DESIGN AND FABRICATION OF A SOLAR PV & THERMAL HYBRID SYSTEM USING PCM & ITS COOLING PERMORMANCE ANALYSIS

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CERTIFICATE OF RECOMMENDATION

This is certified that the thesis entitled "**Design and Fabrication of a Solar PV & Thermal hybrid System using PCM & its cooling performance analysis**" is a bona fide work carried out by **KOUSIK SENAPATI** under supervision and guidance for partial fulfilment of the requirement for Post Graduate Degree of Master of Technology in Energy & Technology, during the academic session 2018-2019.

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The fore going thesis is hereby approved as a creditable study of a technological subject carried out and presented in manner satisfactory to warrant its acceptance as a pre- requisite to the degree for which it has been submitted. It is understood that by this approval the undersigned persons do not necessarily endorse or approve the thesis only for the purpose for which it has submitted.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as a part of his Master of Technology in Energy Science & Technology studies during academic session 2017- 2019. All the information in this document have been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

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DEDICATED

TO

MY PARENTS,

AND MY TEACHERS

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CHAPTER 1

INTRODUCTION

The fossil fuel supplies of the world is limited and the fuel reserves are getting depleted. We don't know the exact amount of fossil fuel reserved in the world. But the energy demand is increasing day by day. So we can increase the efficiency of the system, rather than burning more fossil fuel.

A better alternative is to reduce the amount of energy wasted during the conversion process. One way is to reuse the thermal waste heat from industrial source using waste heat recovery system, rather than to discharge them in atmosphere. Some renewable energy sources are discussed below.

1.13 Energy Sources

The primary sources of energy in the environment include fuels like coal, oil, natural gas, uranium, and biomass. All primary source fuels except biomass are non- renewable. Primary sources also include renewable sources such as sunlight, wind, moving water, and geothermal energy. It is clear that at some time alternative energy sources will replace the fossil fuels. All such sources depends upon either nuclear energy generation by fission or fusion, or on the sun. There are many forms of renewable energy. Most of these renewable energies depend in one way or another on sunlight. Wind and hydroelectric power are the direct result of differential heating of the Earth's surface which leads to air moving about (wind) and precipitation forming as the air is lifted. Solar energy is the direct conversion of sunlight using panels or collectors. Biomass energy is stored sunlight contained in plants. Other renewable energies that do not depend on sunlight are geothermal energy, which is a result of radioactive decay in the crust combined with the original heat of accreting the Earth, and tidal energy, which is a conversion of gravitational energy.

Solar - This form of energy relies on the nuclear fusion power from the core of the Sun. This energy can be collected and converted in a few different ways. The range is from solar water heating with solar collectors or attic cooling with solar attic fans for domestic use to the complex technologies of direct conversion of sunlight to electrical energy using mirrors and boilers or photovoltaic cells. Unfortunately these are currently insufficient to fully power our modern society.

Wind Power- The movement of the atmosphere is driven by differences of temperature at the Earth's surface due to varying temperatures of the Earth's surface when lit by sunlight. Wind energy can be used to pump water or generate electricity, but requires extensive areal coverage to produce significant amounts of energy.

Hydroelectric energy- This form uses the gravitational potential of elevated water that was lifted from the oceans by sunlight. It is not strictly speaking renewable since all reservoirs eventually fill up and require very expensive excavation to become useful again. At this time, most of the available locations for hydroelectric dams are already used in the developed world.

Biomass – This is the term for energy from plants. Energy in this form is very commonly used throughout the world. Unfortunately the most popular is the burning of trees for cooking and warmth. This process releases copious amounts of carbon dioxide gases into the atmosphere and is a major contributor to unhealthy air in many areas. Some of the more modern forms of biomass energy are methane generation and production of alcohol for automobile fuel and fueling electric power plants.

Hydrogen and fuel cells.- These are also not strictly renewable energy resources but are very abundant in availability and are very low in pollution when utilized. Hydrogen can be burned as a fuel, typically in a vehicle, with only water as the combustion product. This clean burning fuel can mean a significant reduction of pollution in cities. Or the hydrogen can be used in fuel cells, which are similar to batteries, to power an electric motor. In either case significant production of hydrogen requires abundant power. Due to the need for energy to produce the initial hydrogen gas, the result is the relocation of pollution from the cities to the power plants. There are several promising methods to produce hydrogen, such as solar power, that may alter this picture drastically.

Geothermal power- Energy left over from the original accretion of the planet and augmented by heat from radioactive decay seeps out slowly everywhere, everyday. In certain areas the geothermal gradient (increase in temperature with depth) is high enough to exploit to generate electricity. This possibility is limited to a few locations on Earth and many technical problems exist that limit its utility. Another form of geothermal energy is Earth energy, a result of the heat storage in the Earth's surface. Soil everywhere tends to stay at a relatively constant temperature, the yearly average, and can be used with heat pumps to heat a building in winter and cool a building in summer. This form of energy can lessen the need for other power to maintain comfortable temperatures in buildings, but cannot be used to produce electricity.

Other forms of energy- Energy from tides, the oceans and hot hydrogen fusion are other forms that can be used to generate electricity. Each of these is discussed in some detail with the final result being that each suffers from one or another significant drawback and cannot be relied upon at this time to solve the upcoming energy crunch.

Here we have discussed various types of renewable energy sources. This sources has so many limitation such as solar PV can’t work in the night or adverse weather situation. But it is more reliable energy source than other renewable energy sources. It has the potential to manage the global energy crisis.

1.2 Renewable Energy scenario in India

India is one of the countries with the largest production of energy from renewable sources. In the electricity sector, renewable energy account for 34.6% of the total installed power capacity. Large hydro installed capacity was 45.399 GW as of 31 March 2019, contributing to 13% of the total power capacity.[1] The remaining renewable energy sources accounted for 22% of the total installed power capacity (77.641 GW) as of 31 March 2019.

Wind power capacity was 36,625 MW as of 31 March 2019, making India the fourth-largest wind power producer in the world. The country has a strong manufacturing base in wind power with 20 manufactures of 53 different wind turbine models of international quality up to 3 MW in size with exports to Europe, the United States and other countries.[3] Wind or Solar PV paired with four-hour battery storage systems is already cost competitive, without subsidy, as a source of dis patchable generation compared with new coal and new gas plants in India Total renewable energy which includes large hydro with pumped storage generation, is nearly 17.5% of total utility electricity generation in India during the year 2017-18. Solar, wind and run of the river hydro being must run power generation and environment friendly, base load coal fired power is transforming in to load following power generation. In addition, renewable peaking hydro power capacity also caters peak load demand on daily basis.

Source	**2014- 15**	**2015-16**	**2016-17**	**2017-18**	**2018-19**
Large Hydro	129244	121377	122313	126134	135040
Small Hydro	8060	8355	7673	5056	8703
Solar	4600	7450	12086	25871	39268
Wind	28214	28604	46011	52666	62036
Bio mass	14944	16681	14159	15252	16325
Other	414	269	213	358	425
Total	**191025**	**187158**	**204182**	**227973**	**261797**
Total utility power	1105446	1168359	1236392	1302904	1371517
% Renewable power	17.28%	16.02%	16.52%	17.50%	19.1%

Figure 1.1 Year wise renewable energy generation in India (source MNRE)

1.3 Solar Energy scenario in India

With about 300 clear and sunny days in a year, the calculated solar energy incidence on India's land area is about 5000 trillion kilowatt-hours (kWh) per year (or 5 EWh /yr). The solar energy available in a single year exceeds the possible energy output of all of the fossil fuel energy reserves in India. The daily average solar-power-plant generation capacity in India is 0.20 kWh per m2 of used land area, equivalent to 1400–1800 peak (rated) capacity operating hours in a year with available, commercially-proven technology. Solar power in India is a fast developing industry. The country's solar installed capacity reached 28.18 GW as of 31 March 2019. The Indian government had an initial target of 20 GW capacity for 2022, which was achieved four years ahead of schedule. India expanded its solar-generation capacity 8 times from 2,650 MW on 26 May 2014 to over 20 GW as on 31 January 2018. The country added 3 GW of solar capacity in 2015-2016, 5 GW in 2016-2017 and over 10 GW in 2017-2018, with the average current price of solar electricity dropping to 18% below the average price of its coal-fired counterpart.

Year	Installed capacity	Annual growth (MW)	Annual growth (%)
2010	161 MW	N/A	N/A
2011	461 MW	300 MW	186.34%
2012	1205 MW	744 MW	161.39%
2013	2319 MW	1114 MW	92.45%
2014	2632 MW	313 MW	13.50%
2015	3744 MW	1112 MW	42.25%
2016	6762.85 MW	3018.85 MW	80.63%
2017	12288.83 MW	5525.98 MW	81.71%
2018	21651.48 MW	9362.65 MW	76.19%
2019	28180.71 MW	6529.23 MW	30.16%

Figure 1.2 Growth of the utilities installed solar capacity in India (source MNRE)

1.4 Solar Energy

Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis.

It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air.

The surface of the sun is at an effective temperature of about 6000K. The sun is effectively a continuous fusion reactor. Its constituents are gases retained by gravitational forces. The energy is produced in the interior of the sun, at estimated temperatures of 8×10^6 to 40×10^6 K.

The total energy intensity of extra- terrestrial solar radiation, measured just outside the earth's atmosphere and integrated over the entire solar spectrum, is called the solar constant.

Solar radiation is considerably altered in its passage through the earth's atmosphere by absorption and scattering. The factors which affect the availability of solar energy are given below.

- Time of the day
- Time of the Year
- Geographical Location
- Atmospheric Condition
- Solar Radiation
- Solar Panel Internal Properties

1.4.1 Why Solar?

Solar Energy can be utilized for varied applications. So the answer to “Why Solar” question can be sought from two different perspectives: utilizing solar energy for grid-interactive and off-grid (including captive) power generation.

1. Solar for grid connected electricity:

Grid interactive solar energy is derived from solar photovoltaic cells and CSP Plants on a large scale. The grid connection is chosen due to following reasons:

• Solar Energy is available throughout the day which is the peak load demand time.

• Solar energy conversion equipment have longer life and need lesser maintenance and hence provide higher energy infrastructure security.

• Low running costs & grid tie-up capital returns (Net Metering).

• Unlike conventional thermal power generation from coal, they do not cause pollution and generate clean power.

• Abundance of free solar energy throughout all parts of world (although gradually decreasing from equatorial, tropical, sub-tropical and polar regions). Can be utilized almost everywhere.

2. Solar for off-grid solutions:

While, the areas with easier grid access are utilizing grid connectivity, the places where utility power is scant or too expensive to bring, have no choice but to opt for their own generation. They generate power from a diverse range of small local generators using both fossil fuels (diesel, gas) and locally available renewable energy technologies (solar PV, wind, small hydro, biomass, etc.) with or without its own storage (batteries). This is known as off-grid electricity. Remote power systems are installed for the following reasons:

• Desire to use renewable - environmentally safe, pollution free.

• Combining various generating options available- hybrid power generation.

• Desire for independence from the unreliable, fault prone and interrupted grid connection.

• Available storage and back-up options.

• No overhead wires- no transmission loss.

• Varied applications and products: Lighting, Communication Systems, Cooking, Heating, Pumping, Small scale industry utilization etc.

1.4.2 Technology

1.4.2.1 Solar Photovoltaic

Solar photovoltaic (SPV) cells convert solar radiation (sunlight) into electricity. A solar cell is a semi-conducting device made of silicon and/or other materials, which, when exposed to sunlight, generates electricity. Solar cells are connected in series and parallel combinations to form modules that provide the required power.

Crystalline Silicon solar cells (C-Si): Monocrystalline and Polycrystalline

Thin-film solar cells: Amorphous Silicon Solar cells (A-Si), CIGS, CdTe

PV modules are manufactured by assembling the solar cells after stringing, tabbing and providing other interconnections.

1.4.2.2 Solar Thermal

Solar Thermal Power systems, also known as Concentrating Solar Power systems, use concentrated solar radiation as a high temperature energy source to produce electricity using thermal route. High temperature solar energy collectors are basically of three types:

Parabolic trough system: at the receiver can reach 400° C and produce steam for generating electricity.

Power tower system: The reflected rays of the sun are always aimed at the receiver, where temperatures well above 1000° C can be reached.

Parabolic dish systems: Parabolic dish systems can reach 1000° C at the receiver, and achieve the highest efficiencies for converting solar energy to electricity.

1.5 Solar Cell

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon.[1] It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Individual solar cell devices can be combined to form modules, otherwise known as solar panels. In basic terms a single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts. Solar cells are building blocks of photovoltaic modules, otherwise known as solar panels.

Solar cells are described as being photovoltaic, irrespective of whether the source is sunlight or an artificial light. They are used as a photodetector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity.

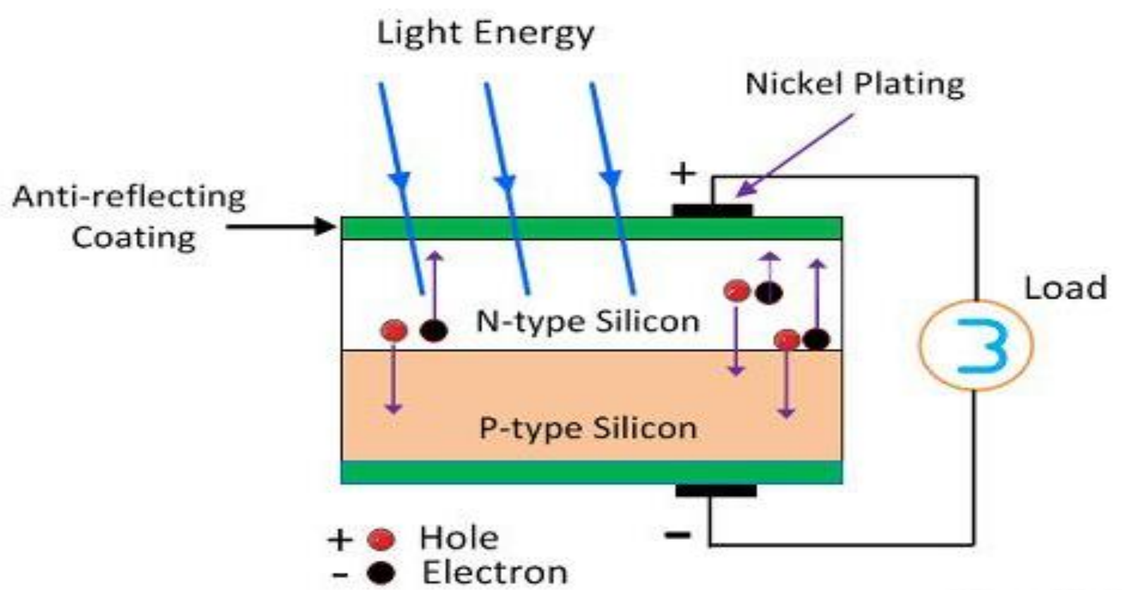


Figure 1.3 Solar cell diagram[41]

The operation of a photovoltaic (PV) cell requires three basic attributes:

• The absorption of light, generating either electron-hole pairs or excitons.

• The separation of charge carriers of opposite types.

• The separate extraction of those carriers to an external circuit.

1.6 Working Principle

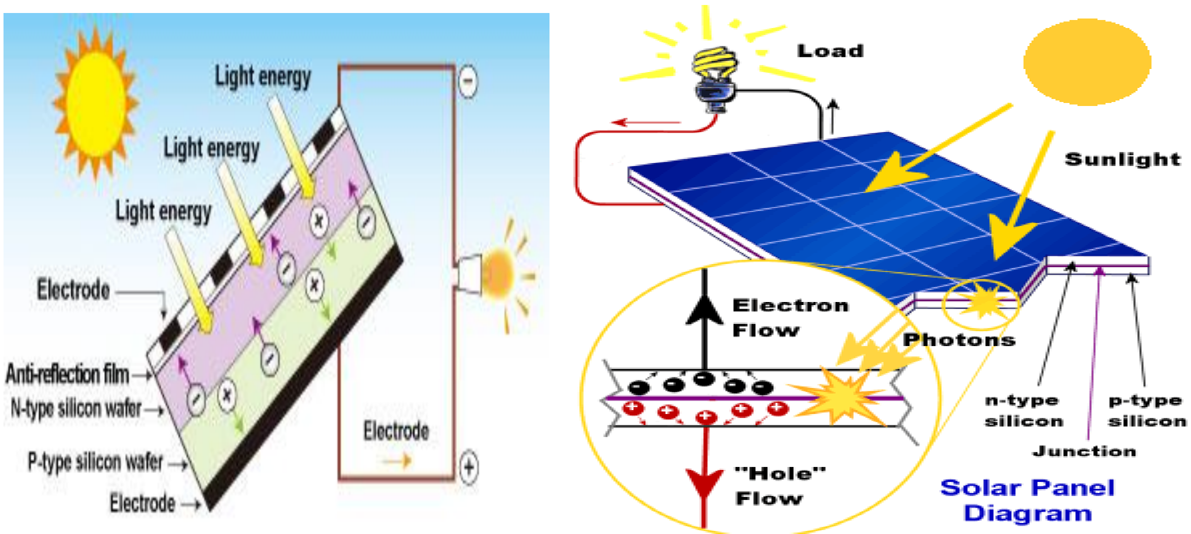


Figure 1.4 Solar cell working principle[42]

When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction. Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction.

Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction. As the concentration of electrons becomes higher in one side, i.e. n-type side of the junction and concentration of holes becomes more in another side, i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it.

1.7 Performance Parameter of Solar Photovoltaic Cell

Before starting our project work it is essential to know the ratings of a solar panel. With the help of these parameters we can easily calculate how efficiently a solar cell can convert the light to electricity.

1.7.1 Short Circuit Current (I_{SC}) of Solar Cell

The maximum current that a solar cell can deliver without harming its own constriction. It is measured by short circuiting the terminals of the cell at most optimized condition of the cell for producing maximum output. The term optimized condition I used because for fixed exposed cell surface the rate of production of current in a solar cell also depends upon the intensity of light and the angle at which the light falls on the cell. As the current production also depends upon the surface area of the cell exposed to light, it is better to express maximum current density instead maximum current. Maximum current density or short circuit current density rating is nothing but ration of maximum or short circuit current to exposed surface area of the cell.

$$J_{sc} = \frac{I_{sc}}{A}$$

Where, I_{SC} is short circuit current, J_{SC} maximum current density and A is the area of solar cell.

1.7.2 Open Circuit Voltage (V_{OC}) of Solar Cell

It is measured by measuring voltage across the terminals of the cell when no load is connected to the cell. This voltage depends upon the techniques of manufacturing and temperature but not fairly on the intensity of light and area of exposed surface. Normally open circuit voltage of solar cell nearly equal to 0.5 to 0.6 volt. It is normally denoted by $V_{OC.}$

1.7.3 Maximum Power Point (P_m) of Solar Cell

The maximum electrical power one solar cell can deliver at its standard test condition. If we draw the v-i characteristics of a solar cell maximum power will occur at the bend point of the characteristic curve. It is shown in the v-i characteristics of solar cell by $P_{m.}$

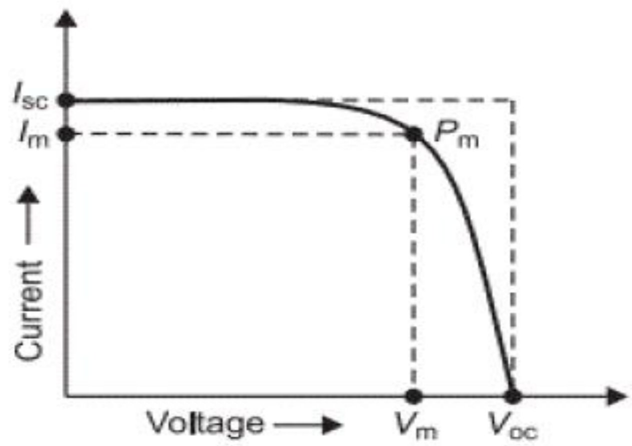


Figure 1.5 V- I characteristics of a solar cell[46]

1.7.4 Current at Maximum Power Point (I_m)

The current at which maximum power occurs. Current at Maximum Power Point is shown in the V-I characteristics of solar cell by I_m.

1.7.5 Voltage at Maximum Power Point (V_m)

The voltage at which maximum power occurs. Voltage at Maximum Power Point is shown in the v-i characteristics of solar cell by V_m.

1.7.6 Fill Factor (FF) of Solar Cell

The ratio between product of current and voltage at maximum power point to the product of short circuit current and open circuit voltage of the solar cell. For a good panel FF is varying between 0.7 and 0.8 and for bad panel it may be 0.4.

$$Fill\ Factor = \frac{P_m}{I_{sc} \times V_{oc}}$$

1.7.7 Efficiency of Solar Cell

It is defined as the ratio of maximum electrical power output to the radiation power input to the cell and it is expressed in percentage. It is considered that the radiation power on the earth is about 1000 watt/square metre hence if the exposed surface area of the cell is A then total radiation power on the cell will be 1000 A watts. Hence the efficiency of a solar cell may be expressed as

$$Efficiency(\eta) = \frac{P_m}{P_{in}} \approx \frac{P_m}{1000A}$$

1.8 The Factors Affecting the Performance of Solar Cell:

1.8.1 Module temperature (T_m)

There are various ambient conditions that affect the output of a PV power system. These factors should be taken into consideration so that the customer has realistic expectations of overall system output. Module temperature is a parameter that has great influence in the behavior of a PV system, as it modifies system efficiency and output energy. As temperature increases, the band gap of the semiconductor shrinks, and the open circuit voltage Voc decreases following the p–n junction voltage temperature dependency of seen in the diode factor q/kT. PV cells therefore have a negative temperature coefficient of Voc. Moreover, a lower output power results given the same photocurrent Iph because the charge carriers are liberated at a lower potential [7, 9]. As temperature increases, again the band gap of the intrinsic semiconductor shrinks meaning more incident energy is absorbed because a greater percentage of the incident light has enough energy to raise charge carriers from the valence band to the conduction band. A larger photocurrent results; therefore, Isc increases for a given insulation, and PV cells have a positive temperature coefficient of Isc. The influences of temperature and irradiance on the cell characteristics are shown in Fig.

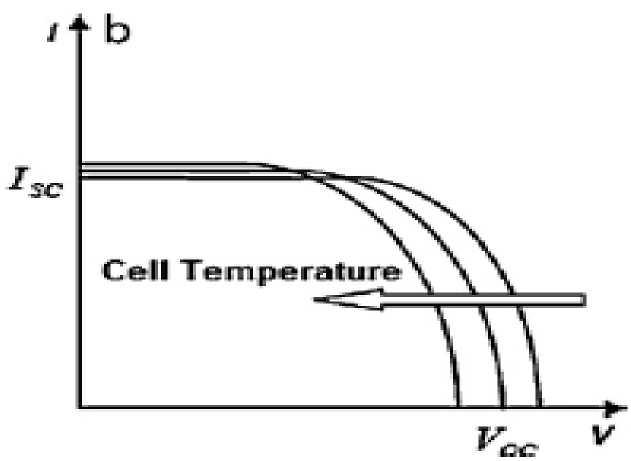


Figure 1.6 Effect of cell temperature on characteristics of solar cell [46]

From the figure the open circuit voltage increases logarithmically by increasing the solar radiation, whereas the short circuit current increases linearly. The influence of the cell temperature on the cell characteristics is shown in Fig. 1.6.

The main effect of the increase in cell temperature is on open circuit voltage, which decreases linearly with the cell temperature; thus the cell efficiency drops. As can be seen, the short circuit current increases slightly with the increase of the cell temperature. However the current increases is quite small in the operating temperature range of 25^{o}C to 50^{o}C and can generally be ignored.

The cell voltage decreases by approximately 2.2mV/^{o}C rise in its operating temperature depending on the silicon resistivity used.

1.8.2 Irradiation

Terrestrial solar cells operating outdoors would experience varying magnitudes of solar irradiance, which is also known as insolation or incident solar radiation. Because of the non-linearity in the input output relationship of a solar cell, the effect of varying insolation on different solar cell parameters will be different.

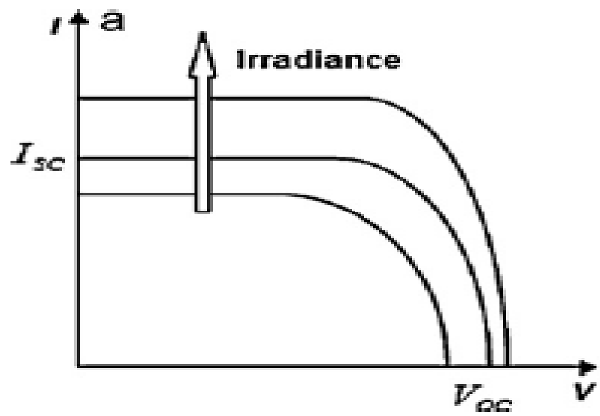


Figure 1.7 Effects of Irradiation on PV cell characteristics [46]

1.8.3 Shading Effect

Shading has a negative impact on the performance of the PV system because shade blocks direct insolation from the panels. A small amount of shade has a large impact on the output of a solar panel, as it changes the flow of electricity through the panel. To protect panel from such adverse effects, a bypass diode is used. The effect is more prominent in crystalline silicon solar panels. Amorphous silicon panels are less affected by shading.

1.8.4 Effects of PV technology types

Many types of PV cells are available today. This section gives details on the types of the PV cells that are currently in the manufacturing, research and development stage.

Monocrystalline silicon cells: These cells are made from pure monocrystalline silicon. In these cells, the silicon has a single continuous crystal lattice structure with almost no defects or impurities. The main advantage of monocrystalline cells is their high efficiency, which is typically around 15%. The disadvantage of these cells is that a complicated manufacturing process is required to produce monocrystalline silicon, which results in slightly higher costs than those of other technologies. Crystalline silicon cell technology is well established and the PV modules have long lifetimes (20 years or more).

Multi crystalline silicon cells: A less expensive material, Multi-crystalline silicon, by passes the expensive and energy-intensive crystal growth process. Multi-crystalline cells are produced using numerous grains of monocrystalline silicon. In the manufacturing process, molten Multi-crystalline silicon is cast into ingots, which are subsequently cut into very thin wafers and assembled into complete cells. Multi-crystalline cells are cheaper to produce than monocrystalline ones because of the simpler manufacturing process required. They are, however, slightly less efficient, with average efficiencies being around 12% .

Amorphous silicon cells: Generally, the main difference between these cells and the previous ones mentioned above is that, instead of the crystalline structure, amorphous silicon cells are composed of silicon atoms in a thin homogenous layer. Additionally, amorphous silicon absorbs light more effectively than crystalline silicon, which leads to thinner cells, also known as a thin film PV technology. Thin film solar has approximately 15% market share; the other 85% is crystalline silicon. The greatest advantage of these cells is that amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible. Their disadvantage is the low efficiency, which is on the order of 6%.

Other types of cells: In addition to the above types, a number of other promising materials, such as CdTe and copper-indium selenide (CuInSe), are used today for PV cells. The main trends today concern the use of polymer and organic PV cells. The attraction of these technologies is that they potentially offer fast production at low cost in comparison to crystalline silicon technologies, yet they typically have lower efficiencies (around 4%), and despite the demonstration of operational lifetimes and dark stabilities under inert conditions for thousands of hours, they suffer from stability and degradation problems [14]. Each semiconducting material has its own properties which make it more or less suitable for use in a PV cell. One of these properties is the so-called band gap, which is the energy gap an electron must cross in order to be promoted from the valence band to the conduction band [7]. In the literature studies, it has been shown that silicon, with its bandgap of 1.12 eV, is not optimal. Materials with bandgaps nearer to 1.5 eV, such as GaAs and CdTe, have higher theoretical efficiencies.

1.8.5 The Effect of Time of Day and Year on Panel Performance:

The intensity of solar radiation varies significantly over the course of a year ranging from no solar radiation during the polar winter to a maximum of 350 to 400 watts per square meter (W/m^2) in the summer. Over the course of a day, the sun's angle above the horizon (solar altitude) influences the intensity of solar radiation; the noon sun is more intense than the rising or setting sun. The maximum altitude of the sun depends on time of year and latitude. However, during the polar winter the sun is below the horizon for 24 hours, and there is no solar radiation, while at midsummer the sun changes little in altitude over the course of the day.

1.8.6 The Positioning of PV Panels:

Solar Panel Orientation refers to our azimuth setting. Most of the energy coming from the sun arrives in straight line. A solar panel or solar array will capture more energy if it is facing directly at the sun, perpendicular to the straight line between the position of the panels installation and the sun. Then we need to have the solar panel turned towards the terrestrial equator (either facing south in the northern hemisphere, or north in the southern hemisphere) so that during the day its orientation allows the panel to catch the greatest possible amount of solar radiation possible.

There are different ways of achieving the required solar panel orientation. We could just point the PV panel or array due south or north using a compass, find the central angle between the summer and winter azimuth settings or more accurately position the panels relative to the central solar noon.

The solar noon refers to the highest position of the sun as it arcs across the sky and is different to 12:00 o'clock noon or midday as a measurement of time. Generally the solar noon occurs between 12:00 o'clock and 14:00 o'clock depending upon the location.

Solar Panel Tilt- Solar Panel Tilt refers to our zenith or elevation setting. Once the best azimuth position is found, the next parameter that is key to producing the most solar electricity is the elevation of the PV panel. For a fixed solar installation, it is preferred that the PV panels are installed with a centralized tilt angle representing the vernal equinox, or the autumnal equinox.

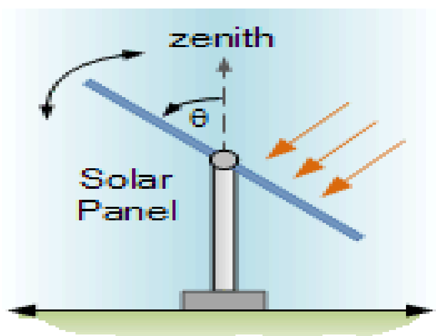


Figure 1.8 Positioning of Solar panel

Then a misalignment of up to 15^{o} either positive or negative makes very little difference to a photovoltaic panels output. Ideally, solar panels should be located where they will receive as much sunlight as possible, averaged out during the course of the day and the course of the year.

The solar panel orientation and tilt of a fixed solar PV panel or array can also be optimized for a particular month or season during the year. For example, a solar power system might be designed to produce maximum power output only in the winter months in order to reduce peak electricity costs thus, the system should be installed so that the optimum solar panel orientation and tilt occurs for the maximum winter power output.

1.8.7 Dirt/Dust

Dirt/dust can accumulated on the PV module surface, blocking some of the sunlight and reducing efficiency. An effective way of improving efficiency of a PV module is cleaning the dust of PV module.

Here we have discussed so many factors that affects the performance of a solar photovoltaic system. But we can reduce this adverse effects up to a certain limit by designing proper PV & T hybrid system. Our aim of present project is designing such a hybrid system, is discussed below.

1.9 Aim & Objective of Present Investigation

• Keeping these considerations in view, the objectives of the present research have aimed as follows:

• To design and fabrication of a low cost highly effective heat exchanger for waste heat recovery.

• Selection of proper Phase Changing Material in suitable thermal range.

•To design PCM based cooling system for cooling the solar cell in order to increase its electrical efficiency and also to extract the waste heat.

•Selection of data acquisition device.

• To analysis the effects, implementation strategies, and specific strengths and weaknesses associated with each approach.

• To develop a model to simulate the cooling and heat transfer in Photovoltaic panel for proposed cooling technique for the PV panel.

1.10 Scope of Present Investigation

In order to improve electrical performance, to recover the waste heat, and to extend the lifetime of solar PV panels, an evolutionary cooling technique using Phase Changing Material is proposed here.

The SaVE OM 37(Phase changing material) may reduce the operating temperature of the solar PV panels and water circulating in copper tube inside the heat exchanger can recover the waste heat. As a result electrical performance of the solar PV panels should be improved. In addition the cooling results in extending the lifetime of the solar PV panels.

1.11 Overview of Thesis

The present thesis is divided into seven parts. Different types of renewable energy resources, energy scenario of India, expansion of renewable energy, solar energy, and the factors effects its performance, aim, objective, scope of present work all are discussed in the first chapter. Next chapter covers reviews of previous work carried out by various researchers in the field of building cooling and PV cells cooling using Phase changing material. Here also described gap of knowledge, possible solution of cooling techniques. Chapter three covers brief description of general theory of cooling, needs of cooling and types of cooling has been provided. Chapter four provides in brief about experimental methodology, experimental setup and data acquisition system which adopted for the present work. Different types of Phase changing material and phase changing material used in this project is discussed in chapter five. In chapter six result obtained in present work along with discussion is provided. The concluding remarks and future scope for further study have been described in chapter seven.

1.12 Conclusion

Energy demand is increasing day by day and the stock of fossil fuel is reducing. As a result of this we have use more and more renewable source of energy. Solar energy has the potential to meet the requirement. In the first chapter basic knowledge of renewable energy, solar energy, principle of solar cell and its performance parameter has been discussed. The study regarding review of the earlier works has been discussed in the next chapter.

CHAPTER 2

REVIEW OF EARLIER WORK

2.1 Introduction

Basic of renewable energy, solar photovoltaic cell and its parameter has been discussed in the previous chapter. The stock of fossil fuel is limited and the fuel reserves are getting depleted. A better alternative is to reduce the amount of energy wasted by increasing the efficiency of the system. The potential of solar energy to solve the energy crisis has also been discussed in the previous chapter.

In this chapter a literature review is a search and evaluation of the available literature in solar photovoltaic cooling technology & application of Phase changing material for various cooling application. A literature review has four main objectives

• It surveys the literature in solar photovoltaic cooling technology and application of phase changing material area of study.

• It synthesizes the information in that literature into a summary.

• It analyses the information gathered by identifying gaps in current knowledge by showing limitations of theories and points of view and by formulating areas for further research and reviewing areas of controversy.

• It presented the literature in an organized way.

Literatures reviews have been given in-depth grasp of solar photovoltaic cooling techniques; and have also been understudied where your own research fits into and adds to an existing body of agreed knowledge.

2.2 Literature Survey

Erlbeck et al. [11] (2018) worked on adjustment of thermal behavior by changing the shape of PCM inclusions in concrete blocks. Most installed phase change materials in real applications are typically spherical microencapsulated paraffin. However, salt hydrates can be a cheap alternative when combined with a suitable macro encapsulation. Such macro encapsulation enables the installation of different shapes and positions within the building material. As a conventional application in the construction sector, direct PCM inclusion through encapsulation in the building materials is assumed to be the most reasonable method. The easiest possible way for this is to use concrete blocks, stone, or wood as the materials. A 5mm thick PCM compound wall equals an 8 cm thick concrete wall in terms of energy storage, and a 1.5 cm thick gypsum board with PCM can store five-times the thermal energy than a usual gypsum board, and the same amount as a 12 cm thick wall. Prior to the experiments, PCM was prepared using deionized water, $MgCl_2 \cdot 6H_2O$, and $CaCl_2 \cdot 2H_2O$, which were purchased from common fertilizer manufacturers. For all measurements, the PCM was a mixture of 50 wt% $MgCl_2 \cdot 6H_2O$ and 50 wt% $CaCl_2 \cdot 6H_2O$ with a melting temperature of approximately 21 °C. The thermal characteristics of the used PCM. The entire system was constructed to measure two different concrete blocks together using one reference block. Heating of the blocks was realized using three infrared radiators each with a power of 500W. Temperature measurements within the PCM, which is encased in a concrete block, were realized using negative temperature coefficient (NTC) thermistors, and the temperature of the reference was measured using a PT100 resistance thermometer. LabVIEW was programmed to either heat or cool the blocks dependent on their actual temperature. A test typically started with cold concrete blocks with crystallized PCM. The temperatures limit for the change of heating to cooling and vice versa were manually selected as 35 °C and 17 °C, respectively, which ensured a completely melted or crystallized PCM. Including the reference block, ten samples were tested for their thermal behavior. This includes two blocks with PCM in a cuboid shape, two in a cylindrical shape, four in a plate shape, and one in a spherical shape. To interpret and compare all the results, MATLAB® was used as the mathematical program. A usual spreadsheet program would be unable to handle the amount of data or generate balancing functions of such high order. Overall, the results show that the PCM mass needs to be adjusted to the local conditions to ensure maximum effectiveness. Otherwise, the additional PCM would not melt completely, lowering the economic impact and unnecessarily increasing the inner temperature of the room. Measurements of the plate shaped PCM packages Plates1 and Plates2 show a small increase in melting time compared to the cuboid samples. Thermal shading thereby describes the isolation of individual PCM elements from the heat source by elements with a lower heat conductivity (PCM) than the surrounding material (concrete) and thus causes a lower heat flux and longer heating period. Overall, it can be said that, by adjusting the design and positions of the PCM packages, the requirements of the local conditions can be successfully achieved. However, the temperature of the concrete block cannot rise until the whole PCM mass is melted, shifts of maximum temperatures of the samples are due to different melting times and specimen distributions within the concrete block. Depending on the local conditions, the requirements can differ in the sense of necessary heat storage effect. Changing the design of a PCM package included in a concrete block generates opportunities to react flexibly to the particular demands, and to optimize the thermal behavior without adding more PCM mass, which increases the costs or decreases the stability of a concrete block. Plate-shaped PCM packages show different thermal behaviors depending on the position, thickness, and orientation of the PCM packages. A thin PCM layer combined with a set up position of the plate shows the best results for crystallization and melting. Generating a thermal shading effect by positioning a PCM package flat into the block one above another increases the melting and crystallization time.

Reza Barzin et al. [12] (2015) studied Application of PCM energy storage in combination with night ventilation for space cooling. In recent years, with dramatic increases in energy consumption in developed and developing countries, the shortage of energy sources and environmental issues has become increasingly important. The building sector is responsible for almost 40% of energy consumption in Europe and 36% worldwide. To reduce energy consumption and to assist with the smoothing of diurnal variation in energy demand, energy-efficient buildings have gained much attention since the 1970s. These days, lightweight buildings are becoming more popular due to their ease of construction and architectural flexibility for retrofitting purposes. However, having a low thermal mass is the main disadvantage of these buildings. External cooling, heating and solar heating loads largely affect their interior temperature. The field tests were performed using two identical fully instrumented test huts with interior dimensions of 2.4 *2.4*2.4 m and designed to operate independently. The first, hut referred to as ''Hut 1,'' is used as the base case for all experiment throughout this study and has interior walls and ceiling finished with ordinary 13 mm thick gypsum boards. In second hut, referred to as ''Hut 2,'' the 13 mm gypsum boards were replaced with PCM-impregnated gypsum boards. Imbibing or direct immersion technique was used to impregnate gypsum boards. In order to impregnate the gypsum boards, two metal trays with dimensions of 0.9 * 0.9 *0.15 m and 0.7 *0.7 *0.09 m were used. After reaching steady temperature the boards were immersed in the molten PCM one by one, each for a period of 10 min. A Compact RIO was used as the control system in each hut to acquire all the necessary data, process them and send corrective commands to the AC unit or ventilation fan. Throughout this study, the control system operates the AC unit. the controller receives the room temperature data and uses the AC unit to keep the room temperature within the low peak temperature range. If the OP rises above the PC, the controller switches to the ''Discharge mode'' in which the controller uses a higher temperature range of 24 and 26 C, referred to as ''high price temperature range'' to reduce cooling load and also allows the encapsulated PCM to absorb heat during this period. The 24 C and 26 C are referred to as ''high price lower constraint'' or HPL and ''high price upper constraint'', or HPU respectively. In order to provide night ventilation, a 20W fan was installed on a 0.25 * 0.25 m opening at the bottom of the entrance door of Hut 2 to blow outdoor air into the hut (with nominal flow rate of 300 m3/h) during the night period as required. The control system automatically operates the ventilation fan and outside the ventilation hours it is fully closed. As demonstrated by numerous research studies, successful application of PCM in buildings can produce savings in energy and electricity costs. However, the above analysis showed that the improper use of PCM could lead to higher power consumption instead. Application of weather forecasts in the control system plays a critical role in electricity saving. However, weather forecast data suggested very little cooling demand in the following day and consequently the controller decided not to use the AC unit. buildings were experimentally tested using two identical test huts at Tamaki Campus, University of Auckland. The experimental results showed that, if PCM is not used with proper control strategy, it may lead to an increase in the air-conditioning energy required. In order for the PCM to work efficiently a combination of ''night ventilation'' and ''free cooling'' method should be applied in which low temperature outdoor air at night is used to charge the PCM inside the building. Using this method to charge the PCM with coolness instead of using AC has significantly improved energy saving. A combination of the proposed method with weather forecast data resulted in an impressive electricity saving of 73% over a one-week period.

A.E. Kabeel et al. [13] (2018) did some research on Comparative study on the solar still performance utilizing different PCM. In the present work, a new theoretical study involving comparative investigation among different PCMs on the performance of conventional solar still has been performed. The most used organic and inorganic PCMs complete with their specified thermos-physical properties with the melting temperature as the main effective properties are studied. The solar still productivity has been improved via different methods. The solar still is represented as an energy storage system for water desalination. Therefore, the PCM could be an effective addition to the solar still storage capacity. In the present work, theoretical performance comparison of conventional solar still using different phase change materials (PCM) as a thermal storage material is performed to obtain the best one. Eight different organic PCMs and the most three used inorganic PCMs are compared. The comparison is based on three objectives, which are solar still productivity, payback period and cost of producing one litre. The present model is solved instantaneously via the energy balance of the conventional solar still components. Many trials have been executed theoretically to evaluate the solar insolation and ambient temperature values based on the geographical location. However, in the present study the actual data for the daily solar radiation and the outside temperature are taken according to the experimental measured data. The measured experiment data are in different days from 9 am to 8 pm in July to August 2016 at the Faculty of Engineering, Tanta city, Egypt. The distilled water cost is influenced by many factors. Fabrication, maintenance, operating costs and the feed water cost are the parameters affecting the payback period of the system. Cost of the distilled water per litre, (litre market cost, LMC), is taken as 0.357$,which is the available local market price for one litre of water. The advantage of the phase change material as a heat storage system is the phase change zone (latent heat). The PCM temperature rise during the transportation from solid to liquid may be small while the storage energy is very large. This is due to the fixation of the melting temperature in the phase change zone. The main parameter describes the performance of the solar still is the daily efficiency. The daily efficiency represents the ratio between the required heat for the condensation (or evaporation) of the product water (Qevap) to the daily average solar radiation (I) at the given area(A). Different PCMs involving organic and inorganic materials in conventional solar still will be different. The thickness effect of the PCM on the still performance also will be presented. The results include the productivity, the cost of unit amount of distilled water and the paypack period. The daily productivity will be estimated from the hourly yield of the fresh water. The solar radiation changes periodically with time from the sun rise to sun set. Accordingly, the hourly productivity increases from zero to peak value and then decreases gradually to minimum value. The increase in the productivity is due to the increase in the temperature difference between the basin raw water and the covering glass that leads to successive increase in both condensate and evaporation. The main conclusion of the above work is Organic PCM A48 with melting temperature of 48 °C is suggested to be the optimum Organic PCM, as it has less negative effect on the environment with the highest productivity. The thickness of the PCM has no remarkable effect on the still productivity. The capric-palmatic PCM is recommended with the restrictions of the impacts on the environments due to the lowest cost of 0.0125 US $/litre and highest productivity in compared to the other organic and inorganic PCMs.

S. Imran Hussain et al [14] (2017) studied on Enhanced thermal performance and study the influence of sub cooling on activated carbon dispersed eutectic PCM for cold storage applications. This research investigates the thermo-physical property enhancement of eutectic (oleic and capric acid) based latent thermal energy storage materials for cold storage applications. Highly porous activated car-bon (AC) nano sheets were synthesized, which act as nucleators to enhance thermo-physical properties. FT-IR results confirm that the interaction of AC was only physical and no exo/endothermic reactions. Reinforcement of high surface energy materials as a nucleating agent helps to overcome inefficient thermal properties of pure PCMS. Some researcher has studied the use of acid based surfactant namely sodium laurate and have observed an increase in thermal conductivity by 4.44% and a reduction in sub-cooling to 0.43◦C on myristic-palmitic eutectics. There are different ways to improve thermal properties of thermal energy storage systems, namely mixtures of PCMs, microencapsulation of PCMs, and another important type is to mix nanomaterials in PCMs. The present work focuses on the formation of new eutectic PCMwith thermally credible two organic PCMs namely oleic acid andcapric acid with a latent heat of 139 J/g and 155 J/g whose trans-formation was at 4◦C and 30.5◦C respectively. Both the PCMs exist in two different states, oleic acid in liquid state and capric acid insolid state under ambient conditions. Equal amount of the samples were mixed together with reference to the eutectic curves for low thermal energy storage applications. In this experiment chemical used are sulphuric acid (H_2SO_4), hydrochloric acid (HCl), potassium hydroxide (KOH), oleic acid ($C_{18}H_{36}O_2$), andcapric acid($C_{10}H_{20}O_2$) were purchased from Merck, India with analytical grade purity and were used without further purification. Hemp fibers were collected from agricultural land in Tamilnadu, India. Binary fatty acid mixtures were formed in confined environment maintained at around 50◦C. From the eutectic curve, the proportion of the oleic and capric acid that suits for low thermal energy storage application i.e operating temperature = 10◦C were prepared. Phase change behavior of the AC dispersed eutectic PCMs dur-ing melting and freezing was experimentally investigated using the well-insulated constant temperature bath set-up. The constant temperature bath set-up encompasses of refrigeration unit and high sensitive heater for attaining the set point temperature in the bath which is maintained at the desired value with the assistance of control unit coupled to the cooling and heating units. The control unit can maintain the set temperature up to ± 1.5◦. The heat transfer fluid was isopropanol for cooling process and water bath for heating process which can go up to −90◦C on cooling and 100◦C on heating without any phase change inside the bath. Nano eutectic PCM was encapsulated inside the balls and the t-type thermo-couples were fitted to the center of the PCM balls to monitor the temperature variation of the PCM. The reinforcement of AC towards thermo-physical property enhancement on base eutectic PCM responds well. Noteworthy enhancements in the energy saving time (Heat transfer enhancement), crystallinity behavior, thermal conductivity, thermal expansion behavior, chemical stability. Heat transfer characterization of the pure and nano enhanced eutectic PCM was carried out to find the solidification and melting rate variation of the PCMs in accordance to the nano particle dispersion. The solidification of the nano reinforced PCMs was tested in the constant temperature bath. The solidification starts whenever the temperature around the PCM balls go lower than the phase transformation temperature of the PCM. Nucleation rate of the PCMs are highly influenced by the thermal environment and the nuclei formation. The nuclei formation throughout the PCM will act as the core for crystalline growth during solidification. Nano particles dispersed to eutectic PCM act as a nucleating agent and increases the thermal conductivity and is evidenced from the change in melting and freezing time. The time taken by the pure eutectic PCM is around 550 s and for 0.1 wt% nano dispersed eutectic PCM it is 250 s, proves that temperature of the heat transfer fluid and heat transfer area remains constant. The only factor that depicts the heat transfer rate of PCM is thermal conductivity, which is indirectly reflected by linear decrement in the time taken for melting and freezing of PCM. The eutectic formed with completely eliminated sub-cooling is readily eligible for banana ripening cold storage application. As faras the implementation of thermal energy storage materials are necessary for energy saving purposes, materials with suitable phase change temperature are to be selected in accordance to the evaporator temperature and the cold storage temperature. Eutectic PCM mixture for cold storage applications was obtainedby combining pure oleic and capric acid. The phase change temperature of the pure eutectic PCM has been found to be 10◦C with 2◦Csub-cooling in it. The sheet like porous structure of the prepared AC was characterized by SEM analysis and FT-IR analysis and further dispersed into eutectic PCM. XRD results shows that the synthesized AC is crystalline in nature and the FT-IR results shows that the incorporation of AC into eutectic PCM is purely physical and no chemical changes occur, hence leading to long term chemical stability.

Changyu Liu et al [15] (2018) did research on Experimental investigation of optical and thermal performance of a pcm glazed unit for building application .Glazed unit are essential part of a building, such as window, glazed façade, and glazed roof etc, which provide vision, air ventilation, passive solar gain and day lighting. In present work, optical and thermal performances of a PCM-glazed unit were experimentally investigated compared with that filled with air, and the influences of solar irradiance, melting temperature and PCM layer thickness on three parameters were analyzed including the transmittance, the temperature difference between upper and bottom surfaces, and the interior surface temperature of the glazed unit. This paper directs against offering experimental data for benchmarking and validation of numerical models that are used for the design of glazed units filled with PCM for buildings, which gives the relation between thermal and optical performance of PCM-filled glazed units under solar radiation. The influences of solar irradiance, melting temperature and PCM layer thickness on three parameters were also analyzed including the transmittance, the temperature difference between upper and bottom surfaces, and the interior surface temperature of the glazed unit. The glazed unit is made of aluminum skeleton and glass with the dimension of 500 × 450 × 4 mm (Height × Width × Thickness), which is used to contain the PCM or air in experiments. When filling the glazed unit with PCM, its four sides were stuck by the glass cement except for one hole with the diameter of 10 mm, and then the liquid PCM was injected into cavity slowly. The data acquisition system is composed of a computer and Agilent data logger that controlled by the data acquisition program. The data of all sensors are recorded every 60 s. The thermocouples were calibrated all together for a range of10–90◦C, which are connected to the Agilent data logger by using the calibration bath equipped with a PT100 temperature probe. The calibration bath was filled with water, which is stable to 0.01◦C.When the calibration starts, a specific value was assigned to the reference bath temperature, and then the thermocouples were put at the same depth of water, and the temperature values were obtained. The optical and thermal performance of glazed unit containing PCM was firstly investigated compared with the ones of glazed unit containing air. Then the effects of solar irradiance, melting temperature and thickness of PCM on the performance were also analyzed. The main goals of present work were to provide detailed data for the design of glazed units filled with PCM of buildings, and to discuss optical and thermal performance of glazed unit containing PCM regarding building applications. the peak temperature difference between upper and bottom surfaces of the glazed unit containing PCM is about 2.3◦C beyond that of air, while the time at peak temperature difference of the glazed unit containing PCM is about 7.8 min later than that of the air. It is concluded that thermal performance of glazed unit containing PCM is improved compared with that of air, which can cut down the energy consumption and increase the thermal comfort of the buildings. Although the optical performance of glazed unit becomes weak when the glazed unit is filled with PCM, transmittance of glazed unit filled with PCM is 50% when the PCM is liquid. Solar irradiance has an effect on the optical performance of double glazed unit containing PCM during its melting process, and it has a big effect on the thermal performance of glazed unit during liquid state of PCM. The melting temperature of PCM has an effect on the optical and thermal performance of glazed unit containing PCM during its melting process, but increasing the melting temperature of PCM is not conducive to improve optical and thermal performance of glazed unit containing PCM when PCM state is liquid.

Lidia Navarro et al [16] (2017) did some research on High density polyethylene spheres with PCM for domestic hot water applications: Water tank and laboratory scale study. Renewable energy systems are characterized as providing energy with fewer CO2 emissions than conventional systems. However, the main drawback of renewable energy is the gap between supply and consumption. The inclusion of PCM to improve the performance of the TES systems have been studied by improving heat transfer through the application of fins, enhancing thermal conductivity, application of tube-in-shell TES, and using microencapsulation. The encapsulation methods most used in domestic hot water systems or solar thermal energy storage applications are the macro-encapsulation (also called core-shell) and shape-stabilized PCM. An experimental set-up was prepared to analyse the effect of adding phase change materials (PCM) in the top part of a water tank. The experimental set-up consisted of a transparent acrylic plastic water tank of 600 *400 *500 mm supplied by an external power source that simulated a solar collector. The tank was instrumented with 15 thermocouples type-T prepared in the laboratory. The experiments consisted of heating the water tank up to 62 C. Once the water reached the maximum temperature these conditions were maintained during 1 h and afterwards the tank was cooled down naturally to 32 C. This experiment was carried out with the water tank without PCM and with different amounts of PCM spheres, thus increasing the energy storage capacity of the water tanks by 17% and 33%, respectively. First of all, an experiment without PCM was performed in order to have a reference pattern, which will be used to discern the effects of PCM inclusion. The water blank experiments took 920 and 932 min, respectively, to cool down to 32 C. In order to analyse the PCM lost out of the spheres two laboratory scale methodologies were designed and evaluated. The aim of these methodologies were to detect the rate of the PCM leakage and if this loss affected the energy storage capacity of the PCM-spheres. First of all the PCM-spheres were pre-treated based on the manufacturer recommendations in order to remove the excess of PCM and to have spheres that were materially stabilized. At first submerge the pcm sphere in the glass of water beaker of 150ml. then Heat up the beaker from 30 C to 70 C during 3 h in a programmed muffle furnace. Next The temperature inside the muffle furnace is maintained at 70 C for 5:40 h. Then cooling down naturally to 30C. Repeat the step for 25 thermal cycles. The second methodology called Washing follows the same procedure as that for Cycling but after each thermal cycle the water is changed to perform the next cycle with clean water. Results obtained in the experimental set-up of the water tank showed that the effect of PCM is beneficial to keep the water hot for longer. However, ICE-Balls with A58 PCM are made of polyethyl- ene, which means that they have a low thermal conductivity. This fact makes it difficult to melt the PCM inside the spheres and it takes long time to charge the PCM which is inside the tank. Moreover, PCM leakage was observed during the tests undertaken in the water tank and a laboratory methodology was designed to analyse this phenomenon since it strongly affects the use of PCM in a real application. The laboratory analysis indicates that the PCM-spheres must be thermally cycled and cleaned before their implementation in real application of domestic hot water.

Laura Colla et al [17] (2017) did some research on Nano- PCM for energy storage and passive cooling applications. The commonly used PCMs for technical applications are paraffin waxes, salt hydrates, fatty acids, and others. Paraffin waxes are one of the most promising PCMs consisting of mixtures of mostly straight chain n-alkanes CH3A(CH2)Nach3. The development of energy storage devices is crucial to the present day and represents an exciting opportunity for innovation. In the last decade, the use of PCMs as heat storage in passive heat transfer device has been widely studied both analytically and experimentally. the addition of nanoparticles to a PCM was proposed by some researcher in order to improve thermal energy storage by increasing heat conductivity. The present study proposes an experimental investigation of two commercial paraffin waxes with melting temperature of about 20 C and 25 C. The phase change process at around the ambient temperature allows the use of their latent heat in common building operations. Two commercial paraffin waxes with a melting point about20 _C and 25 _C, RUBITHERM_ RT20 and RUBITHERM_ RT25, were purchased from Rubitherm Technologies GmbH (Germany).Al2O3, gamma, hydrophilic, nano-powder was purchased from Nanostructured & Amorphous Materials, Inc. (USA); it has a nominal diameter of 10 nm, 99.99% purity and 160 m2/g of Specific Surface Area (SSA). Nanoparticles were added to the liquid paraffin sample, to reach a mass fraction of 1.0% for both RT20 and RT25, using a Mettler PM6100. Thermal conductivity was measured placing the sensor between two samples having parallel plane surfaces to ensure a complete contact between sensor and paraffin waxes. The heat transfer is assumed purely conductive and thermal transport properties are determined by the instrument considering the constant electric current supplied by the sensor and the temperature change as a function of time, by monitoring the total resistance of the hot disk sensor. The solid and liquid specific heat capacity and latent heat were measured by means of a Differential Scanning Calorimeter (DSC). The values of the thermal conductivity of solid PCMs and nano-PCMs were measured at 14 C, which is around 5–10 K below the reference melting temperatures of the two paraffin waxes. From the experimental results, it clearly appears that the addition of the alumina nanoparticles leads to a degradation of some 7– 8% of the thermal conductivity of the base pure paraffin waxes for both RT20 and RT25. On the contrary, the Carbon Black nanoparticles strongly enhance the thermal conductivity of the pure paraffin waxes, with improvements that reached more than 25%.In the case of nano-PCMs, only the paraffin wax undergoes a phase change, while the Al2O3 and CB nanoparticles remain in solid state. Therefore, in the presence of nanoparticles before integrating the peak area, the contribution of 1 wt% of Al2O3 and CB on the measured specific heat capacity (cp,tot) was accounted and subtracted from the overall measured one. The results seem to strongly depend on the base pure paraffin wax; in fact, on average the latent heat of RT20 is increased when 1 wt% of both Al2O3 and CB is added. On the contrary, the alumina nanoparticles does not affect the latent heat of

RT25 while when adding CB nanoparticles, the latent heat decreases. An important advantage of these PCMs is that their melting process occurs at around the indoor ambient temperature; therefore, the latent heat of fusion can be used in many different buildings applications. The Al2O3 based nano-PCMs were found to be unstable and a certain nanoparticle deposition was observed; on the contrary, the CB based nano-PCMs were extremely stable. This work confirms that the use of nanoparticles can be a feasible and viable solution to improve the thermophysical properties of the PCMs, especially the paraffin waxes. Additional experimental and theoretical work is surely needed to understand the underlining heat transfer mechanisms on the basis of the performance of the paraffin waxes in order to develop rigorous procedure for the nano-PCMs development and characterization, as well as their stabilization.

T. El Rhafiki et al [18] (2017) did some work on Numerical analysis of a micro-encapsulated PCM wallboard: Flux meter Applications. In this paper, a numerical model has been developed to investigate the thermal behavior of microencapsulated phase change materials incorporated in building material and to enable more accurate interpretation of the measured data provided by the fluxmeter instrument. In this work, the outside surface of the PCM wallboard is subjected to a temporal linear surface temperature on both lateral sides of the sample. Initially, it is supposed that the building material (i.e. cement mortar) is filled with 20% of BASF's free microencapsulated PCM (Microcanal PCM DS 5001 X) in order to have the possibility of comparing the numerical results by the experiments. It can be shown that the temperature at the center of the building material presents an inflection point due to the phase change process occurring inside the PCM. These points match with the PCM melting temperature. The mathematical model gives the possibility of determining the liquid fraction values of the PCM inside the building material which can serve for understanding the shape of the heat flux on the sides of the sample. The evolution of these parameters as a function of TB, out during the melting and the freezing processes. To highlight the effect of the volume fraction of the PCM in the building material, different values of ε are considered in the simulation. Before melting process of PCM within the building material is studied, it is interesting to find the relation between the heat flux and the thermophysical properties of the building material containing PCM such as the apparent specific heat capacity, the apparent thermal conductivity, and when the phase change occurs, the melting temperature and the latent heat of PCM. one can observe that the heating/cooling rate do not affect the onset of the peak of the heat flux during the melting/freezing process of PCM. Accordingly, peak onset can be employed to specify the melting temperature of the PCM. If we focus on the end of each peak, a clear tendency can be seen. When the heating rate increases, the peak changes toward greater temperatures. This result originates from the increase in the thermal gradient inside the sample. When the building material is heated, heat flows from the outside surfaces and is absorbed by the material. In this article, a physical model was developed to understand and analyze the thermal behavior of a building material comprising PCM. The validity of the numerical code used is ascertained by comparing our results with previously published results. A parametric study was carried out to study the effect of various parameters such as the heating rate and the volume fraction of the PCM on the thermal behavior of these materials. It is found that the thermophysical properties of the studied building material can be easily determined by using heat flux curves on both sides of the building material. It is also found that the use of higher heating rates increases the temperature gradients within the studied sample.

Jingchao Xie et al [19] (2018) worked on Thermal performance analysis of PCM wallboards for building application based on numerical simulation. The use of phase change materials (PCMs) in buildings is an efficient way to reduce the building energy consumption. PCM wallboards used in buildings have been widely studied and optimized in many studies; however, further thermal performance analysis needs to be performed. The PCM wallboard is used in the exterior wall of an air-conditioned room in Beijing. The room studied is on the second floor of a building with dimensions of 5m×5m×3 m. Only the south wall is the exterior wall. To validate the numerical method, a thermal performance testing equipment (Xie)is made and a PCM wallboard heat storage experiment is performed. The PCM wallboard with the initial temperature of 18 °C is placed in the equipment. Then the wallboard is heated by the hot air with the temperature of 34 °C. The temperature of the wallboard center is monitored by the thermal resistance. Beijing, Harbin, Shanghai, Guangzhou and Haikou are chosen to study the application effectiveness of the PCM in different climate regions. The problem of the heat transfer with PCMs in wallboards cannot be solved algebraically because of the non-linearity. The convective heat transferred from the surface of the PCM wallboard to the indoor air is used to evaluate the thermal performance of the PCM wallboard. More convective heat means more energy consumption for air conditioning. To avoid the difficulty of the comparison of the thermal performance in different months resulting from the different order of magnitude of the convective heat in different months, the heat ratio is used for the thermal performance analysis in a whole year. The heat ratio is the ratio between the convective heat value of the PCM wallboard and the convective heat value of the gypsum wallboard. In some cases, even if the PCM wall has good thermal performance to store solar energy or to resist the heat gain, it may not satisfy the design standard for energy efficiency of buildings considering the heat transfer performance. Therefore, a method of evaluating the heat transfer performance of PCM walls needs to be determined. The thermal performance of the PCM wall in different months various a lot, so Kp values for 12 months should be calculated. For the walls with the PCM wallboard, its heat transfer coefficient should not be calculate only considering the convective heat transfer coefficient for the wall surface and the thermal conductivity of the wall layer because the phase change in the PCM wallboard can affect the heat transfer process and the influence of the latent heat should be considered. From the experiments and simulations four new aspects of thermal performance analysis of PCM wallboards were presented. They are, The convective heat of wallboard I is 103 kJ more than wallboard II in June, while it is 72 kJ less in December. Hence, the PCM wallboard with good thermal performance in some seasons may show average thermal performance in other seasons, and the thermal performance analysis during an entire year is necessary. The effect of phase change on the thermal performance during a whole year is analyzed using the heat ratio. the phase change has a significant effect and the thermal performance of the PCM wallboard can be improved considerably by changing the latent heat and phase change temperature. The effect of improving the thermal performance of the PCM wallboard can be seen only in some months, not all months. Maybe in other months, the effect is adverse. The heat transfer coefficient of the PCM wall is defined to evaluate its heat transfer performance.

After calculating the heat transfer coefficient of five PCM walls in twelve months, all the PCM walls do not meet the design standard for energy efficiency of buildings. RTC is defined to evaluate the heat transfer performance of the PCM wallboard. It is used to analyze the thermal performance of the PCM wallboard used in different areas of China. For all areas, RTC has a considerable change in certain months meaning that in these months, the phase change significantly affects the heat transfer capacity.

Mohammad Saffari et al [20] (2018) Thermal stress reduction in cool roof membranes using phase change materials (PCM). A considerable amount of energy is used in the building sector for air conditioning purposes. Additionally, the building sector contributes to the urban heat island (UHI) phenomenon which causes temperature rise in urban areas. Passive cooling techniques could be effective methods to improve the cooling energy performance in buildings [8,9] by moderating the temperature fluctuations in building zones, thus offering long-term energy efficiency and indoor thermal comfort. Cool roof is an emerging passive cooling technology which can contribute to reduce cooling demand in buildings and UHI effects. To implement the new cool roof and PCM passive strategies, a multi-family residential apartment was selected from ASHRAE Standard 90.1–2013 prototype building models and slightly modified. The models were developed by the Pacific Northwest National Laboratory in support of the U.S. Department of Energy (DOE) Building Energy Codes Program. These building prototypes are simulated in different climate zones and could be mapped to other climate regions for international use. In the present study, Rubitherm CSM containing RT50 PCM was used. EnergyPlus whole-building energy simulation software is a powerful building energy and comfort simulation tool for modelling the heat transfer in the building envelope, the energy requirements of the building, and human thermal comfort. EnegyPlus uses both BLAST and DOE-2 programs. A packaged terminal heat pump with constant volume fan control, direction expansion (DX) cooling coil, and electric heat pump according to baseline building HVAC system types recommendations of ANSI/ASHRAE/IES Standard 90.1–2013 [44] was selected to simulate the energy needs in the building. A generic optimization program (GenOpt v3.1.1) [57] was selected because of its capabilities in solving optimization problems corresponding to the building energy performance, where parametric analysis is not feasible or efficient. Moreover, it can be seen that some energy savings could be achieved in all climates except Abu Dhabi, Ankara, and HongKong. Further explanations for this fact could be the elevated out-door temperature during night which prevents the PCM of being solidified. This could be seen in annual cooling energy savings in AbuDhabi which are −2.4 kWh. Cool roof technology is an effective way to reduce the cooling energy loads in the building environment and to scale down the UHI effects in cities. Further on, higher thermal comfort could be achieved for occupants. Cool roofs and reflective coatings can su-fer from high thermal stress which can reduce the performance of the cool roof membrane. In the current study, a simulation-based optimization was carried out to investigate, on one hand, the bene-fits of PCM to reduce the thermal stress of the cool roof membrane, and on the other hand, its influence on the annual total energy performance. In general, if the objective is to protect the cool roof membrane from severe thermal stress, especially in summer, PCM with higher melting range is recommended for reducing the thermal stress of the cool roof membrane since it can be melted with elevated out-door temperature and high solar radiation and during night when the outdoor temperature drops down it can be solidified, otherwise, if PCM with lower melting range is selected it could be hardly dis-charged during night.

S. Harikrishnan et al [22] (2014) did some work on Experimental investigation of solidification and melting characteristics of composite PCMs for building heating application. This paper investigates the thermal energy storage behaviours of the newly prepared composites as phase change materials (PCMs) for building heating application. The composite PCMs have been prepared with lauric acid (LA) and stearic acid (SA) mixture as base material and TiO2, ZnO and CuO nanoparticles as supporting materials. Due to low thermal conductivity of the PCMs, the heating unit is made to run for longer period so as to supply the heat energy for storage in the LHES system, resulting in more energy consumption and thereby, electricity cost for this heating unit is increased. Also, this low thermal conductivity limits the utility of the LHES systems for large scale heating applications. Further, the PCMs are expected to store and release the heat energy at a faster rate since, the availability of the solar energy is intermittent. Thus, the researchers are persistently stimulated to find the new methods that would help in introducing the efficient PCMs for LHES systems. The evolution of nanotechnology has paved the path for the development of high heat transfer fluid called nanofluids, which consist of solid nanoparticles and base fluid. In recent times, this technique has been adopted in LHES system for enhancing the effective thermal conductivity of the PCMs. Lauric acid (Tm = 43–45 C) was purchased from the alfa aesar and stearic acid (Tm = 54 C) was purchased from the thermo fisher scientific India pvt Ltd., India. Copper acetate, titanium butoxide, zinc acetate, glacial acetic acid and ethanol were purchased from SRL, India. Sodium hydroxide (NaOH) pellets were supplied by Lobha Chemie private limited, India. Bi-distilled water was used throughout the experiment. Copper acetate aqueous solution of 0.04 M was prepared in the beaker, in which 2 ml of glacial acetic acid was added and the solution was heated to 100 _C with constant stirring [22]. NaOH pellets were added with the solution gradually until the pH value of the solution reached in between 6 and 7. When the solution reached the desired pH value, the large amount of black precipitation was observed. Then, it was centrifuged and washed for 4–5 times with 2D water. Finally, it was dried in the oven at 100 C for 24 h and it was ground in order to obtain the powder sample by means of agate mortar. Next, for the preparation of TiO2 nanoparticles, titanium butoxide and ethanol were blended in the volume ratio of 1:4. The mixed solution was placed on the magnetic stirring for 10 min at 700 rpm. During stirring action, NaOH solution was gradually added with the solution until the pH value of the solution reached 7. Then, it was centrifuged and washed with 2D water for three times. It was dried in the oven at 100 C for 32 h and it was ground to obtain the powder sample. At last, for the preparation of ZnO nanoparticles, 0.1 M of zinc acetate (as precursor) was dissolved in ethanol (as solvent). With the help of magnetic stirrer, this solution was stirred at about 450 rpm for 40 min. During the stirring action, 5 ml of sodium hydroxide solution was added drop-wise with the solution for maintaining the pH value at 7. Afterwards, the solution was appeared as milky and it was washed with ethanol for three times. The surface morphology of the CuO, ZnO and TiO2 as synthesized particles was studied with the help of field emission scanning electron microscope shows the spherical shapes for TiO2 and ZnO, and rod shape for CuO nanoparticles. DSC measurements were carried out to determine the phase change temperature and latent heat of the base material for melting and solidification due to the addition of nanoparticles. TGA tests for base material and composite PCMs were studied to investigate the thermal stability. The weight loss for base material occurred at the temperature between 110 and 230 C. The weight loss was about 6% at below 120 C, which can be attributed to the removal of absorbed water. The base material was completely degraded between 200 and 230 C, which could be ascribed to the breakage of polymer chain into monomers. PCMs employed in LHES systems are subjected to undergo more number of melting and solidification cycles for long term utility. In this study, various nanoparticles of 1.0 wt% TiO_2, ZnO and CuO dispersed with the base material separately, were used to examine their stability on the thermal properties up to 5000 thermal cycles. Energy storage and release rates of the composite PCMs during melting and solidification processes rely on the thermal conductivity and the temperature difference between HTF and PCM. The solid nanoparticles dispersed in the base material have tendency to increase the viscosity and thereby, it is inevitable to analyse the viscosity of the composite PCMs. Also, it should be noted that the increase in viscosity due to addition of nanoparticles in the base material can be permissible to certain extent. Addition of nanoparticles improved thermal stability of the composite PCMs was confirmed by TGA results and it shows that ZnO nanoparticles had noticeably improved the thermal stability of the composite PCM rather than the TiO_2 and CuO nanoparticles. For 1.0 wt% CuO nanoparticles, thermal conductivity of the composite PCM was increased significantly as compared to the 1.0 wt% TiO_2 and ZnO nanoparticles. From the experimental results, it is clearly understood that the time savings of composite PCM with 1.0 wt% CuO nanoparticles for complete melting and solidification processes were 21.24% and 19.84%, respectively. By considering all these results, it can be concluded that the composite PCM with 1.0 wt% CuO nanoparticles could be reckoned to be a potential candidate to harvest solar energy for building heating applications due to its good thermal properties, thermal reliability and greater enhancement of thermal conductivity.

Letizia Roccamenaa et al [23] (2018) worked on Experimental test bed design and development for PCM-water exchangers characterization. They did the design and the development of an experimental prototype reproducing the behaviour of a PCM-Water heat exchanger with TES purposes is presented. The prototype will be used in the future for the experimental validation of a numerical model that will be used for the optimization of an innovative TES technology at low temperatures. The construction of this prototype appeared fundamental for a complete experimental validation. In fact, it allows us to recreate particular conditions that could be impossible to obtain from the in situ monitoring given the complexity of the reference system. The HIKARI buildings incorporate three sources of renewable energy production (photovoltaic panels on the roof and façades, a geothermal energy system and a cogeneration power plant fueled by locally produced rapeseed oil), and three energy storage technologies (electricity, heat and cold storage systems). The HIKARI's cold storage system exploits the PCM ability to absorb and release a large amount of thermal energy during its phase transition and it is used for optimising and improving the performance of the HIKARI's absorption chiller. Through the presence of the latent heat storage system, in fact, it is possible to reduce the difference between the chiller's cold and hot inlet water temperature and the short cycling. The implementation of this experimental prototype is for this reason necessary, as it is impossible to obtain a complete experimental validation only considering the data obtained from the in situ monitoring. The

HIKARI's low temperature heat storage system consists of 60 m3 of PCM (subject to a phase change between 8 and 9 °C) processed into a gelatinous form and enclosed in cylindrical stick packages that are inserted in plastic cases and subsequently positioned in four insulated thermal storage tanks. A quantity of 100 g of PCM (paraffin Ecojoule) is enclosed in each cylindrical stick package with a height of approximately 274 mm and a diameter of 25–30 mm. The outside dimensions of the plastic case are 465× 345× 280 mm and each case is filled with 156 PCM sticks. An experimental prototype reproducing the HIKARI cold storage system has been developed in the ENTPE Laboratory of Tribology and Systems Dynamics (LTDS) in order to obtain valid experimental data useful for the experimental validation of the numerical model. The numerical model will be based on the formulation of heat balance equations and the apparent heat capacity method and it will reproduce the heat exchange between a single PCM stick and the water flow. The first concept of the prototype consisted of an isolated tank filled with water and containing a plastic case containing PCM sticks equal to those present in the HIKARI reference system. Once the prototype built, an experimental protocol has been established in order to recreate particular situations that will be useful in the future experimental validation and that cannot be obtained using only the in situ data, as they are registered in the working scenario of the system. As the numerical model will simulate the heat exchange between a single PCM stick and the water flow around it, it will be necessary to have single inlet, intermediate and outlet values. For this reason, it was chosen to use the arithmetical mean value of the temperatures registered by all the sensors placed at the same height (3-6-9-12-15, 2-5-8- 11-14 and 1-4-7-10-13), but this option could be invalid if there was an excessive difference between the temperature values registered by the sensors of each group, for example due to the effect of the proximity of the sensors at the tank walls. The objective of this experimental prototype construction was, on the one hand, to reproduce the behaviour of the reference storage system in a small-scale and with the opportunity to modify the boundary conditions, changing for example the inlet water flow rate or the type of PCM, and at the same time to provide valid data of the temperature evolution during the heat exchange between water and PCM. At the end, the effect of the proximity of the sensors at the tank walls on the measures was analysed, in order to decree if the data could be group in 3 outputs (inlet, intermediate and outlet values), necessary condition for a valid comparison with the numerical data. As it was found out that the grouping was possible, it will be possible to validate the numerical model comparing the water temperature evolution along the stick length during the heat exchange. Due to its versatility the prototype will be able to be used in order to test other scenarios or other types of PCMs.

Sayem Zafar et al [24] (2015) did some research on Experimental testing and analysis of R134a clathrates based PCMs for cooling applications. An experimental investigation is conducted to test the thermal behavior and characteristics of R134a clathrates with additives, as phase change materials (PCMs). PCMs' charging characteristics are analysed and evaluated for cooling applications. The formation of refrigerant clathrates is investigated due to their potential use in active as well as in passive cooling applications. PCMs are formed using R134a clathrate and distilled water with different refrigerant proportions and five different additives. PCMs based on refrigerant clathrates have poor thermal transport properties. To make refrigerant clathrates as effective PCMs, additives of different materials have been studied. For instance, adding calcium hypochlorite or benzenesulfonic acid sodium salt improved the cold energy storage capacity and the cold energy transfer rate of R141b based clathrate. Adding alcohol in R134a based clathrate has also been studied which shows it accelerates the cool storage rate and eliminates the floating clathrate during the hydration process. Metallic nano-particles have also been added to study the improvement in thermal transport properties. Studies show that even a small fraction of nano-particles of low thermal conductivity metallic oxides can favorably increase the thermal conductivity of pure a substances, such as water. For the experiments, a cold constant temperature bath is used as a constant temperature source. Refrigerant, water and the desired additive are mixed in a pressurized glass tube. The glass tube, that can sustain high pressure, is used with a mounted pressure gauge and an access valve to fill the refrigerant. The tube is comprehensively tested for leaks and measures are taken to make sure there are no leaks. It is important to use a glass tube since the onset of phase change needs to be observed visually. The experiments are conducted to determine the onset and end set time of R134a clathrate with and without additives. Charging time is important to determine as it yields the total energy used to form the PCM. Low charging time means low energy while increased time means large amount of energy required to form the PCM. The analyses are performed to evaluate the energy and exergy demand for charging of the tested R134a clathrate with and without additives. Note that exergy analysis is a powerful tool for the design, optimization, and performance evaluation of energy systems. The clathrate of R134a forming the clathrate with or without additives is referred to as PCM in this paper from now onwards. Energy and exergy is determine for R134a clathrate at different proportions and then with different additives over arange of mass proportions. Energy analysis is done to quantify the amount of energy required to charge the desired PCMs. The exergy analysis, on the other hand, determines how much of that energy is available to be utilized later. Plots shows that shows the energy and exergy utilization of R134a clathrate having NaCl particles as additives. The energy utilization varied from 505 kJ for 1% additive to 709 kJ for 3% additive. The exergy utilization varied from 318 kJ for 1% additive to 447 kJ for 3% additive. For sodium chloride, the R134a clathrate did not form for higher additive percentages. Energy and exergy tends to increase with the increase in NaCl mass proportion. Like other additive trends, the end-set time dictated the energy and exergy utilization. The test results are analyzed for onset and end set time durations to determine when the solidification starts and ends. The research concludes that 35% refrigerant requires the lowest time to form the clathrate. The copper, aluminum, magnesium nitrate hexahydrate and ethanol decrease the onset time. Sodium chloride increases the onset time when used as an additive. The magnesium nitrate hexahydrate forms the clathrate fastest, followed by copper, ethanol, aluminum and then sodium chloride. The copper and aluminum additives show an improvement of 71%, magnesium nitrate hexahydrate 57% and ethanol by 28%.The magnesium nitrate hexahydrate and copper accelerate the clathrate formation while aluminum and ethanol does not affect the charging time much. Energy and exergy contents follow the same trend as the charging time. Greater charging time does not necessarily mean that the PCM is ineffective for cooling applications.

Hamidreza Behi et al [25] (2017) did some work on PCM-assisted heat pipe for electronic cooling. Today, higher-power computer chips are available, but they generate too much heat that irreparably damages inside components. In this paper, a horizontal phase change material (PCM)-

assisted heat pipe system for electronic cooling was introduced as a potential solution to this problem. Utilizing heat pipes also can be used as a great solution to control low heat transfer rate due to the low thermal conductivity of PCMs. Heat pipes are one of the most popular two-phase heat transfer devices in which a large amount of heat can be transferred with a very low-temperature difference. the cooling contribution of PCM through charging (melting) was studied using commercial CFD software to explain the experimental phenomena at a broader range. The setup included a power supply that provided heating power, cooling water loop that supplied cooling, a heat pipe, transparent glass cylinder with inner diameter and length of 46.00 and 115.00 mm respectively, a data logger, T-type thermocouples and a personal computer. The cylindrical heat pipe was made of copper wherein water was used as a working fluid. A length of 115.00 mm of heat pipe was put inside the PCM cylinder. Leaks were controlled by plastic washer. The cylindrical tube and top cover were connected to the block by three long bolts. Double glass wool thermal insulation in thickness of 10.00 mm was used for insulating the side wall and copper blocks to minimize the heat loss to the ambient. The power supply provided heating power for heat source section which was required to evaporate the working fluid inside the heat pipe. Alike, the condenser of the heat pipe was attached by a copper block that was connected to a cooling loop. The loop itself was equipped with a pump that could circulate water with a constant mass flow rate of 0.0027 l/h. A gear pump (MCP-Z, Ismatec, Switzerland) and a Coriolis flow meter (CMFS015 with 2700 transmitter, Micromotion, Netherlands) were used to keep and record the flow rate in the loop. Simulation of the temperature distribution and liquid fraction of the PCM storage system were conducted using Ansys-Fluent software. The test section was modeled using a 2D axisymmetric geometry. The liquid fraction and temperature distributions of PCM have been reported during the charging process in different input heating powers and the model was validated by using experimental data. To validate the model, the temperature of the PCM measured experimentally during charging mode was compared with the numerical result. The temperature distribution in PCM and heat pipe was obtained during the experimental and numerical studies. As expected, the highest wall surface temperature is observed at the evaporator section and the wall surface temperature decreases from evaporator toward condenser section. The results also revealed that the temperature difference between evaporator and condenser sections is very low which is due to a very high effective thermal conductivity of the heat pipe. According to the graph, it can be seen that the temperature variation along the axial direction of the heat pipe is almost 2 C which demonstrates the high heat transfer capability of the heat pipe. Results revealed that the heat input had a significant effect on charging process. By increasing the heat input at the evaporator of the heat pipe, more heat can be transferred to the PCM section due to the increase in temperature difference between PCM and heat pipe wall. Increasing the temperature difference between PCM and pipe wall leads to higher phase change rate. This study revealed that the module can contribute 86.7% to the cooling application and 11.7% avoidance of heat dissipation by providing additional heat absorption. This heat absorption can eliminate or at least minimize thermal damage in electronic components. In addition, the heat absorption by the PCM took place at phase change temperature; hence, the temperature of the system did not increase dramatically.

Siyu Zhou et al [26] (2018) worked on Modification of expanded graphite and its adsorption for hydrated salt to prepare composite PCMs. $MgCl_2·6H_2O$ is a promising inorganic phase change material (PCM) with abundant resources from salt lakes, while its wide applications are greatly hampered by the drawbacks of phase separation, super cooling and corrosivity, inherent in hydrated salts. Herein a novel expanded graphite (EG) based composite PCM containing $MgCl_2·6H_2O$ was explored, which involved modifying EG for increasing its hydrophilicity, compressing the modified EG (MEG) into round blocks, and immersing the blocks into melted $MgCl_2·6H_2O$. Magnesium chloride hexahydrate ($MgCl_2·6H_2O$, MCH) is a hydrated salt with a melting point of around 117 °C and latent heat of ca. 150 J/ g, making it show potential applications in solar thermal utilization systems [6]. More significantly, this hydrated salt are abundant in salt lakes, making it possess the advantages of rich raw materials and low cost. Especially, nowadays, after potassium and lithium have been extracted from the salts, a huge amount of MCH is left and thus has been considered as a "magnesium problem". However, those intrinsic drawbacks including phase separation, supercooling and corrosivity need to be overcome before the practical applications of MCH as a PCM. MCH (purity > 99%) were purchased from Aladdin and Tianjin Fuchen chemical Co. Ltd. EG was prepared from expandable graphite (50 mesh, Shandong Graphite Co. Ltd., China) using a microwave oven under 750W for 30 s. TX-100 was purchased from Uni-Chem and Guangzhou Fangdong teaching apparatus Co. Ltd. firstly, the EG powder was dried in an oven at 60 °C for 12 h. And a solution was obtained by dissolving a set amount of TX100 into ethanol. After that, EG was dispersed into the TX-100 solution by sonication for 10 min, followed by drying at 80 °C for 17 h to obtain the MEG powder. Secondly, the MEG powder was compressed to a round block with a specific packing density. Finally, the MEG block was immersed into melted MCH that was contained in a closed glass bottle with an aluminum cap. After impregnation at 140 °C for about 4 h, a MCH/MEG composite block was obtained. Thermal properties of MCH and the MCH/MEG composite phase change block were characterized by DSC at a heating rate of 2 °C/min. Note that only 5–10 mg of each sample is commonly used in DSC measurements, and the samples may solidify at any temperatures below their melting points by chance, which results in the random solidification points. Moreover, the thermal conductivity values of MCH and the composite block were measured to be 0.465 and 3.588 W/(m K), indicating that the thermal conductivity of the composite block is about 7.7 times as large as MCH. A novel MCH/MEG composite PCM was explored, which involved modifying EG with TX-100 for increasing its hydrophilicity, compressing MEG into round blocks, and immersing the blocks into melted MCH. The MEG block prepared under the optimal process conditions exhibits an adsorptive capacity of 80% for MCH, making the obtained MCH/MEG composite block consist of 80.1% of $MgCl_2·6H_2O$, 1.1% of TX-100, and 18.8% of EG. And it is shown that the obtained MCH/MEG composite block maintains a similar melting point to that of MCH, and its latent heat is as high as 116.7 J/g. The high latent heat, much enhanced thermal conductivity and good thermal reliability make the $MgCl_2·6H_2O$/MEG composite PCM show great potentials in practical applications.

Amirreza Fateh et al [27] (2017) did some research on Numerical and experimental investigation of an insulation layer with phase change materials (PCMs).The main aim of this research is to develop a detailed dynamic model in order to calculate the effects of PCMs in insulation layers of lightweight walls. In this paper, the results of some actions, used to improve the effectiveness of the models, are investigated. In particular they are the adoption of two distinct cp curves, which improves the accuracy of dynamic simulations and, hence, allows the development of the model using a smaller number of points and a larger time step. Over the decades, a novel use of PCMs have raised the interests of people dealing with energy savings in buildings: the basic idea is embedding PCMs in the insulation layer of lightweight walls to exploit their physical behaviour. During the day, the PCMs in the external walls can absorb the input heat into the building and cause cooling loads to reduce. At night, when the air becomes cold, the PCMs freeze and dispense the heat they stored during the day, towards the internal and external environment .The calculation of the thermal behaviour of walls with PCMs, subject to circadian temperature oscillations, is complex. The accuracy of results depends on the discretization, in space and time and on the precision of the temperature enthalpy curve as well. First of all, the temperature enthalpy curves are recorded, both during a heating phase and during a cooling phase. The second step consists of the validation of the cpcurves, obtained in the course of the first activity. A series of experimental tests is done in parallel with the corresponding numerical simulations. Finally, the second step aimed at the definition of an acceptable set of curves, the model can be used to make numerical simulations of many different arrangements of the wall, in the presence of a PCM layer, for circadian temperature profiles. The mathematical model presented in this paper is the natural development and enhancement of the model described in a previous work. The energy balance corresponds to a differential-equation sys-tem, which was solved using Matlab Simulink. In order to validate the model developed, several dynamic measurements of an insulated wall, with PCM, were carried out in a laboratory setup. This setup consists two thermostats for cooling and heating, the data acquisition unit and a pc. The test chamber consists of two, separate plates controllable by the two thermostats, one at the top and one at the bottom. Asa sample, some XPS insulation with a DuPont Energain board as PCM layer was used. The simulations were carried out for all four different positions of the PCM layer. The heat flux to the plate, which represents the internal environment, was measured during the experimental campaign and was calculated by means of the numerical model, throughout the 48 h, which constitutes the entire duration of each test. It is very important to select the kind of PCM and their position in the wall, in such a way that they can act in the range of temperature near the change of phase in those seasons, in which the daily alter-nation of heat flow rate allows them to shave peaks of heat load. The numerical model owes its accuracy to the use of two different functions to calculate the specific heat for heating and cooling. In fact, the use of a conventional model to represent the specific heat does not guarantee the necessary accuracy for thermal simulation with circadian temperature variation. In the condition tested, the PCM layer shows a promising reduction of the peak heat load that is about 15%. In any case, it is important to recall that the proper design of walls integrated with PCMs requires multiple considerations about the cross link between climate, wall orientation, the melting point of PCMs and the selection of the period of the year, in which they would be most useful.

Yantong Li [28] did some work on Optimal design of PCM thermal storage tank and its application for winter available open-air swimming pool.They did general procedure to optimize the design of a PCM storage tank, including the specification of design objectives, the identification of decision variables (for optimization), the construction of computer simulation platform and the final decision making. In this study, a PCM thermal storage tank is designed to store the heat and release it to the swimming pool during daytime operation. To maximize the reduction in the operational cost, the PCM thermal storage tank is required to store enough heat to maintain the water temperature inside the thermal comfortable range. Traditionally, a PCM storage tank is sized according to the required storage capacity under rated operating condition. Firstly, design objectives should be specified. The typical design objectives in a PCM thermal storage tank design are to minimize the PCM tank volume. For this research popular software that is used to construct the simulation platform for the PCM thermal storage tanks includes TRNSYS, Energy Plus and MATLAB. The swimming pool considered in this study is located in the City University of Hong Kong. It has the total volume of 1963.5m3 and the surface area of 1100m2 with the following dimensions: 50m long and 22m wide. Along the length, the depth of the swimming pool at both ends is 1.2 m, which lasts for 10 m; and the depth in the middle is 2.5 m, which lasts for 15 m. At both sides, the depths changes from 1.2m to 2.5m with the length of 7.5 m. The basic idea is that during the night air-source heat pump operates and charges the PCM thermal tank to 60 °C and then an auxiliary electrical heater is switched on to heat the PCM up to 95 °C. The temperature of 60 °C was set according to the manufacture data as this temperature is the maximum temperature which can be generated from current products in Chinese market. The method employed to model the heat transfer process in the energy storage tank are referred to, in which the heat transfer process in the water tank containing spherical capsules filled with PCM is simulated. In order to validate the reliability of the mathematical models, the numerical results of the PCM storage tank and the swimming pool model were compared with the experimental results. The performance of the PCM storage tank was tested by applying it in the heating system of the outdoor swimming pool. To analyze the economic performance of the PCM thermal storage tank, the traditional method, which uses an electrical heater to heat the swimming pool, was adopted as a benchmark. The optimal design of PCM thermal storage tanks has been investigated in this paper and its basic steps, including design objectives specification, decision variables identification, simulation platform construction and post data analysis, have been illustrated. The optimization method was applied to the PCM thermal storage tank design for an open-air swimming pool, where the volume of the PCM storage tank was considered as the design objectives. Four decision variables were identified, including the water fraction, the number of PCM tubes, the type of PCMs and the initial water temperature of the swimming pool. Their relationships with the design objectives were identified by analyzing the data generated from a simulation platform. The study shows that shows that the optimized PCM storage tank is not only able to meet the thermal comfort requirement during the entire open period in the winter season, but also provide a considerable economic saving for the operation of the heating system.

Kyoung Ok Lee et al [29] (2018) did some work on Thermal performance of phase change materials (PCM)-enhanced cellulose insulation in passive solar residential building walls. This paper evaluated the thermal performance of PCM-enhanced cellulose insulation in residential walls. The PCM was integrated via direct mixing with the insulation. Differential scanning calorimeter (DSC) tests showed that the cellulose would not affect the latent heat of fusion of the PCM in the mixture in a significant manner. The thermal performance of north, east, south, and west facing residential walls with and without PCMs was experimentally evaluated using two identical test houses under full weather conditions. Field tests of PCM-enhanced wall insulation systems were conducted using macro-encapsulation methods with paraffin-based PCM and hydrated salt-based PCM. The performance of these systems was tested using two side-by-side houses of identical construction and under full weather conditions. The overall objective and novelty of this research was to find a practical method by which PCMs could be incorporated into the wall insulation of residential buildings to reduce the peak space cooling load in summer. Field experiments were conducted using two small-scale test houses located in the central part of the U.S. The test houses had dimensions of 1.83m×1.83m×1.52m and used typical residential frame wall construction and geometry. In each test house, a window with an area of 0.32m2 was placed in the south-facing wall. Type T thermocouples were used to measure exterior wall surface temperatures, interior wall surface temperatures, and indoor air temperatures. Heat flux meters were installed on the interior side of each wall to measure the heat transfer rates per unit area through the walls. To investigate if the mixing of PCM with cellulose resulted in significant property changes of the PCM, differential scanning calorimeter (DSC) tests were performed at heating and cooling rates of 1 °C/min with a mass ratio of paraffin to cellulose of 0.7–1. Calibration tests were performed to set the baseline in relation to temperatures and heat transfer between both test houses before the retrofit. For the calibration tests, plain cellulose insulation was installed in both test houses. The heat fluxes through the walls, interior and exterior wall surface temperatures, and indoor air temperatures were monitored, recorded, stored, and analyzed. In addition, it was found that the areas under the heat flux curves of both the PCM-enhanced walls and control walls were comparable. What this means is that PCMs reduced the peak heat fluxes but on a daily basis the PCM-enhanced insulation would not necessarily reduce the total heat transfer through the walls. The reason for this is that thereductions produced by the melting process in the daytime would be cancelled out by increases in heat fluxes produced by the solidification process at night and early morning For the PCM-enhanced insulation, it was found that only the PCM enhanced insulation installed on the west wall affected the peak reduction in a significant manner. The heat fluxes through the west wall were higher than those for the other walls in the afternoons when the peak of the sum of the heat fluxes through the walls occurred. The experimental results showed that on average the peak heat fluxes were time delayed by about 1.5 h. The peak heat flux reductions were different for the four walls. These were 26.0%, 38.5%, 16.1%, and 20.8% for the north, east, south, and west walls, respectively. The daily average peak heat flux reduction for the individual walls was 25.4%. However, the average hourly peak heat flux reduction from the sum of all four walls was 26.6%. This was because the peak heat fluxes for the various walls occurred at different times during the day. Only the west-facing wall showed a significant peak heat flux reduction.

Emad Elnajjar et al [30](2017) did some research on Using PCM embedded in building material for thermal management: Performance assessment study. At present, the thermal energy storage systems (TESS) are becoming more popular in regard to its incorporation in building materials, which in turn will reduce the dependence on fossil fuels for environmental and economic reasons. Some of the other advantages of using the TESS are: reducing the peak power for heating and cooling, shifting the peak heating and cooling loads to less demanding hours, shifting the temperature peak to non-working hours, improving indoor comfort conditions and finally efficiently utilizing passive heating and cooling loads. In this analysis a common UAE's building brick type is used. a two-dimensional segment of a wall built of two square hollow bricks with the dimensions of 40 × 20 × 20 cm. The study investigated the thermal management performance using a brick building with and without three different types of paraffin PCM materials embedded in the square brick's holes. The computational physical domain used in the present analysis with all boundary conditions. The ANSYS Fluent code was used to solve the governing equation with the related boundary conditions. The computation domain grid was generated using GAMBIT software, with quadrilateral mesh domain of total 81160 nodes; the min size in the selected mesh in the brick and the PCM domain are 1 mm and 0.5 mm respectively. The specific heat and the density properties of the PCM were defined according to the temperature dependence as described in equations 3, and 4 respectively. The second order upwind schema was used for solving the pressure, momentum and energy equations. The default Fluent under relaxation factors for the pressure, density, body forces, momentum, liquid fraction and energy parameters. The convergence monitoring the residual levels were set to 10-6 of the momentum, energy and continuity equations. A maximum number of iteration for each step was defined as1000. Time increment for each step was 10 s. The main aim of the present work is to carry out a numerical simulation in order to study the saving of cooling energy due to embedding a PCM material inside a typical brick material used in UAE's buildings. The focus of this paper will be on evaluating a one day versus a seven day assessment on energy saving performance. The present study addresses the energy conserved due to using an embedded PCM material in the UAE's typical building material, numerically. The study focuses on demonstrating the contradictory and deceiving results which can be concluded from a one day versus seven day analysis. A one day evaluation can be deceiving where it suggests that then Octadecane PCM is doing a great job which differs after the first day. Choosing the proper PCM material for thermal management applications is a tricky process and it required at least seven day of analysis assessment. PCM P116 type of PCM with the highest melting temperature demonstrated the best performance and energy saving compared to all other studied cases of bricks with and without PCMs.

2.3 Gap of Knowledge

Photovoltaic solar cells converts solar irradiance into electricity. But the use of solar photovoltaic panel is known for several problems. The major problem is related to applied solar energy resulting in heating the photovoltaic panel to an increased temperature, which results in a decrease in the photovoltaic conversion efficiency.

The operating temperature is the important factor. The effects of temperature on photovoltaic efficiency can attribute to the influences on the current and voltage of the PV panels. This can be easily found on the I-V curve of the panels. It results in a linear reduction in the efficiency of power generation as temperature increases. The efficiency of some types of PV cells is very much dependent on their operating temperature. For crystalline silicon solar cells, the reduction in conversion efficiency is 0.4- 0.5% for every degree of temperature rise. Therefore, reducing the operating temperature of photovoltaic cells is important for the PV panel to work efficiently and protect cells from irreversible damage.

The recent attempts to address the problem of heating of photovoltaic panels and the loss of efficiency resulting therefrom have not been completely successful in satisfactory resolving all the problems relating to the heating of solar panels and the loss of efficiency resulting therefrom.

It has been determined that a system is required that uses a free and abundant source of thermal transfer without the use of electrical energy, valves, or control to optimize energy or cost saving.

2.4 Possible Solution

Reviews of previous works have revealed that a considerable amount of research have been conducted on solar photovoltaic system for cooling surface with a wide variety of technique and coolant. It have been observed that all problems relating to the heating of solar panels and the loss of efficiency therefrom. In this thesis work phase changing material (SaVE OM37) has been used for minimizing the heat and improved the panel efficiency.

Different types of commercial PCM such as RUBITERM, BIOPCM has been used in solar cooling as well as building cooling purposes.

SaVE OM PCM are also used in various thermal storage application. So this type of PCM may be effective for solar cooling. The properties of various types of PCM is discussed in chapter five.

2.5 Conclusion

From the above study it is clear that cooling of PV panel is required to minimize the loss and improve the solar panel efficiency. In this chapter we have discussed different types of PCM used for cooling purposes and different types of cooling techniques knowledge. In the base of earlier work, gap of knowledge, possible solution have also been described in this chapter. Technology of Solar system with different cooling arrangement has been discussed in next chapter.

CHAPTER 3

Cooling Technology for Solar PV System

3.1 Introduction

The main objective of the previous chapter of the study is to review the literature on solar Photovoltaic system cooling and application of Phase changing material for identifying research gaps in the hybrid solar photovoltaic and thermal system. The main factors that effects the efficiency of solar photovoltaic system is Sun's available irradiance and spectral content as well as other environmental factors and component performance of the PV system. In this chapter we will discuss about different types of cooling techniques.

3.2 SPV Cooling

Renewable energy sources are becoming more and more popular, regarding the pollution and depletion of fossil fuel. With increasing human population, a question arises, what will happen after the disappearance of fossil fuels? One of the huge source is solar energy, which manifests itself directly, as solar irradiance, or indirectly as wind, biomass or hydro energy. Solar energy can be transformed into solar thermal as well as electric energy. But electric energy is more valuable because it can be easily converted to useful work. Most efficient way to convert solar energy is converting solar irradiation to electric energy by photovoltaic cell. Although the overall efficiency of a PV cell is 10% - 25%, still it is more efficient than wind or biomass energy.

However, it has been shown than the overall efficiency of photovoltaic cell drops with an increase in temperature. The rate of decrease ranges from 0.25% to 0.5% per degree Celsius, depending on the type of cell material. Especially for concentrated PV cells, which use concentrated sunlight to produce larger amounts of power, and reduce the cost of generally expensive PV equipment, it has been observed that high temperatures greatly decrease the working life of the whole PV system. Therefore, reducing the operating temperature of photovoltaic cells is important for the PV panel to work efficiently and protect cells from irreversible damage. A number of researchers have worked on cooling the PV panels with different approaches. Air circulation is probably the most simple and natural way for this purpose. In order to enhance convection heat transfer, fins were used to extend the heat transfer area. Krauter [8] investigated the method of covering PV modules with a flowing water film above. With the additional evaporation heat transfer, it was claimed that they could decrease the cell temperature up to 22°C and obtained a net increase from 8 to 9%.

It is well known that a decrease in the panel temperature will lead to an increase in electrical efficiency, so in recent years different cooling techniques have been proposed and tested experimentally. Several cooling techniques have been tried, mostly based on active water and air cooling, as these are the simplest techniques. Other cooling techniques include conductive cooling, phase change material cooling, etc. Increase in electrical efficiency depends on cooling techniques, type and size of the module, geographical position and the season of the year, and usually corresponds with a rise of 3% - 5% in overall efficiency. Finally a perspective on other cooling techniques for PV panels will also elaborated on and discussed.

3.2.1 SPV Cooling Technique

Cooling technique for heat applications were proposed early on in PV exploitation, as mentioned in some research paper. The main purpose of cooling is to increase the efficiency of the PV cell as well as it increases the lifespan of the PV cell. However cooling requires a separate system which will remove heat to some extent. The construction and maintenance of that system can be expensive and there is a possibility that the cost of the system maintenance outweigh the benefits of the improved electrical yield. Some cooling technique will be discussed

3.2.1.1 Air Cooling

3.2.1.1.1 Heat Sink

Heat sink is one of the cooling ways which uses a high thermal conductivity metal to remove the heat from the photovoltaic cell. Popovici et al. [8] investigated numerically the temperature reduction of the PV panels during a clear day of summer by using different arrangements of ribbed wall heat sink of air and passive cooling. It was found that the maximum temperature of the panel for the angle 45° was less than that for the angle 135°. The study found that the maximum power produced by PV panel in case of using heat sink was increased by 6.97% and 7.55% compared to the reference case, for angles of the ribs from 90° and 45°, respectively. Farhana et al. [9] studied experimentally the operating temperature variation for the PV module with and without active cooling system to realize the electrical performance of the PV module.

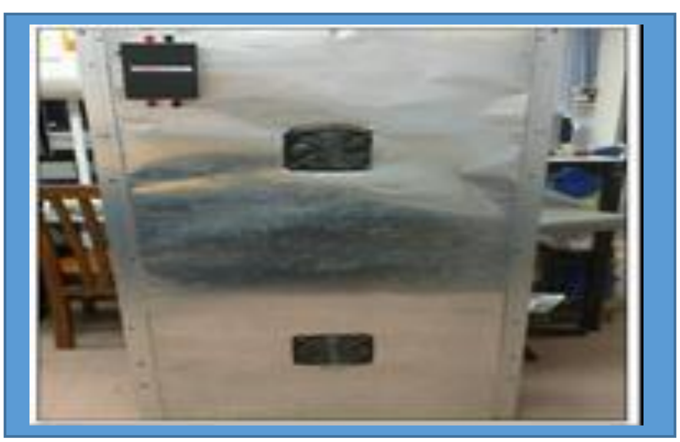


Figure 3.1 Back side of heat sink [44]

3.2.1.1.2 Air channels

Several studies investigated the performance of the PV cells with active cooling by using air channels connected to the back of the PV panel. Teo et al. [10] concentrated on the comparison of the PV module electrical efficiency with and without active cooling. The study investigated experimentally and numerically the influence of the operating temperature on the efficiency of the hybrid photovoltaic/thermal solar system. It was noticed that the electrical efficiency was decreased when the cells operating temperature increased for both cooling and non-cooling cases, but for the cooling case the electrical efficiency was higher as shown in Fig. 3. In addition, the experiments found that there was a linear proportional relation between the PV panel temperature and the irradiation as displaced in Fig. 4. Tonui et al. [11] investigated experimentally the performance of PV/T solar collector using forced or natural air circulation to extract heat. The air channel was modified by two different ways to boost the heat transfer from the channel walls to airflow. The first one was inserting a thin flat metallic sheet at the middle of the channel (TMS system), and the second one was joining rectangular fins at the back of the channel (FIN system) as shown in Fig. 5. The study achieved that the modified PVT/Air systems would participate considerably in enhancing the performance of larger applications of PV systems. Ameri et al. [12] investigated experimentally the performance of photovoltaic/thermal air collector. The panels were installed on the channel of air and on the top of a thin metal (aluminium) sheet (TMS) as shown in Fig. 6. The study indicated that the electrical efficiency of the system had a direct relationship with the solar radiation intensity, PV cells temperature, and the power rate consumed by fans. Therefore, the electrical efficiency in case of forced convection was not always increased with number of fans, but there were an optimum number of fans for high electrical efficiency as presented in Fig

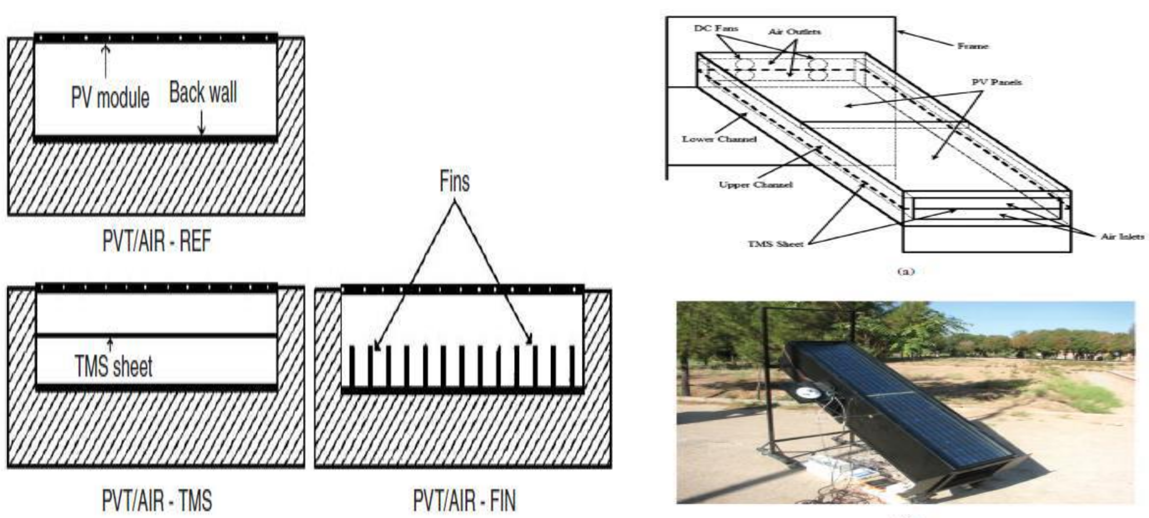


Figure 3.2 air channel [44]

3.2.1.2 Water Cooling

Several studies have investigated experimentally the performance of the PV cells with active cooling water. Nizetic et al. [13] investigated experimentally the impact of water spray cooling on the performance of the PV panel in highest solar irradiation level environment. Both sides of the PV panel were cooled at the same time by utilizing twenty nozzles, ten on each side as shown in Fig. 8. The results were measured for three different cases of cooling: front side cooling, rear side cooling and both sides together and compared with non-cooling case. The research indicated that the water spray cooling has achieved a suitable effect on the PV panel performance and the best case was the simultaneous front and back sides cooling PV panel. Lastly, depending on the experimental results, as presented in Table 1, the water spray cooling system had a proper impact on the PV panel performance. Abdolzadeh et al. [14] studied experimentally the impact of the water spray cooling on the performance of photovoltaic water pumping. The configuration with two modules and 25 lit/h/module water spray was called case 'A' and the configuration with three modules and 5 lit/h/module and 25 lit/h/module water spray were called case 'B1' and case 'B2', respectively were used in the test. In case A and B1 the module temperature was decreased, and the reduction in case A was higher than case B1 as shown in Fig. 9. The experimental results indicated that the system performance was significantly improved by spraying water on the PV module. Irwan et al. [15] studied experimentally the performance of the PV panel by using water cooling method. Indoor test was carried out by a solar simulator consisted of twenty 500 W halogen lamps. Two units of 50W Monocrystalline PV panel were used in the test. A DC water pump was used to spray water was connected to the front surface of one of the panel and the other panel was used as a base panel. It was observed from the experimental results that the operating temperature of the PV panel with water cooling system was reduced by 5–23°C and the power output was increased by 9–22%. So the water cooling is one way to enhance the electrical efficiency of the PV panel as shown in Fig

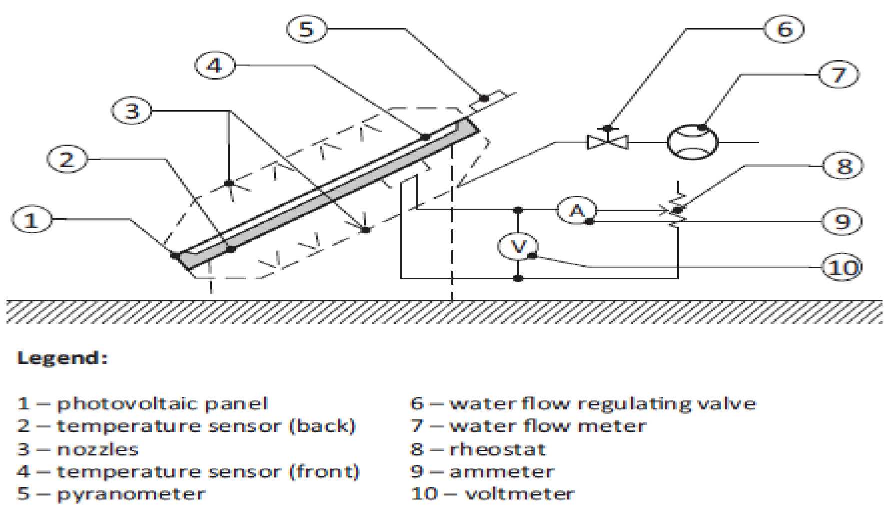


Figure 3.3 Schematic diagram of water spray cooling [44]

3.2.1.3 Fins Cooling

Several studies have investigated numerically and experimentally the performance of the PV cells using different types and shapes of fins. Chandrasekar et al. [19] used aluminium fins combined with cotton wick as a passive cooling system to maintain the temperature of the PV panel. The cooling system was consisted of three aluminium fins (630 × 100 × 60 mm) with cotton wick attached to the back side of the crystalline silicon PV cells as shown in Fig

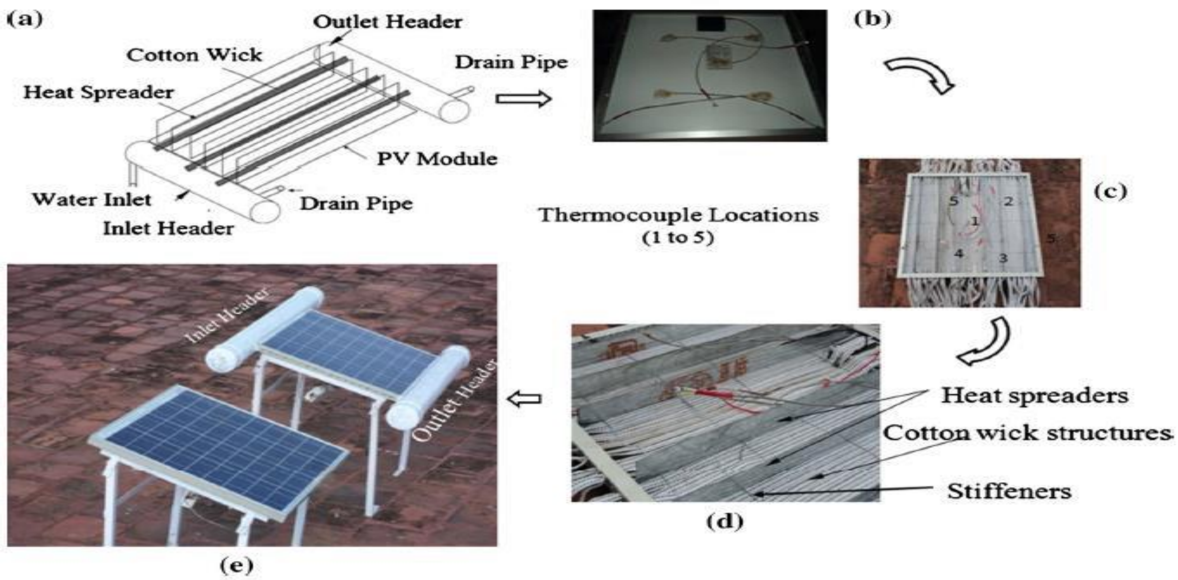


Figure 3.4 Fins integrated with PV panel [44]

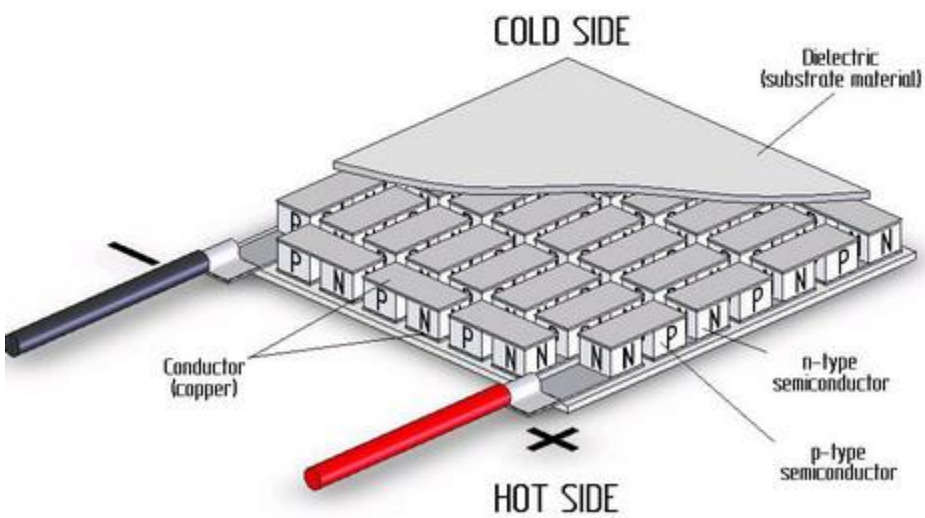
It was observed from the experimental results that the maximum temperature of the PV panel was decreased 12% by using the cooling system and the output power was increased by 14%. Nehari et al. [20] numerically investigated the proper length of the fins to identify the enhancement of the PV panel power during the passive cooling by phase change material (PCM). It was noted that the fins was remarkably decreased the temperature of the PV cells compared to the case without fins. In addition, the fins length of 25, 30, and 35 mm provide a preferable PV cell cooling.

3.2.1.4 Thermoelectric cooling

The basics of thermoelectric cooling lie in the phenomena of Peltier effect. The Peltier effect occurs at an electrified junction as a heat flow in specific direction. On one side of the junction it produces heating, and on the other, cooling effect. The heating /cooling intensity depends upon the temperature difference produced by voltage/ current intensity. Cooling effect consumes electricity.

Thermoelectric Cooler (TEC) is a semiconductor based electronic part incorporates a number of

Thermos electric components, which are connected thermally in parallel and electrically in series. The thermoelectric elements are made out of a couple of p-type and n-type semiconductors. When electric current flows across the thermoelectric components, the heat is conveyed from the cold side to the hot side caused by the Peltier effect. Two unique semiconductors, one n-type and one p-type, are used because they need to have different electron densities. The semiconductors are placed thermally in parallel to each other and electrically in series and then joined with a thermally conducting plate on each side. When a voltage is applied to the free ends of the two semiconductors there is a flow of DC current across the junction of the semiconductors causing a temperature difference. The side with the cooling plate absorbs heat which is then moved to the other side of the device where the heat sink is. The cooling ability of the total unit is then proportional to the number of TECs in it.



Figures 3.5 Thermoelectric cooling [45]

Some benefits of using a TEC are

- No chlorofluorocarbons (CFC).
- Temperature control to within fractions of a degree can be maintained.
- Flexible shape (form factor); in particular, they can have a very small size.
- Can be used in environments that are smaller or more severe than conventional refrigeration.
- Long life, with mean time between failures (MTBF) exceeding 100,000 hours.

3.2.1.5 Nano fluids cooling

Nano fluids are considered to be dispersed mixtures of cooling fluid and solid nanoparticles. Most of the particles used are metal oxides, per example Al_2O_3 or CuO particles. Weight percentage of dispersed particles is around 0.1- 0.2%. The particles have Brownian motion through cooling fluid. Main advantages of Nano fluids are greater thermal conductivity and greater heat capacity. Main disadvantage is pumping process and overall change in flow regime i.e. characteristic turbulent flow occurs at different speeds and geometries, when compared with regular fluids. Klenstreur [] made a numerical model for water and Nano fluid cooling of silicon PV cells and showed the cooling potential of Nano fluid to be somewhat greater than that of water. Electrical efficiency seems to maintain higher values even at increased temperatures, when PV panel is cooled with Nano fluids. The efficiency difference between water and Nano fluid cooling is significant during higher outlet fluid temperatures, and it can be up to 1% total efficiency.

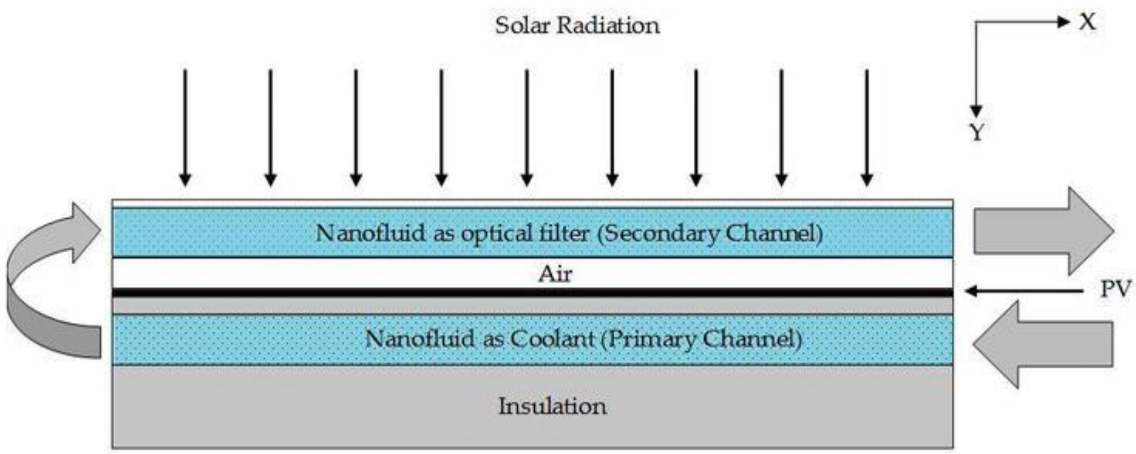


Figure 3.6 Nano fluids cooling [45]

Karimi and Rahimi [] used Boehmite Nano fluid to conduct cooling of polycrystalline module of 0.059m^2. Cooling was made on the back side of the module, via cooling ducts of two different shapes. It was shown that small percentage of Nano fluid in cooling water enhances temperature difference of module surface. For a concentration of 0.1% wt. of Nano fluid, and fluid flow of 0.006 kg/s, a decrease in temperature of about 4.5^{o}C was observed, when compared with water cooling. Strong influence of flow channel shape on cooling intensity was observed. It was proven that Nano-fluid cooling efficiency mainly depends of Nano-fluid content and local flow regime.

3.2.1.6 Cooling with PCM

The improvement in the photovoltaics' energy conversion efficiency can primarily be ensured either by reducing the PV panel's operating temperature, or by applying novel PV technologies, sense of novel materials. In this line of approach, different active or passive based cooling techniques have been analyzed and examined in the last two decades with the primary goal of reducing PV panel operating temperatures and by that ensuring an efficiency increase. In general, in recent years, phase change materials (PCM) have also been considered in PV-PCM passive based cooling applications besides air and water as the assumed coolants for the given application. The authors in (Huang et al., 2004) investigated a PV-PCM system aiming at

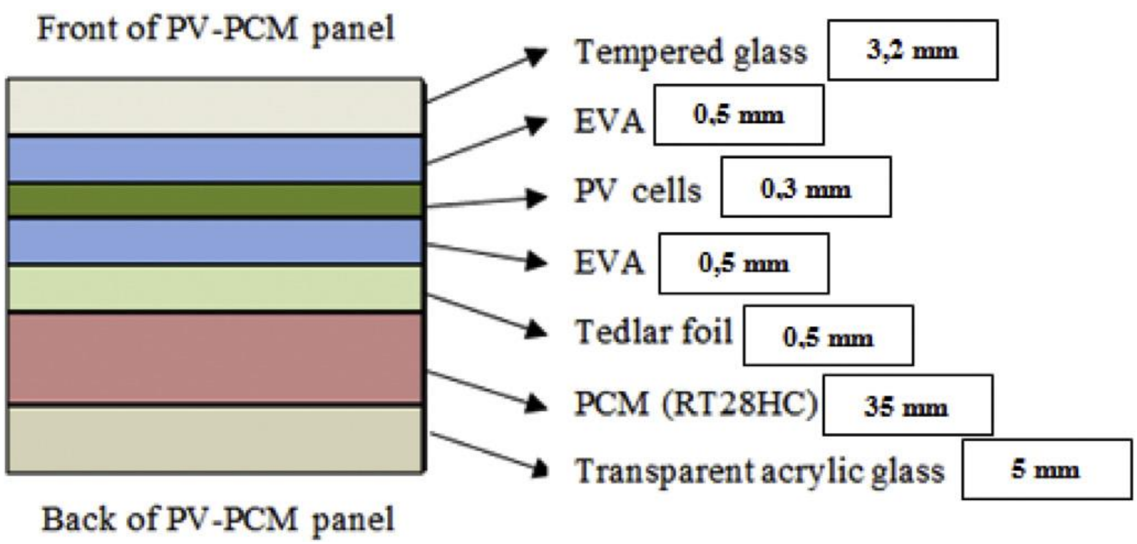


Figure 3.7 Schematic diagram of PV- PCM system [44]

increasing the PV panel's efficiency. This was done by using a one-dimensional (1-D) finite volume method for the numerical analysis; the results of the analysis were verified by referring to experimental ones. Reduction in cell temperature was reported and an increase in the efficiency of the PV panel was monitored when incorporating a PCM into the PV system. Malvi et al. (2011) studied a combined PV solar thermal (ST) system that had incorporated a PCM. One of the interesting aspects of the assessment of PCMs on the efficiency of PV is that the former's temperature should be as low as possible, in order to lead to an increase of the PV's efficiency. On the other hand, as the phenomenon is, at least in some stages transitional, when the PCMs temperature is beyond the external temperature fluctuation, the PCM becomes inactive. It is therefore of particular interest to analyze the coupling of the PCMs impact on the PVs performance, both in its steady-state and its transitional phase, in order to determine the optimum type of PCM, considering the climatic and the operational conditions. The second aspect, i.e. general importance related to the further research an analysis of the PV-PCM systems is potential long-term favorable benefit on the PV panel lifetime due to cooling effect associated with the application of the PCM material. Studies shows that PV-T technology is very promising and has a very large potential in the coming years, because the energy generated from renewable resources increases every year and this technology can be used in many different systems.

3.3 Conclusion

In this chapter we have discussed why photovoltaic cooling is required and different types of cooling such as air cooling, water cooling, thermoelectric cooling, Nano fluid cooling and phase changing material cooling. In this thesis work fabrication of hybrid PV & Thermal system using PCM, cooling using PCM as well as waste heat recovery using water have been taken into consideration. In the next chapter we are going to discuss experimental set up, apparatus used and their specification.

CHAPTER 4

Experimental Methodology & Setup

4.1 Introduction

As a result of gradually shrinking fossil fuel supplies and increasing energy demands, efforts have been made to explore alternative energy resources. Among these resources, solar energy is the most abundant, clean and renewable alternative energy source available. PV system performance is highly dependent on location, weather and condition of PV panels. Panel temperature, shading, inclination angle can affect the system performance up to 70%. Degradation of the panels can also reduce the system performance. So continuous monitoring of PV system is important for maintaining and improving their performance.

4.2 Experimental setup

The experimental set up is shown in photograph 4.1. Experimental set up consists of two solar panel made by TATA BP each of 35 Watt. The PV cell absorbs the light. Part of the light is converted into heat in the PV cell, which can result in an increase in the operating temperature of the PV cell. In order to maintain the temperature of the PV unchanged, a cooling system is integrated which consists of two parts

1. Gravity feed pumping system for water flow through heat exchanger
2. Heat exchanger integrated with PV panel for removing heat from PV panel.

Figure 4.1 Side view of Experimental Setup

Figure 4.2 Front view of Experimental setup

SaVE OM 37 (Phase changing material) is sealed inside jacketed type heat exchanger and cold water is flowing through the copper tube of the heat exchange to remove the heat.

Two data logger is placed in the surface two PV panel to log the surface temperature data of PV panel continuously.

4.2.1 Experimental Setup position

The position of the photovoltaic panel is very important to its effective function. In order for the PV to produce the maximum amount of energy, it should intercept the highest possible flux. This occurs when the panel is perpendicular to the sun's incoming rays.

The maximum variation of the sun's angle is ± 23.5^o. The reason behind select the latitude angle is to get the most energy for the whole year from the fixed flat- plate arrays. The average position of the sun angle relative to the plane of the panel occurs at the two equinoxes. The optimum tilt angle is site- dependent and calculation of this angle requires a solar irradiance prediction computer programme. There is a common agreement that for the higher latitudes the optimum tilt angle is usually 10 to 15^o lower than the latitude angle. Hence a general rule of thumb for the tilt angle of PV panels is to choose an angle which is zero to 15^o lower than the site latitude angle.

4.3 Description of Experimental Layout

Solar photovoltaic module, Data acquisition system, Heat exchanger, Phase changing material, Piping system, Digital multi meter have been used in this experiment. The function of each of them is discussed below

4.3.1 Solar Photovoltaic module

Figure 4.3 Solar Photovoltaic module

At STC (1000W/m^2), AM 1.5 Spectrum, Cell Temperature 25^{o}C

Manufactured By	Tata BP Solar
Model NO	
Peak Power	At 16.4 (Min Pld) 37.0W
Voltage(V_{max})	17.0 V
Current(I_{max})	2.4 A
Open Circuit Voltage(V_{OC})	21.8V
Short Circuit Current(I_{SC})	2.6A
Minimum Bypass Diode	4A

Table 4.1 Technical Specification of Solar Panel

4.3.2 Heat Exchanger

Figure 4.4 Heat Exchanger

This Heat exchanger is manufactured by RAMAN INDUSTRIES PVT LTD. This is jacketed type Heat exchanger. There is two inlet and two outlet. Phase changing material is inserted through one inlet and filled the whole cavity of the heat exchanger then the inlet and corresponding outlet is sealed so that Phase changing material can't escape from the Heat exchanger. Cold water is flowing through the copper tube(diameter 10mm) inside the Heat exchanger.

4.3.3 Digital multi-meter

A multi-meter or multi-meter, also known as a VOM (volt-ohm-milliam-meter), is an electronic measuring instrument that combines several measurement functions in one unit. A typical multi-meter can measure voltage, current, and resistance. Analog multi-meters use a micro-ammeter with a moving pointer to display readings. Digital multi-meters (DMM,DVOM) have a numeric display shown in figure 4.5

Figure 4.5 Digital Multi-meter

4.4 Data acquisition system

We have used Elitech RC5+ data logger for collecting the data. The technical specification is discussed in table 4.2

Technical Specifications

Recording Options	Multi-Use	Certifications	EN12830, CE, RoHS
Temperature Range	-30°C to 70°C	Validation Certificate	Hardcopy
Temperature Accuracy	±0.5(-20°C/+40°C);±1.0(other range)	Software	ElitechLog Win or Mac (latest version)
Temperature Resolution	0.1°C	Report Generation	PDF /Word/Excel/Txt report
Data Storage Capacity	32,000 readings	Password Protection	Optional on request
Shelf Life/Battery	Six months[1]/CR2032 button cell	Connection Interface	USB 2.0, A-Type
Recording Interval	10s~24hour adjustable	Alarm Configuration	Optional, 2 points
Startup Mode	Button	Reprogrammable	With free Elitech Win or MAC software
Stop Mode	Button, software or stop when full	Demensions	80mmx33mmx14mm(LxWxH)
Protection Class	IP67		
Weight	35g		

1. Depending on optimal storage conditions (±15°C to +23°C/45% to 75% RH)

Figure 4.6 Data logger

4.5 Process Parameter

Based on previous literature review it is noticed that the increase of PV cell temperature affects the solar panel performance. Hence in the present investigation SaVE OM37 a commercial Phase changing material is used inside a Heat exchanger connected with the PV panel.

In present investigation we will only consider temperature of PV cells.

4.6 Conclusion

The experimental method is a systematic and scientific approach to research in which the researcher manipulates one or more variable, and controls and measures any change in other variables. Different types of components and their specifications, experimental setup and its position have been discussed in this chapter. In the next chapter we have discussed about Phase changing material.

CHAPTER 5

Phase Changing Material & its characteristics

5.1 Introduction

Energy becomes the one of the basic necessities of life after food. Even in food preparation energy is required. Access to energy resources controlled by the four parameters and these are availability, adaptability, acceptability and affordability. Solar power has the potential to meet all these requirements. As a result solar power has the most potential in solar rich countries in terms of providing energy security. For huge amount of energy generation from the solar panels it needs to improve the efficiency as well as recovery of waste heat. Cooling is a very important factor for improving the efficiency of solar panels, Phase changing material is one of them. In present work commercial phase changing material SaVE OM37 is used. The properties of PCM is discussed below in this chapter.

5.2 Phase Changing Material

A Phase Change Material (PCM) is a substance which is capable of absorb and release large amount of energy, melting and solidifying at a certain temperature. Heat is released or absorbed when the material changes from solid to liquid and vice versa. So PCM are known as latent heat storage unit (LHS). Latent heat storage can be achieved through liquid →solid, solid →liquid, solid →gas and liquid →gas phase changes. However, only solid →liquid and liquid →solid phase changes are practical for PCMs. Liquid →gas phase changes are impractical for thermal storage because large volumes or high pressures are required to store the materials in their gas phase otherwise PCM can lost in environment. Initially, solid–liquid PCMs behave like sensible heat storage (SHS) materials; their temperature rises as they absorb heat. Unlike conventional SHS materials, however, when PCMs reach the temperature at which they change phase (their melting temperature) they absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase.

5.2.1 Classification of PCM

5.2.1.1 Organic PCMs

Organic PCMs are mainly ester based PCM, Paraffin or bio based PCMs

• Advantages

• Chemically stable

• High heat of fusion

• Freeze without much undercooling

• Ability to melt congruently

• Self nucleating properties

• Recyclable, safe and nonreactive

• Carbohydrate and lipid based PCMs can be produced from renewable resources

• Disadvantages

• Volumetric latent heat storage capacity can be low.

• This type of PCMs can be flammable.

5.2.1.2 Inorganic

Salt hydrates (MnH_2O) are mainly Inorganic PCM

• Advantages

• High thermal conductivity & sharp melting point.

• High volumetric latent heat storage capacity & high heat of fusion.

• Availability and low cost.

• Disadvantage

• Incongruous melting and phase separation upon cycling which can cause a significant loss in latent heat enthalpy.

• Nucleating agents are needed and they often become inoperative after repeated cycling.

• Change of volume is very high and super cooling is major problem in solid–liquid transition.

5.2.1.3 Inorganic Eutectics

Inorganic-inorganic compounds and c- inorganic compounds are mainly known as inorganic eutectics

Advantages

• Volumetric storage density is slightly above organic compounds.

• Some inorganic eutectics have sharp melting point similar to pure substance.

Disadvantages

• They still have the same disadvantages as inorganic PCMs, such as reduced thermal performance upon cycling, corrosivity, high volume change, and high super cooling.

• Sharp crystals may form when the salt hydrate PCM solidifies, potentially causing leaks in cases of macro-encapsulation.

5.2.1.4 Hygroscopic

Most of the natural building material are hygroscopic in nature. They can absorb as water condenses and release water as water evaporates. The process is thus

• Condensation (gas to liquid) $\Delta H<0$; enthalpy decreases (exothermic process) gives off heat.

• Vaporization (liquid to gas) $\Delta H>0$; enthalpy increases (endothermic process) absorbs heat (or cools).

So this process liberates a small quantity of energy, large surfaces area allows significant (1–2 °C) heating or cooling in buildings. Wool insulation, earth/clay render finishes are the example of hygroscopic material.

5.2.1.5 Solid – solid Phase changing material

A specialized group of PCMs that undergo a solid/solid phase transition with the associated absorption and release of large amounts of heat. This type of material can change their crystalline structure from one lattice configuration to another at a fixed and well defined temperature. In this process they can absorb or release huge amount of heat as latent heat. Such materials are useful because, unlike solid/liquid PCMs, they do not require nucleation to prevent super cooling. As it is solid to solid phase change material leakage problem is not happened like solid to liquid phase change material. Currently the temperature range of solid-solid PCM solutions spans from -50 °C (-58 °F) up to +175 °C (347 °F).

5.2.1.6 Commercially available PCMs

There is so many commercial PCM available in different temperature range. They are

• BioPCM by Phase change energy solution

• Astorstat HA by Honeywell

• Climsel C by Climator

• Crodatherm by Croda International plc

• PureTemp by PureTemp LLC

• RT by RUBITHERM GmbH

• SavE OM by Pluss Technologies Ltd

5.3 PCM USEFOR THIS EXPERIMENT

Figure 5.1 & 5.2 Sample of PCM in solid & liquid state [pic courtesy PLUSS]

*s*av*E®* OM37 is an organic chemical based PCM having nominal melting temperature of 37 oC . It stores thermal energy as latent heat in its crystalline form. On changing phase this latent heat is released or absorbed, allowing the ambient temperature within the system to be maintained.

OM37 is an organic mix of fatty acids allowing equilibrium between solid and liquid phases to be attained at the melting point. The sav*E®* OM37 is free flowing in molten state and can be encapsulated in various forms.

5.3.1 Why *savE® OM37?*

savE® OM37 has a nominal phase change temperature of 37 oC , a temperature that makes it ideal for several heating/cooling thermal energy applications . Some of its salient features include

• The salt is chemically and thermally stable by using PLUSS® proprietary additives.

• Mixture of organic.

5.3.2 Technical Specification

Product : *SavE®*

Series : OM37

Description : Mixture of Organic materials

Appearance : White waxy flakes (below 37 ^{o}C)

5.3.3 T- History Test

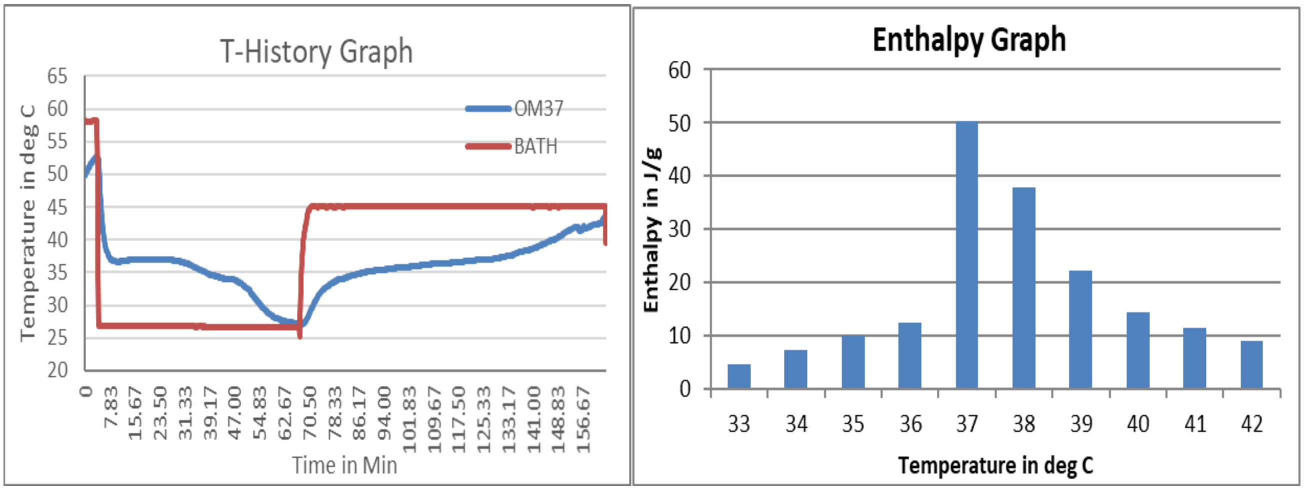


Fig 5.3 T-History graph [pic courtesy PLUSS TECHNOLOGY]

A 30g sample is taken in a test tube in molten condition and placed in a temperature controlled bath. A temperature sensor is placed in the test tube and bath to record the temperatures using a data logger. The bath is maintained at around 20 oC during the freezing cycle and at around 47^{o}C during the melting cycle.

5.3.4 Properties of PCM

Property Value*	**Test Method**	**Test Conditions (if any)**
Melting Temp (°C) 37	PLUSS® T-History	@ 47 oC Liquid Bath
Freezing Temp (°C) 36	PLUSS® T-History	@ 20 oC Liquid Bath
Latent Heat (kJ/kg) 179	PLUSS® T-History	@ 37 to 28 oC
Liquid Density (kg/m3) 860	ASTM D891-95	@ 47 oC
Solid Density (kg/m3) 973	ASTM D792-08	@ 30 oC
Liquid Specific Heat (kJ/kgK) 2.63	PLUSS® T-History	@ 47 oC
Solid Specific Heat (kJ/kgK) 2.55	PLUSS® T-History	@ 30 oC
Liquid Thermal Conductivity (W/mK) 0.13	KD2Pro @ 57 oC	
Solid Thermal Conductivity (W/mK) 0.16	KD2Pro @ 07 oC	

Base Material - Organic

Congruent Melting - Yes

Flammability- No

Thermal Stability (Cycles) -2000

Maximum Operating Temperature (°C) -120^{o}C

Flash Point (°C) -200^{o}C

5.4 Conclusion

This chapter covers the properties of different types of phase changing material. It also covers the properties of commercial PCM SaVE OM37 used in our project. It has been concluded that phase changing material are very important for solar photovoltaic cooling system for minimizing the losses and improving the efficiency. In next chapter, all the results coming out from different studies of the work is presented.

CHAPTER 6

Result & Discussion

6.1 Introduction

As mentioned in the Experimental procedure our main aim of these experiment is to observe hybrid PV & Thermal system is efficient or not. For that purpose we have considered only panel temperature as a variable parameter. So we have recorded surface temperature of panel for both hybrid PV & Thermal system with pcm and panel without pcm. Experimental procedure of 10 days experiments has also been discussed in this chapter.

The entire experiment is conducted at rooftop of Energy Science and Technology department, Jadavpur University.

6.2 Results of Experiment 1

Experiment 1 has been conducted on 25.04.2019 from 11.30 AM to 3.30 PM. The study is aimed to find variation of temperature of PV panel of PCM system and the normal system.

In experiment 1

Temperature	PCM System	Normal System
Highest	58.3	58.6
Lowest	33.7	33.7
Average	52.7	54.3

So the change of average temperature is 1.6^{o}C.

So 1.6^{o}C cooling is done using Phase changing material.

Highest :	58.3 °C	**Start Time :**	04/25/2019 11:23:17
Lowest :	33.7 °C	**Stop Time :**	04/25/2019 15:43:17(Temporary)
Average :	52.7 °C	**Elapsed Time :**	4hr 20min
MKT :	53.6 °C	**Data Points :**	131
Alarm At(Te):	N/A		

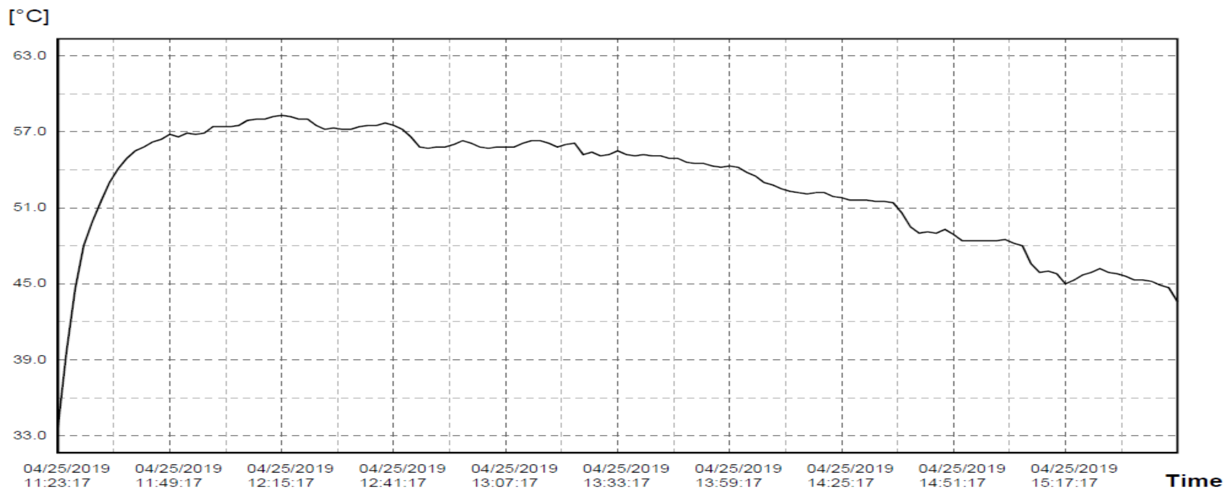


Figure 6.1 Shows the variation of temperature with time of PCM system of experiment 1

Highest :	58.6 °C	**Start Time :**	04/25/2019 11:22:46
Lowest :	33.3 °C	**Stop Time :**	04/25/2019 15:42:46(Temporary)
Average :	54.3 °C	**Elapsed Time :**	4hr 20min
MKT :	54.9 °C	**Data Points :**	131
Alarm At(Te):	N/A		

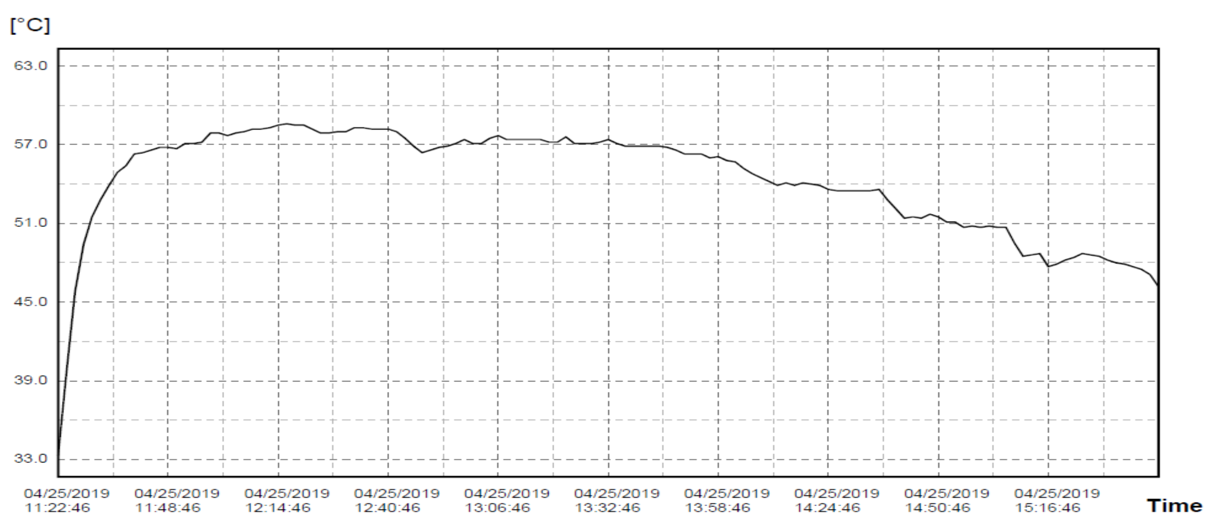


Figure 6.2 Shows the variation of temperature with time of normal system of experiment 1

6.3 Results of Experiment 2

Experiment 2 has been conducted on 02.05.2019 from 10.30AM to 3.30PM. The study is aimed to find variation of temperature of PV panel of PCM system and the normal system.

In experiment 1

Temperature	PCM System	Normal System
Highest	49.3	49.8
Lowest	32.0	31.8
Average	43.1	42.8

So the change of average temperature is 0.3^{o}C.

So 0.3^{o}C cooling is done using Phase changing material.

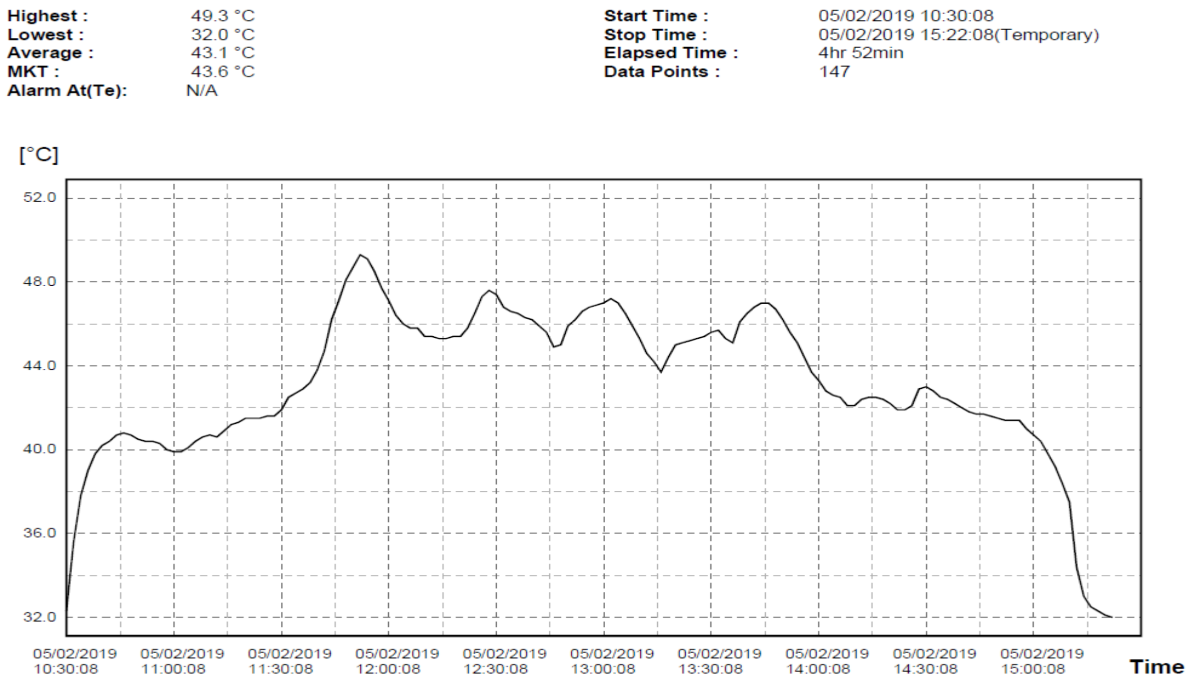


Figure 6.3 Shows the variation of temperature with time of PCM system of experiment 2

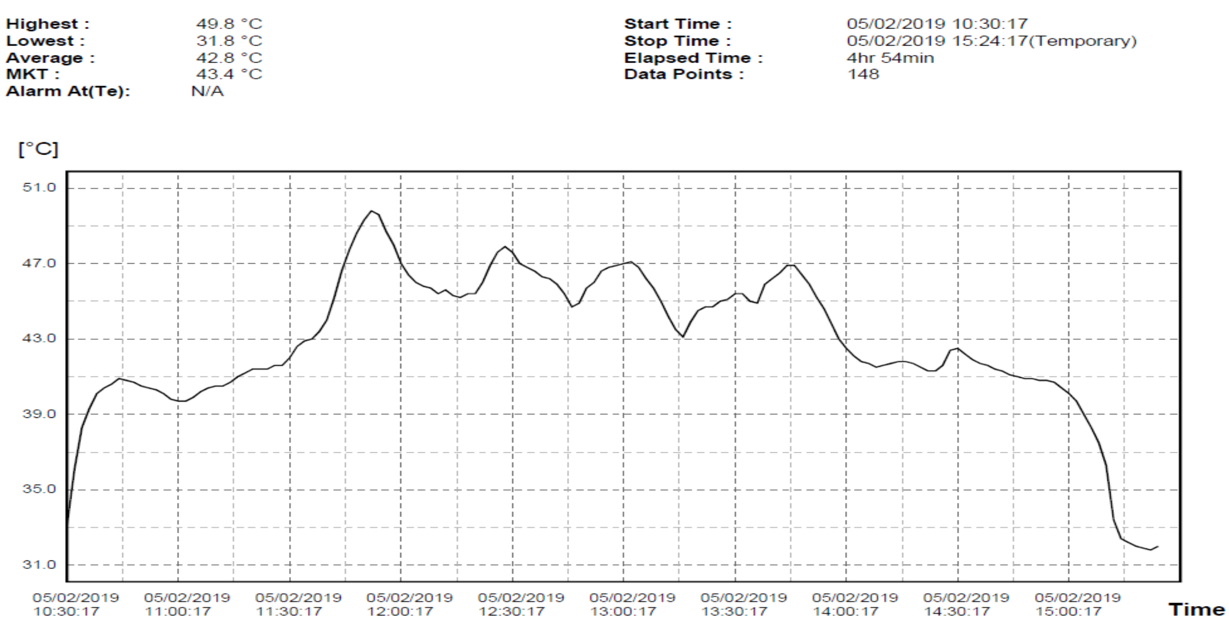


Figure 6.4 Shows the variation of temperature with time of normal system of experiment 2

6.4 Results of Experiment 3

Experiment 3 has been conducted on 06.05.2019from 11.30AM to 4.10PM. The study is aimed to find variation of temperature of PV panel of PCM system and the normal system.

In experiment 1

Temperature	PCM System	Normal System
Highest	56.1	56.9
Lowest	38.3	36.9
Average	51.1	53.0

So the change of average temperature is 1.9^{o}C.

So 1.9^{o}C cooling is done using Phase changing material.

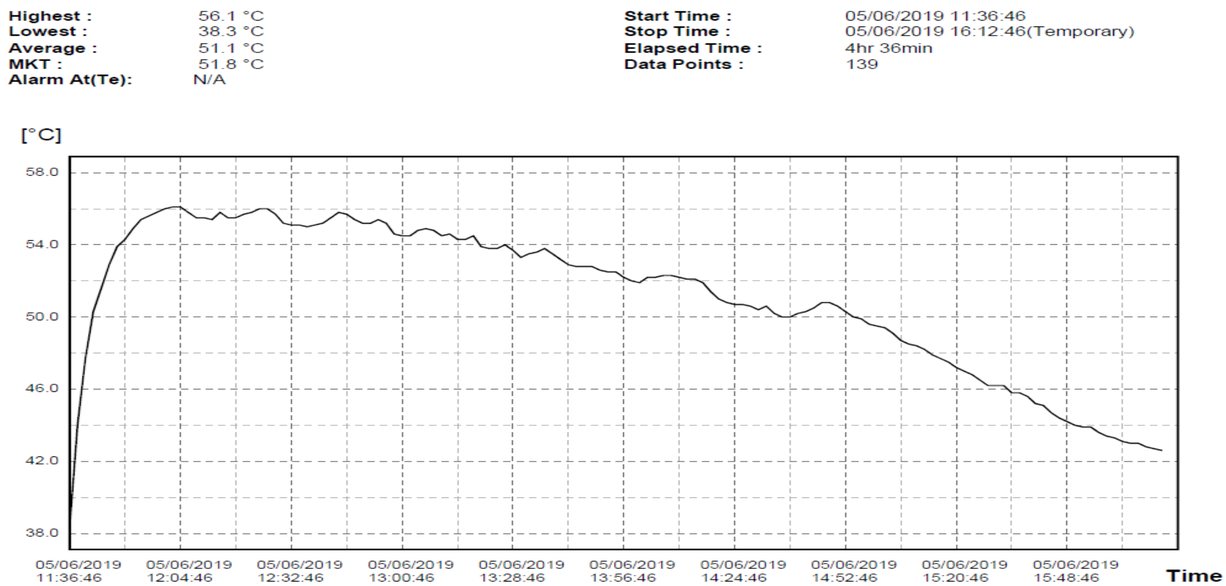


Figure 6.5 Shows the variation of temperature with time of PCM system of experiment 3

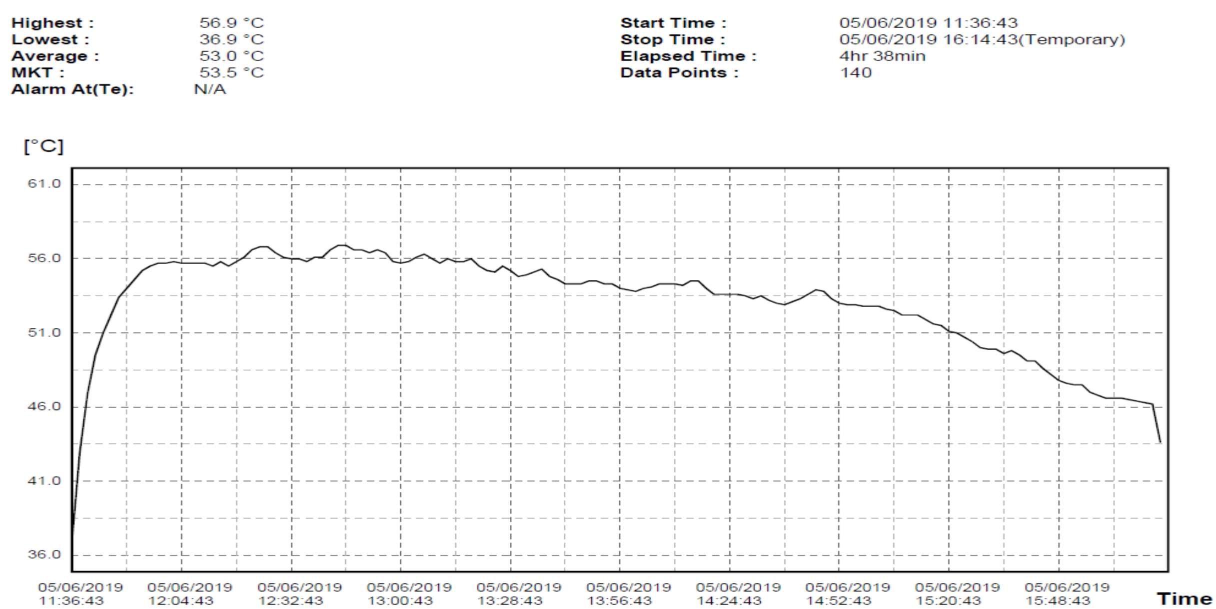


Figure 6.6 Shows the variation of temperature with time of normal system of experiment 3

6.5 Results of Experiment 4

Experiment 4 has been conducted on 07.05.2019 from 11.40AM to 4.00PM. The study is aimed to find variation of temperature of PV panel of PCM system and the normal system.

In experiment 1

Temperature	PCM System	Normal System
Highest	55.1	57.2
Lowest	38.0	38.4
Average	49.3	52.4

So the change of average temperature is 3.1^{o}C.

So 3.1^{o}C cooling is done using Phase changing material.

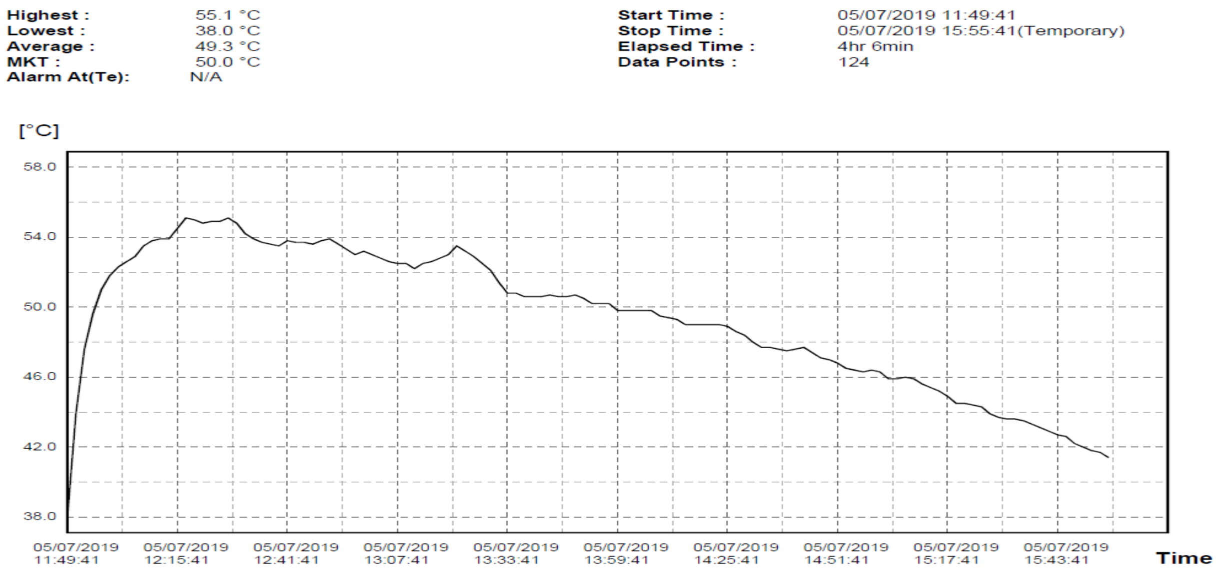


Figure 6.7 Shows the variation of temperature with time of PCM system of experiment 4

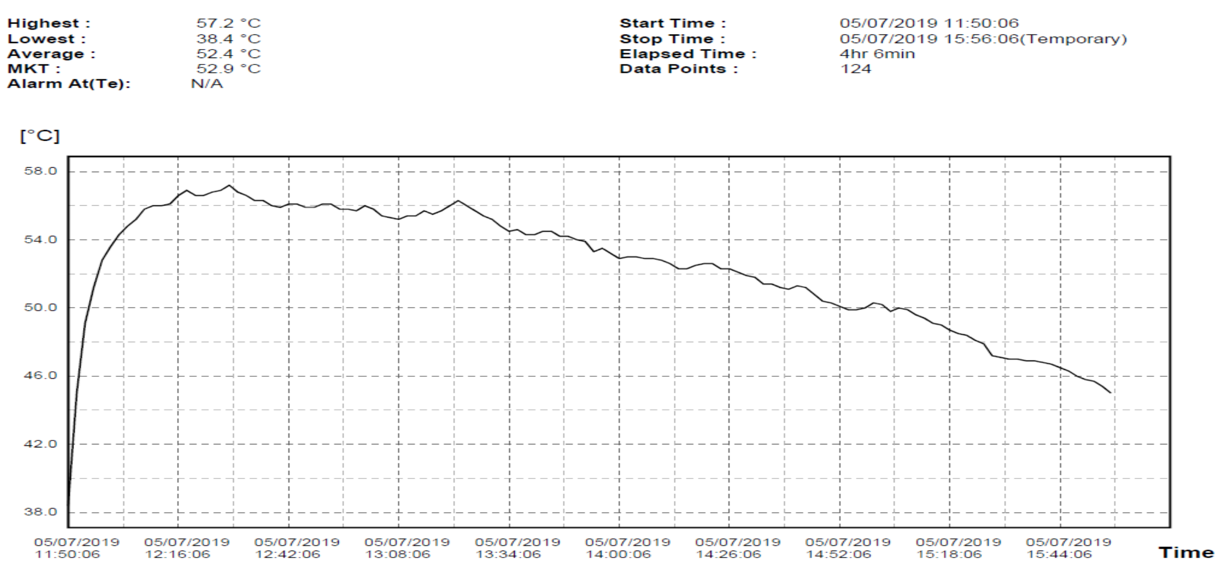


Figure 6.8 Shows the variation of temperature with time of normal system of experiment 4

6.6 Results of Experiment 5

Experiment 5 has been conducted on 08.05.2019 from 11.30AM to 3.50PM. The study is aimed to find variation of temperature of PV panel of PCM system and the normal system.

In experiment 1

Temperature	PCM System	Normal System
Highest	56.8	57.1
Lowest	33.5	33.2
Average	51.0	52.1

So the change of average temperature is 1.1^{o}C.

So 1.1^{o}C cooling is done using Phase changing material.

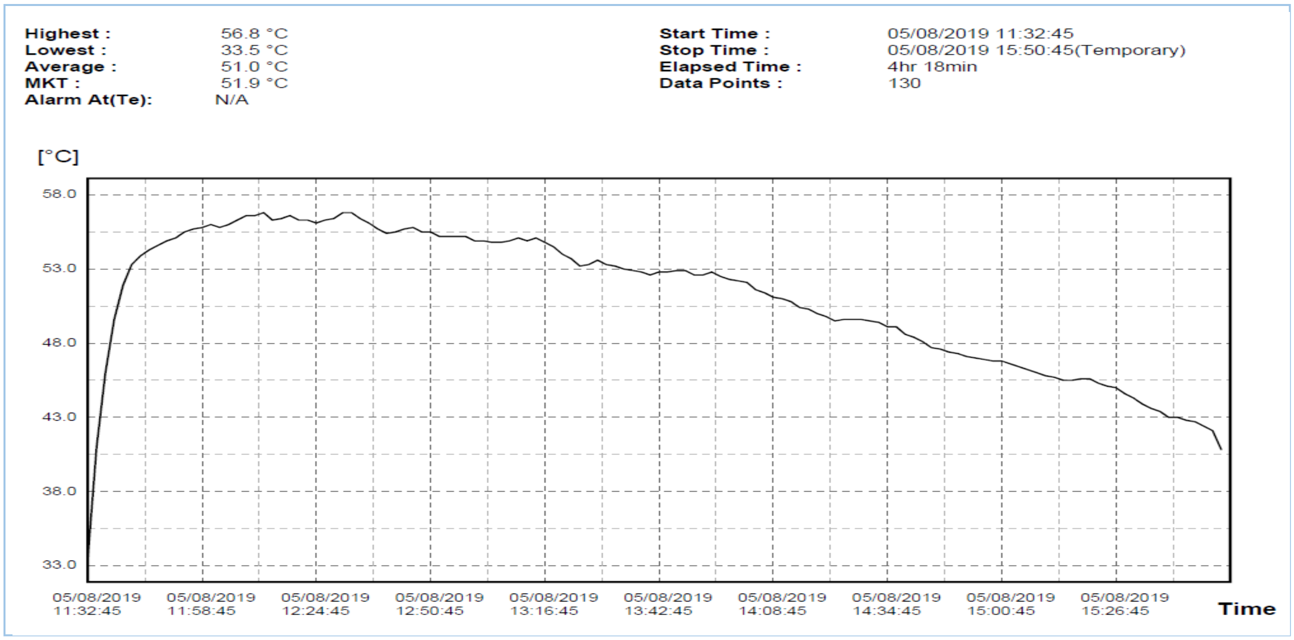


Figure 6.9 Shows the variation of temperature with time of PCM system of Experiment5

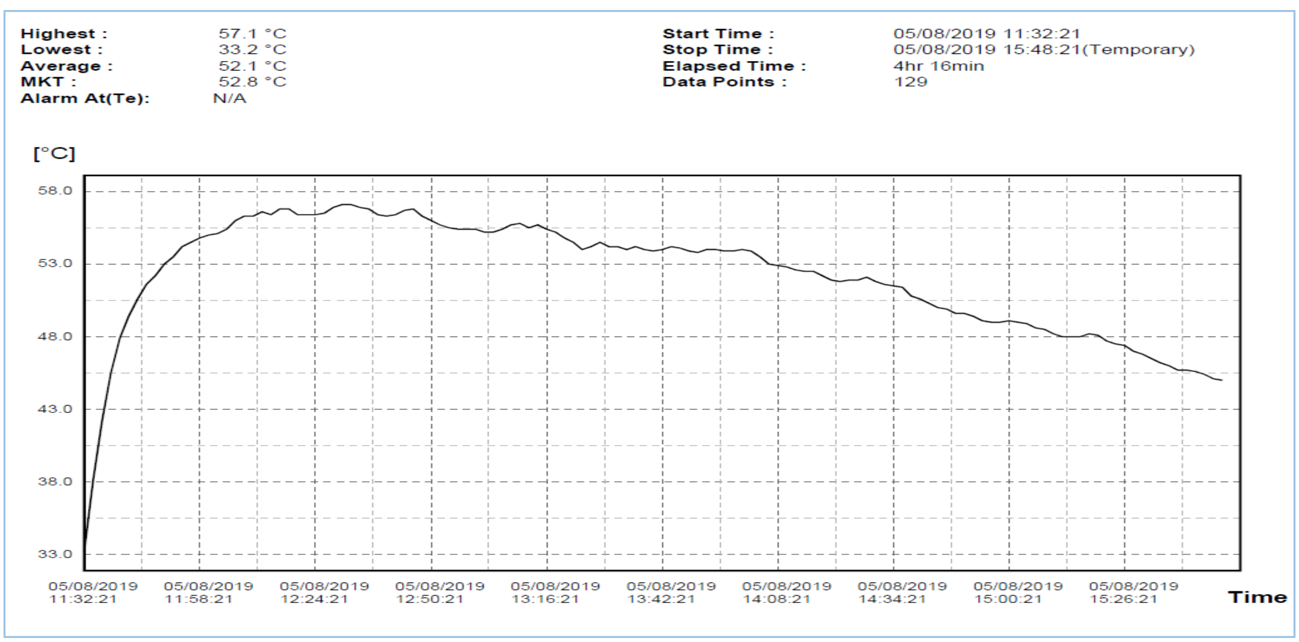


Figure 6.10 Shows the variation of temperature with time of normal system of experiment 5

6.7 Results of Experiment 6

Experiment 6 has been conducted on 13.05.2019 from 10.50AM to 5.20PM. The study is aimed to find variation of temperature of PV panel of PCM system and the normal system.

In experiment 1

Temperature	PCM System	Normal System
Highest	55.7	56.1
Lowest	33.8	33.6
Average	47.1	48.8

So the change of average temperature is 1.7 ^{o}C.

So 1.7^{o}C cooling is done using Phase changing material.

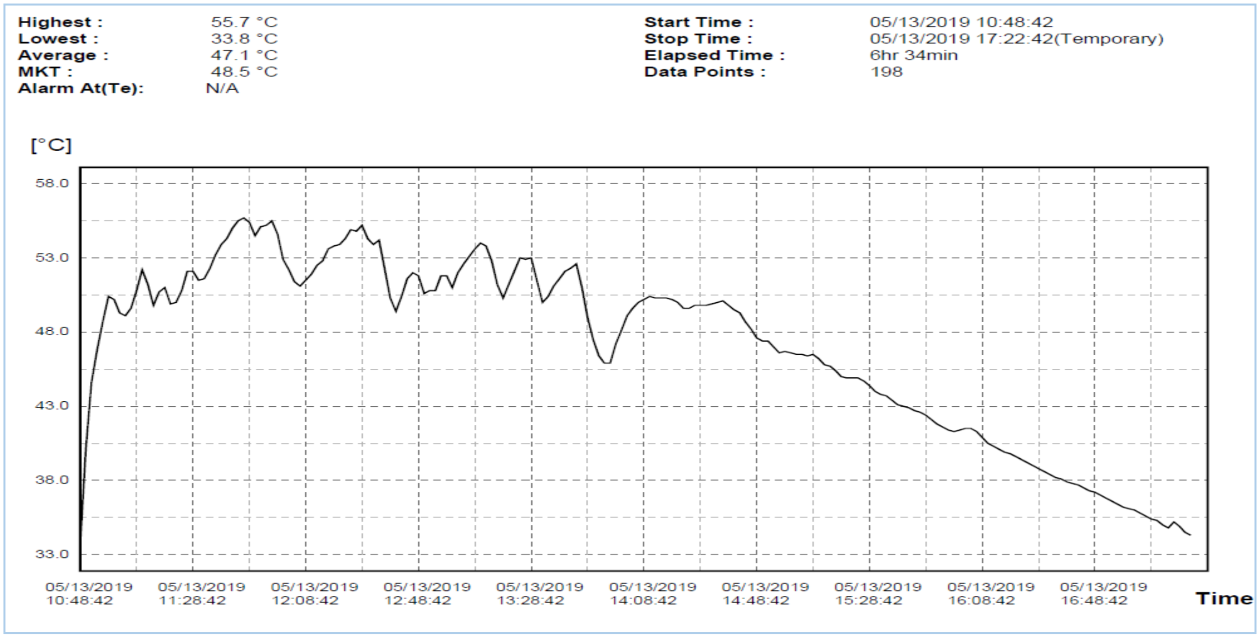


Figure 6.11 Shows the variation of temperature with time of PCM system of Experiment6

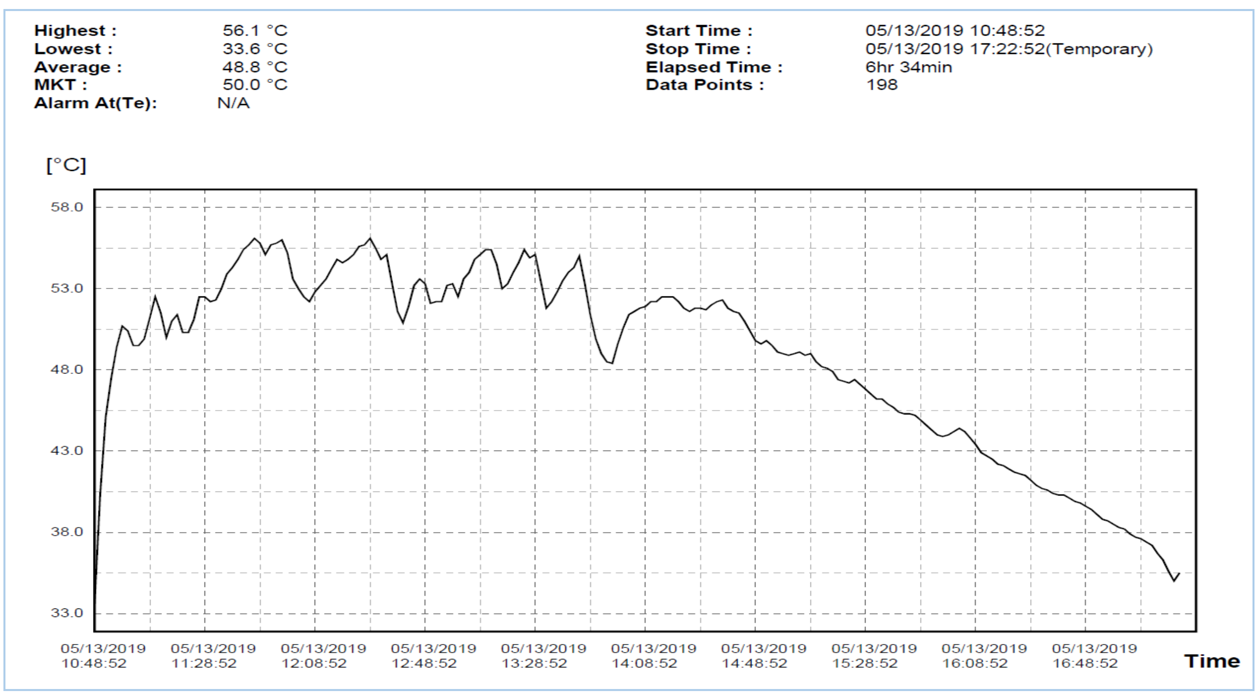


Figure 6.12 Shows the variation of temperature with time of normal system of experiment 6

6.8 Results of Experiment 7

Experiment 7 has been conducted on 14.05.2019 from 11.34AM to 4.30PM. The study is aimed to find variation of temperature of PV panel of PCM system and the normal system.

In experiment 1

Temperature	PCM System	Normal System
Highest	54.9	55.4
Lowest	34	34
Average	46.9	48.4

So the change of average temperature is 1.5 ^{o}.

So 1.5^{o}C cooling is done using Phase changing material.

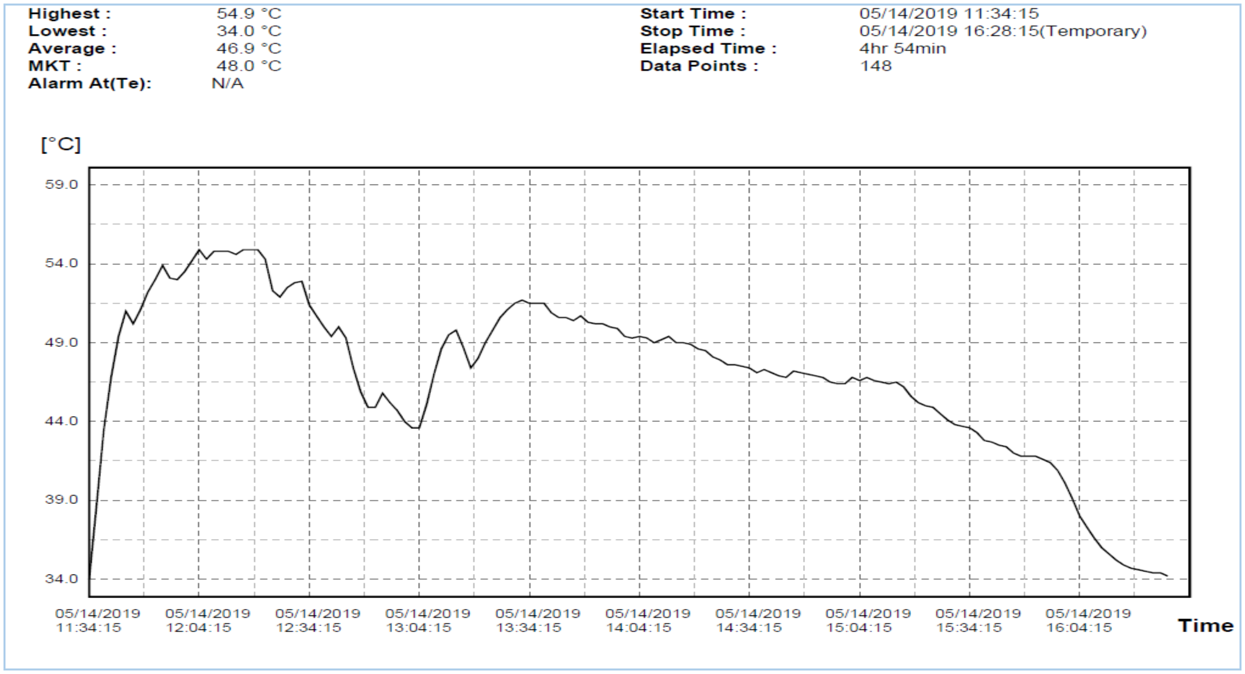


Figure 6.13 Shows the variation of temperature with time of PCM system of Experiment6

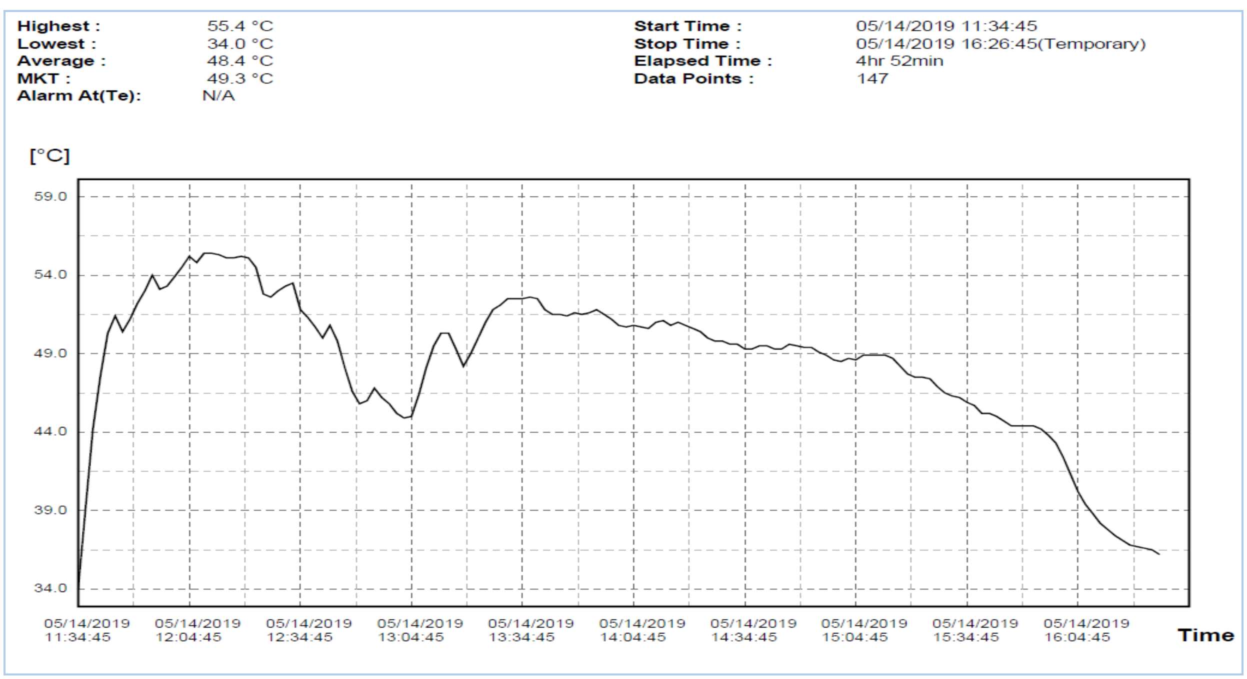


Figure 6.14 Shows the variation of temperature with time of normal system of experiment 6

6.9 Results of Experiment 8

Experiment 8 has been conducted on 15.05.2019 from 11.30AM to 4.15PM. The study is aimed to find variation of temperature of PV panel of PCM system and the normal system.

In experiment 1

Temperature	PCM System	Normal System
Highest	54.2	56.3
Lowest	33.9	34
Average	48.6	52

So the change of average temperature is 3.4 ^{o}C.

So 3.4^{o}C cooling is done using Phase changing material.

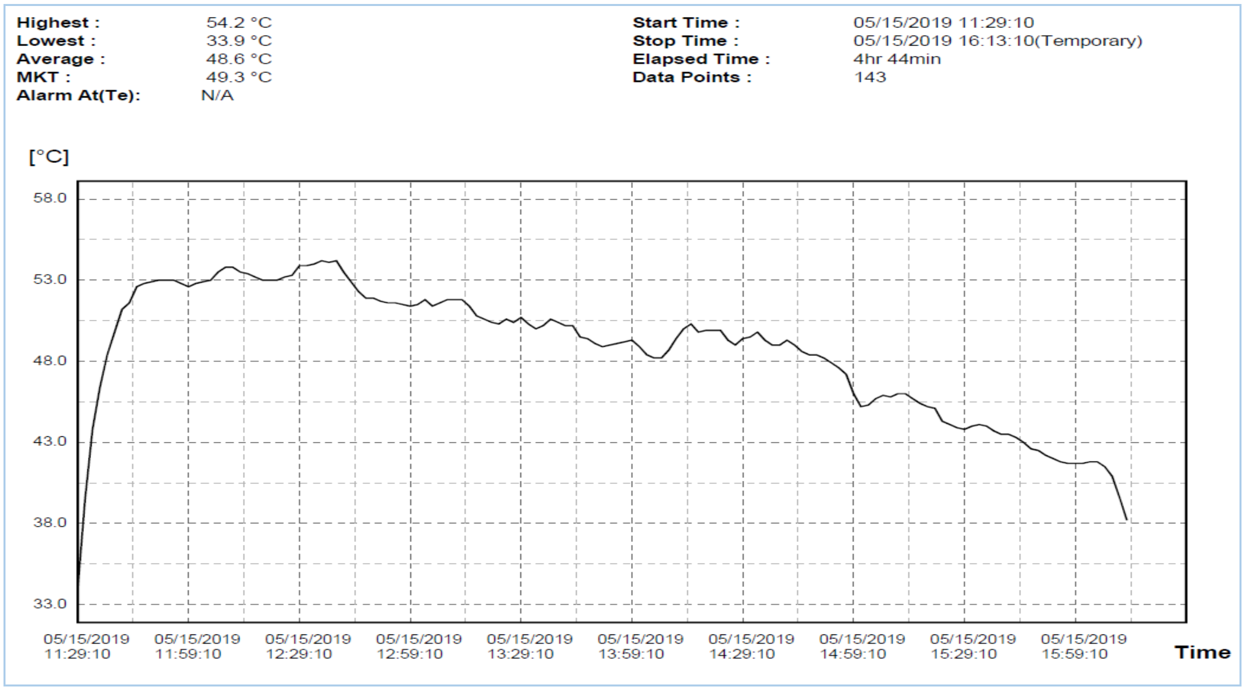


Figure 6.15 Shows the variation of temperature with time of PCM system of Experiment 8

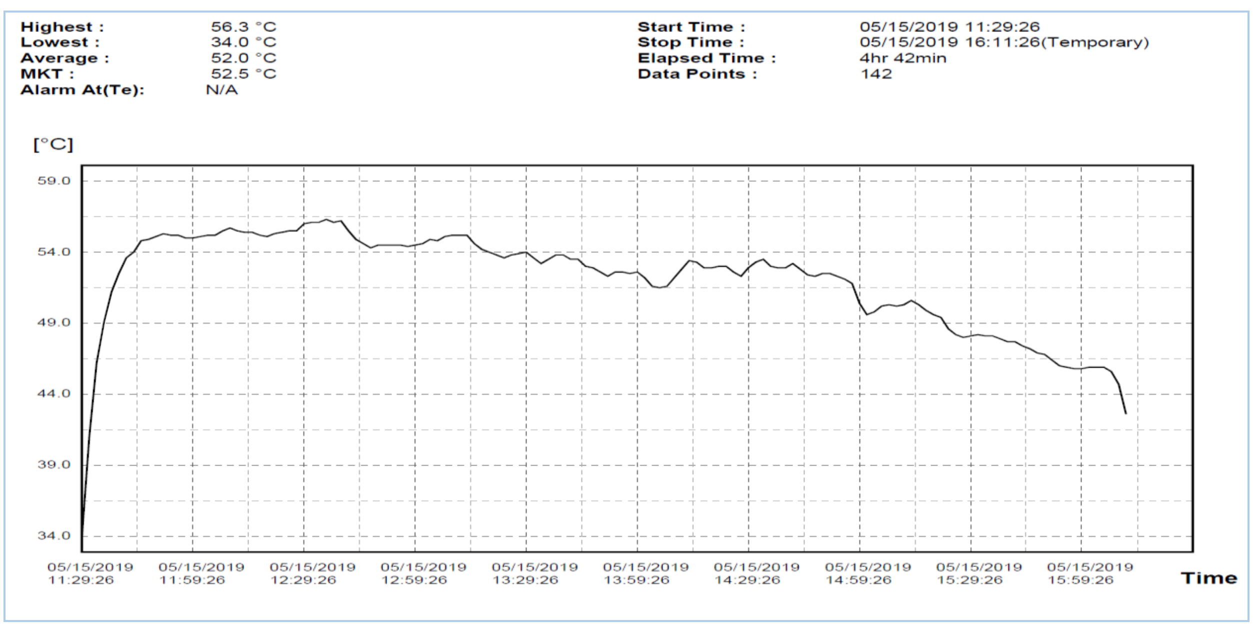


Figure 6.16 Shows the variation of temperature with time of normal system of experiment 8

6.10 Results of Experiment 9

Experiment 9 has been conducted on 16.05.2019from 11.40AM to 09.30PM. The study is aimed to find variation of temperature of PV panel of PCM system and the normal system.

In experiment 1

Temperature	PCM System	Normal System
Highest	57	58.7
Lowest	29.6	29.8
Average	37.3	37.8

So the change of average temperature is $0.5^{o}C$.

So 0.5 ^{o}C cooling is done using Phase changing material.

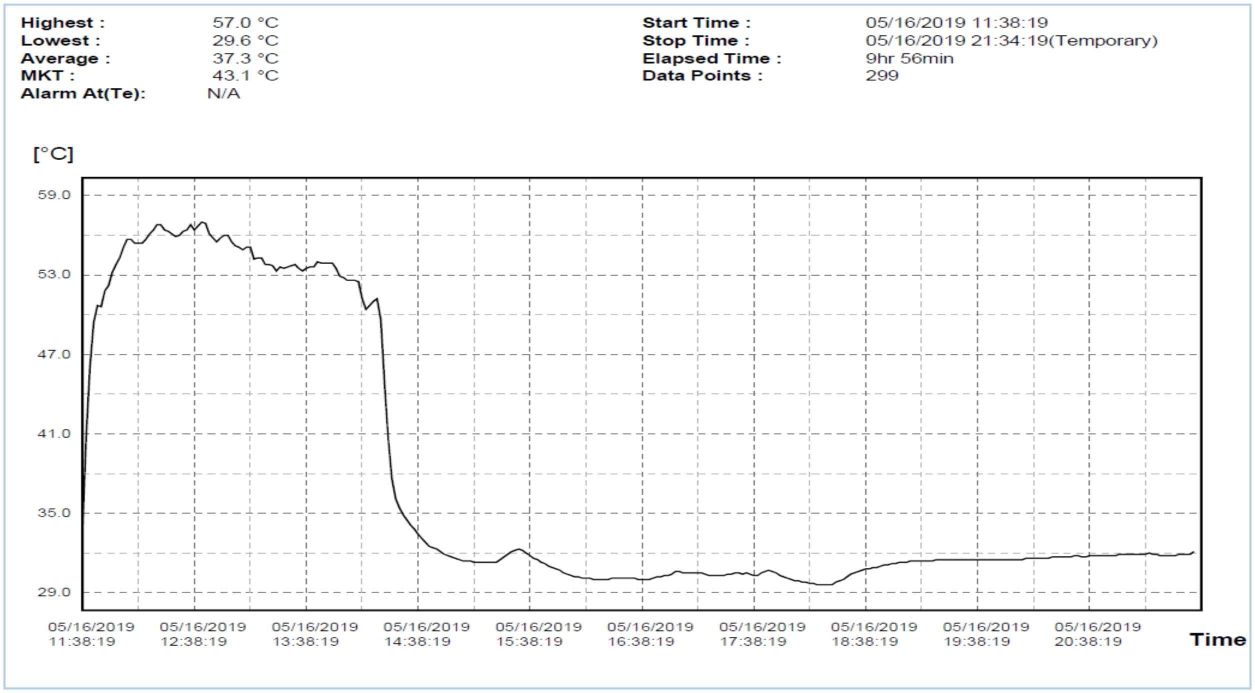


Figure 6.17 Shows the variation of temperature with time of PCM system of Experiment 9

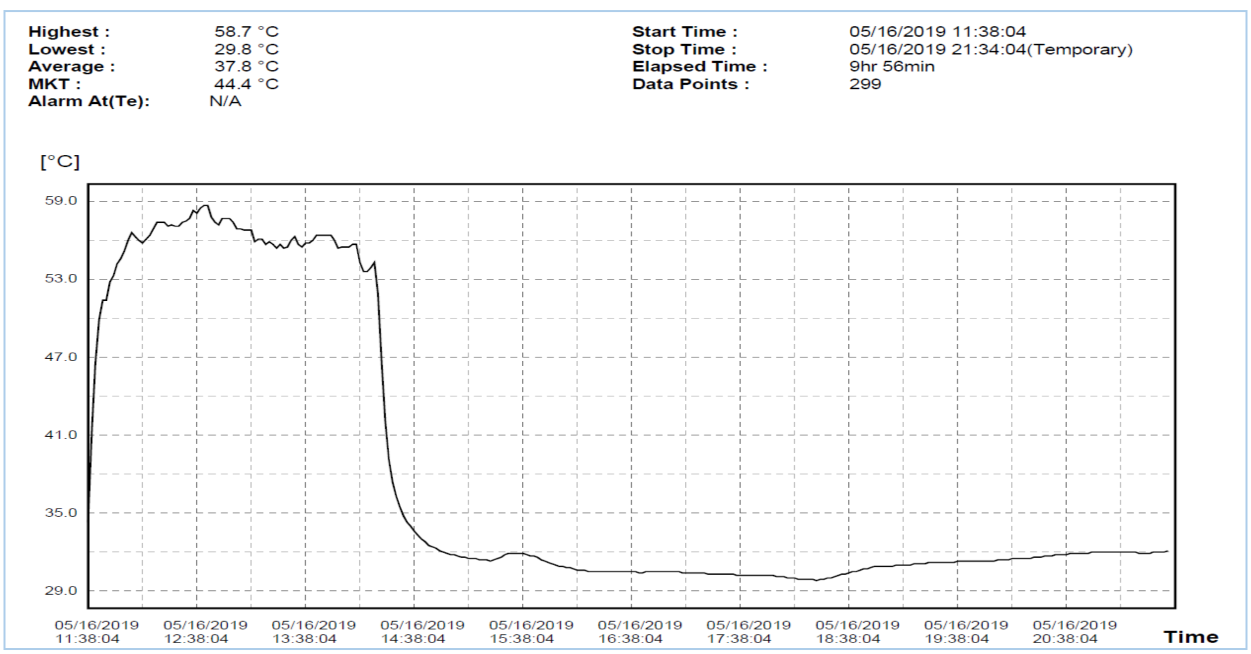


Figure 6.18 Shows the variation of temperature with time of normal system of experiment

6.11 Results of Experiment 10

Experiment 10 has been conducted on 17.05.2019 from 11.10AM to 4.00PM. The study is aimed to find variation of temperature of PV panel of PCM system and the normal system.

In experiment 1

Temperature	PCM System	Normal System
Highest	56.1	56.9
Lowest	34.5	34
Average	49.5	51.6

So the change of average temperature is 2.1^{o}C.

So 2.1^{o}C cooling is done using Phase changing material.

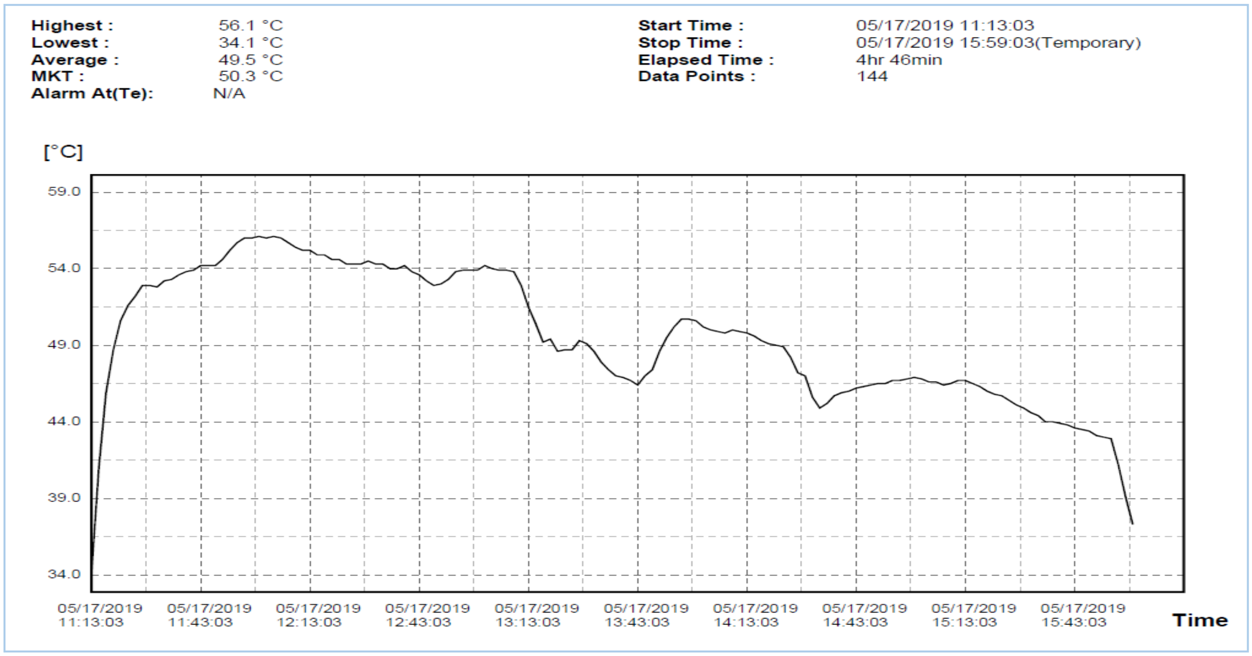


Figure 6.19 Shows the variation of temperature with time of PCM system of Experiment 10

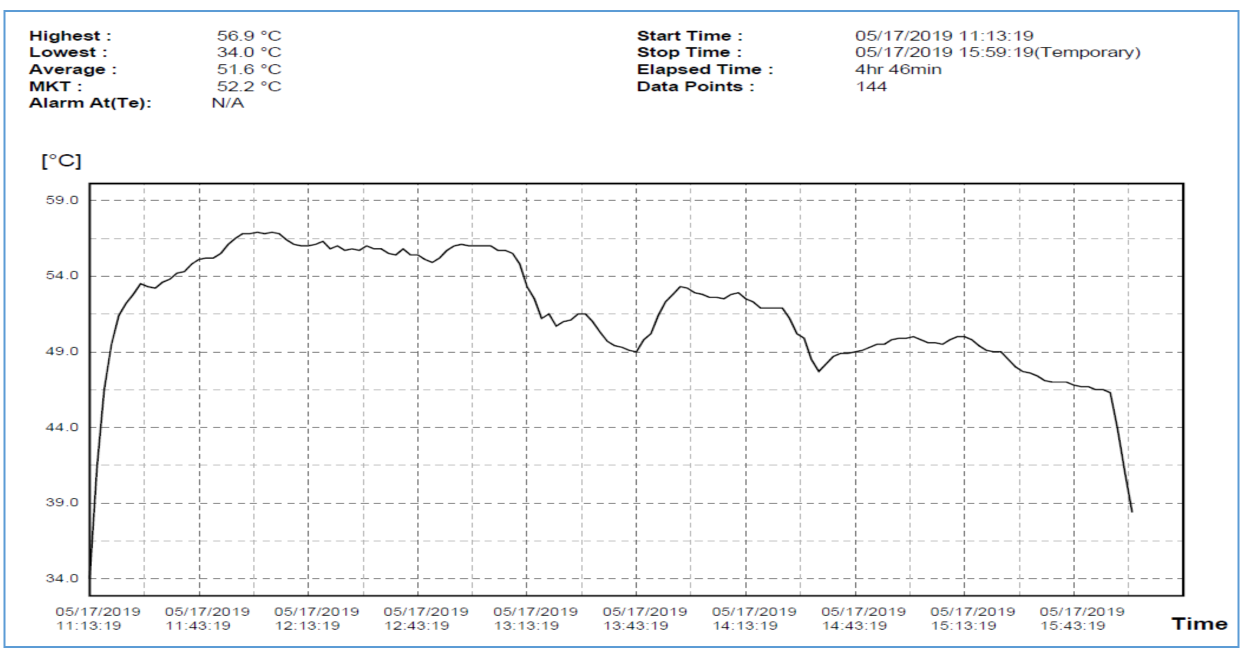


Figure 6.20 Shows the variation of temperature with time of normal system of experiment

6.12 Conclusion

According to the plot obtained from data logger, it has been observed that average panel temperature difference between normal system and PCM integrated hybrid system is up to 3.4^{o}C (Experiment no 8). But in this hybrid system we can get up to 20^{o}C cooling than normal system. PCM has very low thermal conductivity. So continuous water circulation through heat exchanger is mandatory for desired cooling. So far the result of cooling obtained is not satisfactory, what we want to obtained from the system due to lack of water circulation system in heat exchanger to extract the heat from PCM. That infrastructure can't be developed within the stipulated time of the thesis work. If it is available the temperature may be drastically will become down around 20^{o}C. We are also continuing our work towards that direction to incorporate proper heat extraction method by circulating water with the system.

CHAPTER 7

CONCLUSION AND FUTURE SCOPE OF THE WORK

7.1 Introduction

In order to promote solar energy and thereby to help to reduce CO_2 emissions, renewable energies and particularly the solar photovoltaic power is subjected to grants in many countries of the world to improve their viability and thereby to reduce the return periods of investments. This chapter covers the conclusions or final decisions of cooling effect of solar photovoltaic panel as well as future scope of cooling technologies.

7.2 Conclusion

The clean energy technologies, it is highlighted here are transforming how our nation produces and uses energy. While challenges and uncertainty exist for these technologies clear that they are not some far way opportunity, but are now a significant part of the energy landscape. So we should plan to use them to clean our air, reduce our reliance on unstable oil markets, and help build an economy that is more competitive and more efficient, while reducing carbon pollution.

The study was focused on different aspects, challenges and possibilities of Photovoltaic system. In chapter 1 we have discussed energy scenario of India, scope of solar power, basic theory of solar cell, response of effective parameters, aims, scope in cooling technologies. In chapter 2 we have presented literature review on application of phase changing material and solar photovoltaic cooling technology. The review have also been understood the gap of knowledge's, possible solution to be needed, it also have been described in chapter 2. In chapter 3 we have discussed about the recent technology of PV panel cooling. This chapter gives some idea about recent cooling technology. In this work we have adopted a new cooling technology using Phase changing material. To use PCM for PV cooling we have designed & fabricated a new hybrid system. We have designed a jacketed type heat exchanger. The hybrid system & experimental method has been discussed in chapter 4. In this chapter we have also discussed about data acquisition system. In chapter 5 we have discussed about different types of phase changing material. In this chapter we have also discussed physical and chemical properties of a commercial phase changing material SaVE OM37. In this experiment we have considered only effects of temperature for PV panel performance. So in chapter 6 we made comparison of PV panel temperature between PCM system and normal system. In PCM system we got highest 3.4^{o}C cooling. But our PCM integrated hybrid system has the potential for cooling up to 20^{o}C. That can be obtained by proper circulation of water through the heat exchanger. But due to shortage of fund we can't afford the smart flow technique. It was concluded that solar photovoltaic & Thermal hybrid cooling technology has been increased output power as well as improved efficiency of the system. Different types of phase changing material can be tested for better results, have been discussed in future scope of the present work below in this chapter

7.3 Future scope of the work

The most important challenge in front of us is the cost of phase changing material and their poor thermal conductivity. But in recent years huge research is done on phase changing material. So there is a huge variety of phase changing material. So we can use different phase changing material for different temperature zone for better results. For better thermal conductivity we can use inorganic phase changing material.

Some research group is continuing work to apply and improve the thermal storage concept. A far better approach would be to store thermal energy in a thin, transparent film and trigger a blast of heat when it's needed. They deposited their liquid PCM composite on a sheet of glass, put another sheet on top, and sealed it up. They found that they could charge up the mixture with UV light and then discharge it later with visible light, getting the stored phase-change energy back out as heat. Moreover, they could do it selectively so that part of the film solidified and the rest remained liquid.

A PCM composite could do better, except for one drawback: As it goes from solid to liquid, it also changes in volume potentially enough to damage the container. is working to encapsulate the composite inside tiny beads with shells made of silica or calcium carbonate. The confined composite will go through the necessary phase changes, but the strong shell will limit the massive volume change that occurs in an unconfined mixture. The encapsulated beads could be suspended in other liquids, and better methods of delivering light into the materials might be possible. We can also use commercial PCM like BIOPCM, RUBITHERM etc for solar PV cooling.

In summary, low- cost, high thermal conductive mass production of phase changing material is one of the challenging directions for future applied research.

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