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Experimental analysis of a car incorporating phase change material

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ABSTRACT

When in summer period vehicles, in particular cars, are parked outdoors their interior temperature increases dramatically even if the day is cloudy. Hence the thermal discomfort is obvious for the passengers when they get into the vehicle after a car park. In this paper the enhancement of the interior vehicle temperature conditions parked under the sun when a thermal energy storage (TES) system is placed inside the car is experimentally studied. The aim of this paper is to prove experimentally the benefit of using phase change materials (PCM) in terms of interior comfort for car passengers. The use of PCM results in lower air and steering wheel surface temperature and the increase of the thermal comfort of passengers. The benefit of the implementation of PCM inside cars was demonstrated since it maintained lower interior vehicle air and steering wheel surface temperatures.

1. Introduction

The thermal comfort which is the state of mind that expresses satisfaction with the surrounding environment [1] of vehicular occupants is becoming an important issue since the time that people spend in both private and public transport has grown substantially. Therefore the interest in investigating and analysing the system and design requirements for good indoor and vehicle environments has increased. In that sense, the evaluation of the thermal comfort has been under investigation over the last years. Alahmer et al. [2] developed a comprehensible review of the different thermal comfort models through international standards to many research works.

The vehicle thermal situations are eminently sensitive to climatic conditions and the interior of the vehicles is a compartment where often thermal discomfort is obvious. In winter period, at least about five minutes are necessary before obtaining an acceptable temperature in the car if it has been parked outdoors. Similarly, in summer period, it is difficult to settle into a car if it has been exposed some time to solar radiation [3]. Once the passengers get into the vehicle during summer, they can experience thermal discomfort due to the high temperatures inside. Experimental measurements in Fremont, California, concluded that in a closed car the temperature increases with 22–27 °C within an hour [4]. Moreover, Dadour et al. [5] demonstrated that when a vehicle is parked in the sun, temperature levels in the cabin of the vehicle can be more than 20 °C above the ambient temperature. Therefore, in order to cool the car to reach comfortable temperatures values, a lot of air-conditioning power is needed. Obviously, this means more fuel consumption and therefore more CO_2 emissions.

The physical factors affecting human thermal comfort depends upon four physical environmental variables: the air temperature, its relative humidity, the mean radiant temperature, and the relative air velocity [2]. And for thermal comfort in vehicles, the air temperature is the most important environmental variables. Another problem with excess heat inside the vehicles is heat strokes; this mostly occurs amongst young children and pets and leads to severe damage or even death. Grundstein et al. [6] indicate that even during cloudy days with lower ambient air temperatures, vehicle cabin temperatures may reach deadly levels and McLaren et al. [4] concluded the same statement after investigating heat stress from enclosed vehicles in children.

The use of thermal energy storage (TES) by the addition of phase change materials (PCM) is a possible solution to decrease air temperature rises inside the vehicles due to its ability in maintaining materials within a narrow temperature range by absorbing heat gains [7–9]. Some researchers have been investigating the addition of PCM in different places of vehicles. Tan et al. [10] studied experimentally the cold storage characteristics and the heat transfer regularity to meet the requirement of refrigeration in a liquefied gas (LNG) refrigerated vehicle. More related to the situation analysed in this manuscript, Ahmed et al. [11] modified the conventional method of insulation of the refrigerated truck trailer using PCM. An overall average daily heat flow reductions into the refrigerated compartment of 16.3% was observed.

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The aim of this paper is to investigate experimentally the benefit of adding PCM into a car in terms of air temperature reduction and therefore comfort thermal improvement after parking the car under the sun for a period of time.

2. Materials and method

2.1. Car description

The experimental set-up consists of a 5 door Seat Ibiza 2007 as Fig. 1 shows. The dimensions of the car used are presented in Table 1. In this research the experimentation has done at the same location and under similar boundary conditions, therefore only the air temperature will be considered to evaluate thermal comfort inside the car. The air temperature inside the vehicle, the steering wheel surface temperature, the ambient temperature (shade and sunlight) and the PCM temperature were measured and monitored continuously using Pt-100 (1/5 DIN class B) and a data logging system.

In order to have a correct air map temperature of the vehicle cabin the car was divided in five areas, front right, front left, back right, back left and roof. Moreover, different air temperature measurements were done in the height direction (feet, bottom, back and head) as Fig. 2 shows. This implementation of the temperature sensors allow to determine the thermal comfort of different body parts and therefore each passenger can independently be examined. All the temperature sensors located inside the car were shaded using a paper cylinder to prevent higher temperatures due to direct solar radiation. All the temperature sensors were previously calibrated from 10 to 70 °C in MICROCAL T100 equipment of an accuracy of 0.1 °C.

2.2. Phase change material

In the experimentation a commercial PCM (RT-27) from Rubitherm was used. The PCM was used in the vehicle cabin, placed under the roof of the car, and in the steering wheel. The PCM was placed under the roof in order to get a large area of exchange between the internal air and the PCM and therefore have a good thermal heat exchange. Moreover, it is more practical since the roof is the largest available surface in vehicles. In order to hold the PCM plates under the roof of the car, an aluminium structure was built which allows changing easily the PCM plates. The total PCM used in the vehicle cabin was 4 kg (4.55 l), occupying 0.22% of their internal volume. The PCM was available as a bulk material and therefore an encapsulation had to be made using aluminium plates for the cabin. On the other hand, the PCM used on the steering wheel was encapsulated with a plastic bag in order to give to it the correct shape.

Fig. 1. Vehicle (Seat Ibiza) used in the experimentation.

Table 1
Characteristics of the car used in the experimentation.

Characteristics	Value
Long	3977 mm
Width	1419 mm
High	1445 mm
Total volume	2.35 m^3
Trunk volume	0.25 m^3
Internal useful volume	2.1 m^3

The thermophysical properties given by the manufacturer are shown in Table 2. Moreover, Differential Scanning Calorimetry (DSC) analysis was performed using a DSC-822e commercialized by Mettler Toledo. The analysis was performed using a dynamic method from 5 to 50 °C and a heating rate of 1 °C/min. the amount of sample studied was around 15 mg in an aluminium crucible under N_2 atmosphere. Fig. 3 shows the specific heat and the enthalpy curve in function of the temperature.

2.3. Weather conditions comparison

As only one car was available to perform the measurements, the experimentation with and without PCM had to be done in different days. Therefore and in order to compare the results with and without PCM, similar weather conditions needed to be found. The experiments were done always at midday when most dramatic situation can occur. Notice that only similar days in terms of ambient temperature and solar radiation are considered to be compared. Preliminary experiments showed that measurements with almost the same outside temperature can be compared each other since the cabin vehicle difference temperature is below 1 °C.

2.4. Experimental procedure

Before starting the experimentation the PCM (when it is placed inside the car) has to be solidified and the cabin should be at homogeneous temperature around 20 °C. This is done using the air conditioning system of the car and placing it inside a warehouse where the solar radiation is not affecting the vehicle conditions. Then the car is parked in the sun for 2 h simulating a normal car park anywhere. This paper only deals with the conditions that the users would find after letting the car being heated up by the sun. Therefore, in order to evaluate the benefit of introducing PCM inside the car, the results with and without PCM are compared. The front of the car was placed towards the north in order to prevent differences in the experimentation between different days in terms of solar radiation incidence inside the car, especially to the frontal part of the vehicle.

Similar procedure is used when the addition of PCM in the steering wheel is studied. Half of the steering wheel is covered by PCM while the other half remains at normal conditions. Then both surface temperature of each half of the steering wheel were measured. Since the car was placed to the north, the direction of the solar radiation affects by equal any part of the steering wheel. This phenomenon was checked for each experimentation in order to ensure that the results were correct.

3. Results and discussion

3.1. Thermal performance analysis of the interior

The measurements were performed during June and July of 2012. Many experiments have been performed in order to have comparable results in terms of similar outside temperature. Here only those comparable experiments are presented and discussed.