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SUDAN UNIVERSITY OF SIENCE AND TECHNOLOGY

FACULTY OF ENGINEERING

MECHANICAL ENGINEERING – POWER

EXPERIMENTAL STUDY OF A CAR INCOPORATING THERMAL ENERGY STORAGE

A study submitted in partial fulfillment for the requirements of the degree of B.Sc. (Honor) in mechanical engineering (power) :

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October 2017

الآيـة

قال تعالي: (قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا ۖ إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ)

Dedication

We dedicate this thesis to:

Mechanical Engineering –Sudan University of Science and Technology,

Our parents: words are just not expressive enough,

They introduced us to the joy of reading from birth enabling such a study to take place today,

Our brothers, sisters and our best friends, without them none of our success will be possible.

Our gratefulness to **Dr/ Abuelnour Abdeen** for supporting, trusting in our selves ,funding, and guide us through the project to the current success, believing in our skills, so God bless you …

Never forget **Dr/ Ashraf abdelhaleem** for providing the vehicle.

Acknowledgement

All praise and thanks to Allah who provide us with the ability to complete this work. We are thankful to our families who are always supportive and helpful throughout our studies.

We would like to express our special appreciation and gratitude to our advisors **Dr. Abuelnour** for being such a source of inspiration and motivation to us.

Abstract

During day time vehicles, in particular cars, are parked outdoors their interior temperature increases dramatically . therefore the thermal discomfort is obvious for the passengers when they get into the vehicle after a car park. In this pilot study the internal car temperature conditions are suspended under the sun when a thermal energy storage (TES) system is placed inside the car is experimentally studied. The objective of this study is to demonstrate 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 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 temperature.

المستخلص

عندما تكون السيارة متوقفة لفترة طويلة تحت اشعة الشمس درجة الحرارة الداخلية لكابينة الركاب ترتفع بصورة عالية , وبذلك عدم الراحة الحرارية لركاب يكون واضحاً بالنسبة للركاب . في هذه الدراسة الظروف الحرارية لكابينة الركاب تكون معرضة لأشعة الشمس عندما يكون نظام التخزين الحراري موجود داخل المركبة .الهدف من هذه الدراسة التوضيح بصورة تجريبية الفائدة من استخدام المواد متغيرة الطور في تحسين الراحة الحرارية للركاب داخل الكابينة . إن استخدام المواد متغيرة الطور يؤدي إلى درجات حرارة أقل داخل الكابينة وبالتالي تحسين الظروف الحرارية للركاب.

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Abbreviations

PCM = Phase change materials.

TES = Thermal energy storage.

AC = Air conditioning.

ASHRAE = American society of heating refrigerating and air-conditioning engineers.

CHAPTER ONE

CHAPTER ONE

1.1 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 analyzing 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[2].

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.

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[4]. And even during cloudy days with lower ambient air temperatures, vehicle cabin temperatures may reach deadly levels[5] and the same conclusion was reached after investigating heat stress from enclosed vehicles in children .

Fuel economy has long been a dominant design goal for commercial vehicles, but recently issued U.S. Department of Defense (DOD) policy has set increased energy efficiency and fuel economy as immediate priorities for military vehicles as well, putting emphasis on the strategic and operational impact of the military's overall energy usage . System level analyses by both the DOD and the U.S. Department of Energy (DOE) have recognized that improving the management of vehicle heat is critical to achieving higher platform efficiency[6] . Depending on operating conditions, typical vehicles reject approximately 65–75% of the fuel's energy as waste heat through the exhaust or radiator, and in current combat vehicles about 10–15% of the useful energy are devoted to running the cooling system[7]

a number of investigations have been directed at improving overall vehicle thermal efficiency, but these efforts are complicated by the transient nature of the vehicle's thermal load., over any given drive cycle a vehicle can have peak velocity and power demands much higher than the average values, with sudden load changes occurring multiple times over the cycle[8]. Most vehicle thermal management systems are designed to handle expected worst case conditions as steady-state requirements.

However, using the drive cycle, running at a constant 100% cooling capacity for such a transient loading condition would represent an overdesign problem relative to the average requirement, with resultant size, weight, and power (SWAP) penalties to the vehicle. Thus, there exists a need to find better ways to accommodate the unsteady thermal load to improve thermal efficiency and overall fuel economy in modern vehicles

Phase change thermal energy storage (TES) has received much attention for non-vehicular applications to load-level transient thermal behavior, including facility climate control[9] , power generation and cogeneration enhancement[10] , electrical power grid demand side reduction[11] , and electronic component thermal protection [12]. Solid-to-liquid latent heat absorption and release has a benefit over sensible heat absorption due to the ideally isothermal phase front that acts as temporary, nearly infinite thermal capacitance, reducing overall temperature rise with minimal material volume[13] . Properly engineered, phase change materials (PCMs) can buffer thermal transients and allow the system to be designed for the average, rather than the peak, thermal load. Put in other terms, thermal buffering can allow cooling systems to be designed based on total energy, rather than peak power, requirements. This could reduce steady-state thermal overdesign and improve overall vehicle SWAP.

1.2 PROBLEM STATEMENT

Thermal comfort is an important issue since it relates directly to the state of mind and performance of the person operating the vehicle.

Fuel consumption is one of the main concerns of the scientific community now a days due to its contribution to global warming and the increasing of carbon dioxide emissions so it's important to consider it when designing any system.

1.3 OBJECTIVES

The objectives of this research are :

- To design and construct a tool to help manage the temperature inside the vehicle cabin and achieve a thermal comfort

1.4 Significance of Research

- Provide thermal comfort for passengers inside the vehicle
- Help solving the global warming issue by reducing carbon dioxide emissions

CHAPTER TWO

CHAPTER TWO

Literature review

2.1 Introduction

The focus of literature review is on the importance of thermal comfort and the different methods used to achieve it whether it's by using the different types of AC systems or via thermal storage or via combination of the two.

2.2 Air conditioning

Extreme conditions such as heat and humidity can impact on our overall physical and intellectual activity, making even the simplest of tasks and absolute chore , having a proper air conditioning system in place helps reduce heat and humidity . thus reducing the impact on our ability to perform and complete work tasks

2.2.1 Types of air conditioning

Air conditioning , or cooling is more complicated than heating instead of using energy to create heat , air conditioners use energy to take heat away , the most common Air conditioning system uses a compressor cycle similar to the one used by the common refrigerator to transfer heat from the cooled space to the surrounding.

2.2.1.1 Vapor compression refrigeration system (VCRS)

As mentioned earlier (VCRS) is the most used type of refrigeration in AC systems despite of its high energy consumption it has a high coefficient of performance (COP) So it's fit for use in a commercial level , and it has the following types

1. Central AC
2. Split unit

3. Window type

2.2.1.2 Evaporative cooling

Evaporative cooling is less common the (VCRS) .but they are a practical alternatives in hot and dry areas like what we have here in Sudan .they work by pulling fresh outside air through moist pads where the air is cooled by evaporation the cooled air then circulated through the cooled space . this system can save up to 75% of cooling costs because the only mechanical component that uses electricity is the fan . plus dew to the simpler technology it is much cheaper to purchase and easier to maintain.

2.2.1.3 Absorption refrigeration system

The main purpose behind this system is to run the refrigeration cycle without a compressor. Instead of the mechanical energy provided by the compressor it uses heat energy provided by generator. The biggest advantage of this system is that ability to use any heat source available. that means we can use the renewable energy sources like solar energy

2.3 Thermal Energy Storage (TES)

Thermal energy storage is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating or cooling applications and power generation.

(TES) systems are used particularly in buildings and industrial processes .in this applications approximately half of the energy consumed is in the form of thermal energy . The demand for which may vary during any given day and from one day to the next .there for (TES) systems can help balance energy demand and supply on a daily , weekly and even seasonal basis . They can also reduce peak demand , energy consumption and by extension reduce the greenhouse gases effect and reduce carbon dioxide emissions.

2.3.1 Types of (TES)

There are three basic types of (TES)

2.3.1.1 Sensible heat storage

Sensible heat thermal storage is achieved by heating the storage medium and increasing its energy content but not changing state during accumulation. energy is released and absorbed by the medium as its temperature reduces and increases respectively . the application of this type are basically cooling and heating in building

2.3.1.2 Latent heat thermal energy storage

Latent heat is associated with changes of phase energy required charging is used to convert a solid material to a liquid or a liquid to a gas , phase change materials have the benefit of high thermal capacity . in order to use latent heat storage the storage material should have a melting temperature within the range of the charging and discharging temperature of the heat transfer fluid

2.3.1.3 Chemical reaction thermal energy storage

Chemical reaction require a specific temperature at which a chemical product is disassociated in a reversible chemical reaction and heat is retrieved when the synthesis reaction takes place the development of such reaction is already at a very early stage and as the reaction temperature should lie within the charging and the discharging temperature of the (HTF) therefor the use of such technology should case specific.

2.4 Phase change material (PCM) :

PCM is a substance with a high latent heat of fusion which melting and solidifying at certain temperature is capable of storing and releasing large amount of energy

2.4.1 Types of (PCM)

Latent heat storage can be achieved through liquid-solid, solid-liquid, liquid-gas and gas liquid. Liquid-solid phase changes are practical for PCMs. Although liquid-gas transitions have a higher heat of transformation than solid-liquid transitions. Liquid-gas transitions are impractical for thermal storage because large volumes and high pressures are required to store the material in their gas phase

The solid-liquid phase change materials can be divided into four categories:

- Eutectics
- Salt hydrates
- Organic materials
- High temperature salts

2.4.2 Applications of (PCM)

Listed below are few of the applications of PCM

- thermal energy storage
- Solar cooking
- Conditioning of buildings such as ice storage
- Cooling of heat and electrical engines

- Cooling food and beverages
- Medical applications ; Transportation of blood and thermal sensitive pharmaceutical products
- Waste heat recovery
- Solar power plants
- Thermal protection if electronic devices
- Computer cooling
- Thermal comfort in vehicles

2.5 (PCM) in buildings

The electricity demands of urban areas have increased fivefold in the past two decades due to rapid industrialization and population growth[14] . Currently the electricity demand is mostly met by fossil fuels leading to emission of greenhouse gases thus causing global warming. Besides, the increasing energy costs and the adverse impacts on the environment by energy production plants, all contribute to the need to find means to substantially reduce energy consumption. Cooling and heating requirements of buildings are the major contributors to energy consumption worldwide.

Around 30% of electricity consumption is attributed to building air conditioning[15] with significant peaks in summer months between June and August in hot climates[16] . Reducing the cooling load is one of the most effective energy conservation methods in buildings that can potentially be achieved with a combination of building design, thermal insulation and coatings[17] . The amount of energy used in buildings is mainly based on the variations related to weather, architectural design and the envelope features.[18]

Thermal insulation are materials or combinations of materials that are used to provide resistance to heat flow, should have low conductivity for building application in order to reduce the cooling demand in hot climate and durability[19] . Early buildings were insulated with mineral wool, however in 1880 in United States of America and from 70s onwards more effective insulations materials have been discovered and analyzed numerically which are used in building construction in the world[19] . In Europe, inorganic fibrous material, glass wool and stone wool account for 60% of the insulation materials while organic foamy materials, expanded and extruded polystyrene and to a lesser extent polyurethane accounts for some 27% .[20]

Numerous studies have been done on insulation materials and their performance when used in buildings under various circumstances. Ozel[21] performed a mathematical study on the[22] thermal performance of insulation thickness using XPS and EPS insulation on south wall made of concrete, brick, briquette, blokbims and AAC in climatic condition of Elazig, Turkey. Ucar and Figen[23] analyzed numerically the optimum thickness of foam board, XPS and fibre glass insulation for an external wall in Turkey. Chirarattananona et al.[24] conducted a study in the tropical climate of Thailand and found that insulation of wall decreased the cooling load. Kawasaki and Kawai [25] have developed and build an alternative structural insulation composite for buildings, plywood faced sandwich panel with low density fibreboard core. Thermal conductivity and thermal diffusivity were measured in a laboratory and compared with samples of wood-based boards, solid wood and commercial insulators. Few publications showed the development of insulation systems with vacuum panels. This new panels has been developed since the end of the 1990s [26] and was known as vacuum insulation panels. The most appealing feature of these panels is their 5–10 times higher thermal resistivity for heat flow perpendicular to the main faces compared to conventional thermal insulation. Their cost and durability in the buildings are the main drawbacks. Nussbaumer et al.[26] performed experiments and numerical studies with a concrete wall externally insulated with expanded polystyrene boards containing vacuum insulation panels. Some authors have investigated the improvement of thermal inertia of the buildings by including phase change materials (PCM) in the envelopes and some directly in the insulation material.[27] Water vapour and humidity are important factor when selecting the insulation materials for the passive buildings.

Karamanos et al.[28] worked exclusively on stone wool and presented experimental data that reaffirmed the sensitivity of stone wool when water vapour condenses in the material.

National renewable energy laboratory (NREL) in the USA has extensively examined green building design and energy efficiency in variety of climates [29]. Lundström and Wallin [30] computed heat demand profiles and annual electricity-to-heat factors of energy conservation measures in buildings and their impact on system efficiency and greenhouse gas emissions in Sweden. He identified that by improving the buildings' envelope insulation level and thereby, levelling out the heating heat load curve reduces greenhouse gas emissions and improves primary energy efficiency. Ihara et al. [31] studied, the effects of four fundamental façade properties related to the energy efficiency of office buildings in Tokyo, Japan, with the purpose of reducing the heating and cooling energy demands. Some fundamental design factors such as volume and shape were also considered. It was found that the reduction in both the solar heat gain coefficient and window heat transfer coefficient

(U-value) and the increase in solar reflectance of the opaque parts are promising measures for reducing the energy demand. Therefore, the properties of facade material have to be studied under different circumstances and conditions to evaluate the performance of the buildings. Radhi [32] focused on buildings in Bahrain with dominant internal load and performed regression analysis on the existing building. Also, Radhi et al. simulated a series of residential building with the aim of analysing the thermal comfort characteristics of varying fenestration and insulation options, and thermal mass effects [33]. Using the climate data of Riyadh, Al-Sanea and Zedan [34] analysed dynamic thermal characterization of insulated building walls having same thermal mass and optimized insulating thickness under periodic conditions. Various layers of insulations were used by varying there arrangement in order to achieve the optimized performance. The best overall performance was achieved by a wall with three layers of insulation.

Over the past few years, the development of concrete blocks with low thermal conductivity has been gaining interest in the research community. This can be observed in various research fields. For example, three types of concrete blocks were developed with low thermal conductivity [35]. These blocks were able to reduce the heat transfer and reduce cooling loads. More recently, the autoclaved aerated concrete (AAC) has been introduced as a green masonry material. It was found that considerable reduction in heat gain and cooling load could be achieved when the AAC was used instead of cement blocks, which are very commonly used in buildings in UAE[36] . Radhi did a simulation study on AAC building material and showed that it can alone provide up to 7% of energy reduction if used in Emirates. The AAC blocks were able to provide thermal comfort inside the buildings without the use of thermal insulation[37] . However, the classical wall built from cement blocks with an insulation layer was found to provide more energy savings[38] . Radhi analysed insulation of residential villa in Al Ain, UAE. He did simulation study on a typical Al-Ain villa and during his work he applied uniform resistance (R-value) on the walls. Friess et al[39]. did modelling on thermal bridge and its effect on building energy consumption in Dubai. The results showed that 30% of the energy consumption can be reduced by retrofitting existing buildings. Thermal insulation was found to be effective in skin load dominated buildings because of small internal heat gains. The useful electrical savings in residential sector could exceed 50% of the total energy consumption[40]. Based on this, an attempt was made to optimize the thickness of insulation material with consideration to electricity tariff.

In addition to thickness, the placement of insulation material does also have an impact of heat load reduction. Saleh evaluated thermal performance of different arrangements, types and thicknesses of insulation materials in buildings. A better performance was achieved when insulation was located on the outer side of building envelope. Similar conclusions were obtained by Al Nafeez and Rogers who evaluated insulation materials on basis of time lag, decrement factor, cost and R-value, keeping overall thickness and U-value constant of a three layered building envelope.

Kossecka and Kosny[41] carried out energy analysis on the whole-building and concluded that material configuration of exterior wall could significantly affect annual thermal performance.

However, this effect depends upon the type of climate conditions.

Therefore, real open air experimentations are necessary to validate the building insulation performance under specific climatic condition.

Experimental study was done on insulation materials in

Mediterranean ambient conditions by Cabeza et al. [20]The thermal performance of the reference building (2.4 m _ 2.4 m _ 2.4 m) made of hollow and perforated bricks walls were compared with the thermal performance of similar building with, added PUR, mineral wool or XPS insulation materials respectively. It was identified that up to 64% energy use can be reduced in summer and 37% in winter by using insulations. Soubdhan et al[42]. also constructed four small scale test cells (1.22 m _ 1.22 m _ 0.5 m) to test heat transfer via roof only in tropical climate. The walls were insulated with polystyrene and four different scenarios were tested on the roof (having polystyrene, radiant barrier or fibre glass insulations or no insulation). Swinton et al[43]. performed experiments on insulation specimen of XPS, PUR foam, mineral fibre or glass fibres on the external east and west walls in Ottawa, Canada for two years. Thermal mass, in combination with night-time ventilation strategies for cooling load reduction for Hong Kong building was discussed by Yang and Li[44]. Experimental study was done by Ibrahim[45] for six months in UAE for thermal behaviour of insulated building (5 m _5m_ 2.8 m) by XPS foam. The testing was done on east, west walls and roof. Initial results showed a reduction in inside wall temperature. Only room temperature behaviour was observed during the test. More recently, Gruber et al. identified and carried out experimental analysis on the simple automated ventilation system of the buildings as it can have large energy savings potential. The building controller was assessed for indoor climate control by automating the ventilation flow rate during a typical office working day. Experiments were conducted in two different office sites, as well as during two weather seasons of Swedish summer and winter. From the investigation, it was concluded that despite of using a simple controller, it could save between 12% and 19% of energy compared to a system of common practice while maintaining the quality of indoor climate. Meissner et al[46]. carried out experimental analysis, in order to determine the characteristic curves for total cooling capacity, sensible cooling capacity and energy efficiency ratio of two room units. It was performed to improve the modelling of air conditioning system in building simulation tools. Al-Saneaa et al[47]. investigated the effects on dynamic heat-transfer characteristics of insulated building walls by varying amount and location of thermal mass with same nominal resistance (R-value) under steady periodic conditions using climatic data of Riyadh. It was found that maximum savings in yearly cooling and heating transmission loads were about 17% and 35%, respectively, as a result of optimized thermal mass for same R-value. It was recommended that building walls should have insulation placed on outside for applications with continuously operating year-round air conditioner (AC)[47] . Thermal mass location in the envelope plays a significant role on the overall energy consumption of the building. Bond et al. provided fundamental insight into configuring wall layers for improved insulating performance. Thirty-three different walls were evaluated based on four primary configurations with fixed volumes of insulation and thermal mass. Only the layer distribution was varied. Because the total volume of each material was fixed, the overall thermal resistance and capacitance were equivalent for all configurations studied. The best insulating performance was achieved when insulation layers were positioned as close as possible to the inside and outside layers of the wall (i.e., near the indoor and outdoor environments).

In addition, optimal results occurred when both the insulation and thermal mass were distributed evenly throughout the wall.

Reflectivity of roof has also become an inexpensive method in reducing energy usage in warm climates. The surface absorptivity also affects the building energy consumption profile. Al-Saneaa et al. studied the effects of type of masonry material and the surface absorptivity to solar radiation on critical thermal mass thickness in insulated building walls for a fixed wall nominal thermal resistance (Rn-value). The results showed that for a given critical thermal mass thickness, higher energy savings potential were obtained with walls with solid concrete blocks and walls with lower surface absorptivity. Synnefa et al.and Bhatia et al. studied that by increasing roof reflectivity, the energy usage can be decreased in warm climate.

Several studies found that insulation towards the outside (with thermal mass towards the inside) provides better thermal performance than insulation towards the inside . and most agree that, generally, more thermal mass yields lower peak loads, a lower decrement factor, and a larger time lag and .

Insulation materials, while they increase R-value, are not commonly been looked upon as elements that can increase time lag; these are usually associated with thermal mass. On the other hand, thermal masses, while they increase energy storage capability, are not commonly been looked upon as materials that can effect substantial reduction in daily transmission load; the latter is commonly associated with thermal insulation. These common beliefs are based upon facts that increasing amount of mass would not much increase the R-value and increasing amount of insulation would not much increase energy storage capability. This view is simply based upon thermal properties and behaviour of building and insulation materials under static (steady state) conditions.

Studies under dynamic conditions have shown that these issues are rather complicated and interactive; both insulation and thermal mass have wider effects on thermal characteristics than commonly believed.

The hot and humid climate in UAE is one of the harshest in the world, and it presents several barriers to technologies for reducing the energy consumption. The passive design is valid in general terms for any hot and humid climate in the word. The current energy system model is changing worldwide as well as in UAE; several sectors in government, industry and society are more aware of the negative effects of greenhouse gases emissions and economical risks associated on dependence on fossil fuels for coming years. Also, they are aware of the business opportunities associated with a sustainable and green buildings tendency. Recently, there has been a consensus to legislate for energy efficiency in the UAE. A major share has been given to the building sector with special focus on the important role that efficiency codes and green materials play in reducing energy consumption and CO2 emissions

. In UAE the energy required for buildings is higher 45%, since during summer up to 70% of that energy is used for air conditioning

. UAE has experienced a boom in its building industry in the last years, which has caused an increase in the energy demand.

UAE is ranked among the highest energy consumers per capita in the world in 2012 . In addition, real estate buildings has become a core business in Dubai and other UAE regions, the rate of growth in residential villas from 2000 to 2010 in Dubai was about 300%, from 200,000 villas to 600,000 approximately.

Buildings are not only important energy consumers, but they are the place when we spent most of our time, therefore, comfort conditions cannot be compromised to save energy. Those facts are the motivation for this project, which has a general aim to contribute with the reduction of carbon footprint in residential sector. Therefore, energy efficiency in buildings is of prime importance for energy policy. As a part of building energy efficiency research, research centre is working on passive cooling by reducing the solar thermal heat load of buildings in parallel to developing active cooling solutions. Taking advantage of available

building material manufactured by local industries such as polystyrene, polyurethane, ceramic, cement, and glass, research Centre can develop or test thermal insulating material and solar reflective coatings in real environment. The location of Ras al Khaimah (RAK), UAE was chosen because it was planned to build a model passive building in Al-Hamra village townhouse, located in RAK, UAE. The initiative here was to provide detailed experimental base study for low cost solutions to reduce the cooling demand and energy consumption, for new and existing buildings in UAE. Presently, different insulation materials are available in the market. Usually, they are compared by their thermal conductivity and with theoretical calculations, but there were no experimental comparisons available, where the behaviour of such insulation materials in a building was compared over time as it is important to study effects of R-value and the thermal mass together under real conditions as both are important to understand the behaviour of a building. Therefore two important issues must be dealt with; firstly, means of increasing the R-value usually by adding thermal insulation, and secondly, means of increasing thermal energy storage capability. Using heavy thermal masses in building walls is well known in moderate climates (e.g. Mediterranean climate) as means of regulating indoor temperature through night-time natural ventilation .
However, such an advantage cannot be utilized in dusty climates in which reliance is made on the AC equipment (for cooling and heating) for almost all days of the year. For this purpose four solar calorimeters were designed and validated previously .

In UAE the concept of passive design of the buildings and its research are at preliminary stages. Insulated building walls are integrated parts of a building envelope. They protect the inner space from extreme weather conditions and damp down large fluctuations in temperature. As such, the building envelope should provide the necessary thermal comfort for the occupants as well as reduce energy consumption requirements for cooling. This is usually done through increasing thermal resistance (R-value) of envelope and, hence, reducing transmission loads. Therefore, addition of thermal insulation is important, particularly in regions with extreme climates. It is also importance to provide means to increase time lag factor by increasing thermal energy storage capability. The latter is usually regulated through thermal mass in the building envelope . The calorimeters were designed to provide passive design for zero energy buildings for the houses. Therefore, a comparison between typically constructed solid (concrete) walls and a relatively new concept of dry (EIFS) walls in the market was done to evaluate the performance and behavior of these two concepts of construction in hot climate of UAE. It will provide beneficial experimental study in order to propagate building efficiency in the local market of UAE and at the same time provide useful practical data to the manufacturer to assess and improve the manufacturing of these insulation materials as per the local environmental conditions. For this purpose detailed experimental design, monitoring and investigation with different materials and methods are presented.

The thermal and energy performance of three different conditions are presented. In first condition, since surface absorptivity plays an important role in energy savings therefore reflective coating as retrofit material was used on the south façade of one of the calorimeter. In second condition, PIR insulation was added as a retrofit material on the south façade of one of the calorimeter instead of coating. PIR insulation was used instead of PUR because it is moisture resistant and has better mechanical properties . Lastly, a new dry wall technology of EIFS was used on the south façade of the calorimeter instead of retrofitting the existing solid concrete façade, it was commercially available product and was provided by German company, BASF and used as build . The experiments were carried out in open air and then results of the above described cases were compared against the reference concrete calorimeter (typical UAE construction). Summers test with controlled-temperature and winters test with free floating conditions were analysed and discussed. Summers experiments with control temperature conditions were performed when the cooling demands of the buildings are the highest. Controlled-temperature conditions were reached after a sufficiently long time from start of AC operation and when initial transient effects subside. Thermal characteristics and roles played by insulation and thermal mass are so much dependent on climatic conditions and operating conditions of AC equipment . While free floating experiments were performed and analyzed for winters and being presented to evaluate the performance of the insulation materials in humid conditions. The main objective of the present study is to investigate effects of thermal mass on transmission loads, and time lag, in building walls and at the same study the effect of R-value and the interaction.

The design of calorimeter was aimed to compare two buildings being tested under exactly same conditions. The first one acted as a reference; the testing façade of this building was made with typically used building materials in UAE. The next two buildings testing facades were made exactly identical to that of reference building wall furthermore they were retrofitted by adding reflective coating and insulating material respectively. The fourth building testing surface was made with a relatively new technology i.e. dry wall instead of a typical solid concrete wall. Comparing the insulated or coated building with un-insulated one gave the effect of that solar insulating material on the heat flux reduction. The south wall and the roof (the two main insolated surfaces) were less insulated, while the rest of the surfaces were heavily insulated.

Simulations were carried out to estimate cooling load of a 1 m3 cube building, with no internal heat gains or infiltrations. Everyside of the cube was oriented as (North, South, East, West or horizontal) with reference to sun. It was observed that the roof and south façade played a major role in cooling load contribution to the building. The heat flow through the roof was around 31% followed by the south facade which was around 20.5%[48] . The heat flow through the north, east and west was around 11.5%, 18.5% and 18.5% respectively. Therefore it was decided to choose the roof and south façade as testing surfaces. Tests were done on vertical south facing surfaces and are presented in this paper. However, the test on roof (horizontal surface) is not presented in this paper and will be done in future work. Calorimeters as shown in are located in RAK, UAE (Al Jazeera Al Hamra, RAK, UAE Latitude: 25_50 N | Longitude: 55_50 E, GMT+4) and built in 2011–2012 . The design of four calorimeters and their sizing were validated previously[43] . The size of the calorimeter was optimized in order to detect the apparent heat gain and temperature changes between the reference calorimeter and the calorimeter being tested. The structure of the four calorimeters (3 m _3m_ 3 m) for this study were made of four pillars (25 cm _ 40 cm _ 300 cm) with reinforcing bars at each corner of the cubical. The configuration of calorimeter north, west, east surfaces were of AAC blocks with thickness 25 cm and wall area of 3 m _3m (R = 2.11 m2 K/W)[17] . Roof was made using concrete precast beams (25 cm _ 30 cm _ 300 cm) at each corner with 15 cm thick concrete slab resting on beams and 2 cm thick plaster on each side of the slab (R = 0.18 m2 K/W)[17] . Area of the base was 3m_ 3 m and it was filled with crushed gravel, 5 cm thick XPS and concrete slab 15 cm thick (R = 1.687 m2 K/W)[17] . There are no windows and only one door at the north facing facade of the building, which was kept, closed during the experiments. No internal heat sources were kept inside the buildings except for the identical recording instruments. The doors were properly sealed to prevent infiltrations and buildings were unoccupied during experiments. The distance between each calorimeter building is 6 m. The south wall of the first three buildings are solid-concrete and it was made of 15 cm thick concrete with 2 cm thick plaster on each side and the fourth one was made of dry composite wall instead of solid concrete wall, that is known as EIFS. Area of each wall surface is 3 m _ 3 m. Three calorimeters with various insulation methods and materials on south wall were compared against a reference calorimeter with no insulation. The configuration of south walls from inside to outside of each calorimeter is shown in . shows the material physical properties of the construction material. PIR used on building B3 as retrofit has higher specific heat capacity. Whereas, for building B4 the EPS and mineral wool has higher specific heat capacity and being used with higher thickness. Therefore, according to it is being expected that the building B3 and B4 will have better thermal mass properties compared to building B1 and B2. shows the calorimeter dimension in meters when viewed from east surface (side view) and different stages of the construction process of the calorimeter. All the four buildings were calibrated at a set point of 24 _C for heat flux and energy consumption before adding any insulation or coating to the testing surface. In order to calibrate the buildings, building energy consumption and heat flux was measured for a week at a set point of 24 _C. The difference in energy and heat flux consumption was measured and differences of all buildings were compared with that of the reference. Percentage change or correction factor compared to the reference were added to other buildings during measurements. During the experiments the data was sensed and it was recorded at 1 s interval via ADAM module for the heat flux through the south walls, external and internal room temperatures and energy consumption. Details of instrumentations used to collect data during the experiments in the calorimeters along with its accuracies are as follows:

External and internal room temperature and humidity: E+E Electronic – EE08, accuracy 2% for RH and ±0.5 _C for temperature. Room temperature was measured from the middle of the room approximately 1.5 m above the floor. The outside air temperature was measured approximately 5 m above the ground level. Heat flux through south wall (inside): Hukseflux heat flux sensor HFP01, accuracy of 3%. It was fixed on the inside at the middle of the south wall surface (1.5 m above ground and 1.5 m from the adjacent walls). Electric consumption: Kamstrup energy meter-KM162L, accuracy of ±1%. Solar radiation: Vantage Pro 2, accuracy of 0–1800 W/m2 with ±5% of full scale accuracy. The experimental setup enabled to provide the possibility to perform two kinds of test:

Summer:

Controlled temperature-set point 24 _C: Air conditioner was used to control the room temperature at 24 _C during the duration of the test in summers. The average heat flux and the energy consumption of the calorimeters were compared with the reference. The experiments were initiated once the temperature of all the calorimeters was at 24 _C.

Winter:

Free floating test: Temperature inside the room was not controlled and no cooling or heating system was used. Heat flux flow through south walls and room temperatures were measured continually to determine the effect of R-value and thermal mass of insulation materials. This experiment was performed in winters.

Results and discussion

The experiments were carried out from 2012 to 2014. The tests were run simultaneously in all four buildings to measure the performance of each building at same time. Here, one week of hot summer and cold winter season has been selected and the results obtained are presented and discussed in paper, in order to describe the behaviour of the calorimeter under different ambient conditions.

- Summer results

- Controlled temperature-set point 24 _C

The indoor temperature was maintained at set point of 24 _C (±0.5 _C) all time during tests with the help of 1 tonthermal air conditioner in controlled temperature experiments. Summer temperature reached around 35–45 _C at peak time. shows the average daily temperature inside the room as measured during the experiments, the average temperature for the duration of the experiments was approximately 24 _C in all four buildings. gives the average heat flux measured on the south walls of the calorimeters. The heat flux through the reference building (B1) south wall was much higher than that of B2, B3 or B4. The heat flux through the dry wall (EIFS) B4 was the lowest as compared to the solid concrete wall B1.

The average reduction in heat flux by reflective coating retrofitting on B2 south wall was around 22% due to the reflection of the solar radiation from the surface coating. The average reduction in heat flux increased by 69% by retrofitting the south wall with PIR

Figure2 1 four cubical calorimeter at site with different south wall configuration

Board of 5 cm on B3 and by using the EIFS south wall on B4 reduction of heat flux was 75% compared to the B1. It was caused due to the increase in the R-value of the south facade of B3 and B4 calorimeters, hence providing a resistance to the heat flow inside the calorimeters. It is shown in fig 2.1.

Another week of August (August 7th to 13th, 2014) is presented

In fig 2.1, in order to show the measured accumulated electrical consumption profile of air conditioner. The set point of the air conditioner system was set at 24 _C and the average temperatures inside all the calorimeters were always within the range 24 _C ± 5 _C. The energy used to cool the reference calorimeter is much higher than that of the other calorimeters. Using reflective coating as retrofit in B2 the energy consumption reduced by 7.6% compared to reference B1. With 5 cm PIR insulation on B3 energy saving has increased by 23% followed by EIFS dry wall on B4, as it has increased the savings by 25.3% against reference B1 due to reduction of heat flux at south façade.

- Winter results

- Free floating experiments

The results considered in this case were from weeks in December

2014 which has been selected and discussed. Temperatures are typically low variating from 15 to 27 _C as compared to summer.

The humidity during the week also remains on an average by 70%. shows the hourly average heat flux measured in December via south wall inside buildings B1, B2, B3 and B4 and ambient temperature. The pattern shows that the heat flux fluctuation in building B1 was high as compared to the other buildings. The heatflux variation in coated building B2 followed the same trend as that of building B1 but the magnitude was less as the coating was reflecting the radiations. Whereas, in the insulated buildings B3 and B4, the heat flux magnitude were not only less but very steady.

Due to the high thermal resistance of the insulated walls of buildings

B3 and B4, the peak of the heat flux has reduced when compared to the peak of building B1 and B2. Also, due to higher specific heat capacity of the insulated buildings B3 and B4, as shown in the peak of the heat flux has shifted right when compared to the peak of the building B1 and B2 as shown in. Hence it takes longer time for the heat to travel inside the rooms through B3 and B4l therefore, it allowed to maintain the room temperature at a certain value for longer time.

In order to analyse the heat flux behaviour in detail, two days that is from 19 December 2014 to 20 December 2014 were selected from .shows the instantaneous heat flux profile during the selected days in December and the corresponding ambient temperature profile as measured without using hourly average of the measured data. It shows that the heat flux through the testing surface in B1 and B2 followed similar trend but different in magnitude as coating reflects some of the irradiance falling on the surface. Heat flux increased with increase in the ambient temperature with time lag of 4hrs approximately from sunrise to noon. Heat flux through B3 and B4 was rather steady compared to reference due to high thermal resistance, thus avoiding any thermal inertia effect. The heat flux trend in insulated buildings B3 and B4 were inverse to that of B1 during the whole day. Hence, heat flux pattern illustrates that insulation is essential in winter as well as in summers to maintain the temperature inside the room stable with less fluctuations during the whole day. shows the temperature inside the calorimeters and compared against the ambient temperature. The values of the interior temperatures experience soft fluctuations during the week due to relatively high thermal inertia of all the calorimeters. But the temperature in the reference building B1 has a larger daily oscillation compared to the insulated buildings. The indoor temperature shows that the fluctuations in temperature was limited to 2 _C average in case of insulated and coated buildings (B2, B3, B4), compared to average 6 _C in reference. Also the reference building was more sensitive to the outside temperature decrease that occurs on the last four days of the week. Among the insulated buildings their differences are minimal as the three of them

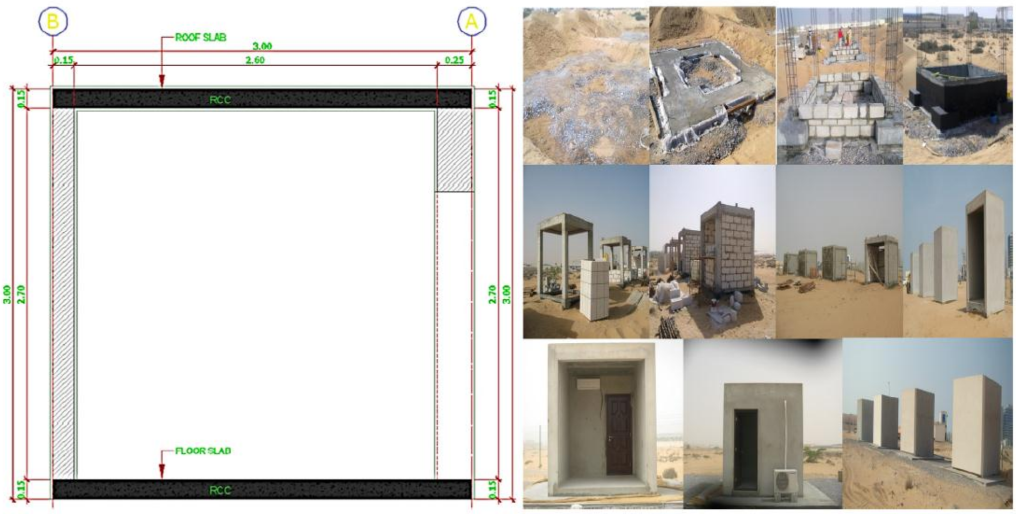

Figure2 2 Dimension of calorimeter in meters (m) and the construction of calorimeter with different south wall configuration

2.6(PCM) in cars

Most of vehicle air conditioners require engine power to operate. Of all auxiliary power requirements AC system has the greatest impact on fuel consumption. Using the AC can increase fuel consumption by up to 20% because of the extra load on the engine. This consumption can be significantly reduced by the use of PCMs .PCM has the ability to decrease the temperature in a vehicle's cabin dew its relatively high latent heat and small melting point and thus making it easier for the AC system to make it to the desired temperature and thus reducing fuel consumption. this process can be achieved by installing A container containing a phase change material inside the cabin

2.7 Previous studies on (PCM) in CARS

2.7.1 A review of phase change materials for vehicle component thermal Buffering

The use of latent heat thermal energy storage for thermally buffering vehicle systems is reviewed. Vehicle

Systems with transient thermal profiles are classified according to operating temperatures in the range of

0–800 _C. Thermal conditions of those applications are examined relative to their impact on thermal buffer

Requirements and prior phase change thermal enhancement studies for these applications are discussed.

In addition a comprehensive overview of phase change materials covering the relevant

Operating range is given, including selection criteria and a detailed list of over 700 candidate materials

From a number of material classes. Promising material candidates are identified for each vehicle system

Based on system temperature, specific and volumetric latent heat, and thermal conductivity. Based on the

Results of previous thermal load leveling efforts, there is the potential for making significant improvements

In both emissions reduction and overall energy efficiency by further exploration of PCM thermal

Buffering on vehicles. Recommendations are made for further material characterization, with focus on the need for improved data for metallic and solid-state phase change materials for high energy density Applications.[1]

Typical vehicles reject (65%-75%) of fuel energy as waste heat through the exhaust or radiator and in current combat vehicles (10-15%) of useful energy is devoted to running the cooling system

A number of studies have been conducted to improve the overall thermal efficiency of the vehicle but these efforts are complicated by the transient nature of the vehicle thermal load, over any given drive cycle a vehicle can have peak velocity and power demands much higher than the average values. With sudden load changes occurring multiple times over the cycle. Running a 100% cooling capacity for such transient loading condition would represent more than 2x system overdesign relative to the average requirements with resultant size weight and power penalties to the vehicle thus there must be a better way to accommodate the unsteady thermal load to improve thermal efficiency and overall fuel economy for modern vehicles

Phase change thermal energy storage has received much attention from non-vehicular applications to load-level transient thermal behavior …solid to liquid latent heat absorption has a benefit over sensible heat absorption due to the ideally isothermal phase front that acts as temporary .nearly infinite thermal capacitance reducing overall temperature with minimal material volume. Properly engineered phase change materials (PCMs) can buffer thermal transients and allow the system to be designed for average. Rather than the peak thermal load, put in other terms thermal buffering can allow the cooling systems to be designed based on the total energy ..rather than peak power requirements,,,this could reduce steady state thermal overdesign and improve overall vehicle (SWAP)

One of the main difficulties on designing a PCM-based thermal system however is matching an appropriate material to the expected thermal condition…thus two things must be identified for successful implementation of a vehicle based PCM system: what are the thermal conditions for the various vehicle components or systems and which ones could benefit from thermal buffering which PCMs are available for use in those TES systems

Low temperature vehicle applications T<100:-

The temperature applications are primarily concerned with adapting the vehicle to the environment..And in-cabin thermal conditions

Energy storage for cold start improvement:

the higher viscosity and decreased combustion efficiency present during vehicle COLD start makes it a prime target for thermal improvement…a number of studies have demonstrated the thermal benefit of using exhaust heat recovery ..one study by Hyundai motors corp. showed a 2.5% fuel economy improvement could be achieved by preheating both coolant and gearbox oil in a commercial vehicle…however cold start duration is not eliminated only decreased while awaiting exhaust temperature rise

Attempting to eliminate the cold start penalty altogether several groups have used PCMs to maintain component warmth long after the engine shutdown.

2.7.2 Reducing heat transfer across the insulated walls of refrigerated truck trailers by the application of phase change materials

A general estimate shows that 80% of communities across the United States receive their goods exclusively by transport trucks, of which a significant number are climate-controlled because they carry perishable goods, pharmaceutical items and many other temperature-sensitive commodities. Keeping the inside of a truck trailer at a constant temperature and relative humidity requires exact amounts of heat and/or moisture management throughout the shipment period, which is regulated via small refrigeration units, placed outside the truck, that operate by burning fuel. These trucks, known as refrigerated truck trailers, are the focus of this paper. In the research presented herein, the conventional method of insulation of the refrigerated truck trailer was modified using phase change materials (PCMs). The limited research carried out in refrigerated transport compared to other refrigeration processes has left spaces for innovative solutions in this area. The research investigated the inclusion of paraffin-based PCMs in The standard trailer walls as a heat transfer reduction technology. An average reduction in peak heat transfer rate of 29.1% was observed when all walls (south, east, north, west, and top) were considered for individual walls, the peak heat transfer rate was reduced in the range of 11.3–43.8%. Overall average daily heat flow reductions into the refrigerated compartment of 16.3% were observed. These results could potentially translate into energy savings, pollution abatement from diesel-burning refrigeration units, refrigeration equipment size reduction, and extended equipment operational life. The research and its results will help to better understand the scope of this technology. The last century witnessed a large increase in freight transport. With growing population and demand, this trend is expected to have a continuous growth in the coming years. Recent publications show that the truck industry, the leading transportation mode, will experience heavy expansion in the US in terms of volume, cost, and energy consumption[49] In spite of lowering the energy intensity over past years, fuel costs still remain high. Trucks alone consumed 19% of the total diesel and gasoline consumed in 2006 in the United States. The total cost of this fuel (mainly diesel) was estimated at $106.0 billion, which increased by $6.6 billion (6.2%) in moreover, in the US, trucks alone consumed about 65%which increased by $6.6 billion (6.2%) in 2007[50]. Moreover, in the US, trucks alone consumed about 65% of the total energy consumption by freight transportation in 2005 . Refrigerated truck trailers represent one classification of these trucks. Like other truck categories, refrigerated truck-trailers can be of various sizes and types. The two basic types are single-unit and truck-tractor. Only insulated refrigerated truck trailers were considered in this paper. From the 2002 economic Census, it is estimated that approximately 8.5% of trucks are refrigerated, which makes up about 11.9% of trucking miles in the US. the refrigeration units of refrigerated truck trailers run on the vapor compression refrigeration cycle. Based on the way the refrigerating units are run, vehicles can be classified in two types. The first one is self-contained, where an independent thermal motor runs the compressor, and the second one is the non self-contained, which depends on the vehicle motor[51]. Refrigerating units in both types take a significant amount of energy to refrigerate the inside of the trailer body as required by the carrying product. The impetus for the current research relies in the possibilities that exist in this particular transportation sector to lower the amount of heat transfer rate from the outside environment to the inside of the trailer via the integration of phase change material to the standard trailer walls. Zhang .and Medina. successfully implemented the integration of phase change materials in building walls and structural insulated panel (SIP) walls, respectively. The encapsulation of PCMs in regular building walls resulted in 11–20% peak heat transfer rate reduction with a PCM concentration of 10%. The reduction in peak heat transfer in SIPs in combination with 10% and 20% PCM were 37% and 62%, respectively. The average reductions in daily heat transfer across the SIPs outfitted with PCMs were 33% and 38% for concentrations of 10% and 20% PCM, respectively. the concentrations were defined in terms of PCM added vs. the weight of the interior siding of the wall integrated PCM in buildings as a thermal barrier and demonstrated the effectiveness of such inclusion. Safer-proposed the idea of using PCMs in transportation application but no results were provided to verify the hypothesis. The use of PCMs in transportation refrigeration systems has attracted far less attention than its building Counterpart.

2.7.3 PCM inside a vehicle's cabin

This paper presents the modeling result 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 released with 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 755g. 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 cabin.

Chapter Three

Chapter Three

Methodology

3.1 Introduction

This chapter is about the methodology and how the experiment was conducted.

First it explores the design of the experiment then we list the different aspects of the experiment.

3.2 Design of the experiment

The objective of the experiment is reducing the temperature inside the cabin of the vehicle using PCM. A container containing a PCM is to be fitted inside the vehicle and several readings were taken.

3.2.1 The vehicle used in the experiment

The vehicle used in this experiment was a TATA mini truck called TATA ACE. Dimensions of the cabin of this vehicle are (1.2m length, 1.5m width.1.8m height)

Figure3 1 Vehicle used in the experiment

3.2.2 PCM used in the experiment

- Polyethylene glycol 600 was used as PCM it has a melting point of 25 degrees Celsius and density of 1.12 g/mL and latent heat of 147 KJ/kg.

The material was poured inside a (50x34x5) mm aluminum container, aluminum was selected for its appealing thermal properties mainly for its high conductivity.

The container was sealed using silicon to prevent any leakage.

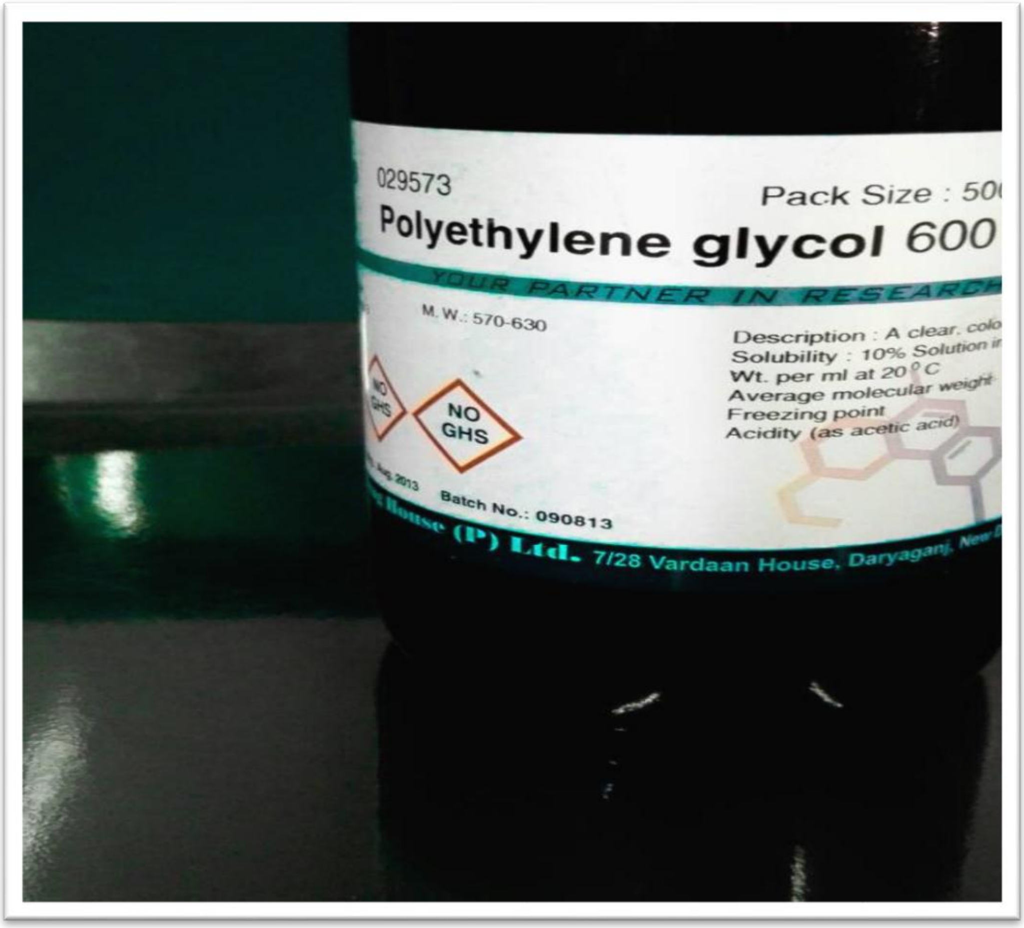

Figure3 2 Polyethylene glycol 600 as PCM

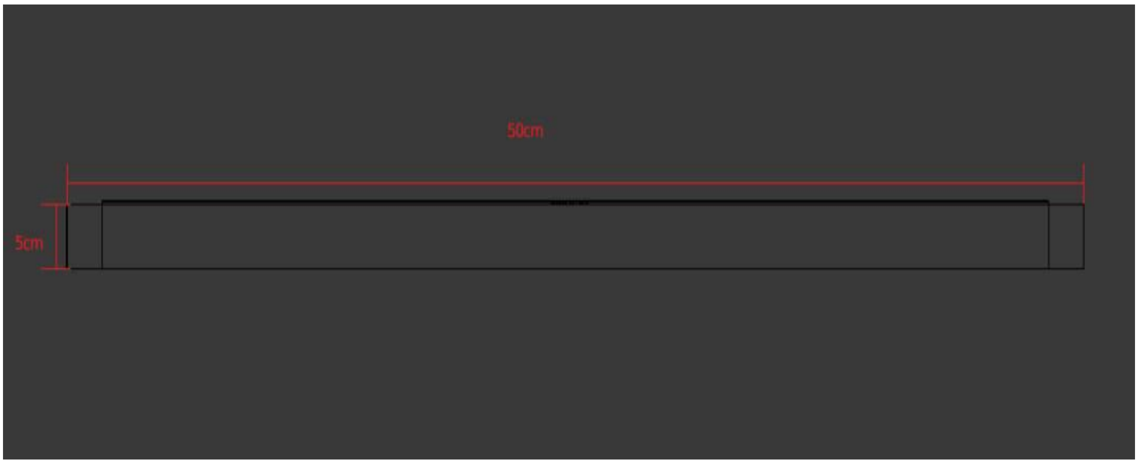

Figure3 3 side view for the container

Figure3 4 side view for the container

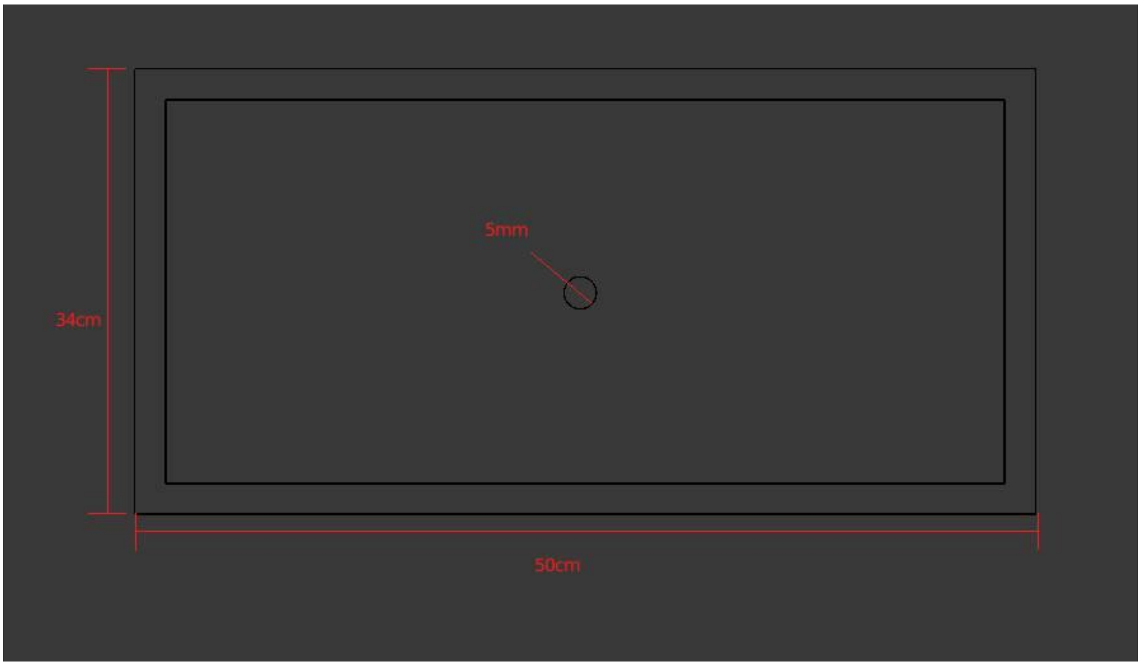

Figure3 5 vertical view for the container

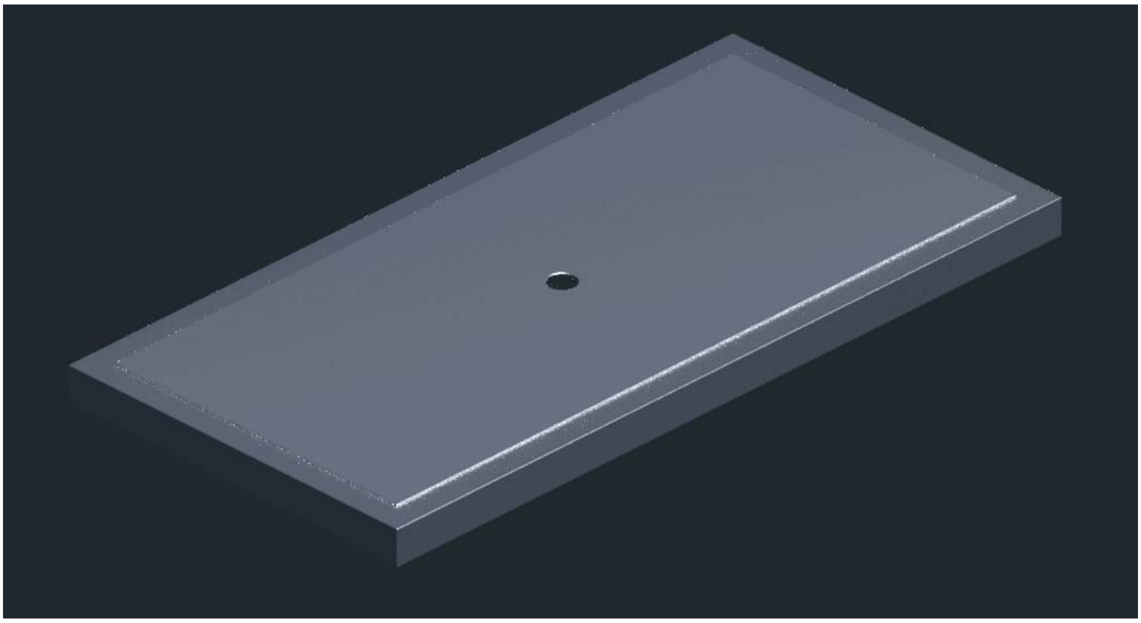

Figure3 6 3D model for the container

3.2.3 Measuring devices

The temperature readings inside and outside the cabin was taken by a thermocouple devise with two sensors one inside the cabin and the other on the outside to measure the surrounding's temperature.

The thermo couple used in this experiment is call K type thermocouple it's one of the most common types of thermocouples. it has range from (-270 up to 1260) degrees Celsius

3.2.3 Process of the experiment

At first data was collected without the use of PCM the temperature inside the car was taken every ten minutes for two hours and the temperature of the surrounding was measured simultaneously by the thermocouple devise starting at 12pm and ending by 2pm in the afternoon and this process was repeated 5 times in a course of five days . In the afternoon the sun is almost vertical and the temperature of the surrounding is at its highest value.

Then the same process was done but this time with the use of PCM and was repeated five times same as before.

Chapter Four

Chapter Four

Results and discussion

4.1 Introduction

In this chapter we will discuss the results and data that were obtained from the experiment conducted on the vehicle using thermal energy storage or PCM .

The results and data will be shown in a diagram form for better comprehension and understanding.

Then data will be discussed and conclusions will be drawn from the data.

The readings were taken in a course of five days for each type (with and without PCM) and then the average was taken and presented in the diagrams.

4.2 Results and discussion

The design and fabrication were completed and data was obtained as discussed in the previous chapter and the data will be shown below

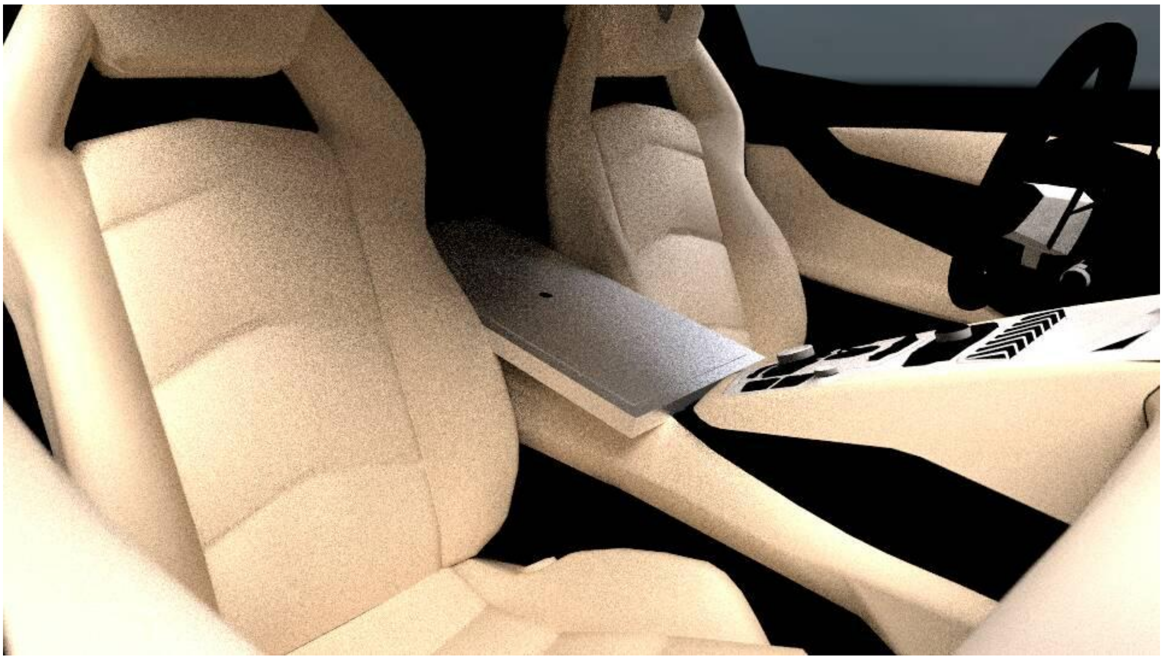

Figure4 1 design for the container inside the cabin

4.2.1 Vehicle without PCM

Figure (4.1) the Y axis represents temperature in degrees Celsius and X axis represents time.it presents the data obtained without the use of PCM

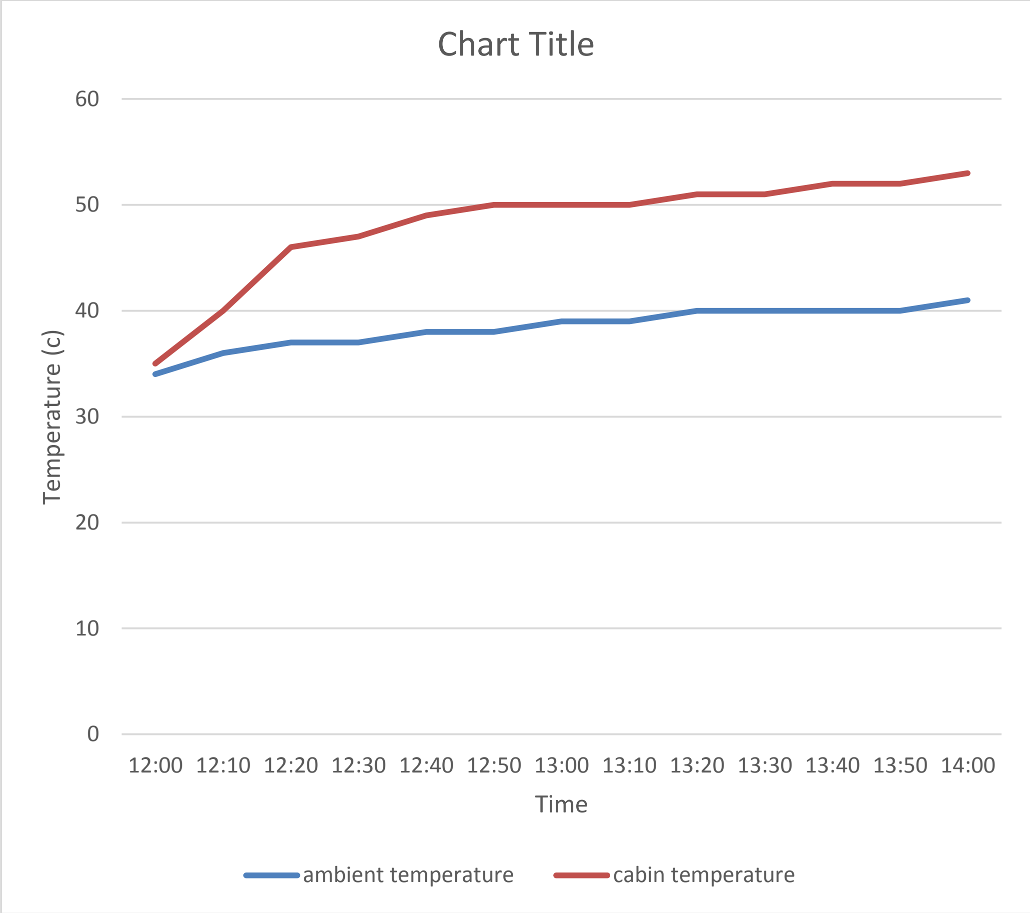

Figure4 2 vehicle without PCM

Shown in the figure 4.2.1 at the beginning of the experiment the temperature of the outside and inside were the same but after a short period time the temperature of the cabin started to rise. At the end of experiment the temperature difference between the inside and the outside rose up to 12 degrees Celsius.

4.2.2 Vehicle with PCM

Shown in figure 4.2.2 the data obtained from the vehicle using thermal energy storage or PCM.

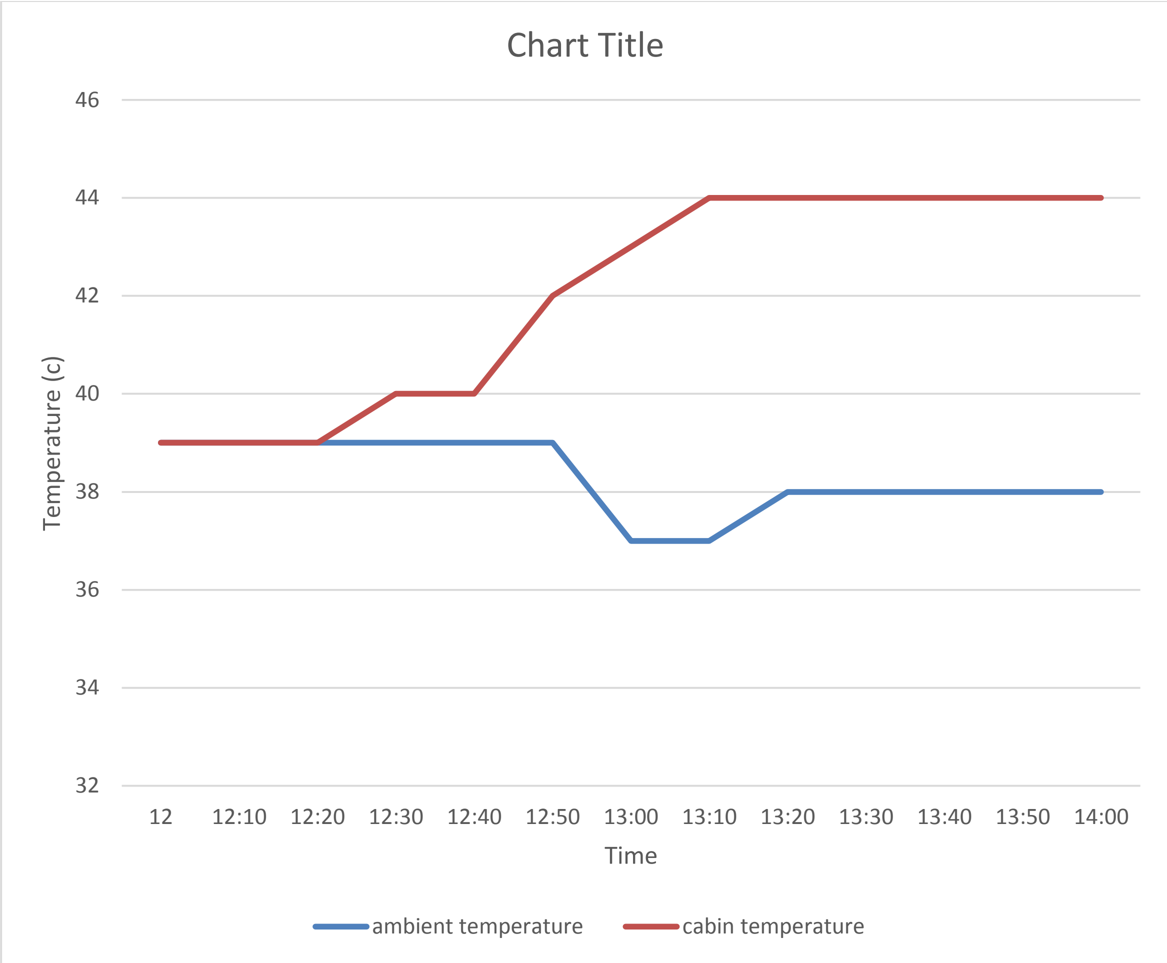

Figure4 3 vehicle with PCM

Shown in the figure above temperatures of the outside and the inside and the inside also started the same but at the end of experiment the temperature difference was only 6 degrees Celsius.

These results show that the use of PCM caused a significant reduction in cabin's temperature which would help reducing fuel costs in air conditioning system of the vehicle.

These data is consistent with the data from previous studies

CHAPTER FIVE

CHAPTER FIVE

Conclusion and recommendations

5.1 Conclusion

The design of the experiment has been constructed to reduce the temperature inside the vehicle’s cabin using thermal energy storage.

During the extreme temperatures of the day a parked vehicle facing direct or indirect solar radiation could reach extreme temperatures.

As seen from the experiment conducted Using thermal energy storage by using PCM could reduce the temperature inside the cabin significantly and by extension reducing cooling load for the AC system which will help reducing fuel consumption.

PCM can also be beneficial in the transport sector especially when the cargo being transported is temperature sensitive such as pharmaceutical items and many other commodities.

5.2 Recommendations

- Choosing a different material with higher melting point (27-30) degrees Celsius. And higher heat capacity for better energy storage.

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