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Phase Change Material (PCM) in Automotive Climate Control System

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***Abstract*: After entering the cabin of an automobile during the summer, especially during the sunny days, drivers feel severe thermal discomfort just after entering the car, especially when the vehicle is parked facing the sun in the parking lot. Therefore, a considerable amount of cooling energy must be used to lower the temperature to a comfortable level so that, when using the phase change material, the comfort level can be maintained. A stationary automobile facing the sun is fitted with this innovative system to control the interior temperature. During the melting and solidification of phase-change materials, the energy of the heating is absorbed and released by pouches lining in the car's top inner side.**

***Keywords*: Phase change material, thermal discomfort, PCM pouches**

1. Introduction

Today's automotive engineers are increasingly concerned with climate control in their vehicles. Currently, HVAC systems are the only available methods, but there may be options available such as keeping the windows open or using aerodynamic cooling, as a result, when driving with windows open and the domain noise level is high, it is also very difficult to maintain a clean interior environment. This is partly due to the increase in aerodynamic drag and partially due to the noise from the domain while the window is open, Solar heating of the inner cabin is sensitive to relative wind speeds that are approximately 2-4 m/s. This causes vehicle fuel inefficiency. During parking, the vehicle's relative wind speeds are nearly as fast as absolute wind speed. It is absolutely essential to keep the cabin temperature low during summer when ambient temperatures are very high during the peak times, say 12 to 3 pm. Additionally, there have been accidents involving young children and animals (dogs) that have been left in cars facing the sun during the summer time. Several car models come equipped with air-conditioning systems, which maintain a comfortable environment in the interior compartment. As a result, you burn more fuels and consume more cooling energy, causing more pollution to be released into the atmosphere and higher costs. Many applications of phase changing materials (PCM) depend on the ability to store a lot of heat during the phase change.

1.1 Thermal energy storage mechanism

TES methods can be divided according to the storage mechanism into 3 methods, which is indicated in Figure 1.1.

1. Sensible heat
2. Latent heat
3. Thermochemical

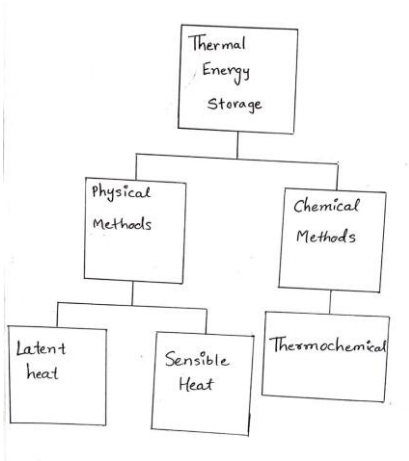

Fig. 1.1. Types of thermal energy storage

1.2 Working of Phase change materials

Working of PCM is schematically depicted in Fig1.2. By absorbing heat from the outside, PCM absorbs a considerable amount of latent heat as it breaks internal chemical bonds at phase change temperature. A reverse cooling cycle requires the PCM temperature to drop below the phase change temperature (undercooling) for phase reversal to start so that the energy barrier required for nucleation of the second phase can be overcome. At phase change temperature, phase reversal begins once phase reversal begins (due to latent heat released) and continues once latent heat is returned to the environment. Phase reversal requires a certain amount of subcooling or undercooling, and this property explains the applicability of PCM to certain applications.

Latent heat of PCM is many orders higher than the specific heat of materials. Therefore, PCM can store 2-3 times more heat or cold per volume or per mass as can be stored as sensible heat in water in a temperature interval of 20 °C. As heat

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exchange takes place in narrow band of temperature the phenomenon can be used for temperature smoothening also.

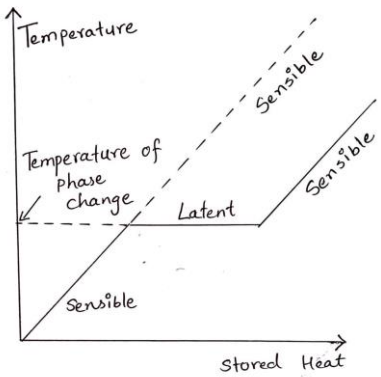

Fig. 1.2. Latent Heat Storage for the case of Solid- liquid phase change

Properties of PCMs aside from heat of transformation, part transformation temperature and sub-cooling demand area unit thermal physical phenomenon, cyclic stability, congruent melting of PCM, and small volume modification throughout state change, low pressure, chemical stability and compatibility of PCM with different materials like plastics. additionally, to those technical necessities, safety issues, low cost, simple convenience, and sensible recyclability area unit vital criteria in choosing an acceptable PCM for a selected Application. it's troublesome to induce a PCM ideal for a selected application. certain quantity of trade-off between totally different properties is so essential. choice of an acceptable PCM, determination of its amount necessities supported heat-balance calculations, packaging of PCM, style of warmth exchanging and warmth distribution surfaces area unit different vital steps in developing an efficient PCM-based device or product.

1.3 Classification of PCMs

A large range of state change materials (organic, inorganic and eutectic) area unit accessible in any needed temperature vary. A classification of PCMs is given in Fig. 1.3. There are a unit an outsized range of organic and inorganic chemical materials, which may be known as PCM from the purpose of read melting temperature and heat energy of fusion. However, aside from the temperature within the in operation vary, majority of state change materials doesn't satisfy the standards needed for associate degree adequate storage media as mentioned earlier. As no single material will have all the desired properties for a perfect thermal-storage media, one has got to use the accessible materials and check out to form up for the poor property by associate degree adequate system style. as an example, antimonial fins will be accustomed increase the thermal physical phenomenon of PCMs, supercoiling could also be suppressed by introducing a nucleating agent or a 'cold finger' within the storage material and incongruent melting will be repressed by use of appropriate thickness. In general, inorganic compounds have nearly double meter heat energy storage capability (250–400 kg/dm3) than the organic compounds (128–200 kg/dm3).

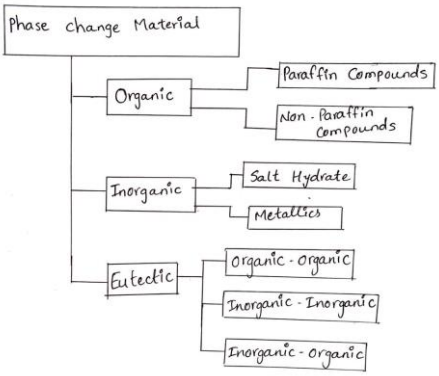

Fig. 1.3. Classification of PCM

1.4 Physical, Technical and Economic Requirements of PCM

A suitable phase change temperature and large phase change enthalpy are two most important requirements of PCM to store or release large amount of energy. There are also other requirements for most of the applications which are grouped as physical, technical and economic requirements.

1 Physical requirements
- Phase change Temperature
- Phase change enthalpy
- Cycling stability
- Little sub cooling
- Thermal conductivity

2 Technical requirements
- Volume change
- Chemical stability
- PCM compatibility
- Non flammable

3 Economic requirements
- Low price
- Recyclability

2. Literature Review

[1] in this study, it is mentioned, during this paper modelling of PCM integrated building roof system. In physical system thought-about could be a unstained panel filed with PCM placed in between the roof high block and also the bottom concrete block, that type the roof of the PCM area.

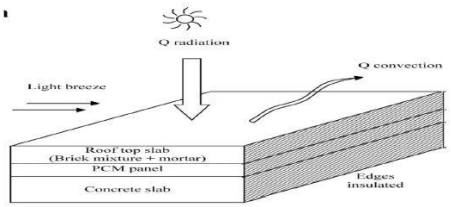

Fig. 2.1. PCM fitted in celling

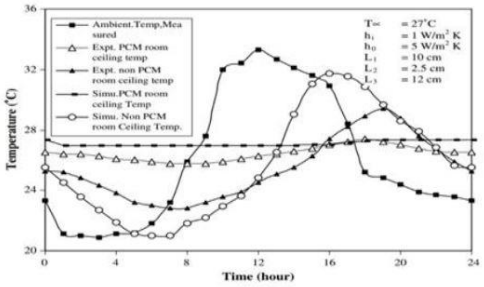

Fig 2.2 Experimental and simulated temperature of celling in the PCM and non PCM room

PCM (48% Cacl2+4.3% Nacl+0.4% Kcl+47.3% H2o) it's use in building roof material for thermal comfort.

[2] it is mentioned during this paper thermal management of automotive interiors with natural action material. The ingenious methodology includes the use completely different natural action materials with different melting temperature ranges in every of the seats (2.3), and associate automobile's control panel (2.4) will be heated so as to enhance the passengers' thermal comfort whereas saving energy. once utilized in Seats (2.4), natural action materials will be incorporated into Seat heater systems.

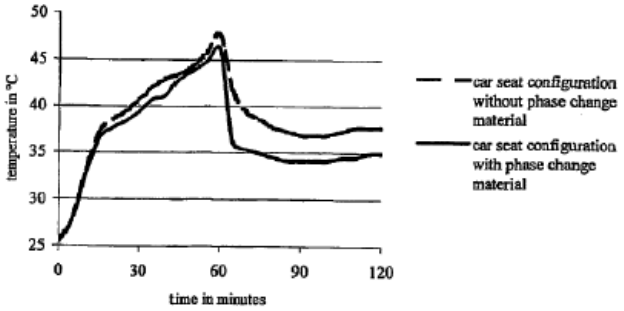

Fig. 2.3. Temperature range of car seat with PCM and non PCM

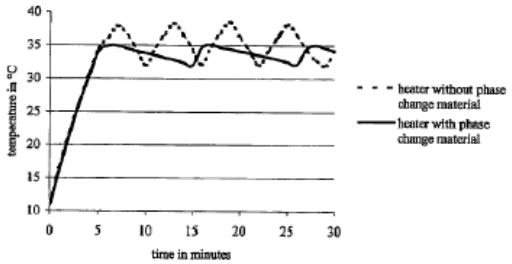

Fig. 2.4. Temperature range of car heater with PCM and non PCM

[3] Experimental Investigation of Thermal Performance in a very Vehicle Cabin check Setup with PCM within the Roof. a completely unique roofing structure is being designed to enhance H resistance. once the vehicle is in use or throughout the nocturnal cycle, it exploits natural action material qualities to store heat from radiation and later on unharness it to the outer atmosphere via external convection. additionally, to natural action materials, thermal energy is employed for storage. it's a high heat of fusion, that makes it a way of storing and cathartic giant amounts of energy. Heat getting into the vehicle cabin was controlled by insulating this PCM within the roof of the vehicle. The thermal performance of the new roofing structure and traditional roofing has been compared through experimental and numerical analysis. The cabin cooling method may well be considerably reduced as a result of this trial. A hot day yielded an almost 22oCe distinction in cabin temperature between the vehicle and close temperature. As a result, the inside temperature of the cabin may well be abundant lower because the new roof structure reduces the flow of warmth from the roof.

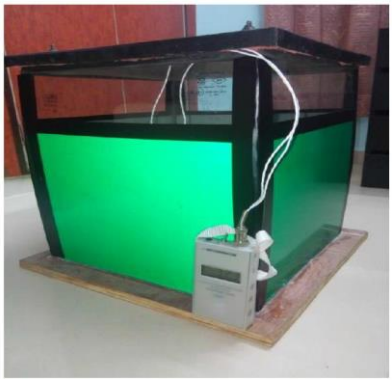

Fig. 2.5. Fabricated setup of PCM

Table 2.1 Temperature at different times

	TEMPERATURE (°C)			
	ROOF WITHOUT PCM		ROOF WITH PCM	
	Probe	Probe	Probe 1	Probe
11 AM	36	35.8	33.5	33.2
12 AM	43	44.2	34.8	35.3
1 PM	45.1	45.6	36.3	36.2
2 PM	47.6	49	35.9	36.8
3 PM	48	47.3	34.4	35
4 PM	44	45	31	32.4
5 PM	37.3	39.8	31.8	31

[4] CFD analysis of application of natural action material in automotive climate-controlled system. the warmth absorption and removing capabilities of PCM area unit accustomed manage the warmth created within a automobile cabin because of radiation during this analysis study. a skinny layer of PCM coating over the automobile outer surface, notably on the highest and on the wind-shield has been created. As a result, the temperature within the automobile cabin is maintained in comfort condition while not victimization the cooling. Today, CFD is taken into account a much better various to unravel such advanced issues in trendy industries. A comparison analysis is disbursed victimization CFD to analyze the subsequent cases:

- Max Cabin temperature once AC is in OFF mode and no PCM is coated = 314 K (fig.2.6)

• Max Cabin temperature once AC is in ON mode and no PCM is coated= 307 K (fig two.7)
• Max Cabin temperature once AC is in OFF mode and PCM is coated = 301 K (fig.2.8)

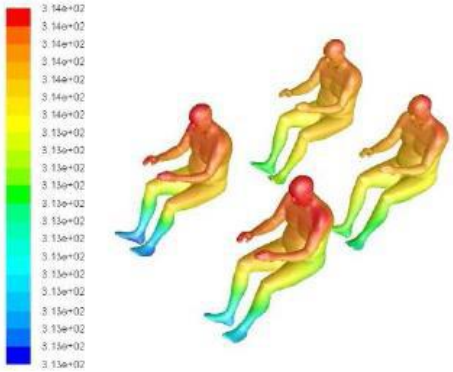

Fig. 2.6. Temperature contour (k) for case 1

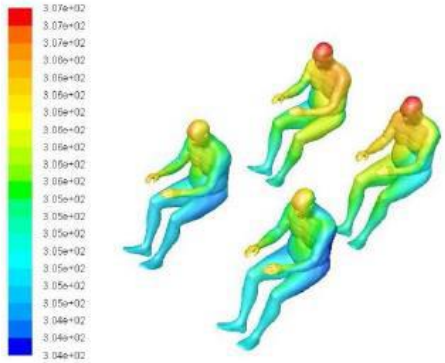

Fig. 2.7. Temperature contour (k) for case 2

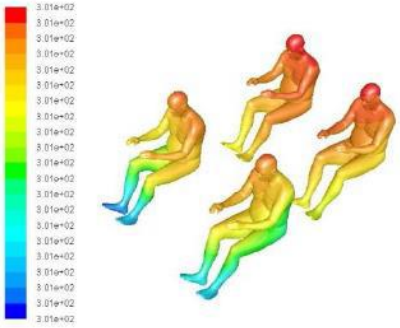

Fig. 2.8. Temperature contour (k) for case 3

[5] Filling of natural action material: Filling the PCM could be a major drawback. It consists of 2 methods: one. Encapsulation. 2. Filling the PCM as a layer. as a result of filling the PCM as a layer will increase the value, we've set to use the encapsulation methodology instead. The natural action material of selection is placed in aluminium foil pouches and sealed to stop leaks throughout the section transformation. Those Al pouches can then be crammed, sealed, and mounted on high of the automobile cabin. the benefits of encapsulation are: 1. Reducing PCMs reactivity towards the surface surroundings. 2. dominant the changes within the storage material once natural action happens.

[6] In mid-size cars, radiation is incident totally on the highest most cowl. because of this, the temperature gets higher and affects the human comfort. As a result, air conditioners area unit accustomed extract heat from within cars these days, however their use raises the load, that will increase fuel consumption and emissions. so as to stop these problems, natural action material is employed in situ of air conditioners. The cooling is removed during this case, and also the high cowl is stuffed with natural action material. The natural action material is crammed within the aluminium pouch and sealed. These pouches area unit situated on the highest cowl of the automobile. As a result, natural action materials extract the warmth from within the vehicle. the amount of the action material determines the quantity of warmth extracted. the warmth absorbed by the air within the cabin and is capable Q total=167.6 KJ. the quantity of needed PCM (n Nonadecane) to be used within the automobile for interesting the thermal energy within the cabin has been calculated to be 755 g.

3. Experimental Process

3.1 General Terminology

- Arduino Mega 2560

The Arduino Mega 2560 could be a microcontroller board supported the ATmega2560 (datasheet). it's fifty-four digital input/output pins (of that fourteen are often used as PWM outputs), sixteen analog inputs, four UARTs (hardware serial ports), a sixteen MHz oscillator, a USB association, an influence jack, AN ICSP header, and a button. It contains everything required to support the microcontroller; merely connect it to a laptop with a USB cable or power it with an AC-to-DC adapter or battery to urge started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.

Fig. 3.1. Arduino Mega 2560

- DS18B20 Temperature Sensor

The DS18B20 Digital measuring system provides nine to 12-bit (configurable) temperature readings that indicate the temperature of the device. info is shipped to/from the DS18B20 over a 1-Wire interface, in order that only 1 wire (and ground) has to be connected from a central microchip to a DS18B20. Power for reading, writing, and performing arts temperature

conversions is derived from the info line itself with no would like for an external power supply. as a result of every DS18B20 contains a novel serial number, multiple DS18B20s will exist on identical 1-Wire bus. this permits for putting temperature sensors in many various places. Applications wherever this feature is beneficial embody HVAC environmental controls, sensing temperatures within buildings, instrumentality or machinery, and method observance and management.

Power supply vary is three. 0V to 5.5V. Measures temperatures from -55°C to +125°C.

Gabriel Daniel Fahrenheit equivalent is -67°F to +257°F.

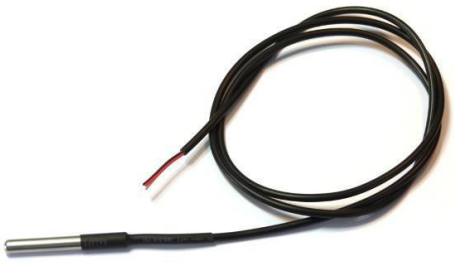

Fig. 3.2. DS18B20 Temperature sensor

- Micro SD Card Module

The micro- Coyote State Card Module could be a straightforward resolution for transferring information to and from a customary Coyote State card. The pin out is directly compatible with Arduino, however also can be used with alternative microcontrollers. It permits you to feature mass storage and information work to your project.

This module has SPI interface that is compatible with any Coyote State card and it use 5V or three.3V power offer that is compatible with Arduino UNO/Mega.

Coyote State module has numerous applications like information lumberjack, audio, video, graphics. This module can greatly expand the aptitude associate degree Arduino will do with their poor restricted memory.

Fig. 3.3. Micro SD Card Module

- DS3231 Real time clock

The DS3231 may be a cheap, extremely correct Real clock which may maintain hours, minutes and seconds, as well as, day, month and year info. Also, it's automatic compensation for leap-years and for months with fewer than thirty-one days.

The module will work on either three.3 or five V that makes it appropriate for several development platforms or microcontrollers.

Fig. 3.4. DS3231 Real Time Clock

- DHT11 Temperature and Humidity Sensor

This DHT11 Temperature and wetness detector options a label digital signal output with the temperature and wetness detector capability. it's integrated with a superior 8-bit microcontroller. Its technology ensures the high reliableness and glorious long-run stability. This sensing includes a resistive element and a detector for wet NTC temperature measure devices. it's glorious quality, quick response, anti-interference ability and high performance.

every DHT11 sensors options very correct standardization of wetness standardization chamber. The standardization coefficients keep within the OTP program memory, internal sensors discover signals within the method, we should always decision these standardizations coefficients. The single-wire serial interface system is integrated to become fast and straightforward. Small size, low power, signal transmission distance up to twenty meters, sanctioning a spread of applications and even the foremost exacting ones. the merchandise is 4-pin single row pin package.

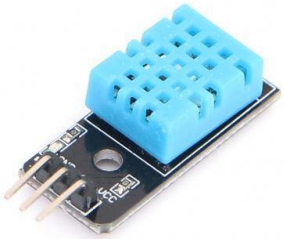

Fig. 3.5. DHT11 Temperature and Humidity Sensor

- Resistor 4.7k

A resistance could be a passive two-terminal electrical element that implements electrical phenomenon as a circuit part. In electronic circuits, resistors are wont to cut back current flow, change signal levels, to divide voltages, bias active parts, and terminate transmission lines, among alternative uses. high-octane resistors that may dissipate several watts of electric power as heat, could also be used as a part of motor controls, in power distribution systems, or as take a look at masses for generators. fastened resistors have resistances that solely modification slightly with temperature, time or in operation voltage. Variable resistors may be wont to change circuit parts (such as a volume management or

a lamp dimmer), or as sensing devices for warmth, light, humidity, force, or chemical activity.

Fig. 3.6. Resistor Carbon Film 4.7k

- Jump Wire

A jump wire (also referred to as jumper wire, or jumper) is associate electrical wire, or cluster of them in an exceedingly cable, with a connecter or pin at every finish, that is often wont to interconnect the parts of a bread board or alternative paradigm or check circuit, internally or with alternative instrumentation or parts, while not fastening. 23

Individual jump wires area unit fitted by inserting their "end connectors" into the slots provided in an exceedingly bread board, the header connecter of a printed circuit, or a bit of equipment.

Fig. 3.7. Jump Wire

- Phase Change Material

1. HS24

HS24 is associate inorganic chemical based mostly PCM having nominal temperature reduction temperature of 24ºC and melting temperature of 25ºC. It stores thermal energy as heat of transformation in its crystalline kind. On dynamical section this heat of transformation is free or absorbed, permitting the close temperature among the system to be maintained. HS24 is brought about of the correct mixture of numerous additives permitting equilibrium between solid and liquid phases to be earned at the melting point.

Table 3.1 Properties of HS24

Property	Value
Melting Temp (ºC)	26.00
Freezing Temp (ºC)	25.00
Latent Heat (kJ/kg)	199
Base Material	Inorganic
Flammability	No
Max operating Temp (ºC)	80

Fig. 3.8. HS24 PCM pouch

2. OM30

OM30 is associate degree inorganic chemical primarily based PCM having nominal physical change temperature of 30C. It stores thermal energy as heat in its crystalline type. On dynamical part this heat is free or absorbed, permitting the close temperature inside the system to be maintained. OM30 is recognized of the correct mixture of varied additives permitting equilibrium between solid and liquid phases to be earned at the temperature. The OM30 is free flowing in liquefied state and might be encapsulated in varied forms.

Table 3.2 Properties of OM30

Property	Value
Melting Temp (ºC)	31.00
Freezing Temp (ºC)	30.00
Latent Heat (kJ/kg)	230
Base Material	Inorganic
Flammability	No
Max operating Temp (ºC)	120

Fig. 3.9 OM30 PCM pouch

3. Aluminium Pipe

Table 3.3 Specification of Aluminium Pipe

Specification	Value
Diameter of pipe (mm)	10.00
Length of pipe (cm)	120
No of pipe (OM30)	38
No of Pipe (HS24)	18

Fig. 3.10. Aluminium pipe

3.2 Experimental Setup

Table 3.4 DS3231 Sensor setup Layout

Sensor pins	Arduino mega board
GND	GND
VCC	5V
SDA	SDA 20
SCL	SCL 21
SQW	-
32K	-

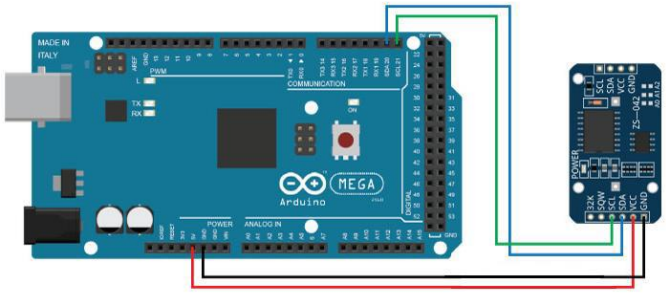

Fig. 3.11. DS3231 Sensor Setup layout

Table 3.5 SD Card module setup layout

Sensor pins	Arduino mega board
MOSI	51
MISO	50
SCK	52
CS	53

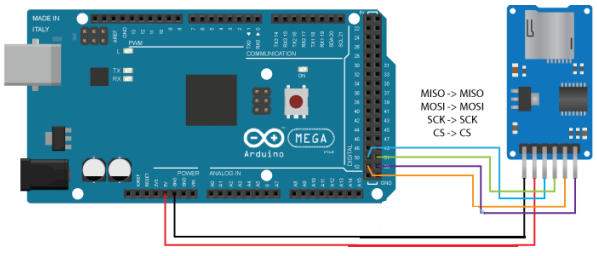

Fig. 3.12. SD card module setup layout

Table 3.6 DS18B20 Sensor setup layout

Sensor pins	Arduino mega board
RED	5V
GREEN	7
BLACK	GND

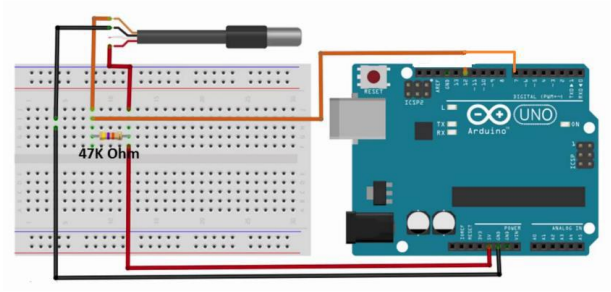

Fig. 3.13 DS18B20 Sensor setup layout

Table 3.7 DHT11 Sensor setup layout

Sensor	Arduino mega board
S	2
+	5V
-	GND

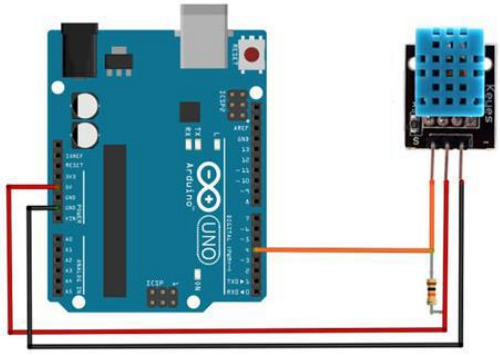

Fig. 13.14. DHT11Sensor setup layout

4. Design and Working

4.1 Project Design

Fig. 4.1. Project design

Fig. 4.2. Project Design

4.2 Experiment 1

First of fill aluminium pipes with PCM. Pipe diameter is 1cm. we have two phase change material first is OM30 and second is HS24, we fill 40 pipes of OM30 which is in liquid form and 20 pipes fill with HS24 which is also in liquid form. Sealing all pipes with wooden cap to both sides. Then after we fitted all 60 pipes below the headliner as shown in figure, for this experiment we use maruti alto 800 car. In this experiment we use Arduino mega, three temperature sensors and one humidity sensor. For analysis of temperature inside the cabin we put car in sunlight for 24 hours reading, we stick one temperature sensor to outside of the car with tape and other two temperature sensor in cabin, one is at driver seat and other back side of cabin, then after we start the experiment we take 4 day temperature reading outside as well as inside of car, we also take 2 day parking reading.

4.3 Experiment 2

The second part of our experiment that we take charging and discharging reading.

In this part first of all we open the all doors of car because of getting equilibrium condition of temperature inside the cabin and this temperature is approx. 34c than after we close all doors and start the AC to drop temperature, we drop 10c and note the time, then after we start the fan and AC off, because of getting 34c temperature again, we note charging time. Then we fit the PCM pipes and again start the AC to drop temperature up to 25c, we note discharging time. Then we start the fan to reach 34c and not charging time, then after we compare data time, then after we compare data of without PCM and with PCM. We do this process 3 time at different mass flow rate. In this process we know how PCM affect to drop the temperature.

In this overall process there are biggest problem we faced that is leakage occurs in pipes because melting temperature of PCM we use that is 30c and 24c, above this temperature approx. at 45c leakage is start because pressure generate in pipes due to evaporation of materials, the best way to fill pipes first of all seal the pipe with m-seal or welding is best way than after fill the PCM and seal other side.

5 Result and Discussion

5.1 Experiment 1 Result

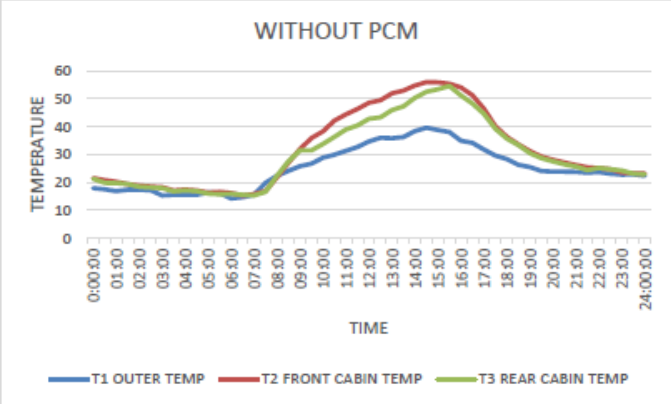

Fig. 5.1 Without PCM graph

We can show in figure 6.1 is that, as 9 AM to 4 PM the radiation of heat is high, the average outer temperature is in between 30-40 ºC at that time cabin temperature is 50-60 ºC.

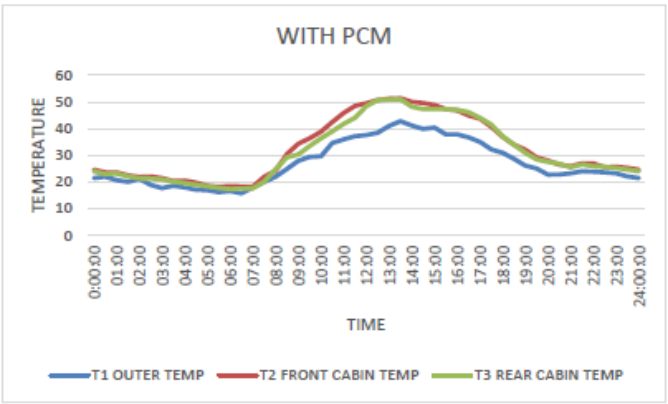

Fig. 5.2. With PCM graph

In this graph we show that 30-40 co at that time cabin temperature is 50-55 co. it menaces PCM reduce 4-5 co in car cabin.

5.2 Experiment 2 Result

Table 5.1. Experiment 2 Result

OM30 (NOTE – TEMPERATURE RANGE 24ºC - 34ºC)					
		Without PCM		With PCM	
	Air Flow (m/sec)	Time	Temp(ºC)	Time	Temp (ºC)
FAN 1	1.9	4.06	24	4.37	24
		4.21	34	4.47	34
FAN 2	2.9	5.19	24	4.59	24
		5.29	34	5.09	34
FAN 3	4.5	5.37	24	5.55	24
		5.44	34	6.04	34

HS24 (NOTE – TEMPERATURE RANGE 24ºC - 34ºC)					
		Without PCM		With PCM	
	Air Flow (m/sec)	Time	Temp(ºC)	Time	Temp (ºC)
FAN 1	1.9	11.23	24	11.41	24
		11.29	34	11.47	34
FAN 2	2.9	12.07	24	11.56	24
		12.11	34	12.60	34
FAN 3	4.5	12.12	24	12.33	24
		12.22	34	12.38	34

In this experiment we do charging and discharging process. First of all, we equilibrium outer and cabin temperature than after we reduce temperature it by A.C flow and again we increase the temperature we note time.

We do same process with PCM and not charging to discharging time we show in table 6.1 is that at fan 1 it takes 5 minutes more to increase the temperature.

6 Conclusion

Using phase change material in car cabin. We show that it reduces maximum 4-5 ºC temperature by using proper phase change material. Which latent heat is high, it's maximum temperature and control humidity. Phase change material based cold thermal energy storage has important now a days because it I employed in many applications like free cooling of buildings, air conditioning, medical, cold parking etc. it is concluded that phase change material based cold energy storage is an efficient method for cold energy storage.

Though a suitable PCM has been successfully developed, further work is needed to develop less corrosive PCM in contact with some metals and to search more additives to alter the phase change temperature at desirable. These will allow for adjustment of the needed for the PCM needed different applications. PCM panels have been successfully applied in domestics, freezers for minimizing temperature fluctuations during door opening and electrical power failure. The next step is to apply PCM panels to larger or different facilities, such as ice cream trolleys, delivery vans or medium cold stores. The quality of the frozen food has been analyzed in the past mainly under temperature fluctuations. However, from the ice cream temperature behavior during transport and storage without refrigeration system.

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