Experimental Investigation of Thermal Performance in a Vehicle Cabin Test Setup With Pcm in the Roof

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Abstract. Heat flow from the roof with radiation through glass windows obviously high level that contributes to the total heat gained of a vehicle cabin. The cabin temperature of closed stationary vehicles in direct sunlight can quickly rise to a very level that may damage property and harm children or pets left in the vehicle. The problem that is faced by many car users today is very hot interior after certain minutes or hours of parking in open or un-shaded parking area. The heat accumulated inside the vehicle with undesired temperature rise would cause the parts of the car’s interior to degrade. Even the passengers are affected with the thermal condition inside the vehicle itself. The passenger has to wait for a certain time before getting into the car to cool down the interior condition either by lowering down the window or switching on the air conditioner at high speed that really affect the fuel consumption. A new roofing structure to improve its total thermal resistance is developed. Its uses phase change material properties to trap the heat from solar radiation and then release it back to the outer atmosphere by external convection when the vehicle is in use or during the nocturnal cycle. Phase change material, which has become an attractive means to store. Thermal energy, which has a wide range of applications, has been used. Phase change material has a high heat of fusion which is able to store and release large amount of energy. This PCM has been insulated in the roof of the vehicle to arrest the heat entering into the vehicle cabin. Experimental and numerical analyses have been conducted to compare the thermal performance of the new roofing structure and the normal roofing. By this experiment, the cooling process of the cabin could be much lower. The experimental investigation revealed that, on a hot day, the interior temperature of the vehicles cabin was approximately 22ºCe higher than the ambient temperature. The results show that the new roofing structure could effectively reduce the inlet of heat from the roof into the cabin. As a result, the interior temperature of the cabin could be much lower.

1. Introduction
When a vehicle is parked in an un shaded area the heat present inside the vehicle cabin increases to an average of 80ºC. The increase in the internal temperature of the cabin can be so high that it may damage the interior parts or the children or pets left in the cabin. The vehicles roof is like a sheet metal roof which receives a incident solar radiation up to 1000 W/m k. in clear sky conditions, from the incident radiation 20 to 95% may be absorbed as heat. As a fact the interior temperature will be almost 11º C higher than the outside temperature when parked even for ten minutes. The hot interior is the main problem that is faced by many people after certain time of parking in an unshaded area. The part inside the interior of the car such as the dashboards and many plastic parts may degrade because of the
excessive temperature of the car interior. The user has to wait for some time so as to let the interior temperature of car to cool down by either rolling down the window or by switching on the a/c. The increase in the temperature of the vehicle may make the passengers and the users very uncomfortable. Moreover the vehicle cabin may face aging problem and may damage the goods and materials kept in the vehicle. According to the finding in USA, every year has recorded many children deaths due to heatstroke due to being left inside the vehicles. In years 1998-2002, the number of children deaths recorded was 29 persons per year. In 2003, this number has increases to 42 and 35 persons in 2004. annually hundreds of children experience many heat illness for being left inside the vehicles [9]. The problem arises when the vehicle is parked in a direct heat and sun the temperature rise in parked vehicle is mainly due to the solar radiation and green house effect the solar radiation enters the car through the glasses and is partially trapped within the car the measured temperature inside the car in a summer days could reach up to 120ºC where the outside temperature ranges from 35ºC to 45ºC. The amount of irradiative heating from 12 am to 3pm is measured it could be seen that the irradiation was 1106W/m² approximately at 1pm. so to reduce this condition of thermal heat inside a vehicle we have decided to stop the heat entering into the cabin by arresting the heat at the roof itself. For that using a PCM has been used which has the ability to absorb the heat and store it within the material itself. Phase change materials can change phase from solid to liquid and vice versa. Phase change material has the ability to absorb heat and convert into liquid. And when it releases heat it converts back into solid state.

A new design is developed from the normal roof structure of the vehicle available in modern markets. A phase change material is inserted between the insulator layers and the upper metal sheet layers it could be found that the phase change properties of PCM couldn't only be utilized to store thermal energy as in heat storage application but also to improve thermal insulation effect of the PCM combined roofing structure. The vehicle roofing material is standard roof and the real roof of Tata sierra. The insulated roof contains the PCM in it. The special ability of a PCM arrests the heat at the roof itself without allowing the external heat from entering into the cabin this layer is very much useful in decreasing the temperature in vehicle cabin when it is parked.

The special ability of the phase change material is that is absorbs the heat radiation and stores within itself. The PCM changes its phase from solid to liquid as it stores the heat radiation within itself. Its a substance with high heat of fusion which melts and solidifies at certain temperature and it is capable of storing and releasing large amount of heat energy. The PCM is initially at solid state. As the environmental temperature increases, it absorbs energy in the form of heat. When the ambient temperature reaches the melting point, the PCM absorbs large energy of heat at an almost constant temperature. This continues until all the materials is then converted into liquid phase. In this way, heat is stored in a PCM and the temperature is maintained in a level that is optimum. When the temperature around the material gets low, it gets solidified as it releases the heat back into the atmosphere.

The aim is to design and fabricate the roof of a four wheeler which has the ability to resist the heat from flowing into the vehicle cabin so as to maintain a moderate temperature in a vehicle cabin when the vehicle is parked at an un shaded area. The main scope of the design is to make the cabin temperature much more comfortable to the passengers as they get into the parked vehicle. The installation of this roof design will reduce the interior temperature of the vehicle cabin. Due to this roofing structure deterioration of plastic parts can be decreased. The driver doesn't need to keep the windows of the car lower so as to ventilate the interior hot air. When the children and pets are left in the cabin of the car they would not be affected by the increasing temperature of the car cabin.

2. Materials and methods
2.1 materials used

- PCM -- 1-dodecanol
- Roof -- Roof of TATA sierra
- Side glass -- Window glass of Maruti Omni van
- Temperature Sensor -- DIGITEMP 9100
- Base -- Wood

2.2 PCM 1-dodecanol

1-Dodecanol is a phase change material manufactured by PCM product having its phase change temperature at 24°C to 27°C. The product has density of 831 kg/m³. The maximum operating temperature is 259°C. It is a tasteless, colourless solid with a floral smell. It is soluble in ethanol and diethyl ether. The properties of the selected are shown in the table 1.

| S. No | CONTENTS   | PROPERTIES         |
|-------|------------|-------------------|
| 1     | Temperature| 24°C to 27°C      |
| 2     | Density    | 831 kg/m³         |
| 3     | Max. Temp. | 259°C             |
| 4     | Taste      | Tasteless         |
| 5     | Colour     | White crystals    |
| 6     | Odour      | Floral smell      |

The costs of different PCMs were compared to check cost efficient material. The cost comparison of those PCMs is shown in table 2.

| S.No. | PCM MATERIAL    | COST/KG   |
|-------|-----------------|-----------|
| 1.    | HEPTADECANE     | Rs. 75,480/- |
| 2.    | 1-DODECANOL     | Rs 900/-   |
| 3.    | METHYL PALMITATE| Rs 18,460/-|
| 4.    | METHYL STEARATE | Rs 3,59,800/-|

2.3 Roof

The roof is a basic structure made up of steel. Here the roof is made up of roof of Tata sierra. The roof is cut into dimension of 400×400 mm and painted in black colour as the heat absorbed by black is more. There are two roofs made for the experiment one of the roof is insulated with the PCM and the other roof is kept as it is. The amount of the heat entered the cabin is less in the insulated cabin and the
when the roof without the insulated PCM is kept the amount of heat entered is more and thus the cabin’s temperature increases.

2.3.1 Roof without PCM
The roof without PCM is made up of steel of the car TATA SIERRA. It doesn’t have any insulated PCM so that the heat entering the vehicle cabin is more and the vehicle cabin’s temperature increases rapidly. The plain roof which is made is shown in Figure 1.

![Figure 1. Roof without PCM](image)

2.3.2 Roof with insulated PCM
The roof with PCM is also made up of the same material that is TATA SIERRA steel roof. The roof contains the insulated material. The material used is a PCM which has the special ability to arrest the heat within itself. The process thus lessens the amount of heat entering into the vehicle cabin. As the heat entering the cabin decreases, the temperature inside cabin is low when compared to the roof without the insulation. The below shown figure.2 shows the constructed and the insulated roof it contains the PCM between the two layers of the roof metal and insulation.

![Figure 2. Roof with PCM](image)

3. Fabrication of experimental Setup
The test setup is constructed with the above mentioned materials. The laminated glasses were joined together with help of liquid sealant such that the heat from the cabin doesn’t escape from the setup. The roofs were cut from a car roof and another layer of sheet metal is cut and placed between the roof and the insulation to place the PCM in position. Another roof of the same material was made without the insulating PCM so as the difference can be seen in temperature. The construction was completed as the designed setup as shown in figure 3.

![Fabricated setup of pcm](image)

**Figure 3.** Fabricated setup of pcm

The vehicle cabin is represented by a test setup made up of exactly the same materials present in a vehicle. It consists of the laminated glass, steel roof and the base wood. The glasses are stuck together in the shape of a cube by using the liquid seal which has the property to stick glass together. The glass is stuck and kept to dry for a day or two, the glass is again stuck to a base wood to give it a base stand. The steel roof is cut from the top of a car-TATA SIERRA. The top of the car is made up of hard steel. The insulation material used is a PCM the PCM is a phase change material which has the ability to absorb heat and convert its phase from its solid state to liquid state. And when the material releases heat it converts its phase back into solid state. The PCM is kept at a bottom steel plate made of the same material as the roof. The two different plates are joined together the design of the basic setup was created using solid works software and the basic structure was designed before it was made. After the design was finalised the fabrication procedure was started.

4. **Results and discussion**

4.1.  *Temperature variation with and without PCM*
The table 3 shows the temperature of PCM in an insulated cabin and non-insulated cabin measured during four different days. The temperature was measured at peak hours (around 2 pm) of each day. The amount of heat present inside the cabin setup is almost the same ranging from 49°C to 55°C in a non-insulated roof.

| TEST DATE | TEMP WITHOUT PCM | TEMP WITH PCM |
|-----------|------------------|---------------|
| 12.03.2016 | 55°C            | 41°C          |
| 14.03.2016 | 53°C            | 42.3°C        |
| 17.03.2016 | 55.8°C          | 42°C          |
| 18.03.2016 | 49°C            | 39°C          |

When the insulated roof was installed in the setup the range of temperature of the cabin was noted much lower than the previous experiment with the non-insulated roof, and the results were much better as it could decrease the temperature for at least 10°C. The temperature sensors were kept at two different locations one at the bottom corner and one at the top corner. The temperature range of the complete cabin setup can be measured with the help of this arrangement. The temperature at different location is noted.

| TEMPERATURE (°C) |
|------------------|
| 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    |

The table 4 shows the different types reading of the vehicle cabin at two particular days and of two different roof types. The readings were taken for a complete day with the non-insulated roof, the amount of heat and temperature present inside the cabin was noted and recorded. It was noted that the temperature is less at the early hours of the day and it gradually increases as the time increases. The cabin temperature is very high at peak hours and it gradually decreases as the external temperature
decreases. And the next day the readings were noted for the cabin temperature with the insulated roof. The temperature was noted at two different locations of the vehicle cabin. The temperature sensors were kept at the top corner of one end and the bottom corner of the other end so as to find the complete temperature range of the vehicle cabin test setup. It was noted that the temperature variations was a gradual increase and decrease, but the temperature inside the cabin is much low than the earlier. The efficiency of the roof was seen at the peak hours the PCM could arrest most of the heat at the peak time. This shows the ability of the PCM chosen to arrest more heat at most of the time without allowing the heat from entering into the vehicle cabin.

4.2 Temperature variation with time

The graphs of the results obtained by the experiment are represented as shown in Figure 4 and Figure 5. The below graph shows the different variations of the temperature present inside the car cabin with and without the PCM roof. The variations were noted for a complete day. The variations show a gradual increase and a gradual decrease of the temperature of the vehicle cabin. The temperature was noted the maximum at the peak hours. The same was noted for the cabin with the PCM roof, the temperature was maximum at the peak hours. But, the PCM insulated roof had a difference of around 13°C between the two different cabin setup at the hottest hours of the day.

![Figure 4. Temperature variation with time](image-url)

The other graph shows the maximum temperature of the vehicle cabin, the temperature was measured at 1-2pm of each day so as to find out the maximum temperature range of the cabin test setup ranging at the peak temperatures. The temperature of the cabins were noted much high with the normal roofing structure than the temperature of the cabin with the insulated roof structure the insulated roof had arrested most of the heat from entering into the cabin.
5. Conclusion

This project shows a new design of vehicle roof structure, which has been done by adding a layer of PCM in the roof of the vehicle. The result shows a decent decrease in the temperature of the vehicle cabin when a PCM insulated roof is attached to the vehicle roof. The experiment has fulfilled the purpose of decreasing in the amount of temperature of the vehicle cabin when a vehicle is parked in a sunny place or an un-shaded area.

The results obtained are favourable to the experiment. When the temperature measured of both the non-insulated and the insulated cabin, the insulated cabin had very less internal temperature than that of the non-insulated cabin. The results were calculated for three types of readings, one reading was taken at peak temperature around 12:30 pm to 2:00 pm of four different days, another reading was taken for the whole day from 10 am to 5 pm with the non-insulated roof, other reading was taken the next day with insulated roof for the same time period and the readings were noted. Experimental results have shown that the new design has a better thermal performance than the normal roof structure of the available vehicles. The new design may help to reduce up to about 30% of the energy amount required for cooling down the heat entering into the cabin from the roof. The saving rate could be even much higher in case of natural wind and movement of the car in use. Thus, the PCM insulated roof test cabin had the lowest cabin temperature when compared with the regular cabin, the PCM had solved the purpose of arresting the external heat from entering into the vehicle adding to the increase of the cabin temperature and if all the vehicles are insulated with the PCM the cabin’s temperature would be very less and it would decrease deterioration of the vehicle plastic parts. This is a promising design which could be massively produced due to its simple structure and reasonable price.

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