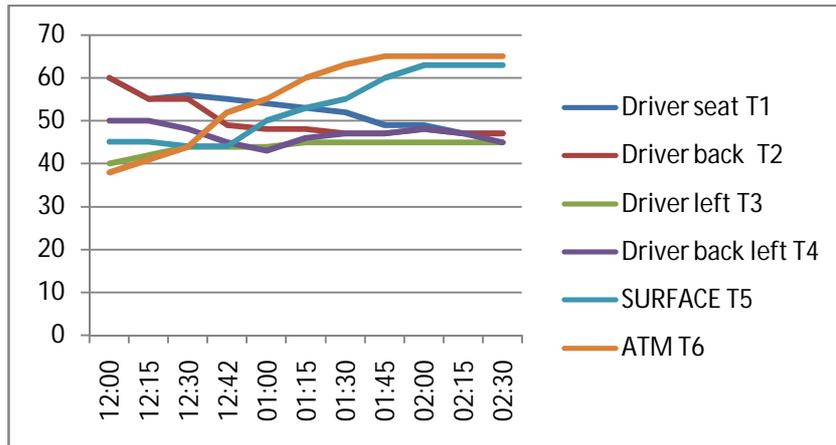


Fig: 5: Car lining without PCM

## CAR LINING WITH PCM 3 KGS:

TIME	FRONT SEAT T1	FRONT PCM T2	PCM T3	BACK SEAT T4	SURFACE T5	ATM T6
11:25	60	45	40	43	50	36
11:44	49	44	39	42	50	37
12:18	48	44	38	43	48	35
12:31	48	42	37	44	45	35
12:46	47	42	36	45	43	37
01:03	48	41	36	47	46	34
01:18	49	39	35	47	47	34
01:34	46	38	34	49	47	35
01:43	48	37	34	50	48	35
02:00	50	36	34	55	47	38
02:10	55	37	33	56	45	34
02:20	55	36	33	56	43	34

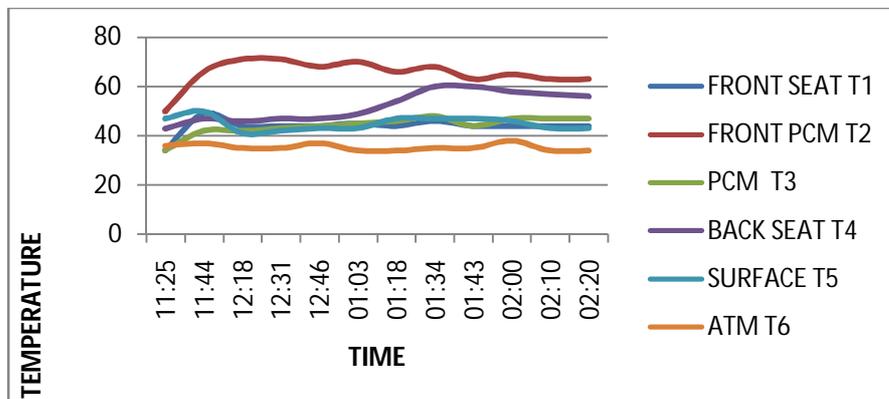


Fig: 6: CAR LINING WITH PCM 3 KG.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

### CARLINING WITHOUT PCM WHEN DOORS ARE OPENING,

time	DS T1	DL T2	DBR T3	DBL T4	ATM T5	top Surface T6
10:15	32	34	30	31	32	38
10:25	31	32	30	31	30	38
10:35	32	35	30	30	30	38
10:45	30	33	30	30	31	39
10:55	30	34	30	31	30	39
11:05	31	34	30	31	31	40
11:15	31	34	30	31	31	39
11:25	31	35	30	31	31	40
11:35	31	34	30	31	31	40

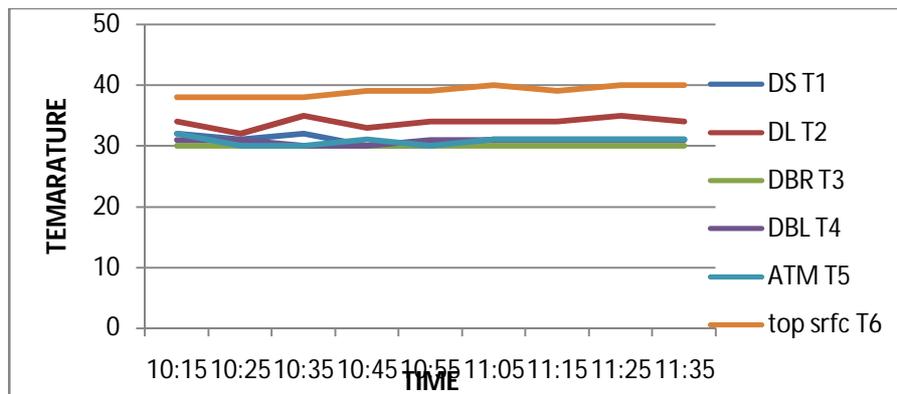


Fig: 7 CAR LINING WITHOUT PCM WHEN DOORS ARE OPENING

### CARLINING WITH PCM 5KGS

time	DS T1	DL T2	PCM T3	DBS T4	ATM T5	top surface T6
11:40	36	35	35	36	38	40
11:50	41	42	34	38	42	39
12:00	44	44	35	40	44	40
12:10	46	47	36	42	45	40
12:20	44	43	35	40	42	39
12:30	45	45	36	41	43	40
12:40	44	44	35	41	42	41
12:50	40	38	33	38	38	42
01:00	43	42	34	40	40	44

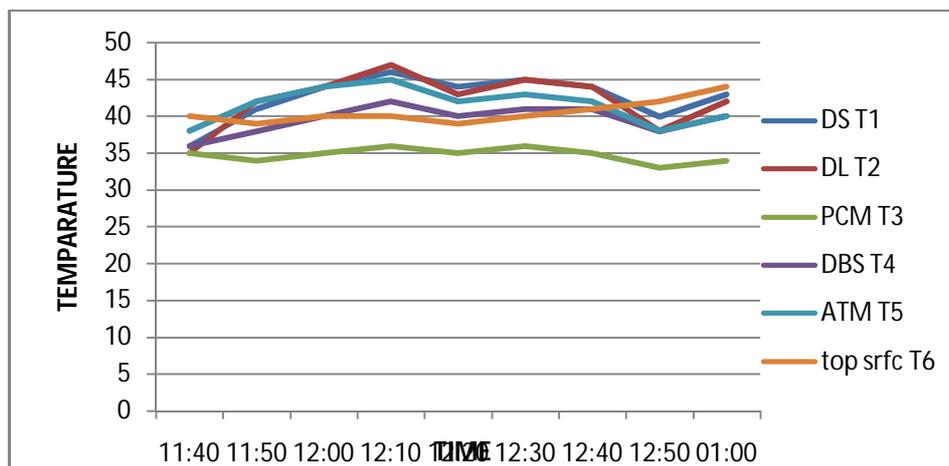


Fig. 8: CARLINING WITH PCM 5KGS

#### IV. CONCLUSION

Design for the temperature control in an automobile parked or driving in the sunshine is introduced. Through simple calculations the amount of required paraffin PCM to be used inside the car for absorbing the thermal energy in the cabin has been calculated by theoretically required PCM to be 1000grams and by practically required PCM to be 5000 grams.

#### REFERENCES

- [1] K. Yamashita, T. Kuroda, Y. Tochiara, T. Shibukawa, Y. Kondo, H.Nagayama, "Evaluation of summertime thermal comfort in automobiles," Environmental Ergonomics, pp. 299–303, 2005.
- [2] A. Grundstein, V. Meentemeyer, J. Dowd, "Maximum vehicle cabin temperatures under different meteorological conditions," Int. J. Biometeorol, vol. 53, pp. 255-261, 2009.
- [3] Kenisarin, M; Mahkamov, K (2007). "Solar energy storage using phase change materials". Renewable and Sustainable Energy Reviews. **11** (9): 1913–1965.
- [4] Jump up Sharma, Atul; Tyagi, V.V.; Chen, C.R.; Buddhi, D. (2009). "Review on thermal energy storage with phase change materials and applications". Renewable and Sustainable Energy Reviews. **13** (2): 318–345
- [5] S. Kim, L.T. Drzal: High latent heat storage and high thermal conductive phase change materials using exfoliated *graphite nanoplatelets*. Solar Energy Materials & Solar Cells, vol. 93, 2009, pp. 136-142.
- [6] Engine cooling (electric and combustion) Thermal comfort in vehicles Jackson III et al., 2002.
- [7] Medical applications in transport of blood at controlled temperature, operating tables, hot cold therapies Saly, I.O. 1996; Junghanss, 2009
- [8] Encapsulation in textile fabric to maintain human comfort temperature Mondal , 2008 ; Sanchez, et al. 2010
- [9] PCM Thermal Solutions, <http://www.pcm-solutions.com>
- [10] Doerr, Donald F., "Heat Stress Assessment and a Countermeasure," Biomedical Laboratory Kennedy Space Center, November, 1997.
- [11] Micro Climate Systems, Inc., <http://www.microclimate.com>
- [12] Phase Change Material Trade Study for the Lo Te C Project," (unknown author; report obtained from Dr. Alex Hoehn).

#### BIOGRAPHY

**Srinivasa Rao Gampala**, I had completed my B.Tech in Mechanical Engineering from the Affiliated College of JNTU Hyd., I have completed my M.Tech from National Institute of Technology Karnataka Surathkal (NITKS) in the Department of Metallurgy and Materials Science. From the completion of my P.G I have been working as an Assistant Prof in engineering colleges, presently working in (SBIT) Khammam, in the Dept. of Mechanical Engg

**Ambadipudi Sunil** did his B.Tech from affiliated college, JNTU Hyd, and also he acquired his Masters Degree from JBIT Hyd in the specialization of "Industrial Engineering". He dedicated to work towards in technical field.

**S.venkateswarlu** did his B.Tech from VJIT and P.G from JNTU Ananthapur. He completed his P.G in the specialization of "Refrigeration and Air Conditioning" from JNTU Ananthapur, in the Department of mechanical engineering. He has vast experience in teaching field from the completion of his P.G. Presently he is working as an Assocs. Prof. in the Dept. of Mechanical Engg. From Swarna Bharathi Institute of science and technology (SBIT),