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ERGONOMIC CHAIR DESIGN FOR THERMAL COMFORT USING PHASE CHANGE MATERIALS

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Abstract— The metabolism process of humanoids is well designed for emitting the heat constantly. But no heat transfer phenomena occur from the spinal side of the body in sitting posture. The proper heat transfer is arrested in the sitting posture; this makes the human to feel discomfort. The bus drivers are the primary victims who face this problem every day and cause of the disease called "hemorrhoid." This project mainly focused on modifying and constructing a convenient chilled cushion chair with jam-backed Phase Change Material (PCM) to overcome such problems. This chair absorbs body heat when occupied and discharges while vacant. The stages when liquid change to solid and solid change to liquid occurs nearly by a constant temperature. The chair provides a cooling effect and also a cushioning effect to the occupier. The PCMs are having large latent heat and provide a cooling effect by maintaining nearly by constant temperature to the human body. The jam-backed chilled cushion chair is invented for improved thermal comfort for the driver for some extended time by the proper temperature that acceptable level of the human. The performance tests are carried out to evaluate the working of the pad.

I. Introduction

In general, the human body always attempts to change its thermal condition according to the surrounding medium [1]. The thermal sensation of the human is related to the thermal balance of the body. So, heat conduction, radiation, convection, and heat loss due to the main evaporative causes to affect the thermal comfort of humans. In this regard, the energy balance of the human body is used for the determination of the human body's energy dispersion [2]. In sitting posture, conduction, convection, and perspiration, heat transfers are arrested. Because clothing and cushioning are highly insulating materials. Even though radiation is the only practical way of heat transfer in sitting posture, the amount of heat radiated under the seat is very small and considered as negligible. Therefore, the heat transfer through the seat in sitting is not possible, and that part of the body experiences a large amount of heat. It has been observed that prolonged sitting can cause "hemorrhoid" type diseases. It happens mostly for travellers who take a long journey without any movement from their place. Notably, the drivers suffer from this discomfort mostly. People usually use a towel to escape from the massive heat generation. But it is not found to be an effective method for thermal comfort. It is essential to consider the human body heat transfer rate while designing a cooling seat pad for the thermal comfort of travellers in the journey. It is crucial to consider the human body heat transfer rate while designing a cooling seat pad for the thermal comfort of travellers in the journey.

A detailed literature survey has been done on the various aspects of the field of a project, which includes the human body heat transfer, latent heat storage (LHS), and the cooling seat cushion. Matjaz P et al. [3] has correlated the exergy consumption of the human body with the thermal sensation. Du et al. [4] studied the human thermal sensation and skin temperature to predict the heat loss from the human body under changes in the environmental conditions. Also, many research works have been carried out to explore the internal body heat balances and thermal sensations during climatic variations [5][9]. Kurazumia et al. [10] have measured the conductive, convective, and radiative heat transfer areas in nine postures, including chair sitting and standing, which are necessary for calculating the heat exchange between the human body and the environment. It performed the energy and exergy analysis on the human body for the summer season and found the maximum metabolism energy loss of the human body is 58.2 W/m^2. Zalba et al. [11] reviewed the thermal conductivity, the heat of fusion, density, and melting temperature of phase change materials (PCM). Xie et al. [12] reviewed inorganic hydrated salts for thermal energy storage. Liang et al. [13] studied the thermal properties of phase change material. Also, they identified the effect of viscosity and nucleating agents on the ability of thermal energy storage. Mondal et al. [14] summarized the various physical and chemical methods for the incorporation of PCM in textiles and mentioned the drawbacks of the PCM incorporated textiles. Shang et al. [15] patented a cooling comfort seat cushion incorporating PCM to be used in the ambient temperature of 23°C. Chen et al. [16] designed a hybrid air cushioning system using energy-absorbing materials to reduce vibration.

In the present project, a cooling seat pad filled with PCM is designed and fabricated to give better thermal comfort for the passengers, especially for the drivers, for more than four hours of extended travel. The phase change material used in this cooling seat pad is identified. The heat transfers of the human body and the corresponding storage density of the PCM are calculated. Then, the performance tests carried out on the pad. Finally, the observations and conclusions are inferred and presented.

II. Design of Cool Seat Pad

The cold seat pad contains a PCM layer, an insulation layer, and an outer cover, as shown in Figure 1.

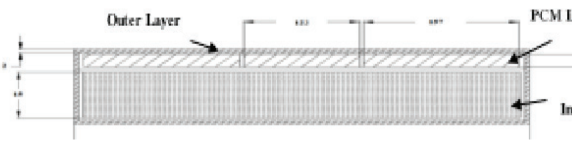

Figure 1: 2D drawing of the cooling seat pad

The pad is designed for easy insertion and removal of the PCM pouches. A small layer of polystyrene foam (when fully compressed) is added to the outer cover to give additional cushioning effect and to provide optimum heat transfer. It prevents moisture present in the air not to be condensed on the top of the cover. The second layer consists of multi-layered nylon pouches filled with PCM. In the PCM layer, there are nine PCM pouches are schematically arranged, as shown in Figure 2. The insulation layer of $15x10^{-3}$ m is made to prevent heat from reaching the PCM layer from the bottom of the pad. The 3D model of the cooling seat pad is shown in Figure 3.

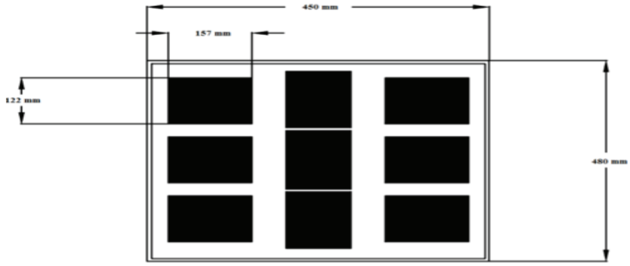

Figure 2: The arrangement of PCM pouches in the cold seat pad

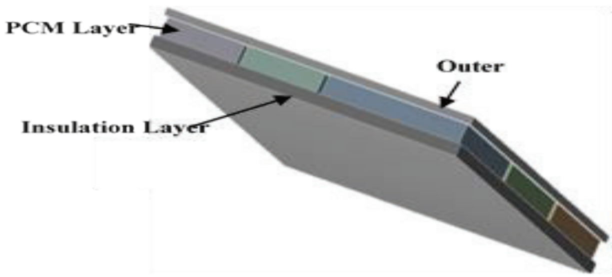

Figure 3: 3D model of the cooling seat pad

The specifications of various materials used for the fabrication of the cooling seat pad are presented below.

- Outer Cover

The material used for the outer cover is high-quality Rexine. Though the thermal conductivity of the Rexine is less (0.22 W/m-K), the small thickness ($2x10^{-3}$ m) ensures better heat transfer. The lack of porosity of water through Rexine gives an additional advantage to the pad.

- Phase Change Material

The PCM used for the cooling seat pad is HS 22, a hydrated salt due to its high latent heat capacity (185 kJ/kg) and high thermal conductivity (0.56 W/m-K for solid and 1.13 W/m-K for liquid).

- Encapsulation Material

The PCM is encapsulated by a transparent multi-layered nylon pouch of thickness 200 microns. As the thickness of the capsule is minimal, there is no need to consider the thermal conductivity of the nylon for design and heat transfer.

- Insulation Material

Polystyrene foam is used as insulating material. This insulation layer prevents heat gain reaching the PCM layer from the bottom side of the pad. The thickness of the insulation layer is 0.015 m, and the thermal conductivity of polystyrene foam is 0.045 W/m-K.

III. Heat Transfer Calculations

A. Heat Transfer from Human Body

The heat emitted by a human body is not constant for all. It varies concerning the metabolism and activity of the human. The value of the heat transferred also varies concerning the position. It has been found that the amount of heat transferred from a human body because of the metabolism process is 1.2 Met in sitting posture for an average man of weight 65 kg.

The value of human body heat is expressed in Met.
(1 Met = 58.2 W-m^{-2})

Amount of heat transferred in sitting posture
= 58.2 × 1.2 = 69.84 W-m^{-2}

Assuming an average man sitting on the cold seat pad and emitting heat at the rate of 1.2 Met. Hence, the heat flux applied to the pad by the man is 69.84 W-m^{-2}.

Area of the cool seat pad = 48 × 45 =2160 cm^2
Area of the seat pad = 0.216 m^2

The rate of heat transfers into the pad = heat flux × area of the pad = 69.84 × 0.216 = 15.08 Watts. Therefore 15.08 Watts is emitted from a human body to the seat pad from the total amount of heat. Rate of heat transfer into the pad for 1 hour = 15.08 × (3600/1000) = 54.3 kJ-hour^{-1}.

Assuming the body emits heat at a constant rate as mentioned above,
Total heat transfers for 4 hours = 54.3 × 4 = 217 kJ.

This amount is considered for the design of the cooling seat pad. Even though radiation heat loss also occurs in a sitting posture, it is neglected as the amount is minimal.

B. Heat Capacity of The Phase Change Material

The operating temperature limits of PCM are taken as 20ºC to 22ºC in the solid phase and 22ºC to 28ºC in the liquid phase. It is assumed that the phase change has taken place at 22ºC.

Sensible Heat capacity in solid phase = specific heat × change in temperature = cps × Δt = 2.2 × (20-22). Sensible heat capacity in solid-phase = 4.4 kJ-kg^{-1}.

Sensible heat capacity in liquid phase = specific heat × change in temperature = cpl × Δt. Sensible heat capacity in liquid phase = 3.04 × (28-22) = 18.24 kJ-kg^{-1}.

Latent heat capacity of the PCM = 180 kJ-kg^{-1}.

Total heat capacity of the PCM = Sensible Heat in solid-phase + Latent Heat during phase change + Sensible Heat in the liquid phase.

Total heat capacity of the PCM = 4.4 + 180 + 18.24 = 202.64 kJ-kg^{-1}.

Required Mass of PCM

$$= \frac{\text{Design Heat rate (kJ)}}{\text{Total Heat Capacity of PCM (kJ}-\text{kg}^{-1})}$$

$$= \frac{217\text{kJ}}{202.64\ \text{kJ}-\text{kg}^{-1}}$$

Required amount of PCM = 1.2 kg.

For safety considerations, the mass is taken more than that if required. The mass of PCM is taken as 1.5 kg. As this project focuses on the pure conduction heat transfer between the human body and the cooling seat pad, the losses due to convection and evaporation are not concentrated. The total operating time of the cooling seat pad within the specified temperature limits is four hours.

C. Fabrication of Cool Seat Pad

The fabrication of a cool seat pad involves the encapsulation of PCM, stitching of insulation layer with PCM layer, and stitching of outer cover. The PCM is encapsulated in rectangular pouches of length

157 mm and breadth 122 mm. The material used for making the pouch is a multilayer nylon of thickness 200 micron. The cold seat pad contains nine pouches of the same dimensions. The arrangement of the PCM pouches in the seat pad has been shown in Figure 4.

Each pouch contains 0.2 kg of hydrated salt with some air gap. The air gap in the PCM pouch is provided to prevent the volume expansion during phase change. The insulation layer and the PCM layer are stitched one after another. The outer cover, which is made up of Rexine is stitched with the thermal layer of $2x10^{-3}$ m polystyrene foam.

Figure 4: Arrangement of PCM pouches in the cold seat pad

IV. Result And Discussion

All the PCM pouches are inserted inside the cooling seat pad in a solid-state. The initial temperature of the PCM pouches is found to be 20°C. The thermocouples are placed at various places of the seat pad to measure the change in temperature. Two thermocouples are placed on the surface of the backside PCM pouches. One thermocouple is placed at the front PCM pouch, which is nearer to the thighs. The fourth thermocouple is placed on the surface of the seat pad. The initial temperature of the surface of the seat pad is found to be 25°C approximately. A man of weight 65 kg is made to sit on the seat pad for 4 hours. The body temperature of the man is 38.8°C. For every time interval of ten minutes, the temperature of the PCM and the corresponding surface temperature of the seat pad are observed. The observations are continued for four hours. Finally, the result shows that the surface temperature of the seat pad is lesser than the atmospheric temperature and able to withstand by the human throughout the testing. The temperature at the surface of the seat pad varies from 25°C to

30°C. But the heat of the PCM when inserted is 20°C and when removed, is 26.4°C. The ambient temperature is 35°C. Therefore, the seat pad provides a cooling feel to the man for four hours. The temperature of PCM after four hours is found to be at 26.4°C. Even after four hours of observation, the seat pad gives coolness.

The body temperature of the human sitting on the pad is 38.8ºC, and the weight of the human is 65 kg. Also, the column chart presents the surface temperature of PCM with a surface temperature of the seat is in Table 1 and Figure 5.

Table 1: The surface temperature of the PCM pouch and surface temperature of the seat pad for various time intervals

Time (minutes)	**The surface temperature of PCM (˚C)**	**The surface temperature of the seat (˚C)**
0	20	25
30	21.7	25.9
60	22.3	26.1
90	22.5	27
120	22.7	27.6
150	23.6	28.1
180	24.5	28.5
210	25.9	29.3
240	26.4	30.2

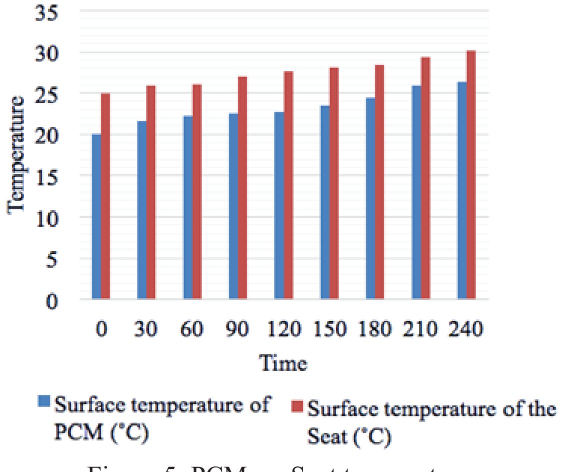

Figure 5: PCM vs. Seat temperature

V. Conclusion

The design and fabrication of a storage-based portable cooling seat pad are taken up for the benefit of the people who are travelling with prolonged sitting. First, the concept is evolved based on research articles and patents. Design and heat transfer calculations are done for the human body heat transfer and the storage capacity of the phase change material. The suitable materials are identified, and the suitable PCM is identified for the required melting point range and the storage capacity. Further fabrication processes are done, and the seat pad is tested under various circumstances. Finally, the results show that the pad works more than expected. It can continuously produce cooling for passengers for more than four hours.

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