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Application of Phase Change Materials (PCMs) in Maintaining Comfort Temperature inside an Automobile

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***Abstract*—**This paper presents the modeling results of an innovative system for the temperature control in the interior compartment of a stationary automobile facing the solar energy from the sun. A very thin layer of PCM inside a pouch placed in the ceiling 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 about 755 g. The PCM-temperature controlling system is simple and has a potential to be implemented as a practical solution to prevent undesirable heating of the automobile's cabin.

***Keywords*—**Phase Change Material (PCM), automobile's cabin, temperature control

I. Introduction

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. Therefore a huge amount of cooling energy from the AC must be used to lower down the temperature to the comfort condition. There has also been accidental death of young children or animals (dogs) that had been left in the cars parked facing the sun in the summer days. In order to maintain the comfort condition in the interior compartment while driving the car, many car models are equipped with air-conditioning systems. This results in consuming more cooling energy and therefore burning more fuels that causes more costs and more pollution released to the atmosphere.

On the other hand, during the winter months, after turning on the heating system, it usually takes minutes before the comfort condition is reached. Some car models have extra heating systems installed in their seats to tackle the problem. The electrical energy necessary for running the seat heating system is provided by the car's battery. Due to the 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, and increasing the battery lifetime energy savings are necessary.

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Thermal energy storage via phase change materials (PCMs) is one of the most promising candidates as zero power usage means to decrease the temperature profile fluctuation in the car cabin for both summer and winter months. PCMs are latent heat storage materials that the thermal energy transfer occurs when a material changes from solid to liquid, or vice versa. Unlike conventional (sensible) storage materials, PCM absorbs and releases heat at a nearly constant temperature. The high heat transfer during the melting process and the crystallization process, both without any temperature change, is responsible for the PCM's appeal as a source of heat storage.

Phase change materials are mainly divided into two categories; organic and inorganic materials. More than 500 natural and synthetic PCMs 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. Paraffin is used exclusively in building, garment, and home applications due to their range of melting points which fall in the human being comfort condition. These are crystalline alkyl hydrocarbons with different chain lengths that have been used in the present design.

Compared to other PCMs, the paraffin 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. A disadvantage of the paraffin is their low resistance to ignition which can be increased by adding the fire retardants.

In this paper a design implementation of a temperature control system using the PCM is investigated and the required amount of PCM for heat removal from the automobile's cabin during a sunny day is determined.

II. Conceptual Design

Fig. 1 shows the configuration of a PCM layer installed in the ceiling part of the automobile. The key component of the temperature control system is the PCM pouch which is shown in blue color 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. 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.

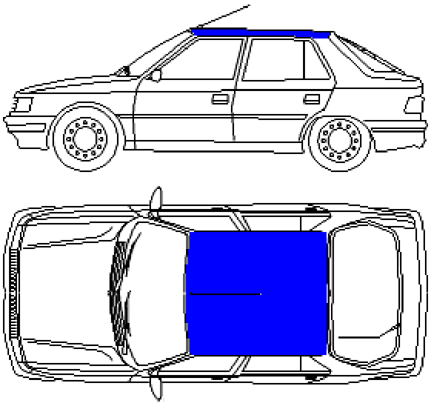

Fig. 1 The configuration of the PCM layer in the automobile's headliner

The basic components of the PCM-temperature control system are illustrated in Fig. 2. There is a foam layer between the PCM pouch and the metal body of the automobile which eliminates the heat exchange with the environment. The leather layer is for satisfying the interior design criterions.

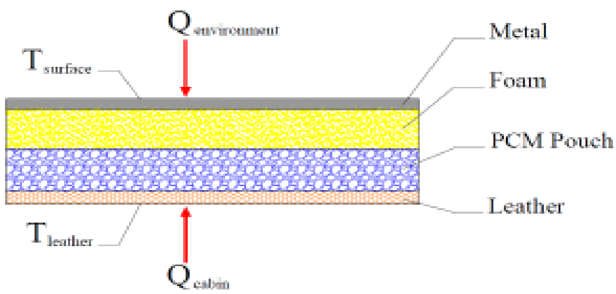

Fig. 2 Cross-section of the automobile's headliner using PCM-temperature control system

III. Design Specification

Fig. 3 shows the time course of cabin temperature in an automobile parked in the sunshine in July in Fukuoka [1]. The cabin temperature began to increase at sunrise and peaked at 68.5 °C at 13:50. Since the maximum cabin temperature ranging from 41-76 °C [2], a 76/68.5 = 1.11 factor multiplied by the cabin temperature measured by Yamashita et al. [1]. The PCM-temperature control system is designed to maintain the cabin temperature at about 35 °C.Since the cabin temperature is designed to maintain at around 35 °C, the PCM, *n*-Nonadecane, which has the melting temperature of 32 °C is chosen. The *n*-Nonadecane belongs to the paraffin type. The properties of the *n*-Nonadecane PCM are shown in Table I.

TABLE I
PROPERTIES OF PCM *N*-NONADECANE [3]

Description	Value
Formula	$C_{19}H_{40}$
Melting Temperature	32 °C
Specific Gravity	0.777 at 32 °C
Specific Heat	594.04 $J.mol^{-1}.K^{-1}$ at 32 °C
Latent Heat	222 $J.g^{-1}$

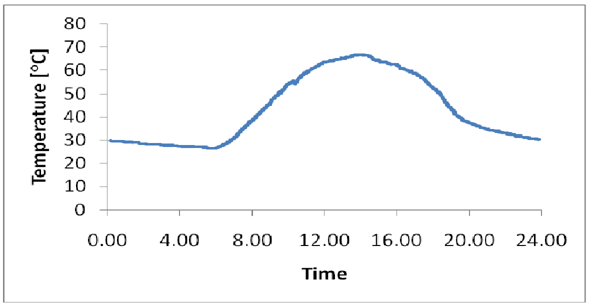

Fig. 3 Changes in cabin temperature in an automobile in summer [2]

IV. Calculations

As it was shown in Fig. 2, 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:

$$\dot{Q}_{\text{Total}} = mC_p \frac{dT}{dt} \quad (1)$$

in which:

$$\dot{Q}_{\text{Total}} = \dot{Q}_{\text{Cabin}} + \dot{Q}_{\text{Environment}} \quad (2)$$

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].

Fig. 4 shows the $\dot{Q}_{\text{Total}}$ versus time which is calculated by Eq. (1). The colored area in this figure is the heat absorbed by the air in the cabin and is equal to $\dot{Q}_{\text{Total}} = 167.6\ \text{kJ}$. The amount of PCM, m_{PCM}, required for absorption of that heat is determined by the following equation:

$$Q_{\text{Total}} = m_{\text{PCM}} \lambda_{\text{PCM}} \Rightarrow m_{\text{PCM}} = 755\text{g} \quad (3)$$

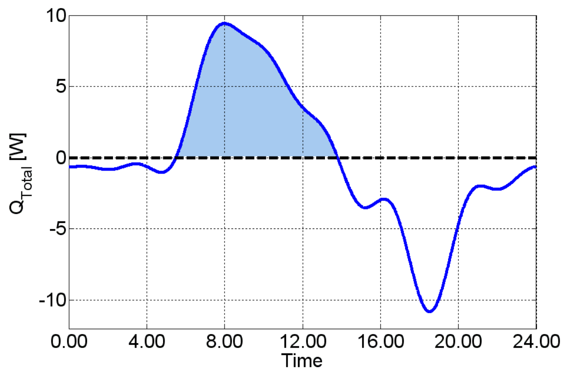

Fig. 4 Changes in energy in an automobile in summer

In the actual design, a factor of safety of about 10% should be included to cater for non-ideal conditions in the practical environment.

V. Conclusion

A novel design for the temperature control in an automobile parked or driving in the sunshine is introduced. Through simple calculations the amount of required PCM (*n*-Nonadecane) to be used inside the car for absorbing the thermal energy in the cabin has been calculated to be 755 g.

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