A

Dissertation Report

On

DESIGN AND PERFORMANCE ANALYSIS OF A DOUBLE PASS SOLAR AIR HEATER WITH THERMAL STORAGE

By

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DECLARATION

I **Rajdip Kumar Choudhary** hereby declare that the dissertation entitled **"Design And Performance Analysis of a Double Pass Solar Air Heater With Thermal Storage"** being submitted by me in partial fulfillment of the degree of **M. Tech (Energy Engineering)** is a research work carried out by me under the supervision of **Dr. Nirupam Rohatgi** and the contents of this dissertation work, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma. I also certify that no part of this dissertation work has been copied or borrowed from anyone else. In case any type of plagiarism is found out, I will be solely and completely responsible for it.

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Abstract

Use of renewable energy plays a major solution for energy crisis and reduces the CO_2 emission which reduces the greenhouse effect and other dangerous respiratory disease. In the category of renewable energy, Sun is the ultimate source and harnessing the solar energy in proper ways can eliminate the energy crisis of the world. In solar air heater, solar energy is collected by means of an absorbing plate and the collected heat energy is transferred to heat transferring medium such as air.

For this work, I have designed a solar air heater which can work either as a single pass solar air heater with thermal storage or as a double pass solar air heater with thermal storage. In this design, paraffin wax was to be used as the thermal storage material. This design was fabricated and tested in MNIT, Jaipur, India for 12 days and the various temperature data were tabulated. The design was tested for two different inlet air velocities, 6 m/s and 9 m/s for both single and double pass configurations. The overall efficiency was calculated and it was found that the double pass solar air heater is approximately 20% more effective than the single pass solar air heater. It was also observed that the solar air heater could heat the air even without receiving solar radiation. Finally, it is inferred that the solar air heater with thermal storage can be used even at night.

Contents

Nomenclature

Letters

A	Area of the of Solar Air heater	m^2
C_P	Specific heat of Air	kJ/kg K
h	Heat transfer coefficient	W/m^2 K
I	Solar intensity	W/m^2
k	Thermal conductivity	W/m K
l	Thickness	m
Q	Heat transfer from various surfaces	kJ
T	Temperature	^0C
U	Heat loss coefficient	W/m^2 K
V	Inlet Air velocity	m/sec

Subscripts

amb.	Ambient
in	Inlet
out	Outlet
f	Fluid
e	Effective
r	Radiative
av	Average
F_R	Heat Removal Efficiency
p	Absorber plate
x	Length

b-a	Bottom to ambient
c, C	Convective
b	Bottom
t	Top
g	Glass
g-a	Glass to ambient
i	Insulation, and instantaneous
o	Overall
th	Thermocol
s	Sides of the solar still

Greek Letters

α	Absorptivity
ε	Emissivity
η	Efficiency
σ	Stephen-Boltzmann Constant ($W/m^2\ K^4$)
τ	Transmissivity

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CHAPTER.1

Introduction

Both living and non-living things in this world need energy in some form. All of them have the capacity to do the work by the utilization of some energy. Need of energy has become the basic feature for everyone in the world. The threat of extinction of the conventional sources of energy has paved its way for seeking alternate sources of energy. Use of renewable energy plays a major solution for energy crisis and reduces the CO_2 emission which reduces the greenhouse effect and other dangerous respiratory disease. In the category of renewable energy, Sun is the ultimate source and harnessing the solar energy in proper ways can eliminate the energy crisis of the world.

The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW, which is many thousands of times larger than the present consumption rate on the earth of all commercial energy sources. Thus solar energy can be used to supply enough amount of energy to all the present and future needs of the world. This makes it one of the most promising unconventional energy sources [6].

Simply stating, a solar collector collects heat by absorbing solar radiation. The energy in the form of electromagnetic radiation from varying wavelengths (infrared to ultraviolet) can be termed as solar radiation. Basically, it consists of an absorber plate, supportive walls, ducts or channels of fluid flow, glazing, air blower or fans and insulation in order to reduce heat losses. Parts of solar air collector must be thermally well insulated in order to reduce thermal heat losses. Another important term in this is glazing, which obtains solar radiation to stay between absorber and glazing, and to be absorbed by blackened absorber. This in turn minimizes convective and radiative losses to the atmosphere. Heat is then transferred to air through the medium of an air duct which is placed between glazing and absorber plate. [8]

Flat-plate solar collector is the main component of any solar heating system. What this device does that is it absorbs the incoming solar radiation and then converts it into heat and also does the work of transferring this heat to a fluid flowing through the help of collector. However, these conversions depend on how different materials perform, i.e. the absolute performance of materials, such as glazing materials, collector absorbing plates and used fluids. [3]

For the solar to meet the energy needs both at night and during daytime periods of cloud cover, storage of energy is essential. Solar radiation is an inherently time-dependent energy resource. However, we know that energy can neither be created nor be destroyed, only transferred from one form to another. Hence, in this case also, radiant energy can be converted into a variety of forms that are feasible to be stored such as thermal energy, kinetic energy, potential energy, chemical energy and so on. However, the time dependence of the solar availability, the nature of the load, the cost of auxiliary energy, and the price of process components all play a role in determining the optimum capacity of the storage device for a given solar process.

For minimizing the final cost of delivering energy, factors mentioned above must all be weighed carefully for a specific application to arrive at system design. [10] According to the way heat is stored, the use of TES is basically classified. Examples are sensible heat in hot liquids and solids, latent heat in molten and vapor, thermos-chemical heat appearing in chemical reactions, and sorption heat in adsorption processes. On the other hand, LHS uses latent heat of material to store thermal energy. Latent heat can be defined as the amount of heat absorbed or released during change of material from one phase to another and the amount of thermal energy stored in the form of sensible heat or latent heat in the material can be calculated by reference.

It has been noted as of now that studying the literature the rock bed, paraffin wax and pecked bed are commonly used as LHS in solar air heaters. Some improvements were noted in terms of thermal performance of SAHS some previous works as a use of these heat storing materials. But still, further study and research is necessary for an optimum design of SAHS which must be not only simple but also user friendly at the same time. It must be easy to maintain and also work in poor ambient conditions. It needs to be cost effective too and have an improved efficiency over other conventional designs. [8]

1. 1 Objective of work

In solar air heater, solar energy is collected by means of an absorbing plate and the collected heat energy is transferred to a heat transferring medium such as air. A large number of researches are going on to improve the performance of the air heater by integrating flat plate collector with packed bed and energy storage systems. For the same flow rate, the efficiency of the double pass solar air heater with thermal storage was found to be higher than that of the single pass solar air heater with thermal storage.

1. To design and fabricate the double pass solar air heater with paraffin wax as thermal storage material.

2. To compare the performance of solar air heater in double pass mode with single pass modeTo study the effect of thermal storage on the performance of solar air heater.

3. To compare the performance of solar air heater in double pass mode with single pass mode.

CHAPTER2

Literature review

A comprehensive literature review has been done on energy and energy analyses of different solar air heater systems in the present chapter. Number of researches is going on to improve the performance of the air heater by integrating flat plate collector with packed bed and energy storage systems.

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2.1Fin integrated Air Heater

Sunil Chamoli et.al [1] the experiment was performed on a double pass solar air heater. It was conducted analytically as well as experimentally. Both the methods showed an increase in performance of a packed bed, fins integrated double pass solar air heater than a conventional one. The study was also conducted with corrugated absorber surface. But no study is conducted on a artificially roughened double pass solar air heater

Chii-Dong Ho et.al [16] The design and working of a double pass solar air integrated with fins and baffles was analyzed for the effect of recycling operation by experimental as well as theoretical approaches. By observing the results it was found out that the values deviate by 15 – 23% from that of theoretical predictions. The performance of different kinds of were compared. That included the single-pass, double-pass with recycle, fined double-pass with recycle, and fined plus baffled double-pass with recycle. The primary objective of the double pass heater to be introduced was aimed to increase convective heat transfer coefficient and enlarging the heat transfer area.

After the experiment when the result was analyzed, the collector efficiency of the fined plus baffled double-pass with recycle design was found to be much higher than the other designs. The optimal reflux ratio is about 0.5 for the fined plus baffled double-pass design while considering both the collector efficiency and the pumping power requirement

Alta et al [25] investigated the energy and energy efficiency of three different types of solar air heaters, two having fins and one without fins besides one heaters with fins has single glass cover while the other two have double glass cover. The energy and energy output rates of the solar air heaters were evaluated at different air flow rates viz. 25, 50 and 100 m^3/m^2 h, tilt angle at 0º, 15º and 30º and temperature conditions versus time. They found that the heaters with double glass covers and fins are more effective and the difference between the input and output air temperature is higher than that of the other cases. It was also found that the lower air flow rates will be beneficial in applications where higher temperature differences are more important. Besides it has also been observed that using more transparent covers and fins increases the values of temperature differences. While transparent cover decreases convection heat losses, fins obtain more heat because of an increase in the heating time by circulating air inside.

2.2 Use of Obstacles in Solar Air Heater

Akpinar and Kocyig˘it [24] they designed a new type of solar air heater, then fabricated and experimentally investigated with and without obstacles. The experiments were performed at two different air mass flow rates of 0.0074 and 0.0052 kg/s. It was found from the experiment that the efficiency of the solar air collectors depends on various other parameters such as solar radiation, surface geometry of the collectors and extension of the air flow line. The energy efficiency was calculated and was found to be around 20% to 82% while those of energy efficiency varied from 8.32% to 44.00% at the above said mass flow rates. The highest efficiency was found to be for the solar air heater (SAH) with absorbent plate in flow channel duct for all operating conditions. The lowest values were obtained for the SAH without obstacles. Also the efficiency of the collector increased as we increased the mass flow rate. This result denotes that the energy loss of the system decreased due to the increase in the collector efficiency. Study also showed that there exists a reverse relationship between dimensionless energy loss and heat transfer. The deciding parameters in order to decrease the energy loss were the collector efficiency, temperature difference of the air. Then a set of new relations were proposed to evaluate of the energy and energy analysis of SAH. It was concluded from the experiment that the proposed procedure can be successfully employed for predicting the SAH performance.

Esen et.al [26] worked on the energy and energy analysis of a novel flat plate solar air heater (SAH) with and without obstacles. The experiments were carried out at different values of mass flow rate of air and different levels of absorbing plates in flow channel duct. The measured parameters were solar radiation and temperatures at different state of points such as inlet, outlet, at the absorbing plate and the ambient. After the analysis of the results it had been found that, the optimal value of efficiency was in the middle level of absorbing plate in flow channel duct for all the operating conditions and it was also found that the double-flow collector supplied With obstacles (60.97%, for 0.025 kg/s and State II) were better than that of without obstacles (25.65%, for 0.015 kg/s and State I).

SompolSkullong et.al [12] This experiment is based on the study of turbulent flow and heat transfer characteristics in a solar air heater channel fitted with combined wavy-rib and groove tabulators. The primary objective of the experiment is to obtain Reynolds number in the range of 4000 to 21,000 by managing the airflow rate. The triangular wavy ribs are put continuously on the tested groove channels to produce recirculation flow in the channel having a constant heat-flux on the upper wall only. The various cases of the rib pitch to channel ratio (PR = P/ H = 0.5, 1 and 2) having a single rib-to-channel height ratio (BR = b/H = 0.25) are studied in the present analysis .The wavy ribs are situated at an angle of about 45° relative to main flow direction. The 3 different types of rib arrangements are as follows

- rib-groove on the upper wall only
- inline rib-groove
- staggered rib- inline groove on two principal walls

The conclusion of the experiment is that the highest heat transfer rate and friction factor is obtained by using combined rib groove on both upper and lower wall in comparison to with/without ribs. It is generally found at higher thermal performance to that groove alone.

Kurtbas and Durmus [17] they have designed a new solar air heater and evaluated it on the basis of energy analysis. In this analysis they used five types of solar collectors with dimensions of 0.9m x 0.4m. The flow line increased where it had narrowed and expanded geometrically in shape. Then the solar collectors were engaged to four different cases with dimensions of 1m x 2m. That is the reason why heating fluids exit the solar collector after at least 4.5 m displacement. Turbulence occurs in fluid flow and in this process heat transfer is increased according to the collector geometry. In this analysis they found that the efficiency of the collector increases with the increase of mass flow rates. This is because of an enhanced heat transfer to the air flow. Also an increase in efficiency depends on the surface geometry of the collector and extension of the air flow line. Few more important parameters in order to decrease the energy loss are collector efficiency, temperature difference of the air and pressure loss.

2.3 Use of Granular Carbon as a Heat Absorbing Media

Abhishek Saxena et.al [8] at the current status of research, concentration is mainly focused on the enhancement of heat transfer rate and efficiency. One such addition to the research scenario is the introduction of Granular carbon which is a long term heat absorbing media inside solar heater. The analysis of thermal performance has been done on different configuration by operating it on natural and forced convection. The primary aim of the experiment was to operate it economically by substituting the use of blower of higher power consumption. As the moving parts are absent, the operating cost and power consumption is decreased.

2.4 Double Pass Solar Air Heater.

A.A. El-Sebaii et.al [2] the experiment is performed on a Double pass flat solar air heater and a V-corrugated plate solar air heater. The different parameters on which the comparison is done are outlet temperatures of flowing air, output power and overall heat losses. Other parameters such as mass flow rates of air on pressure drop, thermal and thermos hydraulic efficiencies are also analyzed. We can conclude from this experiment that double pass V-corrugated plate solar air heater is 11-14% more efficient than that compared to double pass flat plate solar air heater. . It is also noted that peak value of thermo- hydraulic efficiencies of both the solar air heaters are obtained when the mass flow rate of the flowing air is 0.02 kg/s.

C. Choudhury et.al [14] in this experimental study, the ratio of the annual cost and the annual energy gain has been calculated for Two-pass solar air heaters with single and double covers above the absorber. The data of the cost-benefit ratios of the solar collectors are collected over a wide range of design and operational parameter (t, L, D1 and D2) and compared with those of single-pass collectors with no cover, a single cover and a double cover.

The primary aim was to shorten the duct lengths and decrease the air mass flow rates. The overall performance of the two-pass air heater with a single cover was found to be least costly as compared to the other designs.

Ozgen et al. [23] He made a device for inserting an absorbing plate made of aluminum cans into the double-pass channel in a flat-plate solar air heater. In this experimental study, three different absorber plates were designed and then tested. While making the first type, they staggered these zigzag on absorber plate. In Type II they were arranged in order, while in Type III a flat plate was without cans. The experiments were carried out at air mass flow rates of 0.03 kg/s and 0.05 kg/s. From the experiments it can be concluded that the double-flow type of the solar air heater with aluminium cans has been introduced for increasing the heat-transfer area has the improved thermal efficiency. The performance of double-flow type solar air heater is found to be more efficient than that of the devices with one flow channel over or under the absorbing plate because of the double heat-transfer area in double-flow systems, in which air was flowing simultaneously over and under absorbing plate,

A.A. El-Sebaiiet.a [13] the thermal performance of a double glass, double pass solar air heater with a packed bed was experimentally and theoretically performed in the summer of 2003. Limestone and gravel were used as packed bed materials. He experimented the effect of various operational and configurationally parameters such as effects of the mass flow rate of air and the mass and porosity of the packed bed material. It was concluded from the experiment that, It is better to use gravel instead of limestone as a packed bed above the absorber plate.

It is recommended to operate the system with/without the packed bed with values of mass flow rate of air equal to 0.05 kg/s or lowers to have a lower pressure drop across the system, and therefore, a reasonably high thermo hydraulic efficiency.

Thermo hydraulic efficiency with gravel is found to be higher

2.5 Use of PCM as Heat Storage Material

S.S. Krishnananth et.al [7] a double pass solar air heater was designed and integrated with thermal storage system. For thermal storage medium Paraffin wax is used. The performance analysis of this heater was studied for different configurations. It delivered comparatively high temperature.

The efficiency of this air heater fabricated with thermal storage was found to be higher than the air heater without thermal storage system. The conclusion made through this experiment is that the presence of the thermal storage medium at the absorber plate is the best suitable configuration.

Enibe et.al [21] worked on the design, fabrication and performance evaluation of a passive solar powered air heating system based on energy analysis. This type of solar air heater consists of a single-glazed flat plate solar collector integrated with a phase change material (PCM) heat storage system. The PCM is prepared in modules, with the modules equi spaced across the absorber plate. The spaces between the module pairs serve as the air heating channels, the channels being connected to common air inlet and discharge headers. The experiments were carried out under the climatic conditions of Nsukka (Nigeria) in the daytime with no-load conditions where the ambient temperature varied in the range of 19–41 °C, and a daily global irradiation varied in the range of 4.9–19.9 MJ/m^2. Peak cumulative useful efficiency was found to be about 50% while peak temperature rise of the heated air was about 15 °C. The system has been found suitable for the use as a solar cabinet crop dryer for aromatic herbs, medicinal plants and other crops, which do not require direct exposure to sunlight.

Koca et al. [22] He investigated the flat-plate solar collector with phase change material (PCM). He used energy and energy analysis. The chemicals used as PCM was $CaCl_2.6H_2O$ in thermal energy storage (TES) system. The collection of the solar energy and storage has been clubbed in single designed collector unit. PCM was stored in a storage tank located under the collector. For the purpose of transferring the heat from collector to PCM a special heat transfer fluid was used. The experiments were carried out for 3 different days in the month of October. After the careful valuations of the observations they found that stored and instantaneous solar radiation show bell-shaped variation during every data taken during those days. When reviewed we saw that significant difference between energy and energy efficiencies had been reported. The energetic efficiency was always higher than that of exegetic efficiency. Performing the experiment and observed data calculations show the energy efficiencies of latent heat storage systems with PCM are very low

CHAPTER 3

Design and fabrication of solar air heater

3.1 Solar air heater

Solar air heater is a solar thermal technology in which the energy from the sun, solar radiation, is captured by an absorbing medium and used to heat air. Actually, the solar air heater device intercepts solar radiation, converts this radiation to the heat in air and distributes the air for use. An absorber plate, one or more channels for the flowing air, insulation for the bottom and lateral sides of the solar collector and one or more transparent covers are the main components of a solar air heater. The use of a blower is optional for the air supply. Detailed information about solar air heaters is given below

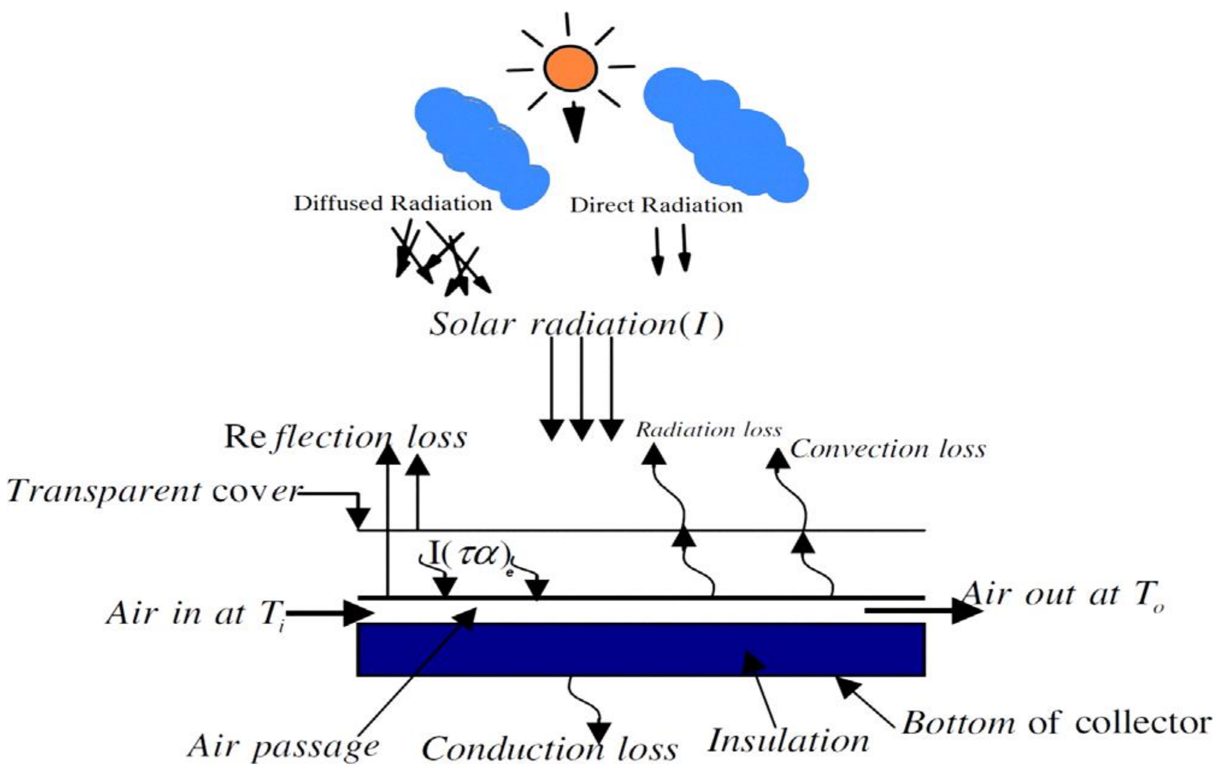

Figure3.1: Conventional solar air heater [9]

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3.1.1 Double pass solar air heater

In double pass solar air heater, there are two overlapping air flow channels. Air enters from the upper channel and leaves from the lower channel, changes direction at the channel end and enters the lower channel. The flow direction of air is counter flow in this type of air heater. Air flows straight through the bottom channel either through the top channel. Due to this reason solar air heater is termed as "single flow double pass". Two different constructions of a single flow double pass solar air heater are described later. Figure illustrates one of the constructions. As can be seen, there are two overlapping air flow channels. These channels are separated from each other by a glass and an absorber is placed at the bottom side of the lower channel. Air flows from the first and the second transparent sheet. Then it is received by the absorber. Insulation is performed on the bottom side of the absorber. In the second design, the absorber plate is located as a separator between the upper and lower channels as illustrated in Figure .The upper air flow channel is made by the glass cover and the absorber plate while the lower air flow channel is located between the same absorber plate and the insulated lower plate.

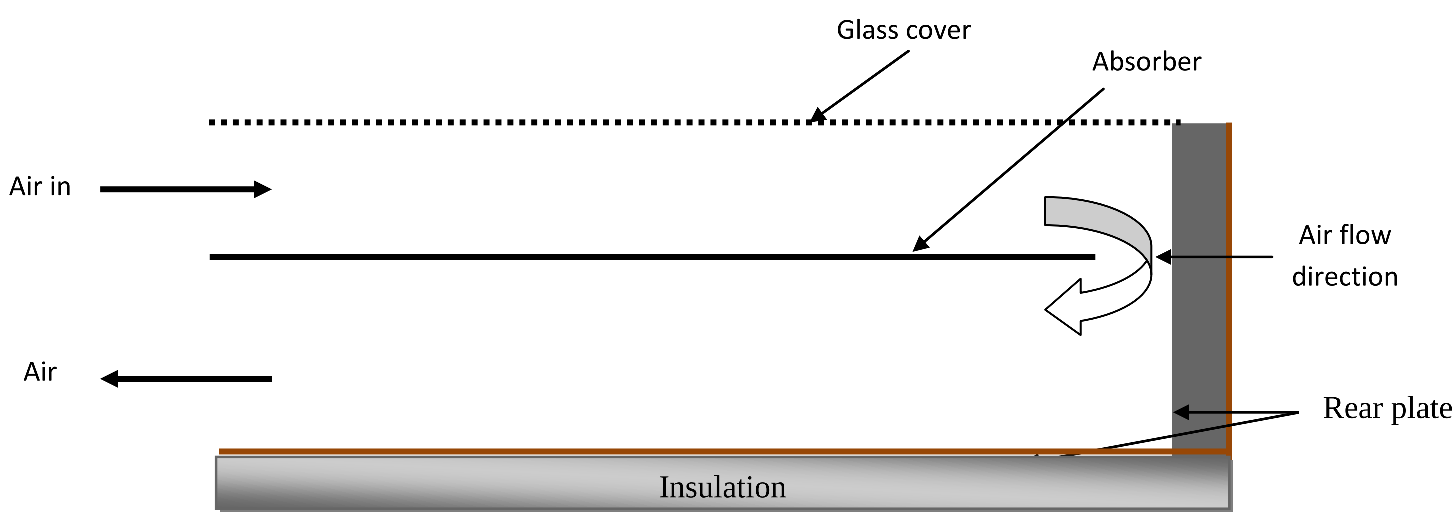


Figure 3.2: double pass counter flow solar air heater air flow above the absorber plate

3.2 Design and fabrication of major components of solar air heater

The main objective is to increase the convective heat transfer between the working fluid air and the absorber surface while at the same time minimising the overall heat losses from the system. A wide range of Solar Air Heating Collector (SAHC) designs have been proposed and discussed in the literature in recent years to improve the performance of conventional systems in my work I have designed a solar air heater which can work either as a single pass solar air heater with thermal storage or as a double pass solar air heater with thermal storage.

The SAH is a combination of two pass with thermal storage design. It is an assembly of the following eight major units:

[1] stand of air heater

[2] Enclosure

[3] Absorber Plate

[4] Insulation

[5] glazing cover

[6] Duct of air heater

[7] Orientation of Solar air heater

[8] Storage pipe with thermal storage.

3.2.1 Stand of air heater

It is used to support the main units of solar air heater. One major concern was to fabricate it at the correct geometric angle so as to obtain maximum solar incident radiation. At Jaipur, the latitude angle is 27^0, so this was chosen as the tilt angle of the stand. As there is not many functions of the stand, it was decided that the material should be cheap. Therefore, Mild steel was chosen.

- Material of the stand :- Mild steel
- Thickness of Angle :- 0.5 mm
- Dimension :- 25mm x 25mm x 5mm
- Length of small leg :- 225mm
- Length of big leg :- 713.07mm

Figure 3.3: Stand of air heater

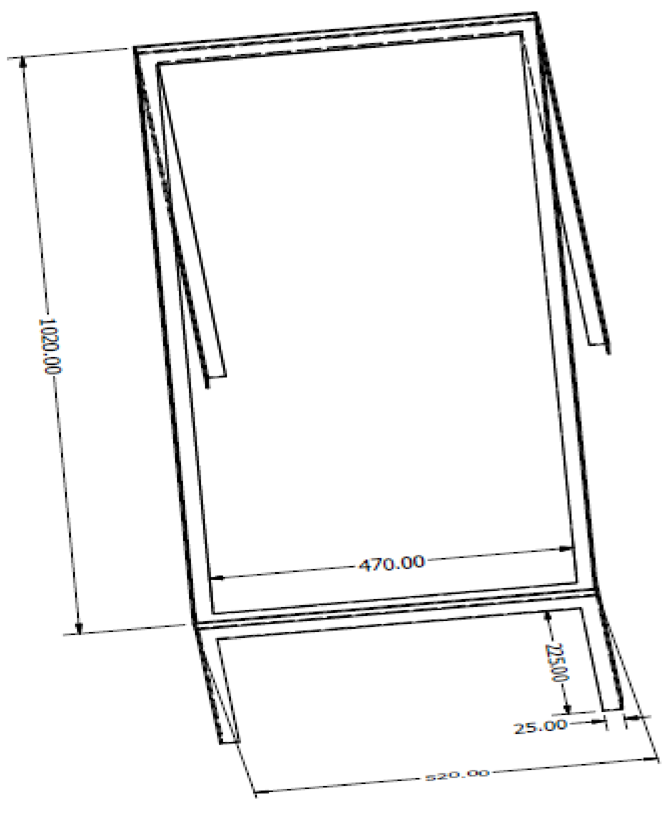


Figure 3.4: dimensions of Stand of air heater

3.2.2 Enclosure

The enclosure of double pass solar air heater is made up of Galvanized Iron Sheet. This shape is made because it can move more air and also it is easy to construct. The Enclosure is placed with insulating material of thermocol along all sides. This is done so as to prevent the heat from escaping outwards. Then Galvanized Iron of 0.5 mm thick Sheet is placed along the sides of the Enclosure and along the bottom. This enclosure is split into two halves, enclosure 1 and enclosure 2. The enclosure 1 which is below for preheating of air and the chamber 2 that is above for final heating of air. Galvanized Iron Sheets are easy in Bending and cutting in to design shape. Galvanized Iron Sheet having low cost and long life we chosen this type of material.

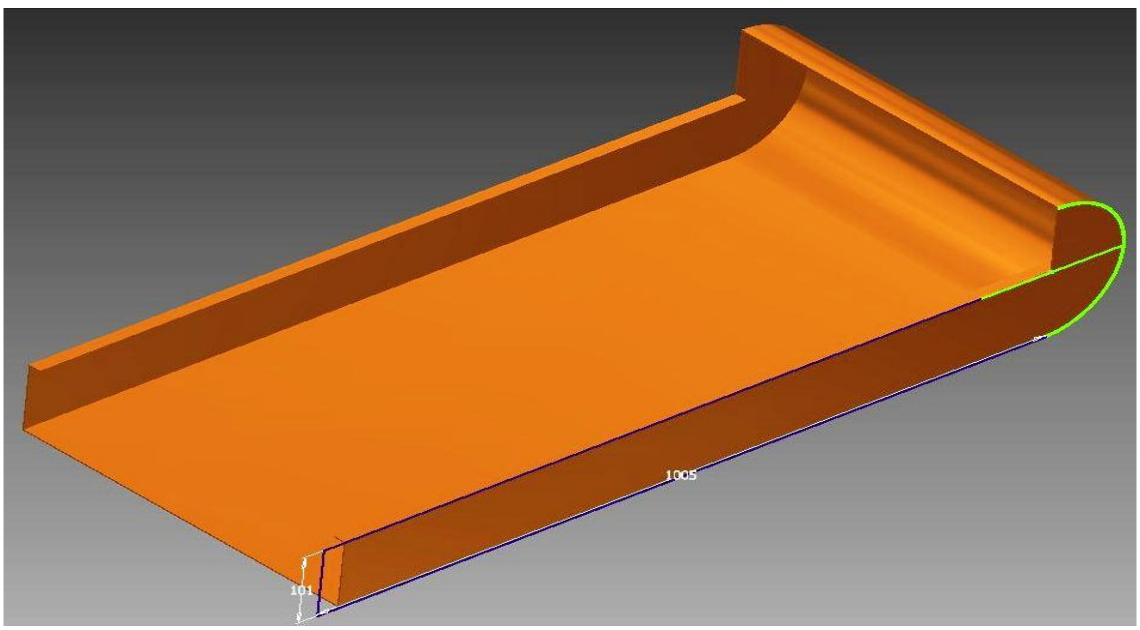


Figure 3.5: Enclosure 2 of air heater

- Material of the Enclosure :- Galvanized Iron Sheet
- Thickness of sheet :- 0.5 mm
- Dimension of enclosure 1 :- 1020mm x 550mm x 220mm
- Dimension of enclosure 2 :- 1000mm x 500mm x 100mm
- Radius of U type shape of enclosure 1 :- 133.50 mm
- Radius of U type shape of enclosure 2 :- 110 mm

3.2.3 Absorber plate

Absorber plate absorbs as much of the irradiation as possible through the glazing and loose heat upward to the atmosphere and downward through the back of the casing. The absorber plates transfer the retained heat to the transport fluid (air). The absorber plate should have high thermal conductivity, adequate tensile and compressive strength, and good corrosion resistance. Copper is generally preferred because of its extremely high conductivity and resistance to corrosion. Collectors are also constructed with aluminum, steel, Galvanized Iron (GI) sheets and various thermoplastics and metal ions.
Standard procedure for fabricating an absorber plate is to take a sheet of metal (like copper or aluminium) and insulate the non flow surface depending on type of solar air heater. Solar radiation absorbed by this metal sheet would heat it and some of the heat is transferred to air. This hot air is for the practical applications. The absorptance of the collector surface for shortwave solar radiation depends on the nature and color of the coating and on the incident angle.

By suitable electrolytic or chemical treatments, surfaces can be produced with high values of solar radiation absorptance and low values of long wave emittance. Typical selective surfaces consist of a thin upper layer which is highly absorbent to shortwave solar radiation but relatively transparent to long wave thermal radiation and bottom layer that has a high reflectance and a low emittance for long wave radiation. Selective surfaces are particularly important when the collector surface temperature is much higher than the ambient air temperature. In our experimental setup i.e. Design and Performance Analysis of aDouble Pass Solar Air Heater with Thermal Energy Storage or Aluminum was used having thickness of 1 mm blackened with blackboard paint.

Table 3.1: Thermal Conductivities of Various Metals

Material	Thermal Conductivity
Copper	386 W/mK
Aluminium	202.5 W/mK
Brass	110.7 W/mk
Bronze	25.9 W/mK
Carbon steel	63.9 W/mk

Copper is known to have higher thermal conductivity but due to its high cost it is not used. Next to copper stands aluminium with a better thermal conductivity value. The other metals like brass, bronze and carbon steel have low thermal conductivity value and are difficult to process. That leaves with the choice of aluminium. Hence is chosen according to the requirements.

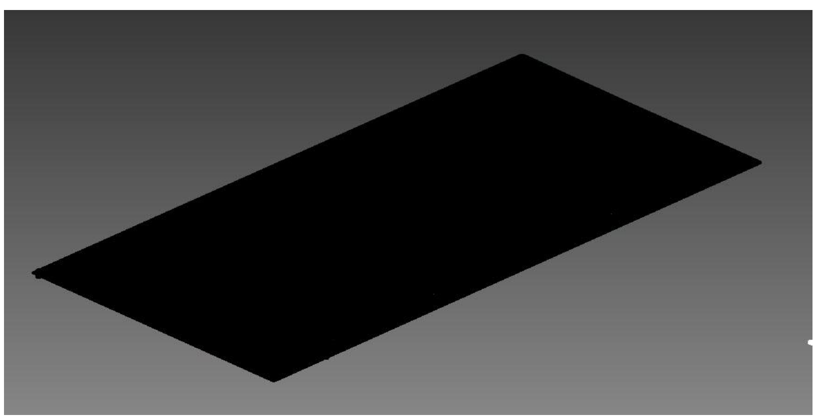


Figure 3.6: Absorber plate of air heater

The dimensions of the absorber plate are

- Material of the plate: Aluminium Sheet
- Length of the plate: 100 cm
- Breadth of the plate: 50 cm
- Thickness of the plate: 0.1 cm
- Selective coating material : black paint

3.2.4 <u>Insulation</u>

The bottom and side wall of the collector is covered with some insulation to minimize the conductive heat loss from there. Commonly used insulating materials are: thermocol, wooden sieves, cotton, rubber sheet, polyvinyl sheet, glass wool etc. Insulation should have very low thermal conductivity, stability at high temperature, no degassing up to around 200^0C,self supporting feature without tendency to settle, easy of application. In our experimental setup i.e. Design and Performance Analysis of aDouble Pass Solar Air Heater with Thermal Energy Storage thermocol was used having thickness of 2.5 cm

Table 3.2: properties of various insulating Metals

S.No.	*Name of material*	*Thermal conductivity at 200°C (W/m°C)*	*Density (kg/m³)*	*Out gassing*	*Saging*	*Colour change*	*Remarks*
1.	Crown white wool	0.034	48	No	Yes	No	Good but expensive
2.	Crown bonded 150	0.066	48	Yes	No	Yes	Not good
3.	Spintex 300 industrial	0.975	48	No	No	No	Good, reasonable cost
4.	Glass wool	0.044	48	No	Yes	Yes	Good
5.	Calcium silicate	0.07	251.60	No	No	No	Good, but component system becomes very heavy
6.	Expanded polystyrene	0.017	32	Yes	No	Yes	Not good
7.	ISO Cyanurate	0.020	32	No	No	Yes	Under testing
8.	Phenotherm	0.029	32	Yes	No	Yes	Not good
9.	Thermocole	0.035	16	Yes	No	Yes	Not good
10.	Polyurethane foam	0.016	32	Yes	No	Yes	Not good
11.	Cellular foam	0.093	400	Yes	No	Yes	Not good
	PIPE SECTIONS						
12.	Rocklloyd	0.075	48	No	No	No	Good
13.	Isoloyd	0.021	32	No	No	No	Good
14.	Thermocole	0.035	16	No	No	No	Good
15.	Foam	0.017	32	No	No	No	Good

Polyurethane foam is known to have higher low thermal conductivity but due to its high cost it is not used. Next to Thermocol with a less thermal conductivity value and easy to available and low cost. The other metals like Glass wool and Crown white wool have high thermal conductivity value and are difficult to process. That leaves with the choice of Thermocol. Hence is chosen according to the requirements.

3.2.5 Glazing cover

The glazing cover is the most critical component of any solar air heater. It is mounted above the absorber plate. Glass can transmit as much as 90% of the incoming shortwave solar irradiation while transmitting virtually none of the long wave radiation emitted outward by the absorber plate. Low iron content glass has a relatively high transmittance for solar radiation (approximately 0.85–0.90) and has transmittance zero for the long wave thermal radiation emitted by sun-heated surfaces. Ideally, the glazing materials should also be strong enough to resist high winds, rain, hail, and small earth movements. In our experimental setup i.e. Design and Performance Analysis of a Double Pass Solar Air Heater with Thermal Energy Storage toughened transparent glass was used having thickness of 5 mm. And its maximum transmissivity is approximately 80%. Inclination of the glass is kept 27^0 because the latitude of Jaipur is 27^0 glass cover has been sealed with foam to make the air heater leak proof to avoid air leakage which is most important for efficient operation.

3.2.6 Duct for air inlet or outlet

A partitioned duct is provided for the inlet and outlet of air. It prevents heat loss to the Surrounding and low temperature incoming air.

Material of duct: -MS sheet of thickness 1 mm
Material of Pipe: - MS
Length of pipe: - 200mm

Diameter of Pipe:-50mm

Dimensions as shown in the figure

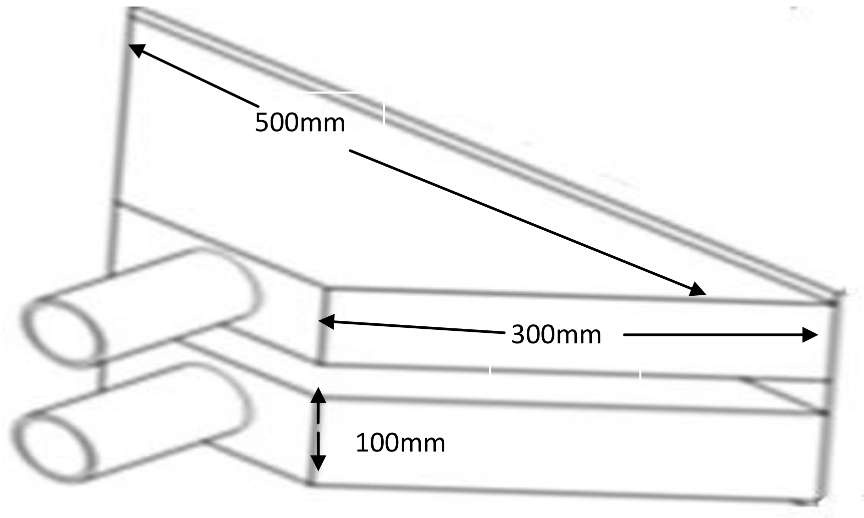


Figure 3.7: Duct for air inlet or outlet

3.2.7 Orientation of Solar air heater

For a particular location at solar noon sun is on the top of that location. At solar noon solar azimuth angle is 180^0 from the north (i.e. south). So the orientation of solar still is fixed such that it is facing south. And south direction can be measured using a compass.

3.2.8 Thermal Energy storage material and Thermal storage container

Storage of solar energy is important for the future success of solar energy utilization. Thermal energy storage (TES) is achieved with greatly differing technologies that collectively accommodate a wide range of needs. It allows excess thermal energy to be collected for later use, hours, days or many months later, at individual building, multiuser building, district, town or even regional scale depending on the specific technology energy demand can be balanced between day time and night time; summer heat from solar collectors can be stored inter seasonally for use in winter; and cold obtained from winter air can be provided for summer air conditioning.

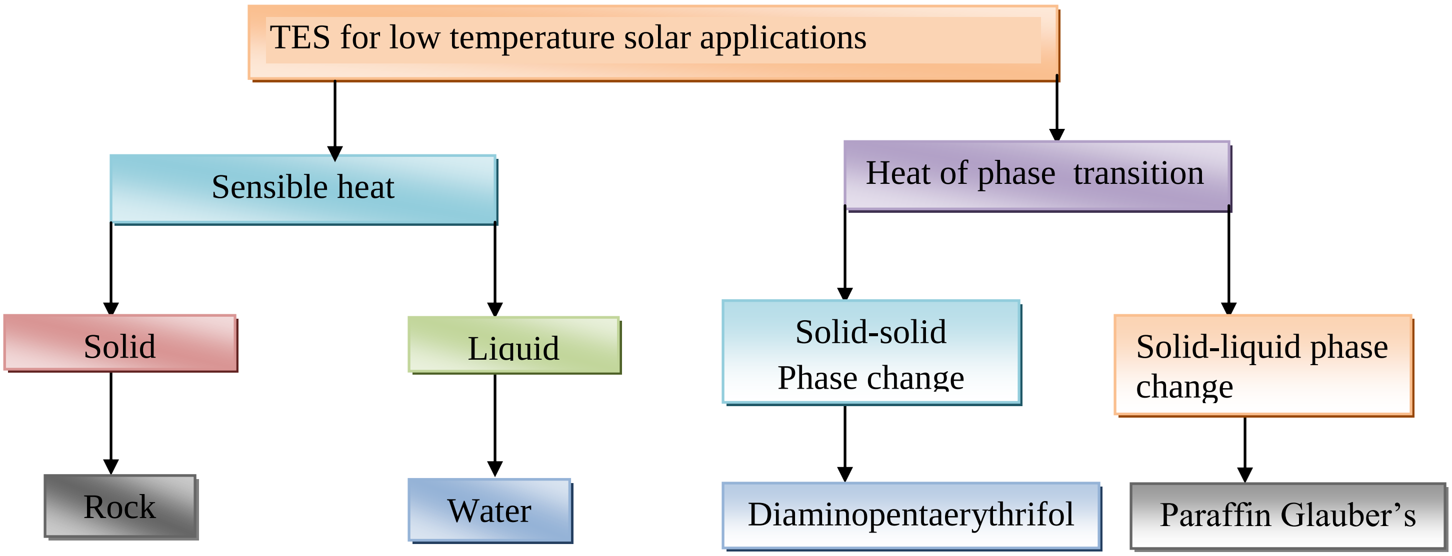


Figure 3.8:Major technique for thermal energy storage at low temperatures.

The major problem is the selection of materials having suitable thermo physical characteristics in which solar energy in the form of heat can be stored. The materials can be divided into two broad types. those that store energy in the form of sensible heat and those that undergo a change of state or physical-chemical change at some temperature within the practical range of temperature provided by the solar heat collectors as likely 90 to 120^{0}F.

If we talk about the thermal heat storages purposely for solar thermal applications, then (i) SHS: as sensible heat in solids (e.g., rocks, or liquids such as water). The heat storage medium thereby experiences an increase in temperature without undergoing a change in its phase, (ii) LHS: as latent heat of fusion in suitable chemical compounds (e.g., paraffin waxes and inorganic salts).The heat storage medium absorbs the heat added and undergoes a phase transition from the solid to the liquid state at a desired temperature within the operating temperature range. For heating and hot water applications, water and PCMs constitute the principle storage media. Soil, rock and other solids are used as well. Some PCMs are viscous and corrosive and must be segregated within the container in order to be used as a heat transfer medium. A variety of solids are also used; rock particles of 20 to 50mm in size are most prevalent. Well-designed packed rock beds have several desirable characteristics for energy storage .The Heat transfer coefficient between the air and the solid is high, the cost of the storage material is low, the conductivity of the bed is low when air flow is not present, and a large heat transfer area can be achieved at low cost by reducing the size of particles. TES systems are suggested for storing thermal energy at the medium (38^0C– 304^0C) and high temperatures (120^0C–566^0C). Oil-rock TES, in which the energy is stored in a mixture of oil and rock in a tank, is less expensive than molten nitrate salt TES but is limited to low temperature applications. The selection of the type of TES depends on various factors such as the storage period. Both the LHS and SHS or thermal heat storage with both the economic viability, operating conditions properties are used for various solar heating applications.

Table 3.1 shows the characteristics of the most commonly used thermal storage materials, including sand-rock minerals, concrete, fire bricks, and ferroalloy materials to be used in solar applications. These materials have working temperatures from 150^0C to 1100^0C and have better thermal conductivities. The only disadvantage is their heat capacities being rather low, ranging from 0.56 kJ/(kg^{0}C) to 1.3 kJ/(kg^{0}C), which can make the storage unit quixotically large. The common advantage of SHS is its low cost compared to the high cost of latent heat storage. On the other hand LHS materials (PCMs)

Table3.3: Thermal properties of some commonly used thermal storage materials.[10]

TES	Specific heat (kJ/kgK)	Thermal conductivity (W/mK)	Density (kg/m3)	Latent heat of fusion (kJ/kg)
Rock bed	1	3.26	2240	—
Brick	790	0.90	1920	—
Concrete	840	0.79	1600	—
Pebble bed	0.8	2.9	1430	—
Paraffin wax	2.1–8.4	24.06×10^{-2}	920–795	189
Hytherm oil	0.73	0.97	725	—
Glauber’s salt	2.5	2.25	1330–1460	251
Organic PCM	2	—	800	190
Inorganic PCM	2	—	1600	230

Granular carbon	0.93	0.11	460	—
Water	4178	0.612	998	334
Al composites	0.89	0.21	2707	—
Iron gravels	0.56	37	7200	—

Can store or release a large amount of heat when reforming their phase structures during melting or solidification processes. Since the phase-transition enthalpies of PCMs are usually much higher (100–200 times) than sensible heat, LHS has much higher storage density than SHS. These materials have phase change temperatures ranging from100^0Cto900^0C and latent heat ranging from 124 to 560 kJ/kg. Unlike SHS, in which materials have a large temperature rise/drop when storing/releasing thermal energy, LHS can work in a nearly isothermal way, due to the phase change mechanism. This makes LHS favorable for solar thermal applications, while the most suitable TES materials for solar thermal applications are those materials which can be worked both as SHS and LHS. By using these materials the system performs well in sunshine hours because of higher sensibility and during off sunshine hours just by releasing the heat absorbed throughout sunshine hours. **.**

Figure 3.9: Thermal Storage Pipe

The dimensions of the thermal storage are

- Thermal storage container material :- 0.5mm thick Aluminum Rectangle hollow pipe
- Thermal storage container material Length :-475mm
- Thermal storage container material Area :-62.5mm X 37mm
- Thermal storage material:- Paraffin wax
- Weight of paraffin wax :-770gm per container (80% fill)
- Number of Thermal storage container :-7
- Pitch of Thermal storage container :-130mm

3.3 Fabrication and Assembly

By performing various machining processes, every parts of the air heater are fabricated based on the design and dimensions. After the fabrication we assemble the all parts in one.

Table 3.4: Process Performed on Various Parts

S.No	Parts	Material used	Process done
1	Enclosure	Galvanized Iron Sheet	Cutting ,Bending, Welding
2	Absorber Plate	Aluminium Plate	Cutting
3	Thermal Storage Pipe	Aluminium Pipe	Cutting, Brazing
4	Stand	MS Angle	Cutting, Drilling, Welding
5	Glass	Toughened Glass	Cutting

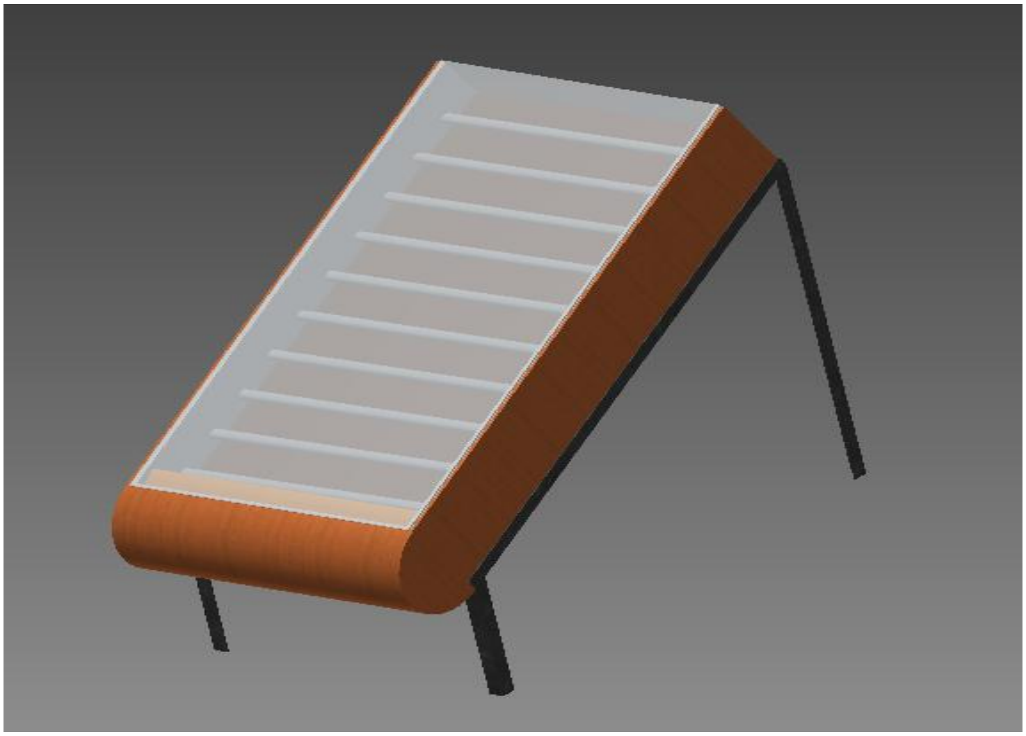


Figure3.10: Assembled View of Solar Air Heater without duct

3.4 Performance Analysis of a Conventional Solar Air Heater

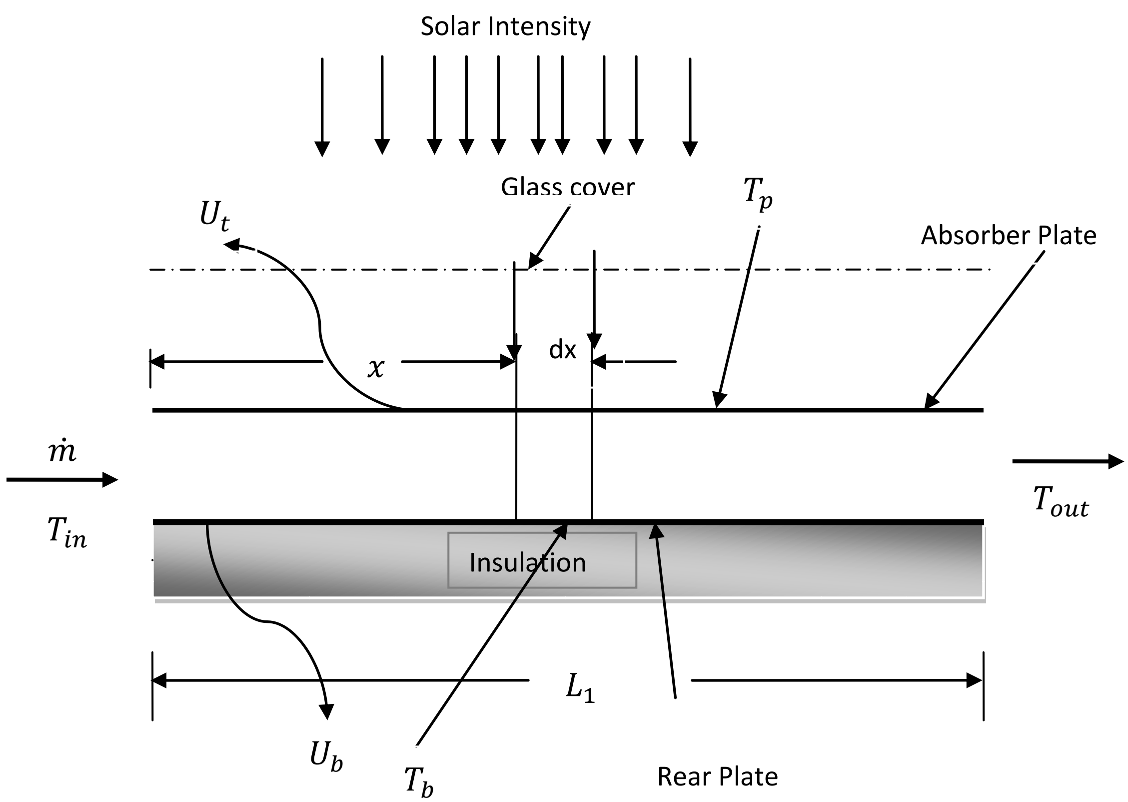


Figure 3.11: Analysis of Conventional Solar Air Heater

We consider a conventional air heater .the heater has an absorber plate of length L_1 and width L_2.the air flow in a parallel plate passage below the absorber.

The heat balance equation on the absorber plate.

$$SL_2dx = U_tL_2dx\left(T_p - T_a\right) + h_{fp}L_2dx\left(T_p - T_f\right) + \frac{\sigma L_2 dx}{\left(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_b} - 1\right)}\left({T_m}^4 - {T_b}^4\right) \qquad 3.1$$

Here $S = I_t(\tau\alpha)_e$

S =Flux absorbed in the absorber plate

<u>The heat balance equation on the Bottom Plate</u>

$$\frac{\sigma L_2 dx}{\left(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_b} - 1\right)}\left({T_p}^4 - {T_b}^4\right) = U_bL_2dx(T_b - T_a) + h_{fp}L_2dx\left(T_b - T_f\right) \qquad 3.2$$

U_b=Bottom loss coefficient

U_t=Top loss coefficient

h_{fp}=convective heat transfer coefficient between the absorber plate and the air.

h_{fb}= convective heat transfer coefficient between the bottom plate and the air

<u>The heat balance equation on the element of Air stream</u>

$$\dot{m}c_p\, dT_f = h_{fp}L_2dx\left(T_p - T_f\right) + h_{fb}L_2dx\left(T_b - T_f\right) \qquad 3.3$$

$$h_r\left(T_p - T_b\right) = \frac{\sigma}{\left(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_b} - 1\right)}\left({T_p}^4 - {T_b}^4\right) \qquad 3.4$$

For small value of$\left(T_p - T_b\right)$, it is show that the expression $\left({T_p}^4 - {T_b}^4\right)$ can be approximated by

$4T_{av}{}^{3}\left(T_p - T_b\right)$ Where $T_{av} = \frac{(T_p - T_b)}{2}$

$$h_r = \frac{4T_{av}{}^{3}\sigma}{\left(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_b} - 1\right)}$$

We assume U_b is very smaller in magnitude so bottom losses are equal to 0

So bottom loss term can be deleted from equation 3.2

Equation 3.1 to equation 3.3 rearranges

$$S = U_t\left(T_p - T_a\right) + h_{fp}\left(T_p - T_f\right) + h_r\left(T_p - T_b\right) \qquad 3.5$$

$$h_r\left(T_p - T_b\right) = h_{fp}L_2 dx\left(T_b - T_f\right) \qquad 3.6$$

$$\frac{\dot{m}c_p}{L_2}\frac{dT_f}{dx} = h_{fp}\left(T_p - T_f\right) + h_{fb}\left(T_b - T_f\right) \qquad 3.7$$

From equation 3.6

$$T_b = \frac{h_r T_p + h_{fb} T_f}{h_r + h_{fb}} \qquad 3.8$$

Equation 3.8 values put in to equation 3.5 we get

<u>Absorber plate temperature</u>

$$T_p = \frac{S + U_t T_a + h_e T_f}{U_t h_e} \qquad 3.9$$

Where

$$h_e = \left[h_{fb} + \left[\frac{h_{fb} h_r}{h_r + h_{fb}} \right] \right] \qquad 3.10$$

So

$$\left(T_p - T_a\right) = \frac{S + h_e\left(T_{f-} T_a\right)}{U_t + \ h_e} \qquad 3.11$$

From equation $(3.5) - (3.7)$ we have

$$\frac{\dot{m} c_p}{L_2} \frac{dT_f}{dx} = s - U_t\left(T_p - T_a\right) \qquad 3.12$$

$\left(T_p - T_a\right)$Value is substitute into the equation 3.12

Then we get

$$\frac{\dot{m} c_p}{L_2} \frac{dT_f}{dx} = \frac{1}{\left(1 + \frac{U_t}{h_e}\right)} \left[s - U_t\left(T_f - T_a\right)\right] \qquad 3.13$$

$$F^{'} = \left(1 + \frac{U_t}{h_e}\right)^{-1} \qquad 3.14$$

So we can write the equation 3.13 into this way

$$\frac{\dot{m}c_p}{L_2}\frac{dT_f}{dx} = F'\left[s - U_t\left(T_f - T_a\right)\right] \qquad 3.15$$

Inlet temperature

Solve the above differential equation in term of air temperature $T_f$at a distance x withboundary condition at$x = o\ , T = T_{in}$

$$T_f = T_a + \frac{s}{U_t} - \left(T_{in} - T_a + \frac{s}{U_t}\right)e^{\left(-\frac{F'U_tL_2x}{\dot{m}c_p}\right)} \qquad 3.16$$

Outlet temperature

Similarly by putting at $x = L\ , T = T_o$

$$T_o = T_{in} + \left(\frac{s}{U_t} - (T_{in} - T_a)\right)e^{\left(-\frac{F'U_tL_2x}{\dot{G}c_p}\right)} \qquad 3.17$$

$$G = \frac{\dot{m}}{LL_2} \qquad 3.18$$

Useful heat gain rate for the collector

$$q_u = F_R A\left[s - U_t\left(T_{fin} - T_a\right)\right] \qquad 3.19$$

$$F_R = \frac{\dot{m}c_p}{U_t A}\left[1 - e^{\left\{-\frac{F' U_t A}{\dot{m}c_p}\right\}}\right] \quad 3.20$$

Collector efficiency

$$\eta = \frac{q_u}{I_t A_C} \quad 3.21$$

CHAPTER 4

Experimental setup

4.1 Setup of solar air heater

An experimental set up was constructed and tested in Malaviya National Institute of Technology, Jaipur, India. The experiment was conducted at no load in summer season to perform thermal analysis. The schematic diagram of experimental set up is shown in Fig.4.1. The experimental set up has been designed, fabricated and tested for data collection. The double pass arrangement collector consists of two passages; first passage is formed between the glass cover and absorber plate the second passage where in air flows in the reverse direction is formed between the absorber plate and the rear plate side. In this collector, the first passage is filled with thermal storage pipe on the absorber plate; storage material (paraffin wax in the rectangle hollow pipe) whereas the second passage of the collector has been kept empty. Both the passages length is equal. These collectors are fixed facing south and kept inclined at an angle of 27° with respect to the horizontal to maximize the solar radiation intensity falling on collector all year round. The absorber plate of collector is made up of a 1.0 mm aluminium sheet blackened with blackboard paint on the upper side facing solar radiation. Below the absorber plate rear sheet (GI sheet) of 0.5 mm thickness, followed by 25.0 mm thick thermocol sheet and then 0.5 mm thick Galvanized iron sheet have been placed. This is done in order to prevent the heat loss to the surrounding from the bottom of the collector. Transparent glass cover of 5.0 mm thickness is fitted above the absorber plate. In the first passage, sidewalls are covered with5mm mirrors and they are fixed with the help of silicon sealant gum, glasses are fixed into the sidewalls at angle115°. Mirror glasses reflect the solar radiation on the absorber plate and thermal storage pipe. Two passages are connected by a smooth U-turn made up of Galvanized iron sheet and insulated to avoid heat losses to the surroundings. Sides of the solar collector are provided with Galvanized iron sheet to prevent from getting damaged due to rain water. These collectors are supported on a frame made up of M.S. angle iron of size25 mm X 25 mm X5 mm. Entrance and exit duct have been provided at the inlet and outlet of the test collector to stabilize air flow. These are made from MS plate of thickness 1.0 mm in Fig. 4.1 .The inlet section is connected to blower through flexible pipes. A centrifugal blower of 2.2 kW (0.24h.p) capacities has been used to blow air. The air was forced through the upper channel in the double pass collector between the top glass cover and the absorber plate and then recalculated in opposite direction through the lower channel between the absorber plate and rear plate into the collector through the entrance section. Temperature of each storage pipe, absorber plate and air at different locations along the length of collector has been measured with the help of calibrated copper-constantan thermocouple (T type thermocouple). The intensity of solar radiation has been measured by means of a solarimeter. To improve the system performance, the thermal storage system i.e. phase change material was integrated with double pass solar air heater. Paraffin waxes in the aluminium capsules were used to store the excess thermal energy. The absorber plate and aluminium capsules are painted with black color to absorb maximum temperature.

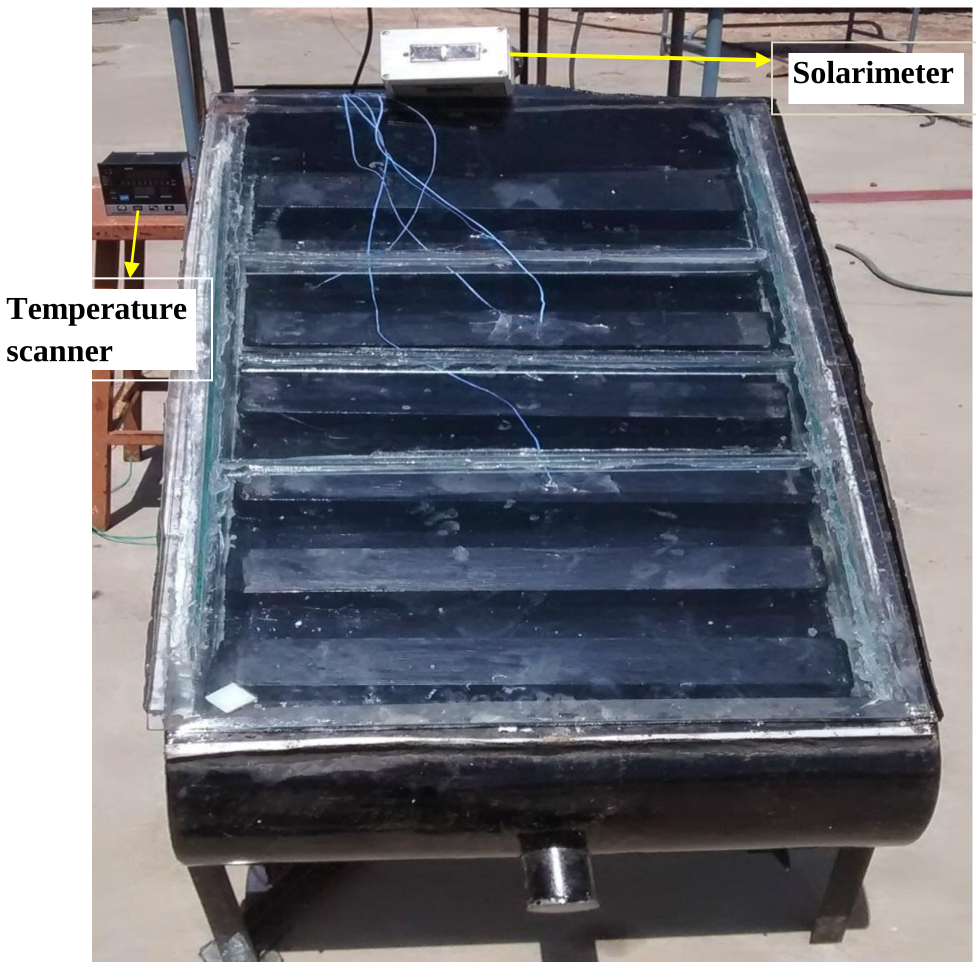


Figure4.1: Experimental setup

4.2 Instrument Used

Mainly four instruments are used in our experiment for measuring of temperature, solar intensity and air velocity.

- Digital temperature scanner.
- Solarimeter.
- Digital anemometer.
- Thermocouple wire

4.2.1 Digital Temperature Scanner

A 8-Channel digital temperature scanner as shown in Fig 4.2 is used to sense the response of thermocouples in terms of temperature (^{0}C) which are attached to different points in solar still. A detailed specification is given in Table 4.1. In this temperature scanner cold junction compensator is built with the instrument itself and it is automatically activated for thermocouple types when we attach the thermocouple wire to the binding post of the instrument. It is completely compensated by software and this iscalledsoftware compensation.

Figure4.2: Masibus 8 Channel Temperature scanner (model 8208)

Table 4.: Specification of Masibus 8 Channel Temperature scanner (Model 8208)

Type	Range	Accuracy	Resolution
E	-200 to 1000°C	$\pm$0.1% of instrument range $\pm$ 1 digit for temperature equal to or higher than 0° C $\pm$ 0.25% of instrument range $\pm$ 1 digit for temperature below 0° C	0.1°C (1°C B,R,S TYPE TC)
J	-200 to 1200°C		
K	-200 to 1370°C		
T	-200 to 400°C		
B	450 to 1800°C		
R	0 to 1750°C	$\pm$0.25% of instrument range $\pm$ 1 digit(B,R,S TYPE TC)	
S	0 to 1750°C		
N	-200 to 1300°C		
RTD	-199.9 to 850.0°C	$\pm$ 0.1% of instrument range $\pm$ 1 digit	
0 to 75mV	-1999 to 9999	$\pm$ 0.1% of range $\pm$ 1 digit	1 Count
0 to 100mv			
0.4 to 2V			
0 to 2V			
0-20 mA*			
4-20 mA*			
0 to 5V			
1 to 5V			
0 to 10V			
-10 to 20mV			

Source:www.masibus.com

4.2.2 Solarimeter

In this study a solarimeter was used as shown in Fig.4.3 to measure the total solar radiations (direct as well as diffuse) received from entire hemisphere on an inclined surface of solar Air heater in terms of solar intensity (i.e. in watt per meter square) the working principle of solarimeter is that sensitive surface is exposed to the sun directly. It is having a rectangular photo sensor. When light falls onto the photo sensor it converts the solar irradiations into solar intensity

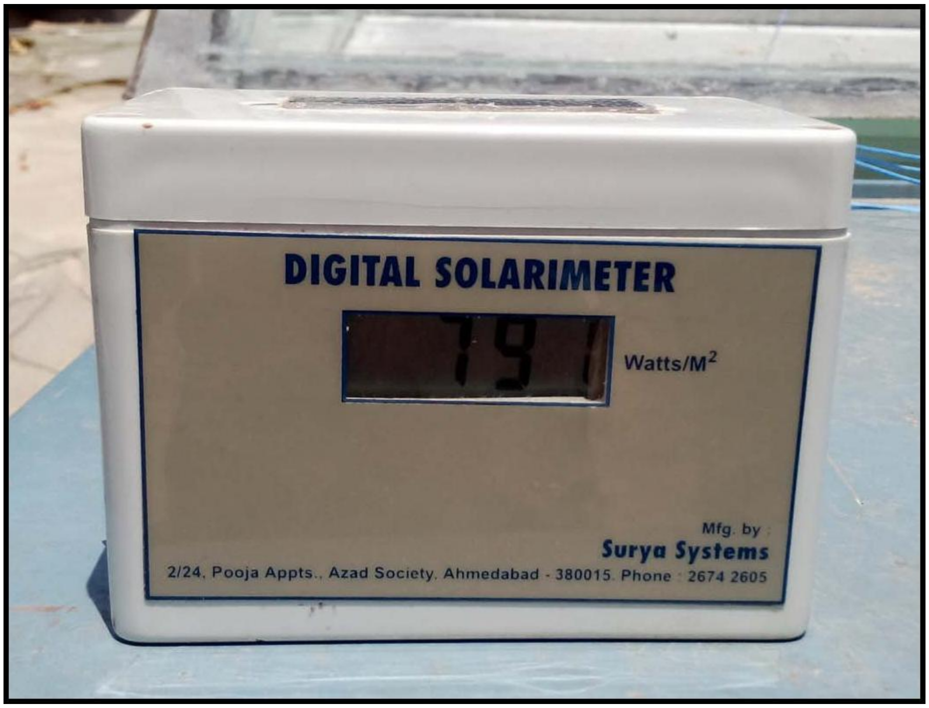


Fig 4.3.Photo of Digital Solarimeter

4.2.3 Digital Anemometer

In this study an Anemometer was used as shown in Fig.4.4 for measurement of air blow velocity of blower.

An anemometer is a device for measuring wind speed. Coupled with a weather vane which indicates the direction of the wind, it forms a complete setup for describing the wind at any given geographical location

Figure4.4: Digital Anemometer (4201)

4.2.5 Thermocouples

When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, there is continuous current which flows in the thermoelectric circuit. Sir Thomas Seebeck made this discovery in 1821. There are several types of thermocouples for different temperature ranges.

Table 4.2. Compositions, Temperature ranges and Letter Designations of the thermocouples

Thermocouple-type	Conductors-positive	Conductors-negative	Temperature-Ranges (^{0}c)
B	Platinum-30% rhodium	Platinum-6% rhodium	400 to 1820
E (chromelconstantan)	Nickel-chromium alloy	Copper-nickel alloy	-200 to 1000
J (iron-constantan)	Iron	Copper-nickel alloy	-200 to 1200
K (chroel-alumel)	Nickel-chromium alloy	Nickel-aluminium alloy	-200 to 1372
N (nicrosil-nisil)	Nickel-chromium Silicon alloy	Nickel-silicon Magnesium alloy	-200 to 1300
R	Platinum-13% rhodium	Platinum	0 to 1768
S	Platinum-10% rhodium	Platinum	0 to 1768
T (copper-constantan)	Copper	Copper-nickel alloy	-200 to 400

Source www.ni.comandwww.labfacility.co.uk

In our Experimental setup of solar Air heater there is Eight T-types (copper-constantan) thermocouples have been attached to measure the temperature at different locations. Its temperature ranges are given in Table 4.2.

Thermocouple no. 1 is attached to glass cover to measure the glass temperature. The same procedure has been done with another thermocouples attached at different locations to assume uniform temperature at that location. Thermocouple no. 2 and 3 are attached to storage cover to measure the storage temperature at different points finally averaging all the two temperature and assume that the storage temperature is uniformly distributed. Thermocouple no. 4 to 5 is attached to the absorber plate of the solar Air heater, Thermocouple measure the temperature at different points finally averaging all the two temperature and assume that the absorber plate temperature is uniformly distributed. Thermocouple no. 6 is kept in the atmospheric air in shaded area to measure the ambient temperature. Thermocouple no. 7 is placed on the inlet of the air of solar Air Heater. Thermocouple no. 8 is placed on the outlet of the air of solar Air Heater.

4.3 Calibration of Thermocouples

A thermocouple is made of two dissimilar electric conductors which are joined at one end called hot junction and another end is attach to the voltmeter (Temperature Indicator) called cold junction. And Hot junction can be prepared in common practice by welding, soldering or simply by twisting the two dissimilar electric conductors to make good electric connection. The output of thermocouple reading is voltage (Seebeck voltage) which is directly proportional to temperature difference of the junctions

There are two common approaches for measuring temperature using thermocouple circuit. In first approach put the cold junction into the ice bath to maintain the known temperature i.e. 0^0C because voltmeter reading (i.e. See beck voltage) will be directly proportional to temperature difference of the junctions. This says that we can’t find the temperature of the hot junction unless we first find the temperature of cold junction.

In second approach measure the temperature of cold junction point by using a temperature sensor like an RTD, a Thermistor, or an integrated circuit sensor which is automatically controlled by the software of the temperature indicator. Even some temperature sensor having its own error and it not gives the actual value of the cold junction temperature because of that there is an error creates in the temperature of hot junction. This error is called cold junction compensation error.

Thermocouples need to be calibrated for errors. Three point calibrations were done. First point is ice point i.e. 0^0C obtained in the mixture of ice and water in an insulated thermos flask. Second point is room temperature and third point is steam point i.e. 99^oC which is the function of pressure.

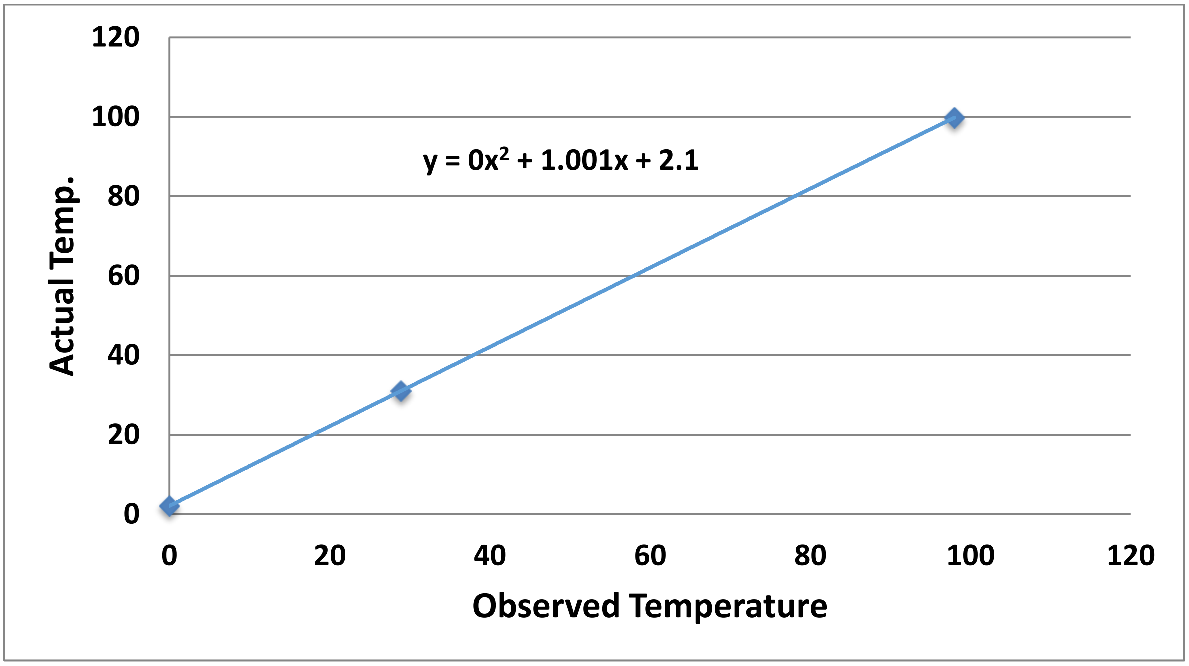
For all three points i.e. ice point, room temperature, and steam point are to be measured using temperature indicator. All the readings are shown in the Table 4.4 are to be measured in ^{0}C and Graph 4.1 and 4.2 show the variation of actual temperature according to observed temperature and also show the trends of variation.

Figure.4.5 Thermocouple calibration

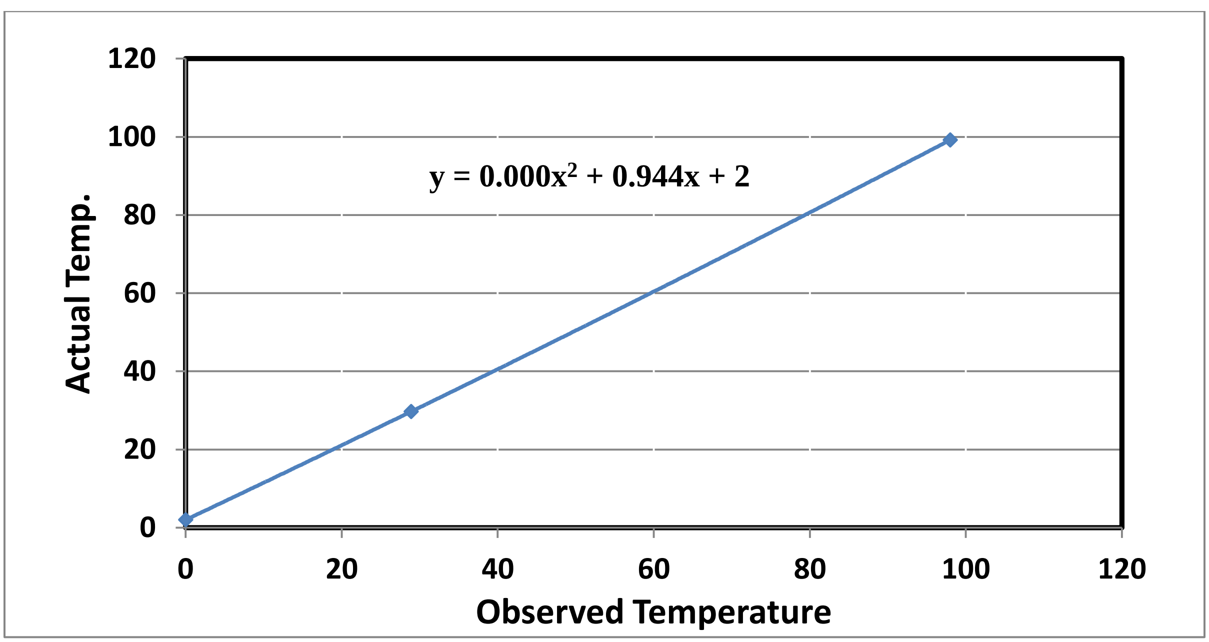
Table 4.3: Calibration of T-Type Thermocouples

Different Points	(All temperatures are in ^{0}C)								
	Tactual	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
Ice Point	0.0	2.1	2.3	3.1	2.5	3	2.5	2	2.3
Room temp.	28.9	31.0	27.2	30.8	27.5	30	31	29.7	28.5
Steam Point	98.0	99.8	98.7	99.8	99.2	98.2	99	99.2	99.2

Graph: 4.1 Variation of actual temperature. To observed temperature T1



Graph: 4.2 Variation of actual temp.to observed temperature T_7



According to Graph 4.1 and 4.2 we can see how actual temperature varies with observed temperature i.e. linear variation according to trend line. The variation of T_{actual} with T_1 is as follows;

$$\boldsymbol{y = 0x^2 + 1.001x + 2.1}$$

According to Table 4.2 we can see how actual temperature varies with observed temperature i.e. linear variation according to trend line. The variation of T_{actual}withT_7 is as follows;

$$\boldsymbol{y = 0x^2 + 0.944x + 2}$$

CHAPTER 5

Experimentation and Observation

5.1Experimentation

For the calculation of efficiency in solar Air Heater we should know about the following parameters which have been measured during Experimentation.

- Temperature of glass, storage, absorber plate, inlet, outlet, and ambient.
- Solar intensity.
- Inlet air velocity

Temperatures of various points have been measured with the help of T-type thermocouples which are connected to the 8-Channel digital temperature scanner. Solarimeter has been used to measure the solar intensity. Anemometer has been used to measure the Inlet air velocity.

Apart from these readings transmissivity of glass has been measured for one complete day from 10 a.m. to 6:30 p.m. at every half an hour after keeping the solarimeter inside the glass with same inclination. Before the experiment glass cover of solar Air Heater was cleaned properly.

At every half an hour the following steps were taken to measure;

- Temperature of all points
- Solar intensity
- Inlet air velocity

5.2 Observations

A total ten sets of experiments were done from 17th May to 1stJune, to take the reading of different parameter for balancing the heat precisely on Double Pass and Single Pass Solar Air

Heater. For the sake of simplicity experimental observations like solar intensity, output, inlet temperature, and temperature of all surfaces of solar air heater, have been summarized in tabular form which are mentioned below in appendix table.

Table 5.1. Double Pass Solar Air Heater With Thermal Energy Storage(DATE-18-04-2015)

Time	Glass Temp(°C)	T_2(°C)	T_3 (°C)	Average Thermal Storage Temp(°C)	T_4(°C)	T_5(°C)	Average Absorber Plate Temp	Inlet Air Temp	Outlet Air Temp(°C)	T_8 (°C)- T_7 (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:30	45.50	57.50	55.60	56.55	52.00	50.48	51.24	37.00	53.00	16.00	33.60	6.00	625.00
11:00	46.20	58.70	56.50	57.60	53.40	52.00	52.70	37.90	55.40	17.50	34.50	6.00	660.00
11:30	46.90	60.80	59.00	59.90	54.30	52.60	53.45	38.80	57.20	18.40	35.60	6.00	690.00
12:00	47.30	62.70	61.50	62.10	56.50	54.20	55.35	40.10	59.60	19.50	36.30	6.00	730.00
12:30	47.60	63.80	62.20	63.00	58.00	56.30	57.15	40.50	60.80	20.30	37.00	6.00	750.00
13:00	48.20	64.90	63.10	64.00	59.20	58.40	58.80	41.00	61.40	20.40	37.70	6.00	750.00
13:30	48.10	64.40	62.90	63.65	59.30	59.00	59.15	41.00	60.60	19.60	38.35	6.00	720.00
14:00	48.30	65.00	63.80	64.40	58.80	58.00	58.40	41.80	61.20	19.40	38.40	6.00	710.00
14:30	48.40	64.70	64.00	64.35	57.80	56.90	57.35	42.50	61.00	18.50	39.00	6.00	675.00
15:00	47.90	63.30	63.60	63.45	57.90	53.80	55.85	43.10	60.10	17.00	39.23	6.00	620.00
15:30	47.10	60.80	61.90	61.35	56.10	53.50	54.80	42.80	57.30	14.50	39.30	6.00	528.00
16:00	46.80	57.70	59.50	58.60	54.30	51.10	52.70	42.50	54.50	12.00	39.10	6.00	430.00
16:30	45.70	54.50	57.50	56.00	53.00	49.50	51.25	41.70	52.90	11.20	39.14	6.00	322.00
17:00	44.80	52.40	55.90	54.15	52.50	48.00	50.25	41.50	50.00	8.50	39.40	6.00	220.00
17:30	43.20	49.80	53.20	51.50	49.20	47.00	48.10	40.50	47.50	7.00	39.20	6.00	50.00
18:00	41.90	47.40	50.80	49.10	46.50	44.00	45.25	39.80	45.00	5.20	38.80	6.00	0.00
18:30	41.50	44.80	48.20	46.50	43.40	40.00	41.70	39.00	42.00	3.00	38.00	6.00	0.00

Table 5.2. Double Pass Solar Air Heater With Thermal Energy Storage(DATE-19-04-2015)

Time	Glass Temp(°C)	T_2(°C)	T_3(°C)	AverageThermal Storage Temp(°C)	T_4(°C)	T_5(°C)	Average Absorber Plate Temp	Inlet Air Temp	Outlet Air Temp(°C)	T_8 (°C)-T_7 (°C)	T_{amb}(°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	44.70	60.30	57.50	58.90	50.40	49.80	50.10	37.20	52.50	15.30	34.00	6.00	550.00
10:30	45.60	62.20	61.60	61.90	52.40	52.00	52.20	37.50	55.00	17.50	34.70	6.00	640.00
11:00	48.00	62.90	62.10	62.50	54.80	53.90	54.35	38.00	57.50	19.50	35.70	6.00	700.00
11:30	49.30	64.10	63.90	64.00	56.40	55.70	56.05	39.00	59.40	20.40	36.60	6.00	730.00
12:00	49.80	66.20	65.60	65.90	57.70	57.10	57.40	39.80	60.90	21.10	37.20	6.00	750.00
12:30	50.00	69.10	68.30	68.70	59.80	58.70	59.25	41.30	63.50	22.20	37.77	6.00	788.00
13:00	50.00	70.20	69.10	69.65	61.20	60.40	60.80	42.10	63.90	21.80	38.31	6.00	771.00
13:30	49.80	68.90	67.60	68.25	60.90	59.10	60.00	42.10	63.10	21.00	39.30	6.00	742.00
14:00	50.20	67.20	66.00	66.60	59.20	58.60	58.90	42.10	62.50	20.40	39.68	6.00	710.00
14:30	49.80	66.20	65.40	65.80	59.30	58.50	58.90	43.10	61.90	18.80	40.58	6.00	655.00
15:00	48.00	64.90	62.30	63.60	56.80	55.60	56.20	42.10	59.70	17.60	40.53	6.00	595.00
15:30	47.00	62.10	61.60	61.85	56.10	55.00	55.55	42.00	57.90	15.90	40.46	6.00	530.00
16:00	45.90	57.90	59.20	58.55	53.70	51.10	52.40	41.90	54.60	12.70	40.44	6.00	403.00
16:30	43.90	56.40	57.20	56.80	51.20	49.20	50.20	41.80	52.10	10.30	40.20	6.00	200.00
17:00	43.20	54.20	53.20	53.70	48.10	46.90	47.50	41.50	49.70	8.20	40.00	6.00	150.00
17:30	42.80	50.00	51.30	50.65	46.30	44.90	45.60	41.20	46.70	5.50	39.00	6.00	0.00
18:00	42.40	49.30	48.40	48.85	43.20	42.80	43.00	39.50	44.50	5.00	38.42	6.00	0.00
18:30	40.00	47.20	46.70	46.95	41.20	41.00	41.10	39.00	43.00	4.00	38.00	6.00	0.00

Table 5.3. Double Pass Solar Air Heater With Thermal Energy Storage (DATE-20-04-2015)

Time	Glass Temp(°C)	T_2 (°C)	T_3 (°C)	Average Thermal Storage Temp(°C)	T_4(°C)	T_5 (°C)	Average Absorber Plate Temp	Inlet Air Temp	Outlet Air Temp(°C)	T_8 (°C)- T_7 (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	46.10	64.00	63.10	63.55	57.40	55.20	53.20	39.70	55.00	15.30	36.35	6.00	540.00
10:30	47.50	65.60	65.20	65.40	58.00	56.10	55.20	40.00	56.70	16.70	37.70	6.00	660.00
11:00	48.40	67.80	67.10	67.45	58.70	56.70	57.70	39.90	59.10	19.20	38.40	6.00	740.00
11:30	49.70	69.30	68.10	68.70	61.60	58.00	59.80	41.80	61.90	20.10	39.20	6.00	770.00
12:00	51.20	69.20	68.30	68.75	62.90	59.00	60.95	42.40	63.70	21.30	40.00	6.00	784.00
12:30	52.60	70.50	70.00	70.25	63.00	60.20	61.60	43.20	65.20	22.00	40.50	6.00	803.00
13:00	51.00	70.10	70.00	70.05	61.00	59.00	60.00	44.10	65.80	21.70	41.20	6.00	790.00
13:30	50.40	70.00	69.40	69.70	62.00	61.00	61.50	44.20	65.40	21.20	42.00	6.00	770.00
14:00	50.00	69.50	69.10	69.30	62.90	60.70	61.80	44.90	65.00	20.10	41.90	6.00	720.00
14:30	49.70	68.00	68.40	68.20	62.60	60.10	61.35	44.90	64.00	19.10	41.60	6.00	655.00
15:00	48.70	66.60	67.40	67.00	62.10	59.30	60.70	44.50	62.70	18.20	41.20	6.00	570.00
15:30	47.90	65.00	66.10	65.55	61.90	58.80	56.90	43.10	60.50	17.40	41.00	6.00	520.00
16:00	46.80	64.00	65.60	64.80	56.00	55.00	52.40	42.70	55.00	12.30	39.80	6.00	380.00
16:30	45.70	60.30	62.40	61.35	54.30	52.70	51.10	41.70	53.70	12.00	39.50	6.00	360.00
17:00	44.90	56.10	59.30	57.70	51.50	49.00	48.20	40.90	50.40	9.50	39.20	6.00	200.00
17:30	44.00	53.00	56.00	54.50	48.80	46.00	47.40	40.20	48.40	8.20	39.10	6.00	0.00

Table 5.4. Double Pass Solar Air Heater With Thermal Energy Storage (DATE-21-04-2015)

TIME	Glass Temp (°C)	T_2 (°C)	T_3 (°C)	Average Thermal Storage Temp (°C)	T_4 (°C)	T_5 (°C)	Average Absorber Plate Temp(°C)	Inlet Air Temp(°C)	Outlet Air Temp (°C)	T_8 (°C)-T_7 (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m2)
10:00	43.20	56.50	55.90	56.20	49.20	48.50	48.85	38.00	14.30	52.30	34.27	9.00	598.00
10:30	44.10	57.50	56.90	57.20	50.20	49.60	49.90	38.80	12.70	51.50	35.61	9.00	640.00
11:00	44.70	60.20	58.50	59.35	51.00	50.20	50.60	39.00	14.10	53.10	36.20	9.00	710.00
11:30	45.80	61.00	60.40	60.70	53.00	51.90	52.45	40.10	15.50	55.60	36.40	9.00	750.00
12:00	46.00	61.60	61.00	61.30	54.20	52.00	53.10	40.30	15.80	56.10	36.59	9.00	750.00
12:30	47.00	63.00	61.70	62.35	55.00	54.50	54.75	40.50	16.70	57.20	36.91	9.00	790.00
13:00	48.20	63.30	62.80	63.05	55.90	54.90	55.40	41.10	16.90	58.00	37.34	9.00	788.00
13:30	47.60	63.10	62.40	62.75	54.40	53.20	53.80	41.50	16.00	57.50	37.73	9.00	740.00
14:00	46.90	62.50	62.80	62.65	54.20	52.60	53.40	41.90	15.60	57.50	38.11	9.00	720.00
14:30	46.10	60.20	61.00	60.60	53.00	51.50	52.25	42.00	14.40	56.40	38.16	9.00	650.00
15:00	45.80	59.40	60.00	59.70	52.10	50.50	51.30	41.50	12.60	54.10	38.49	9.00	545.00
15:30	44.70	56.00	57.50	56.75	50.00	48.50	49.25	40.60	12.20	52.80	38.20	9.00	520.00
16:00	44.10	54.00	54.30	54.15	49.30	47.50	48.40	40.20	10.10	50.30	38.25	9.00	430.00
16:30	43.50	53.20	53.20	53.20	47.00	46.10	46.55	40.00	8.30	48.30	37.96	9.00	310.00
17:00	43.00	51.60	50.90	51.25	46.20	45.60	45.90	40.00	6.10	46.10	37.62	9.00	200.00
17:30	42.50	48.30	49.00	48.65	44.20	44.50	44.35	39.00	6.00	45.00	37.56	9.00	58.00
18:00	42.00	46.90	48.20	47.55	43.40	43.60	43.50	38.50	6.00	44.50	37.16	9.00	0.00
18:30	41.10	45.20	45.50	45.35	42.10	42.50	42.30	38.20	4.00	42.20	36.37	9.00	0.00

Table 5.5. Double Pass Solar Air Heater With Thermal Energy Storage (DATE-22-04-2015)

Time	Glass Temp (°C)	T_2 (°C)	T_3 (°C)	Average Thermal Storage Temp (°C)	T_4 (°C)	T_5 (°C)	Average Absorber Plate Temp(°C)	Inlet Air Temp(°C)	Outlet Air Temp (°C)	T_8 (°C)- T_7 (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	41.20	55.50	55.20	55.20	48.80	47.00	47.90	37.10	52.80	15.70	34.29	9.00	575.00
10:30	42.80	58.70	57.30	56.10	49.30	48.20	48.75	37.60	51.80	14.20	34.33	9.00	637.00
11:00	43.60	59.30	58.20	58.75	52.00	51.20	51.60	38.00	53.60	15.60	34.69	9.00	700.00
11:30	44.90	61.30	60.40	60.85	52.70	52.00	52.35	38.60	54.90	16.30	35.22	9.00	730.00
12:00	45.70	63.00	60.90	61.95	53.50	53.00	53.25	39.00	57.00	18.00	35.77	9.00	810.00
12:30	48.00	64.70	62.90	63.80	54.90	54.00	54.45	40.00	58.40	18.40	37.51	9.00	825.00
13:00	48.60	65.60	64.20	64.90	55.20	54.40	54.80	40.70	59.30	18.60	37.44	9.00	831.00
13:30	47.90	63.60	63.50	63.55	55.40	54.20	54.80	41.00	59.00	18.00	37.52	9.00	800.00
14:00	47.30	62.70	63.30	63.00	52.40	52.10	52.25	41.40	58.30	16.90	38.20	9.00	745.00
14:30	47.30	60.70	61.50	61.10	53.00	51.00	52.00	41.30	57.70	16.40	38.28	9.00	720.00
15:00	46.20	59.90	60.60	60.25	52.10	50.00	51.05	42.00	55.70	13.70	39.48	9.00	610.00
15:30	45.10	56.50	57.90	57.20	50.00	48.00	49.00	41.70	54.50	12.80	39.02	9.00	560.00
16:00	44.40	54.50	55.90	55.20	49.30	48.70	49.00	41.60	51.90	10.30	38.61	9.00	400.00
16:30	43.50	52.70	55.20	53.95	48.90	48.00	48.45	41.40	50.70	9.30	38.70	9.00	320.00
17:00	42.80	51.60	50.90	51.25	46.20	45.60	45.90	40.00	6.10	46.10	37.62	9.00	200.00
17:30	41.70	48.30	49.00	48.65	44.20	44.50	44.35	39.00	6.00	45.00	37.56	9.00	58.00
18:00	41.20	46.90	48.20	47.55	43.40	43.60	43.50	38.50	6.00	44.50	37.16	9.00	0.00
18:30	41.00	45.20	45.50	45.35	42.10	42.50	42.30	38.20	4.00	42.20	36.37	9.00	0.00

Table 5.6. Double Pass Solar Air Heater With Thermal Energy Storage (DATE-23-04-2015)

Time	Glass Temp (°C)	T_2 (°C)	T_3 (°C)	Thermal Storage Temp (°C)	T_4 (°C)	T_5 (°C)	Absorber Plate Temp(°C)	Inlet Air Temp(°C)	Outlet Air Temp (°C)	T_8 (°C)- T_7 (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	43.70	60.70	59.10	59.90	52.10	52.00	52.05	38.00	55.00	17.00	34.56	9.00	620.00
10:30	44.80	61.40	60.20	60.80	51.00	50.90	50.95	39.30	54.00	14.70	35.39	9.00	680.00
11:00	45.90	62.70	61.70	62.20	52.70	51.80	52.25	39.50	55.20	15.70	35.82	9.00	720.00
11:30	46.90	64.00	63.20	63.60	53.60	52.90	53.25	39.60	56.20	16.60	35.94	9.00	750.00
12:00	47.90	64.60	63.70	64.15	54.40	54.10	54.25	39.90	57.20	17.30	36.72	9.00	780.00
12:30	50.00	64.00	63.70	63.85	55.10	54.70	54.90	40.10	57.50	17.40	37.90	9.00	782.00
13:00	49.90	65.20	64.40	64.80	55.50	55.20	55.35	40.50	58.30	17.80	37.96	9.00	799.00
13:30	49.60	65.40	65.00	65.20	55.80	55.40	55.60	40.90	58.50	17.60	38.31	9.00	788.00
14:00	49.30	64.80	64.10	64.45	56.00	55.10	55.55	41.00	58.30	17.30	38.41	9.00	790.00
14:30	49.30	64.00	63.80	63.90	54.80	53.90	54.35	41.70	57.50	15.80	38.77	9.00	680.00
15:00	48.10	62.80	61.50	62.15	53.40	51.60	52.50	41.20	55.80	14.60	38.33	9.00	610.00
15:30	46.10	59.00	59.60	59.30	50.70	49.30	50.00	40.50	53.10	12.60	38.69	9.00	525.00
16:00	45.20	57.20	58.20	57.70	47.90	47.00	47.45	40.10	51.20	11.10	38.57	9.00	465.00
16:30	43.20	56.00	56.40	56.20	46.30	45.40	45.85	39.80	50.10	10.30	38.32	9.00	340.00
17:00	41.50	54.20	54.40	54.30	47.70	44.90	46.30	39.60	48.70	9.10	38.66	9.00	225.00
17:30	40.90	52.20	53.00	52.60	45.90	43.20	44.55	39.00	47.20	8.20	38.06	9.00	50.00
18:00	40.00	50.30	51.90	51.10	43.80	40.70	42.25	38.80	45.90	7.10	37.43	9.00	0.00
18:30	38.70	49.40	49.00	49.20	41.50	40.00	40.75	38.50	44.10	5.60	37.08	9.00	0.00

Table 5.7.Single Pass Solar Air Heater With Thermal Energy Storage (DATE-27-04-2015)													
Time	**Glass Temp (°C)**	**T_2 (°C)**	**T_3 (°C)**	**Average Thermal Storage Temp (°C)**	**T_4 (°C)**	**T_5 (°C)**	**Average Absorber Plate Temp(°C)**	**Inlet Air Temp (°C)**	**Outlet Air Temp (°C)**	**T_8 (°C)- T_7 (°C)**	**T_{amb} (°C)**	**V_{air} (m/s)**	**I_T (W/m^2)**
11:00	42.90	59.60	58.10	58.85	52.40	53.30	52.85	35.20	49.00	13.80	32.50	6.00	688.00
11:30	43.90	60.40	59.00	59.70	53.30	51.30	52.30	36.50	48.20	11.70	33.52	6.00	730.00
12:00	44.60	63.60	61.40	62.50	55.50	54.60	55.05	37.40	50.00	12.60	34.44	6.00	760.00
12:30	47.20	63.80	63.70	63.75	57.20	56.90	57.05	38.00	51.00	13.00	36.50	6.00	775.00
13:00	48.20	64.20	63.90	64.05	58.10	57.80	57.95	39.50	52.60	13.10	37.19	6.00	778.00
13:30	48.80	62.70	63.20	62.95	57.00	57.40	57.20	40.80	53.00	12.20	38.01	6.00	720.00
14:00	48.40	62.10	62.90	62.50	56.30	57.10	56.70	40.90	52.80	11.90	38.60	6.00	690.00
14:30	48.00	62.00	62.60	62.30	56.20	56.40	56.30	41.80	52.90	11.10	38.88	6.00	640.00
15:00	47.90	59.80	60.90	60.35	54.90	55.30	55.10	42.30	52.70	10.40	39.63	6.00	593.00
15:30	47.00	58.70	59.50	59.10	53.40	52.70	53.05	41.70	50.40	8.70	39.00	6.00	490.00
16:00	46.70	56.00	57.10	56.55	52.00	51.60	51.80	41.00	50.20	9.20	38.70	6.00	465.00
16:30	46.20	55.00	55.80	55.40	50.60	51.00	50.80	41.00	49.20	8.20	38.50	6.00	290.00
17:00	46.10	53.00	53.90	53.45	51.60	45.80	48.70	40.70	48.50	7.80	38.50	6.00	200.00
17:30	45.20	50.10	50.90	50.50	48.20	47.10	47.65	40.10	47.00	6.90	38.10	6.00	0.00
18:00	43.70	47.20	48.70	47.95	46.00	45.30	45.65	39.70	44.20	4.50	38.00	6.00	0.00

Table 5.8.Single Pass Solar Air Heater With Thermal Energy Storage (DATE-29-04-2015)													
Time	**Glass Temp (°C)**	**T_2 (°C)**	**T_3 (°C)**	**Average Thermal Storage Temp (°C)**	**T_4 (°C)**	**T_5 (°C)**	**Average Absorber Plate Temp(°C)**	**Inlet Air Temp (°C)**	**Outlet Air Temp (°C)**	**T_8 (°C)- T_7 (°C)**	**T_{amb} (°C)**	**V_{air} (m/s)**	**I_T (W/m^2)**
10:00	43.20	62.90	62.90	62.90	54.40	54.20	54.30	35.90	47.60	11.70	32.00	6.00	600.00
10:30	44.50	62.00	62.20	62.10	55.90	56.00	55.95	36.20	47.30	11.10	33.00	6.00	650.00
11:00	45.30	63.80	63.30	63.55	57.70	57.00	57.35	37.50	50.20	12.70	34.00	6.00	688.00
11:30	46.50	65.00	64.60	64.80	58.40	58.80	58.60	38.50	51.70	13.20	35.00	6.00	730.00
12:00	47.10	65.40	65.00	65.20	59.10	59.20	59.15	39.00	52.80	13.80	36.00	6.00	760.00
12:30	47.20	66.10	65.80	65.95	60.00	60.80	60.40	40.20	54.30	14.10	36.00	6.00	775.00
13:00	48.00	66.70	66.90	66.80	60.40	61.00	60.70	40.90	55.40	14.50	37.00	6.00	778.00
13:30	47.70	65.70	66.20	65.95	58.80	59.60	59.20	41.40	54.80	13.40	37.50	6.00	720.00
14:00	47.40	65.00	65.40	65.20	57.90	58.60	58.25	41.80	52.90	11.10	38.00	6.00	690.00
14:30	47.30	64.40	65.20	64.80	57.70	58.20	57.95	42.40	53.30	10.90	39.00	6.00	640.00
15:00	47.00	63.40	64.00	63.70	57.80	56.20	57.00	42.60	53.30	10.70	40.00	6.00	593.00
15:30	46.70	62.50	63.10	62.80	56.40	55.80	56.10	41.50	53.00	11.50	39.50	6.00	490.00
16:00	46.00	61.10	61.80	61.45	54.40	55.00	54.70	40.90	51.00	10.10	39.20	6.00	465.00
16:30	45.70	59.40	59.80	59.60	52.80	53.80	53.30	40.70	50.60	9.90	39.00	6.00	290.00
17:00	45.10	57.20	57.60	57.40	51.00	51.90	51.45	40.50	49.00	8.50	38.50	6.00	200.00
17:30	44.40	55.50	56.00	55.75	50.40	50.00	50.20	39.80	45.90	6.10	38.00	6.00	0.00
18:00	42.80	53.20	54.00	53.60	48.00	46.50	47.25	39.00	43.80	4.80	37.40	6.00	0.00

Table 5.9.Single Pass Solar Air Heater With Thermal Energy Storage (DATE-30-04-2015)

Time	Glass Temp (°C)	T_2 (°C)	T_3 (°C)	Average Thermal Storage Temp (°C)	T_4 (°C)	T_5 (°C)	Average Absorber Plate Temp(°C)	Inlet Air Temp (°C)	Outlet Air Temp (°C)	T_8 (°C)-T_7 (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	41.20	51.50	52.90	52.20	48.30	47.90	48.10	36.50	44.60	8.10	32.71	9.00	560.00
10:30	43.20	55.40	54.30	54.85	49.20	48.90	49.05	38.20	46.10	7.90	33.78	9.00	610.00
11:00	45.30	56.70	58.00	57.35	52.10	52.20	52.15	38.80	48.50	9.70	34.96	9.00	698.00
11:30	47.80	59.30	58.90	59.10	54.20	53.10	53.65	39.40	50.80	11.40	36.43	9.00	728.00
12:00	49.40	61.10	59.80	60.45	55.60	55.20	55.40	40.50	52.60	12.10	37.69	9.00	747.00
12:30	50.00	62.20	63.20	62.70	56.90	58.40	57.65	41.00	54.00	13.00	38.41	9.00	760.00
13:00	51.00	63.80	64.30	64.05	57.60	60.00	58.80	41.50	54.80	13.30	38.97	9.00	772.00
13:30	51.80	64.70	64.90	64.80	57.80	60.20	59.00	42.50	56.10	13.60	39.99	9.00	782.00
14:00	50.70	63.60	64.00	63.80	57.20	59.40	58.30	42.90	55.70	12.80	40.18	9.00	735.00
14:30	49.90	62.90	63.40	63.15	56.90	58.20	57.55	43.60	55.00	11.40	41.15	9.00	650.00
15:00	49.80	61.60	62.60	62.10	56.60	57.80	57.20	44.10	54.10	10.00	41.58	9.00	560.00
15:30	48.80	60.20	61.30	60.75	55.70	56.20	55.95	44.50	53.70	9.20	41.67	9.00	510.00
16:00	47.50	59.50	59.00	59.25	54.00	55.10	54.55	43.20	51.50	8.30	40.87	9.00	444.00
16:30	46.10	57.80	56.90	57.35	53.30	53.20	53.25	42.10	49.40	7.30	40.00	9.00	350.00
17:00	44.70	55.20	55.60	55.40	51.10	51.00	51.05	41.10	47.20	6.10	38.80	9.00	197.00
17:30	42.30	53.20	52.90	53.05	50.10	49.00	49.55	40.10	45.80	5.70	38.60	9.00	0.00
18:00	40.90	50.10	50.90	50.50	47.50	48.00	47.75	39.20	45.00	5.80	38.10	9.00	0.00
18:30	41.20	51.50	52.90	52.20	48.30	47.90	48.10	36.50	44.60	8.10	32.71	9.00	560.00

Table 5.10.Single Pass Solar Air Heater With Thermal Energy Storage (DATE-01-05-2015)													
TIME	**Glass Temp (°C)**	**T_2 (°C)**	**T_3 (°C)**	**Average Thermal Storage Temp (°C)**	**T_4 (°C)**	**T_5 (°C)**	**Average Absorber Plate Temp(°C)**	**Inlet Air Temp (°C)**	**Outlet Air Temp (°C)**	**T_8 (°C)-T_7 (°C)**	**T_{amb} (°C)**	**V_{air} (m/s)**	**I_T (W/m^2)**
10:00	40.00	53.60	53.90	53.75	48.10	48.00	48.05	34.70	43.50	8.80	31.44	9.00	600.00
10:30	41.70	55.00	54.40	54.70	49.00	48.80	48.90	35.40	44.80	9.40	32.01	9.00	680.00
11:00	43.30	55.90	56.10	56.00	50.40	50.10	50.25	36.00	46.40	10.40	33.00	9.00	745.00
11:30	45.30	57.20	57.70	57.45	51.30	51.00	51.15	37.10	47.90	10.80	35.12	9.00	770.00
12:00	46.60	58.00	59.10	58.55	53.70	53.60	53.65	38.10	50.00	11.90	35.22	9.00	790.00
12:30	47.70	59.80	61.80	60.80	55.00	54.80	54.90	39.00	52.00	13.00	36.83	9.00	830.00
13:00	48.50	60.80	61.00	60.90	55.70	55.50	55.60	39.90	52.60	12.70	37.07	9.00	800.00
13:30	48.30	60.30	60.80	60.55	55.70	55.00	55.35	40.10	52.60	12.50	37.35	9.00	780.00
14:00	47.30	59.80	60.20	60.00	55.60	54.80	55.20	40.20	51.90	11.70	38.42	9.00	720.00
14:30	46.50	58.90	59.60	59.25	55.40	53.80	54.60	40.50	51.40	10.90	38.20	9.00	670.00
15:00	45.80	57.20	58.10	57.65	55.30	51.30	53.30	41.20	50.70	9.50	38.72	9.00	590.00
15:30	45.00	55.50	56.00	55.75	53.00	49.50	51.25	40.80	49.40	8.60	38.53	9.00	520.00
16:00	44.30	54.70	55.50	55.10	52.50	49.40	50.95	41.00	48.40	7.40	38.58	9.00	400.00
16:30	43.80	52.80	53.20	53.00	50.40	47.30	48.85	41.30	47.20	5.90	38.47	9.00	280.00
17:00	42.20	51.00	51.20	51.10	48.00	46.00	47.00	40.30	45.20	4.90	38.36	9.00	210.00
17:30	41.20	48.80	50.00	49.40	46.60	44.90	45.75	39.50	44.00	4.50	38.20	9.00	50.00
18:00	40.50	46.90	47.70	47.30	43.30	42.20	42.75	38.70	42.00	3.30	37.56	9.00	0.00

CHAPTER 6

Results and discussion

All the results of 10 set of experimentation are shown previously in Tabular, Graph. We will summarize all the calculation in this Sec.

On the basis of experimental observed data calculation of half hourly averaged data has been done further half hourly averaged data used for half hourly calculation of temperature difference between outlet temperature and inlet temperature and averaged calculation of thermal storage temperature , absorber plate temperature for whole day which gives the information about how much heat is coming inside the solar air heater from the sun and how much heat is going through it.

We can see from the Table of half hourly calculation of temperature difference of air inlet and outlet as the intensity increases with time (Graph 6.1 to 6.18 shows the variation of intensity ,temp of air heater various part with time) the all types of temperature also increases going up to peak and starts decreasing with decrease in intensity. It means maximum temperature difference takes place maximum at the time when intensity reach at the peak level. Also we can see that the heat is stored in PCM when solar radiation is increasing and goes up to a peak level. It was also observed that the solar air heater could heat the air even without receiving solar radiation. Finally, it is inferred that the solar air heater with thermal storage can be used even at night.

Calculation of efficiency of air heater

The velocity of air coming out of the blower is found by anemometer,

The atmospheric pressure of air, $P = 1.013 X 10^5 Pa$

The mass flow rate of the air entering the blower is given by, $\dot{m} = \rho AV$

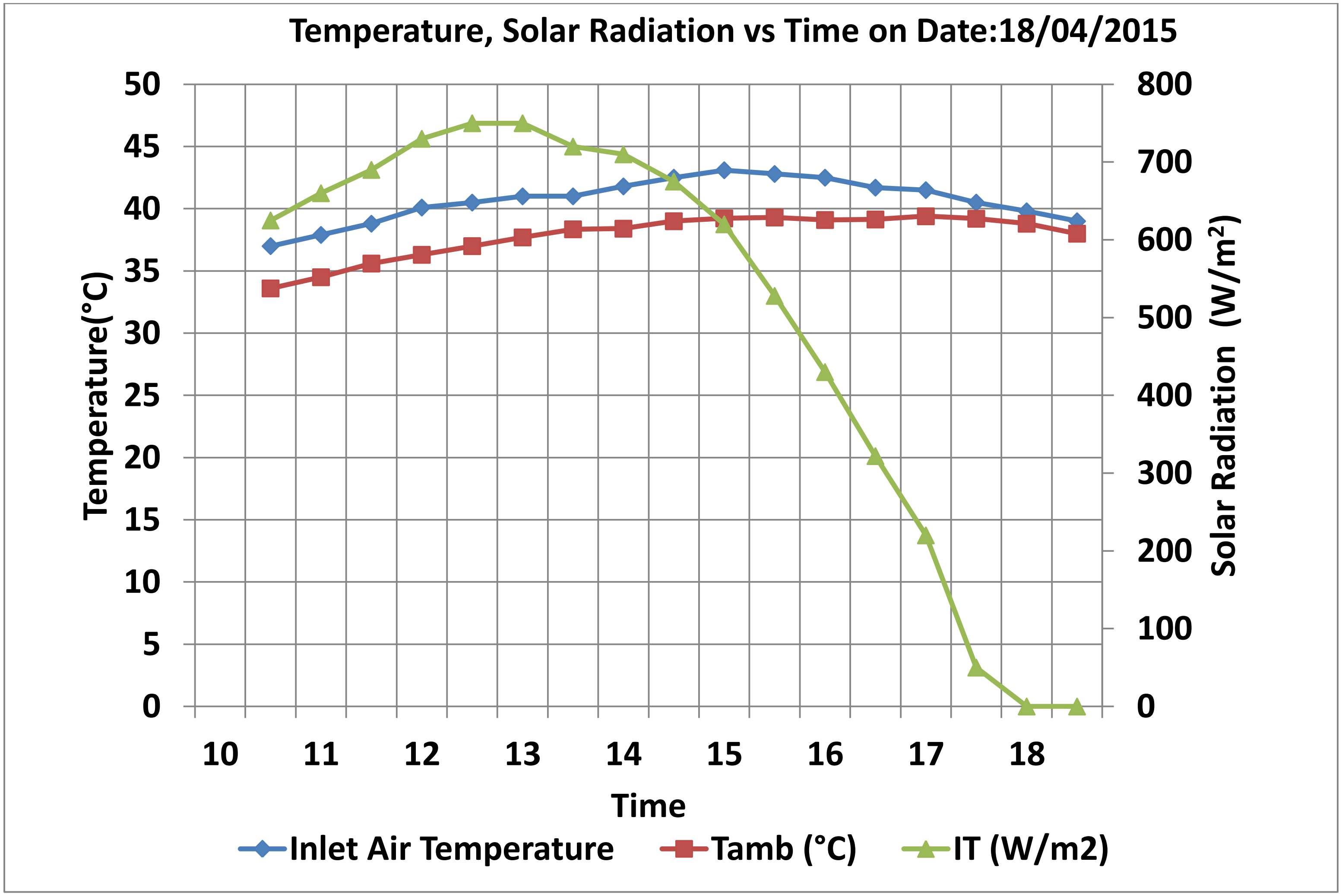
Density, $\rho = P / (RT) = 1.013 X 10^5 / (287 X 303) = 1.16 kg/m3$

Therefore mass flow rate $= \rho X (\pi/4) X d^2 X V$

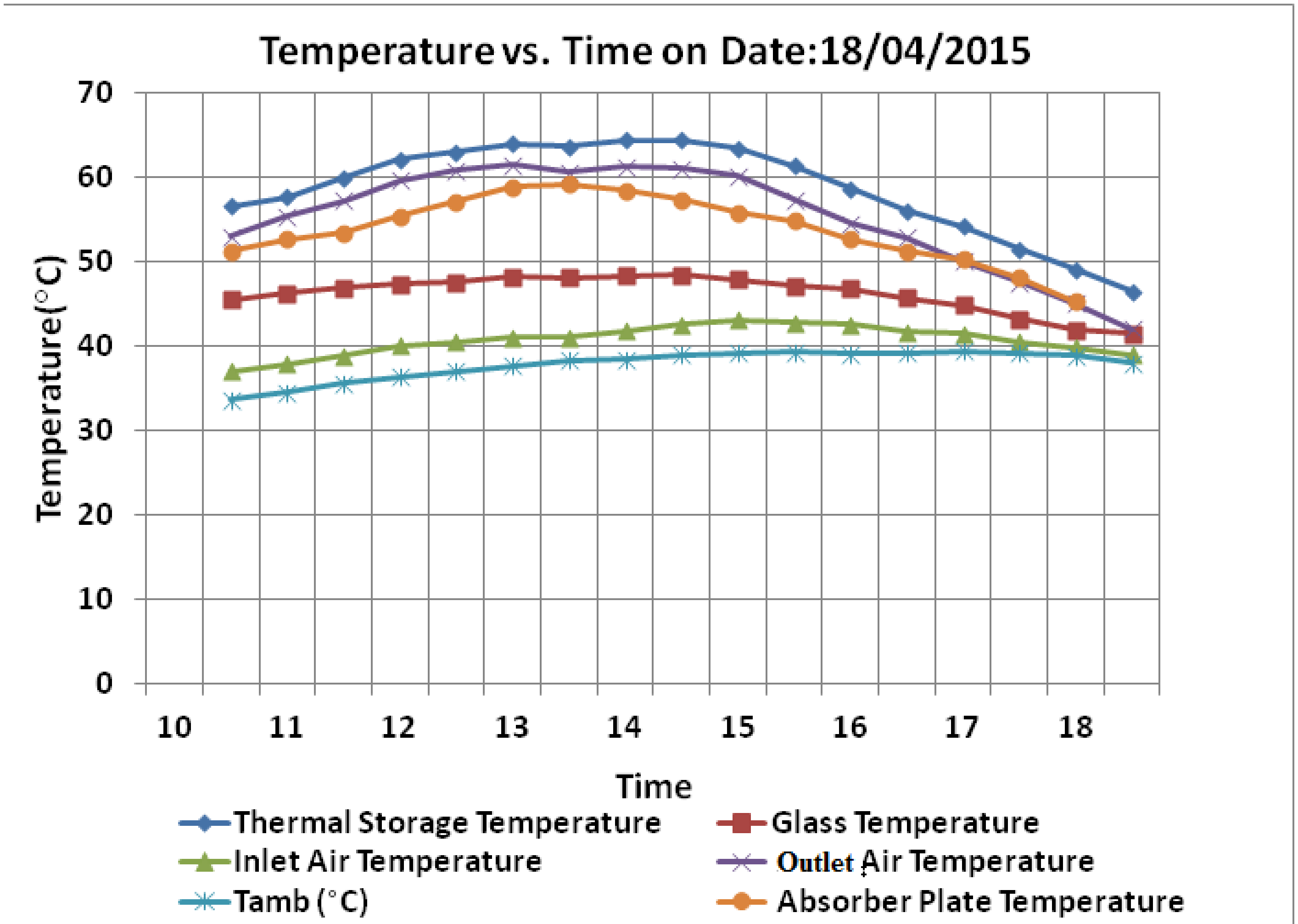
Heat transfer, $Q = \dot{m} c p \Delta T$

Efficiency, $\eta = Q / I_t A_C$

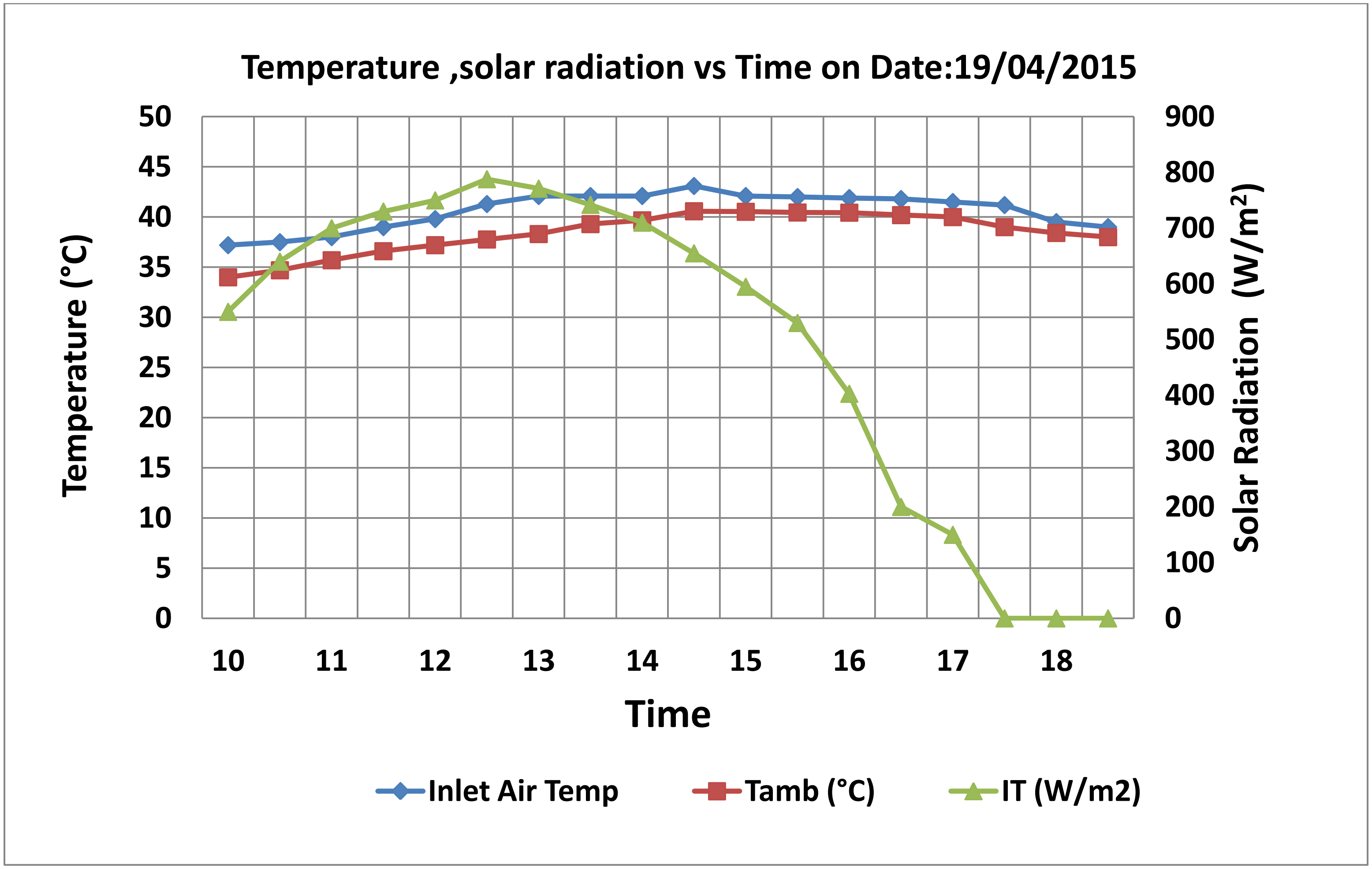
Graph 6.1: Temperature, Solar Radiation vs Time on Date:18/04/2015



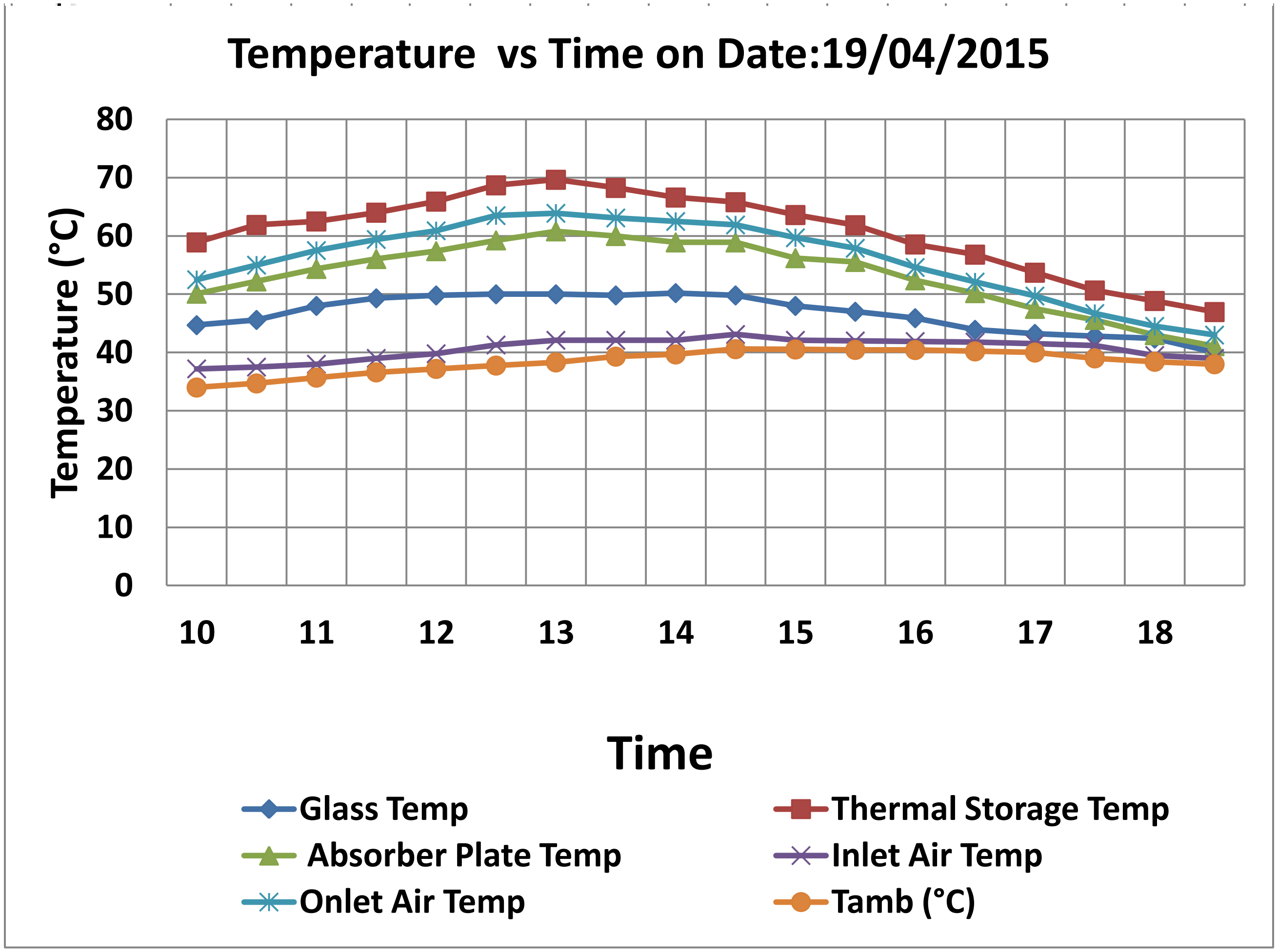
Graph 6.2 Temperature vs. Time on Date:18/04/2015



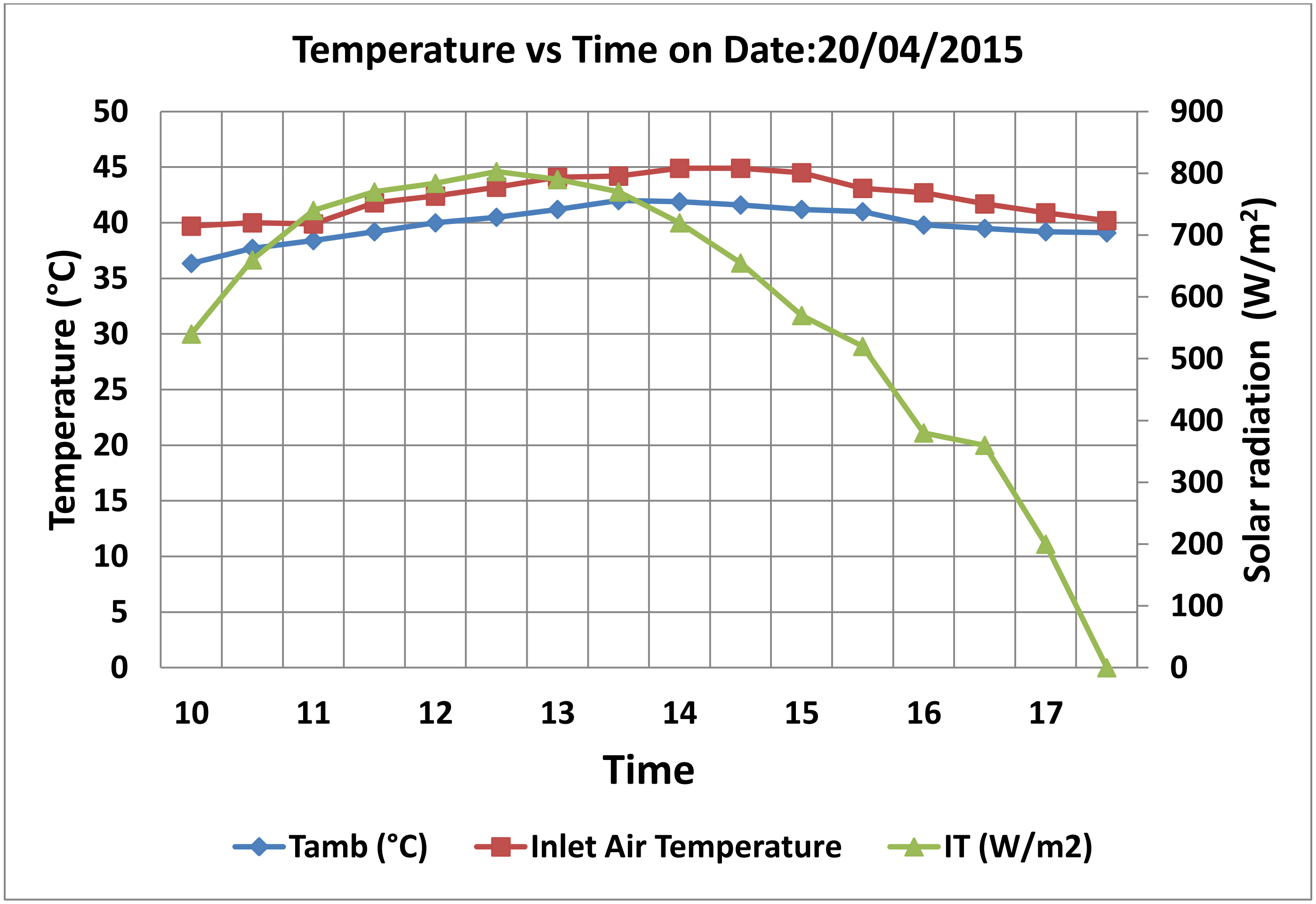
Graph 6.3: Temperature, Solar Radiation vs Time on Date:19/04/2015



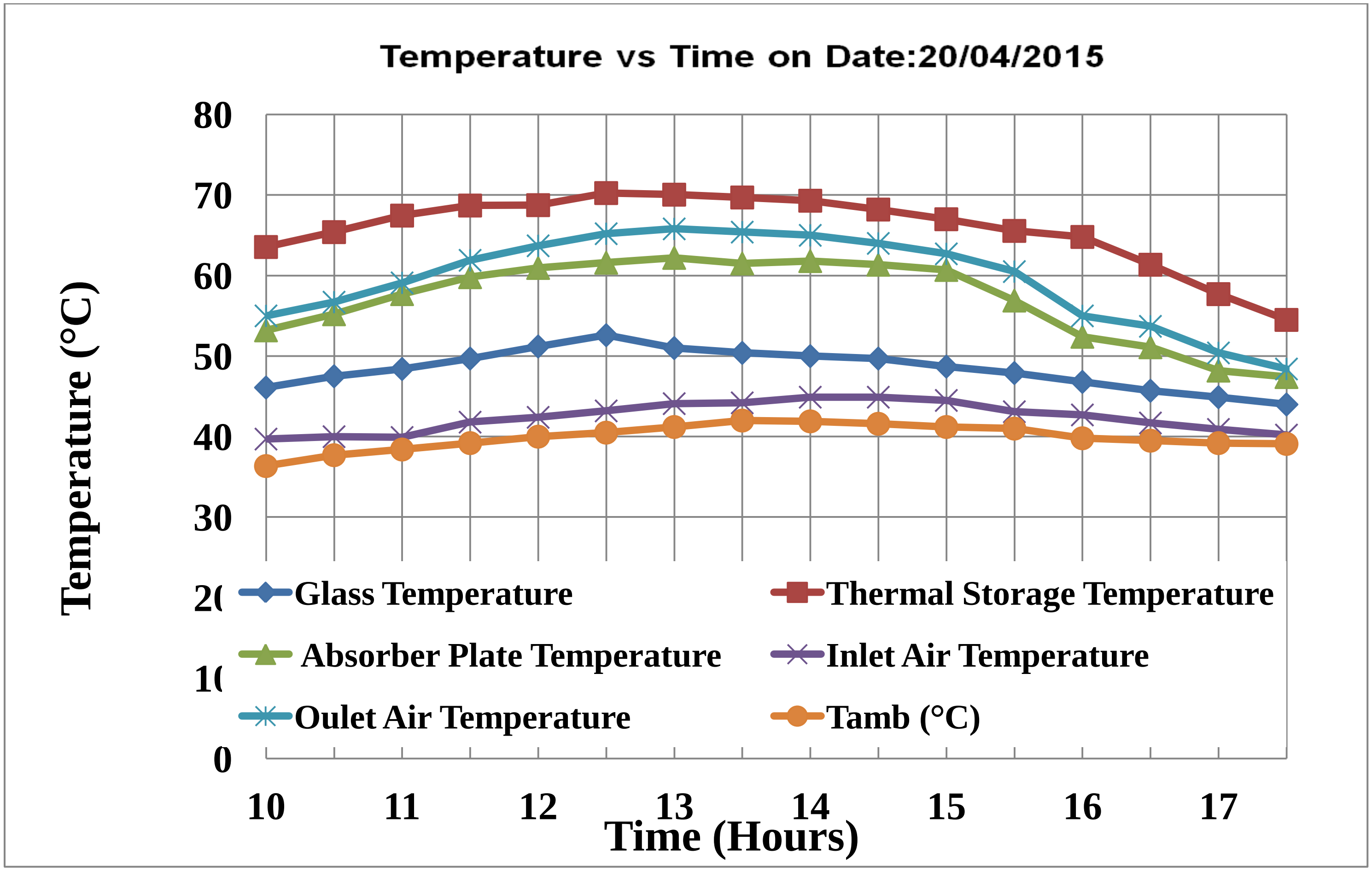
Graph 6.4: Temperature vs. Time on Date:19/04/2015



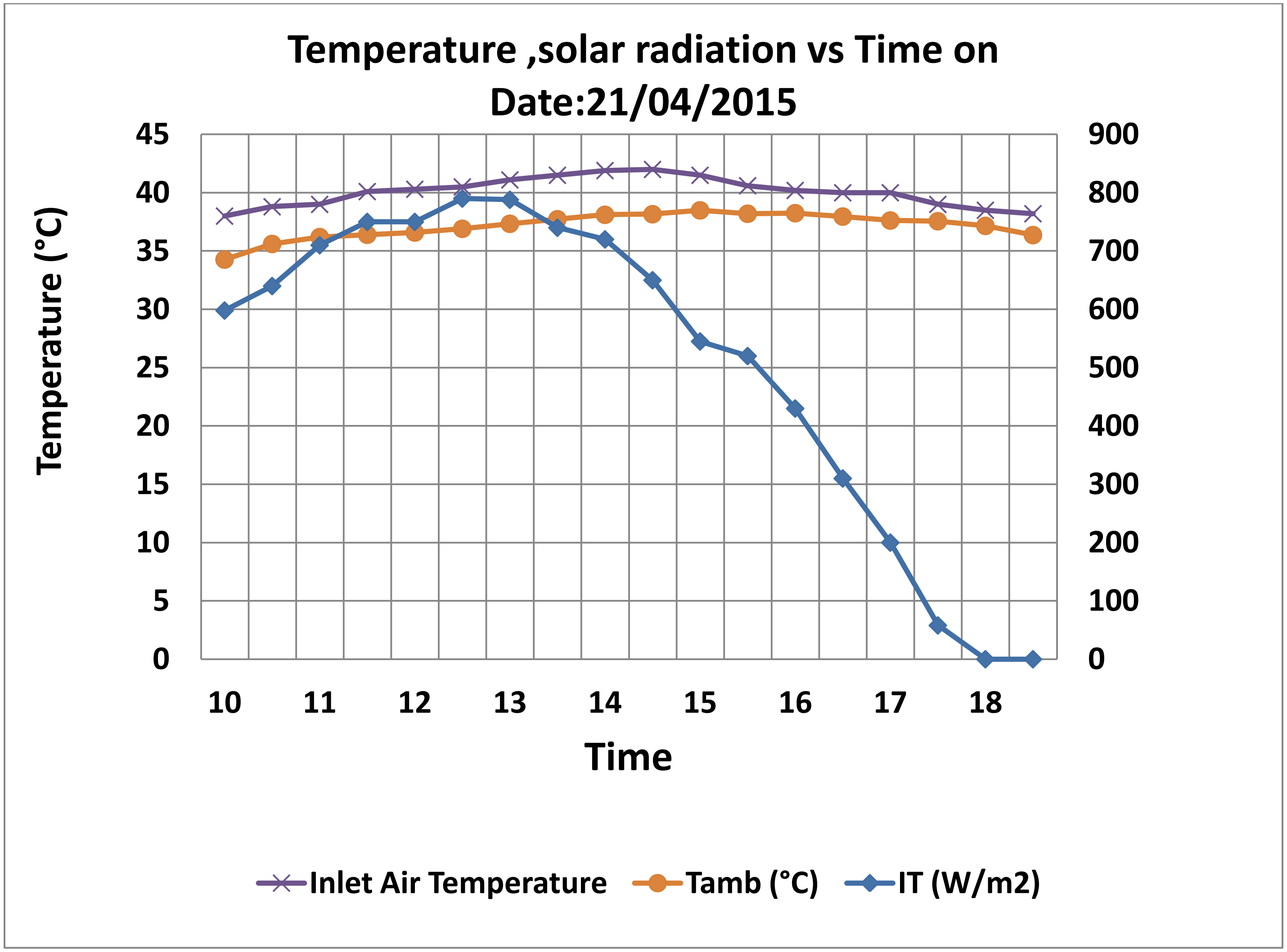
Graph 6.5: Temperature vs Time on Date: 20/04/2015



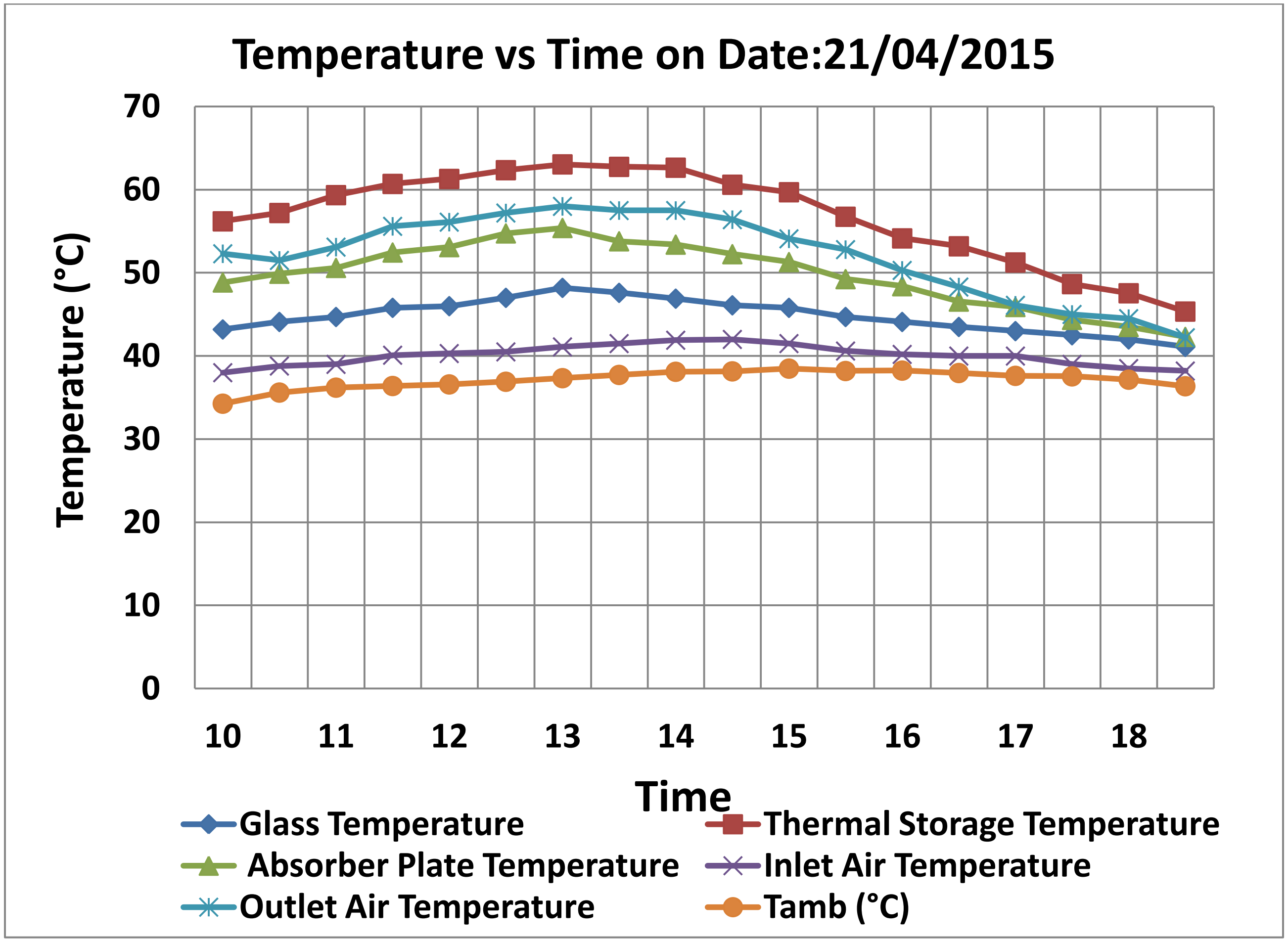
Graph 6.6: Temperature, solar radiation vs Time on Date: 20/04/2015



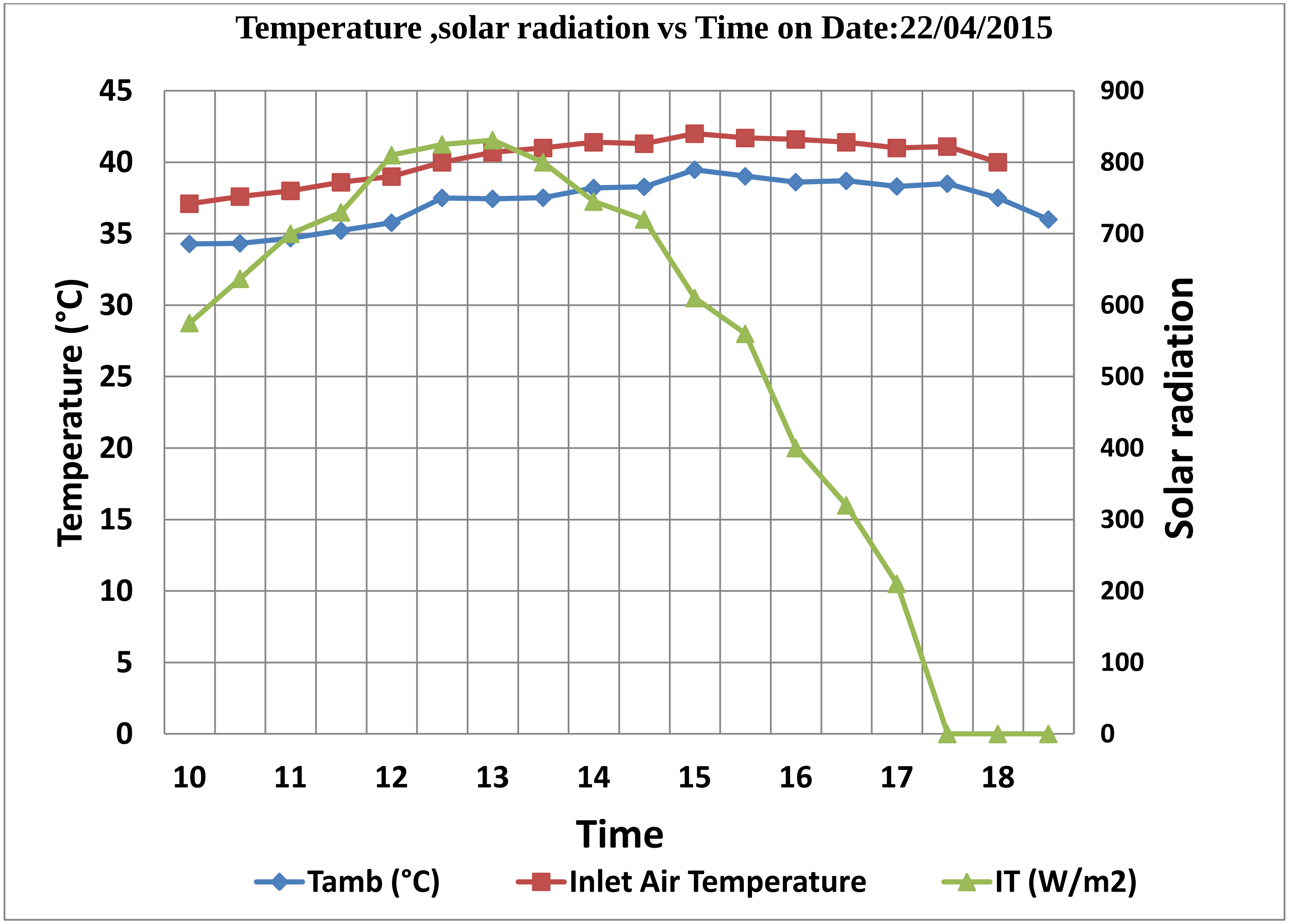
Graph 6.7: Temperature, solar radiation vs Time on Date: 21/04/2015



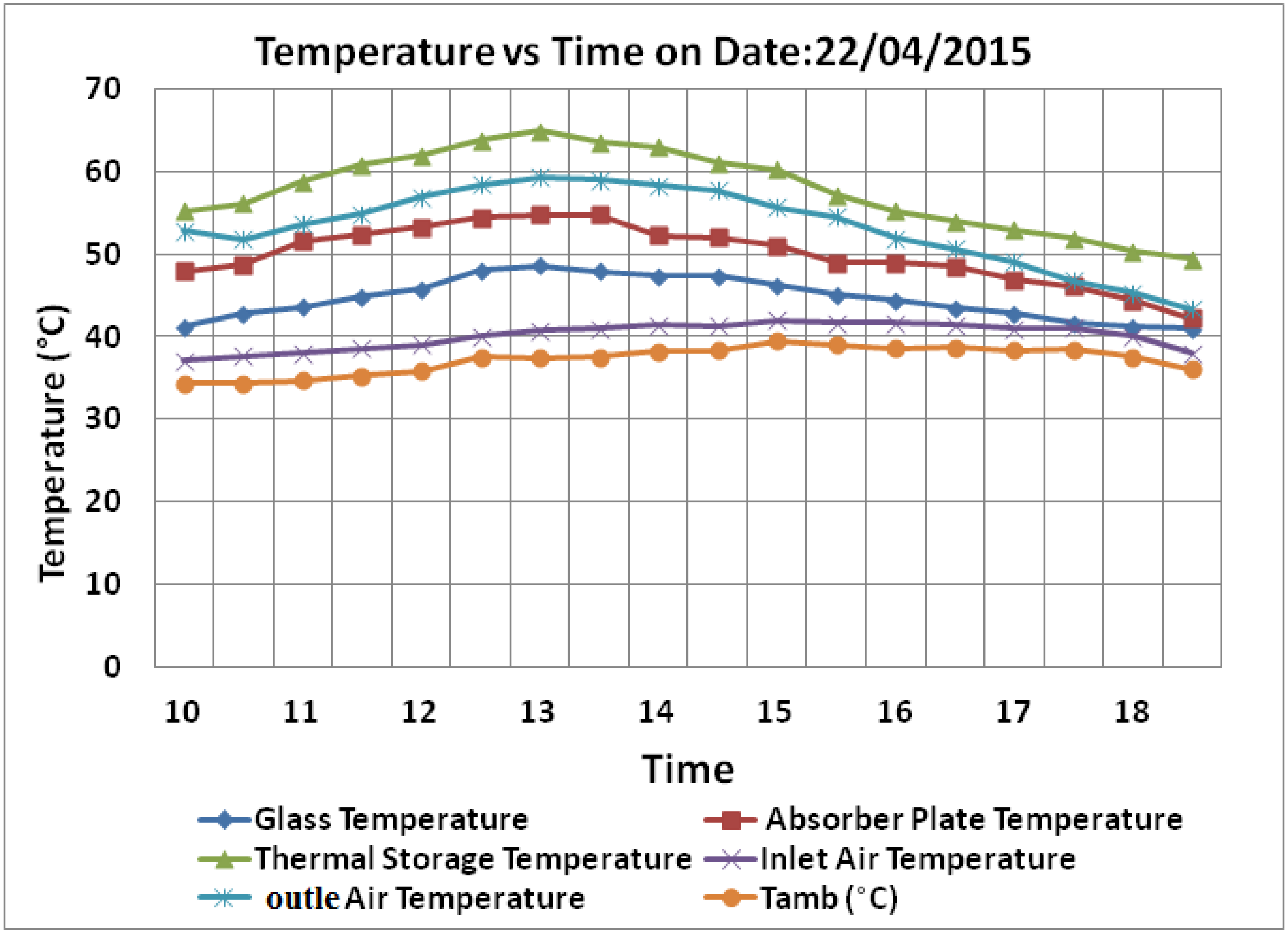
Graph 6.8: Temperature vs Time on Date: 21/04/2015



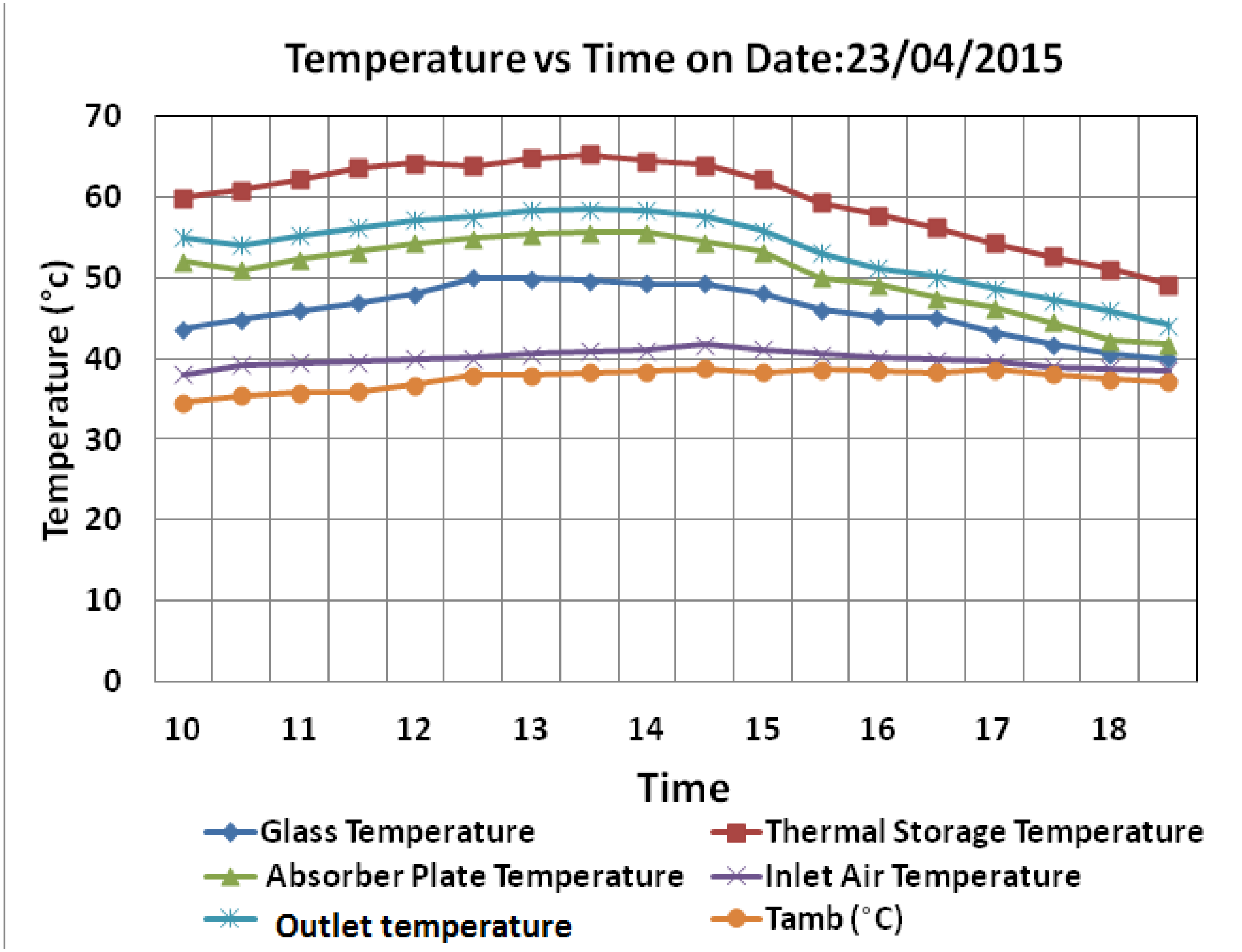
Graph 6.9: Temperature, solar radiation vs Time on Date: 22/04/2015



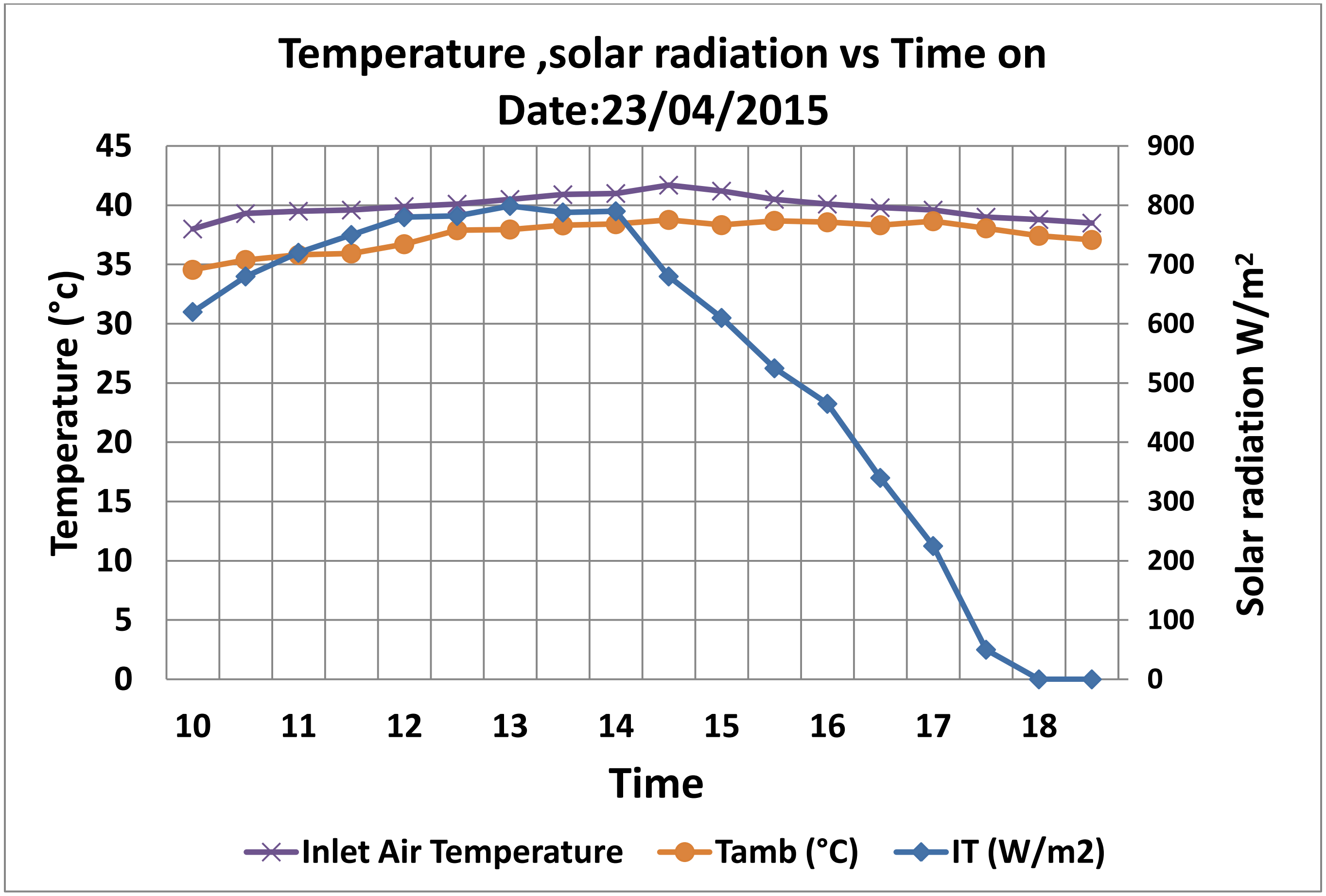
Graph 6.10: Temperature vs Time on Date: 22/04/2015



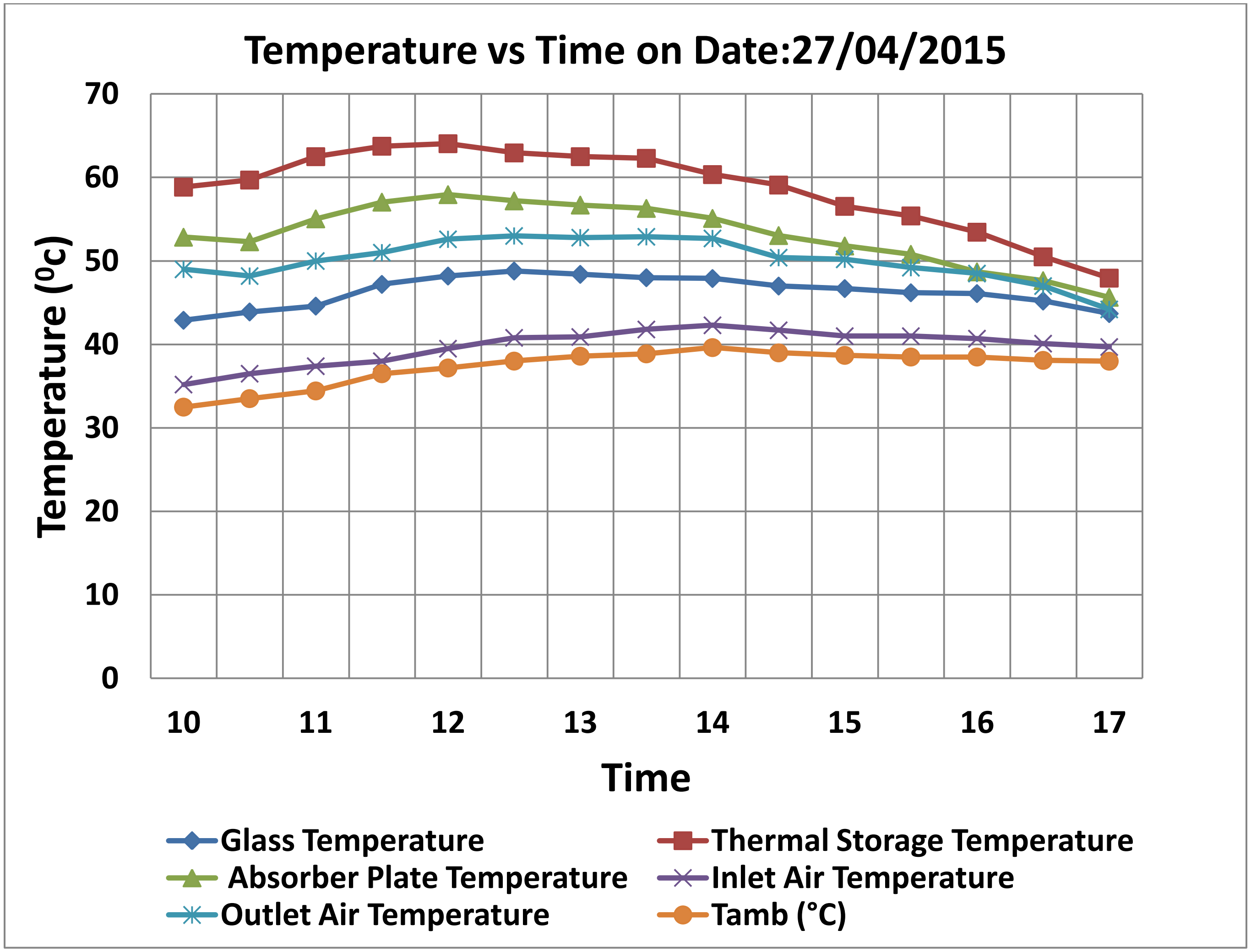
Graph 6.11: Temperature vs Time on Date: 23/04/2015



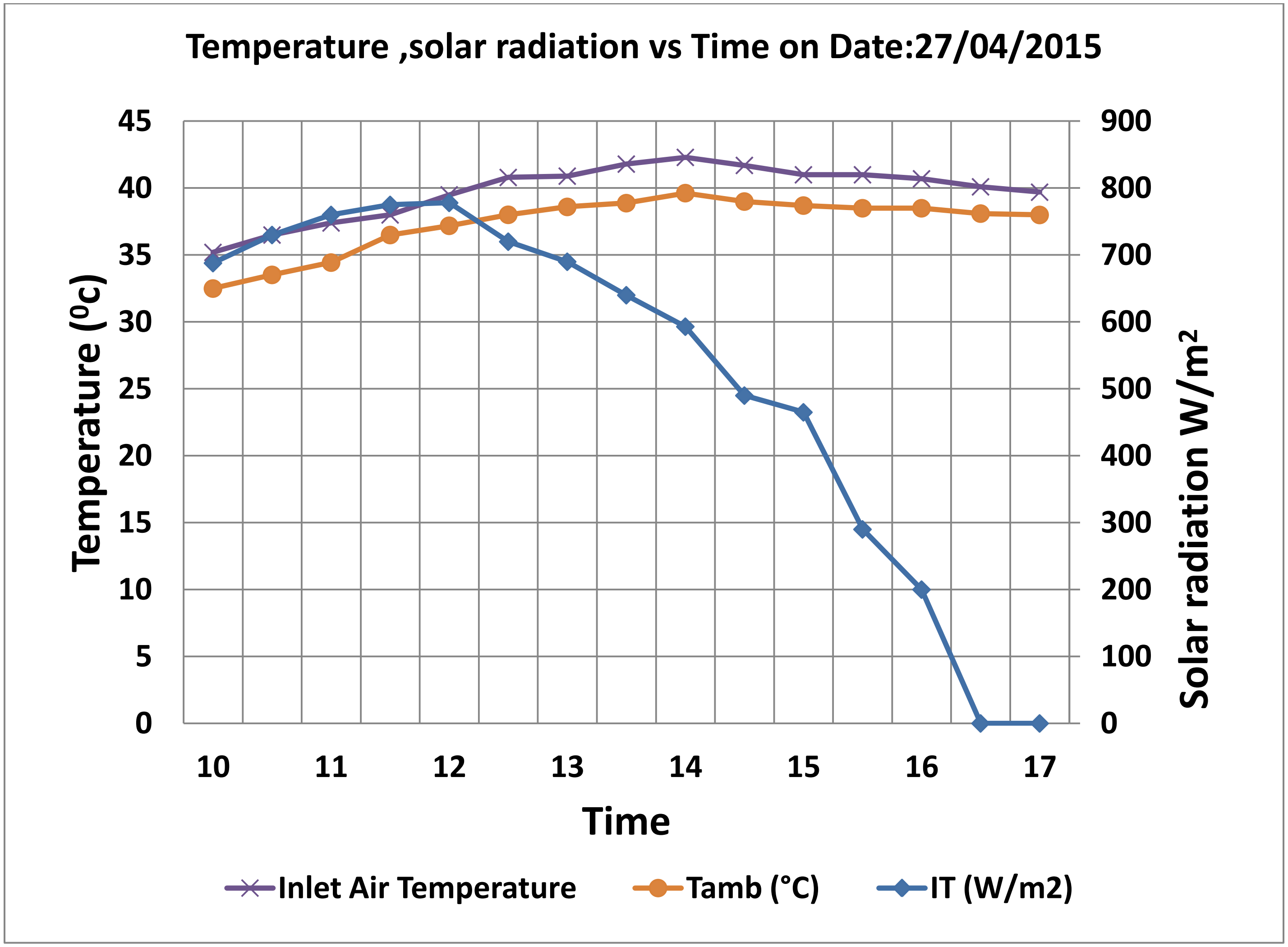
Graph 6.12: Temperature, solar radiation vs Time on Date:23/04/2015



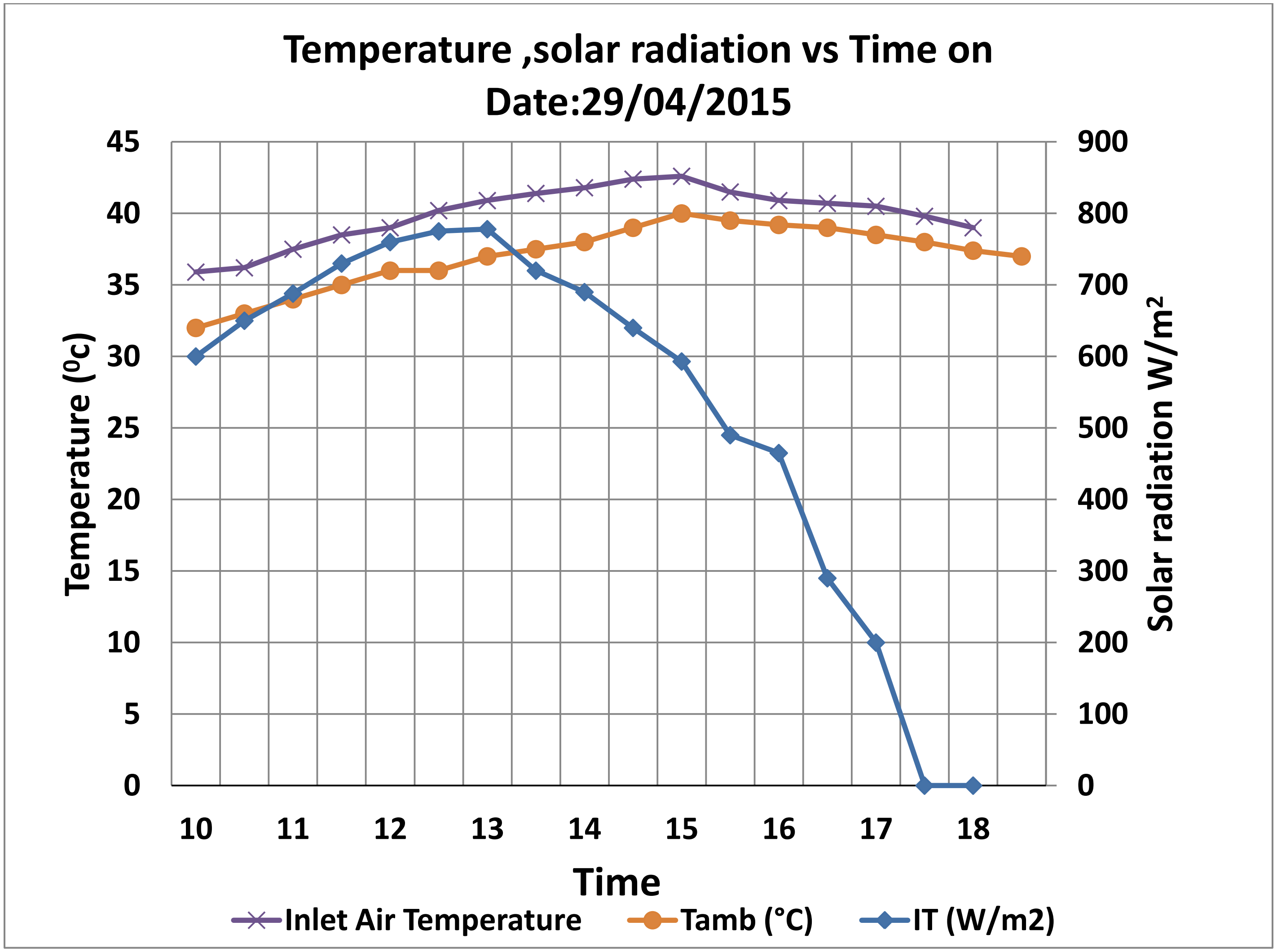
Graph 6.13: Temperature vs. Time on Date: 27/04/2015



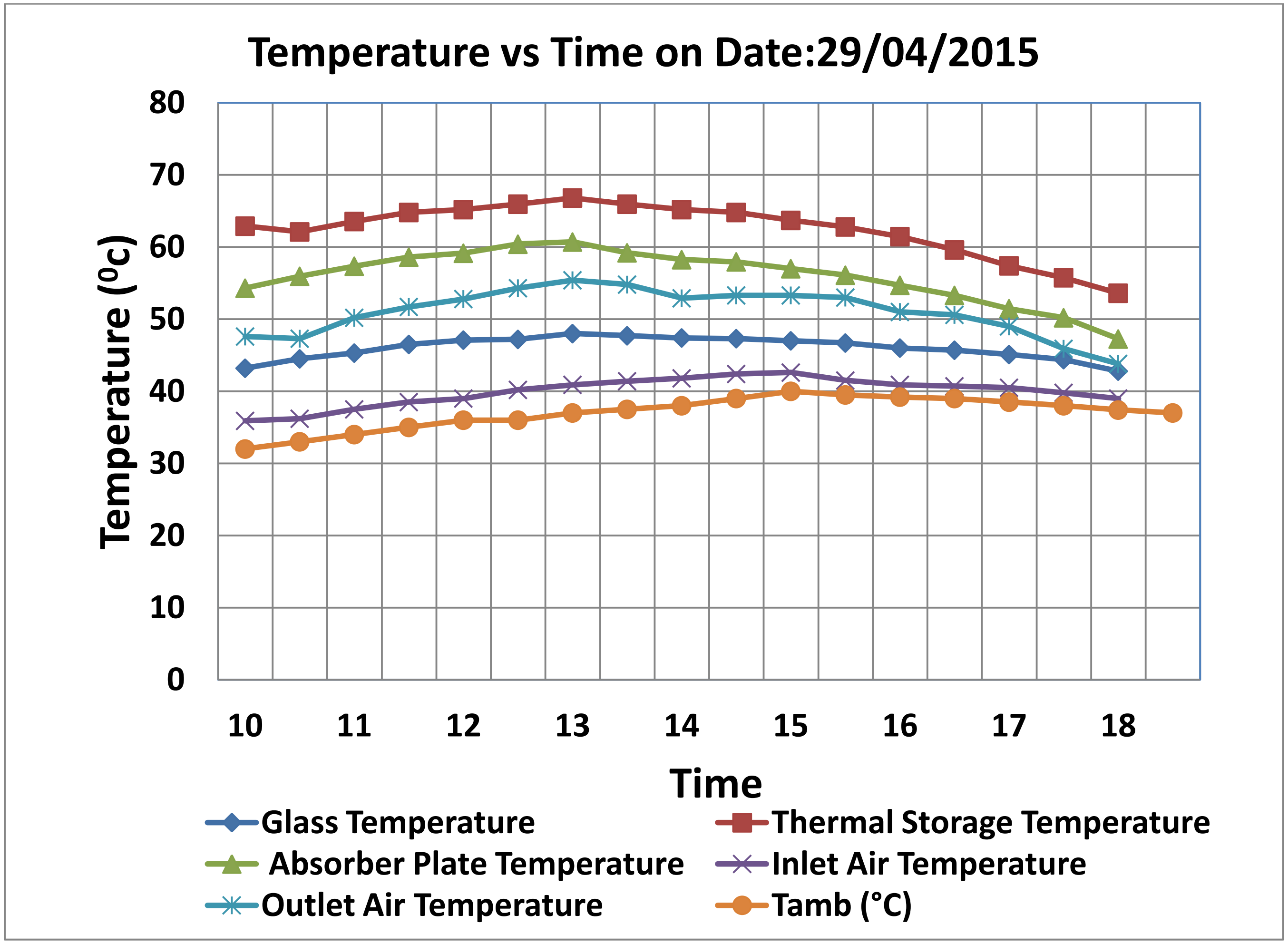
Graph 6.14: Temperature, solar radiation vs Time on Date: 27/04/2015



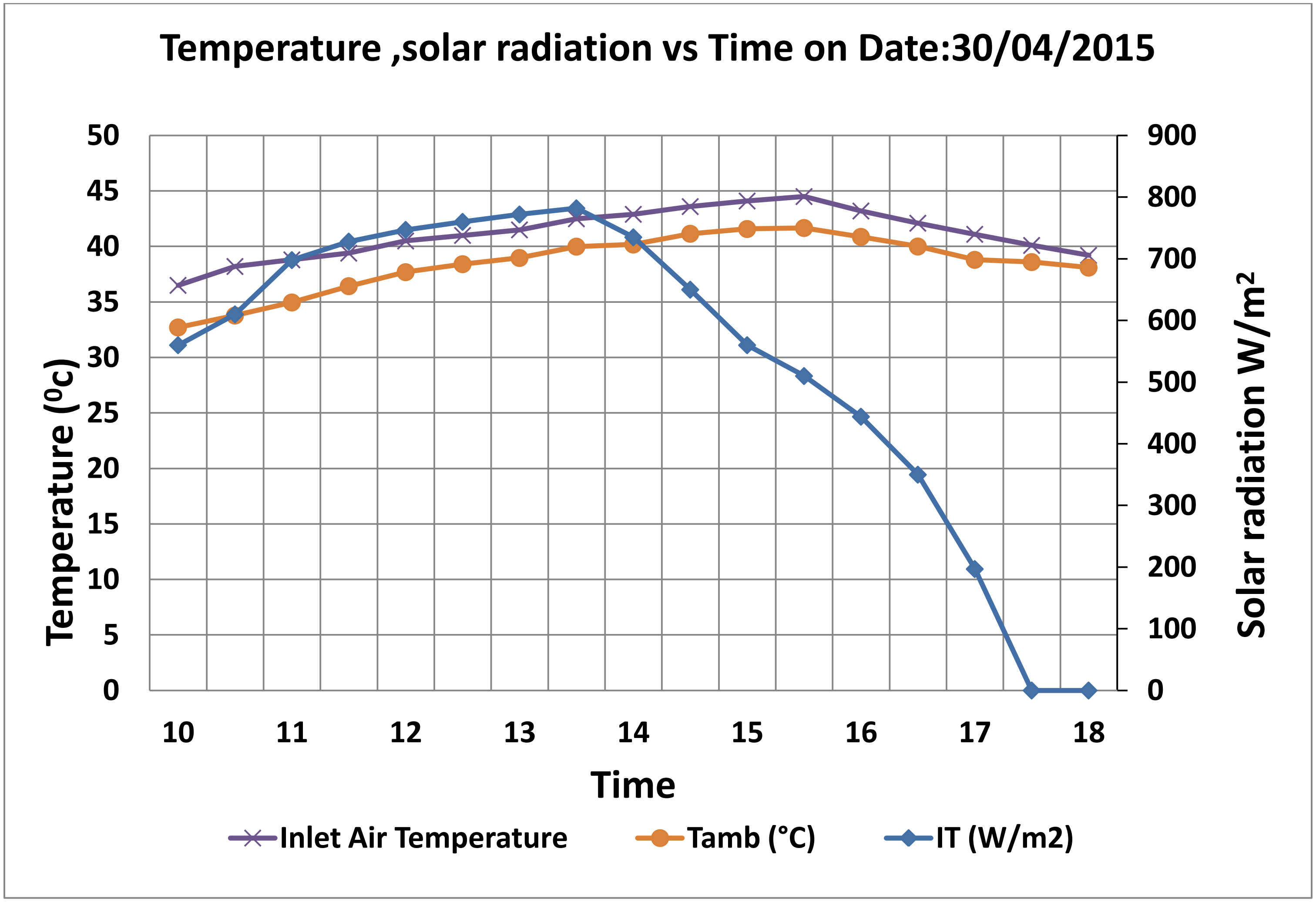
Graph 6.15: Temperature, solar radiation vs Time on Date: 29/04/2015



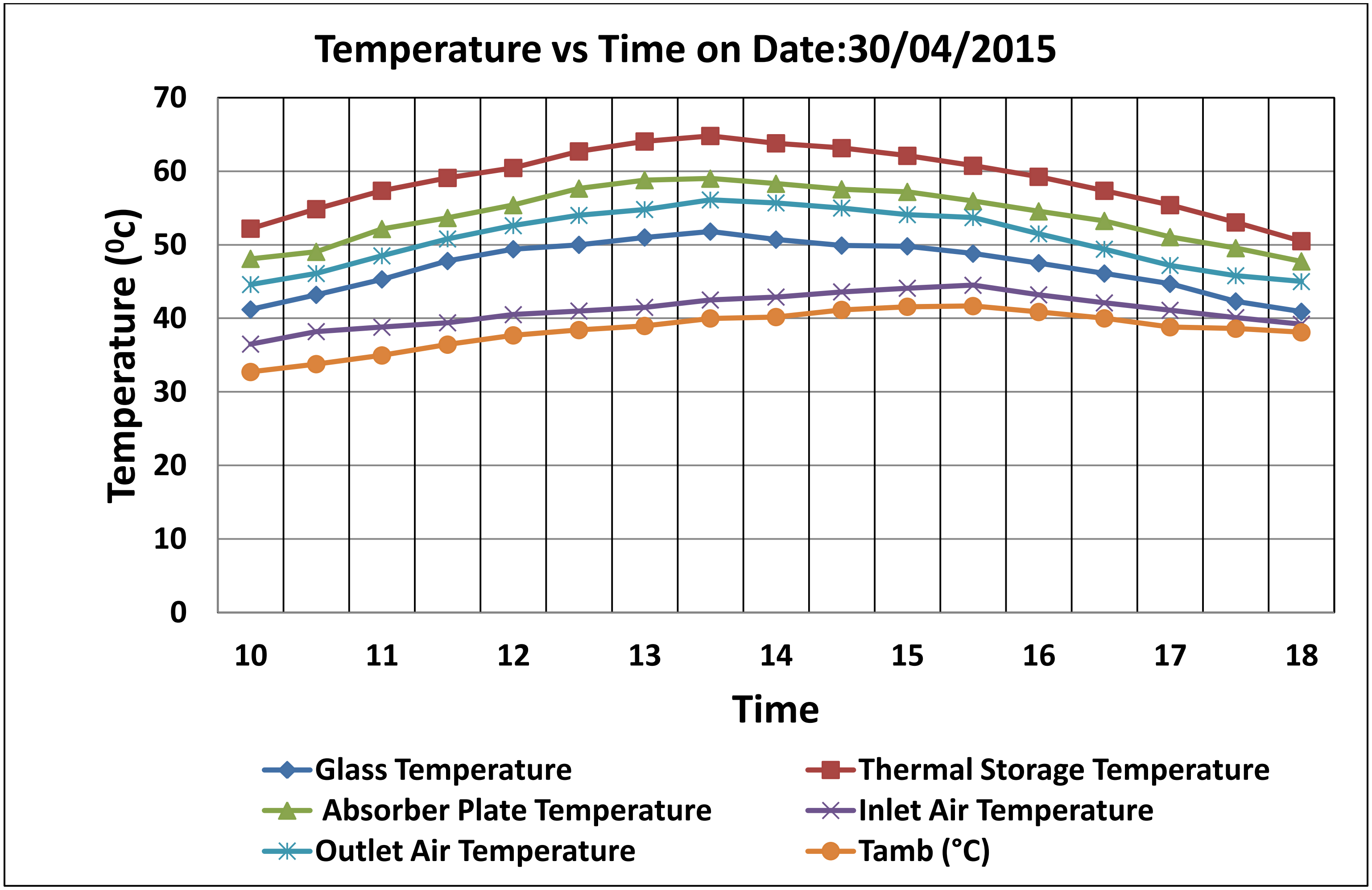
Graph 6.16: Temperature, vs Time on Date: 29/04/2015



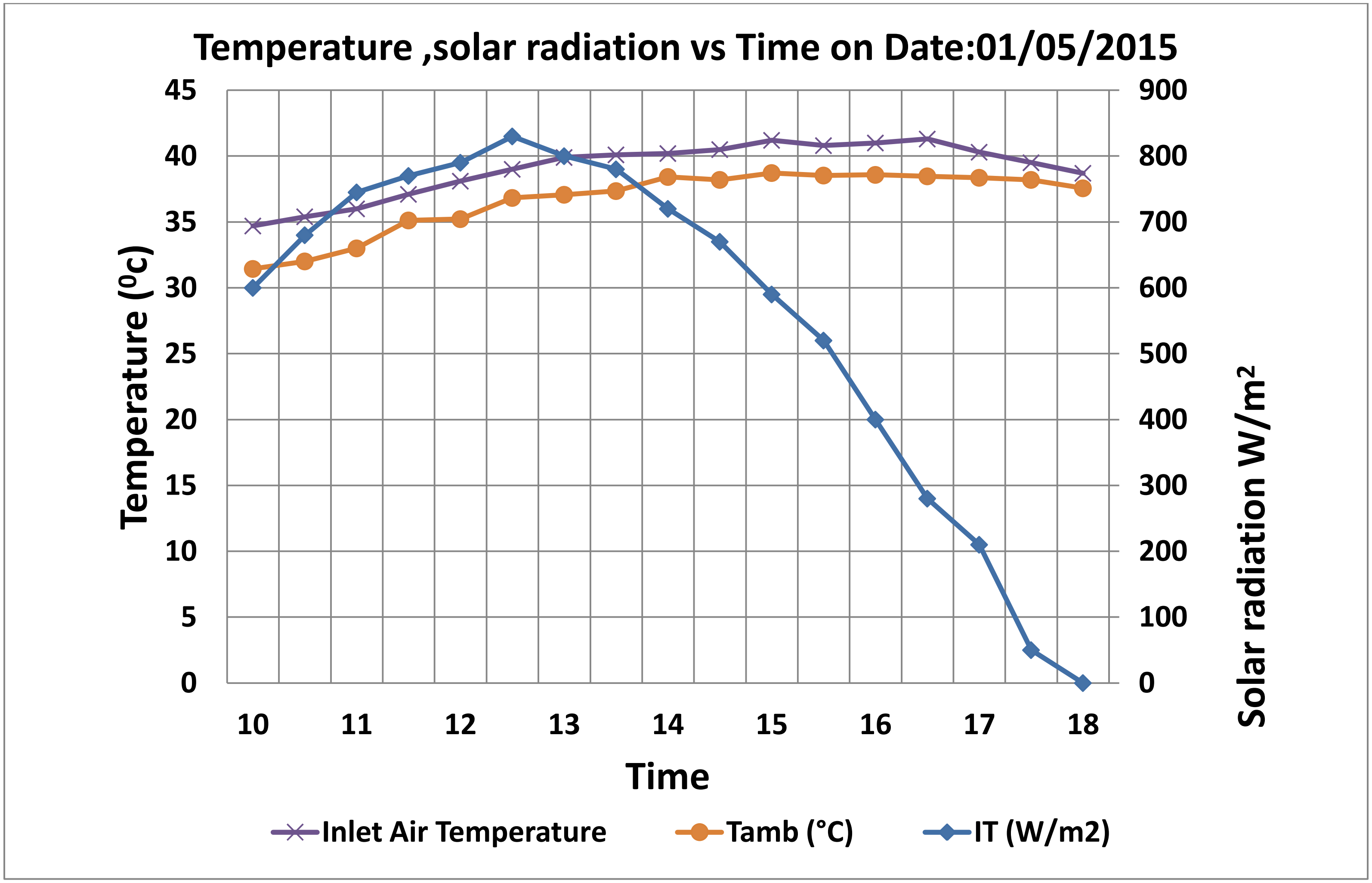
Graph 6.17: Temperature, solar radiation vs Time on Date: 30/04/2015



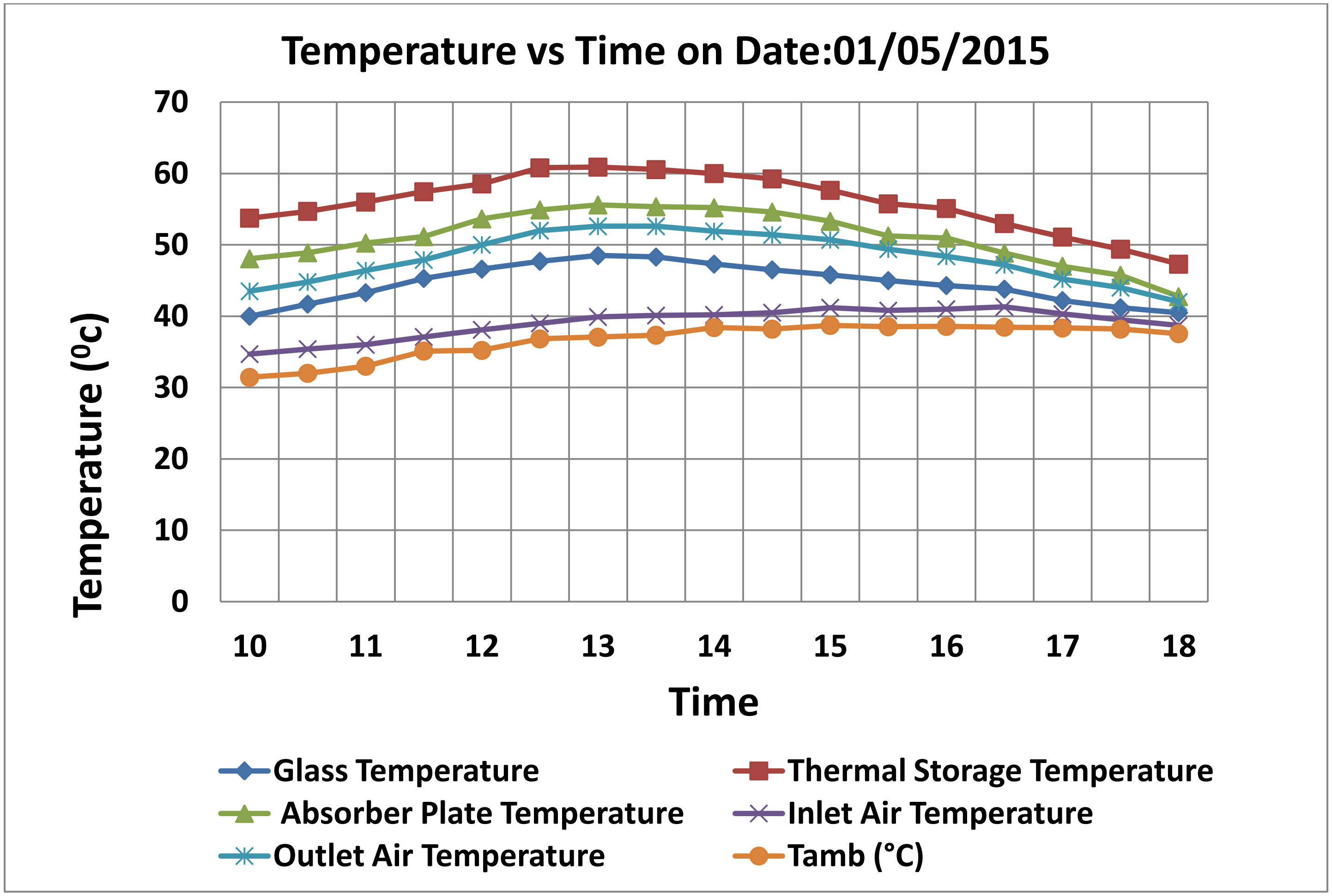
Graph 6.18: Temperature vs Time on Date: 30/04/2015



Graph 6.19: Temperature, solar radiation vs Time on Date: 01/05/2015



Graph 6.20: Temperature* vs *Time on Date: 01/05/2015



CHAPTER 7

Conclusion

A total of 12 sets of readings were done from 18th May 2015 to 1stJune 2015. Following conclusions are made on results obtained during experiment.

- For the same flow rate, the overall efficiency of the double pass solar air heater with thermal storage was found be higher than that of the single pass solar air heater with thermal storage. We can seen from tablet hat overall efficiency of double pass solar air heater is greater than 20% for the same flow rate

- For the same flow rate, the temperature difference between outlet temperature and inlet temperature in double pass was higher than that of the single pass

- It was also found that there was a positive difference between the output and input air temperatures even when there was no solar radiation. This is because of the thermal storage present in the solar air heater.

Table 7.1 overall efficiency of solar air heater.

Overall average efficiency of the double pass solar air heater with thermal storage when inlet air velocity is 6m/s.	71.94%
overall average efficiency of the single pass solar air heater with thermal storage when inlet air velocity is 6m/s.	50.7%
overall average efficiency of the double pass solar air heater with thermal storage when inlet air velocity is 9m/s.	59.73%
overall average efficiency of the single pass solar air heater with thermal storage when inlet air velocity is 9m/s.	42.60%

CHAPTER 8

Research for the Future scope

Design and Performance Analysis of Double Pass Solar Air Heater gives the following idea for the future scope

By using PC Based Data Logging and Control instruments can give the more accurate observed data in every five minutes or less than five minutes if possible to measure the solar intensity and temperature of various surfaces of the solar air heater by which we can also balance the unaccounted heat up to some extent. Because once the heat losses can be determined from the various surfaces of the solar air heater then improvement of solar air heater can be proposed up to some extent to increase the efficiency i.e. output temperature of the solar air heater is goes to high.

By using of selective coating paint on the absorber plate absorber surface should absorb maximum amount of incident solar radiation and emit less radiation due to this reason temperature of absorber plate and storage material goes to increase so outlet temperature goes to high and our efficiency has to be improve.

By using of Anti Reflecting film on glass surface, glass should be transmit maximum amount of incident solar radiation and less amount of solar radiation reflect due to this reason temperature of absorber plate and storage material goes to increase so outlet temperature goes to high and our efficiency has to be improve.

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Appendix a: - List of Experimental observation Data

Table A.1. Experimental Observation Date: 18/04/2015

Time	Glass Temp(°C)	T_2 (°C)	T_3 (°C)	T_4(°C)	T_5 (°C)	Inlet Air Temp	Outlet Air Temp(°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:30	45.50	57.50	55.60	52.00	50.48	37.00	53.00	33.60	6.00	625.00
11:00	46.20	58.70	56.50	53.40	52.00	37.90	55.40	34.50	6.00	660.00
11:30	46.90	60.80	59.00	54.30	52.60	38.80	57.20	35.60	6.00	690.00
12:00	47.30	62.70	61.50	56.50	54.20	40.10	59.60	36.30	6.00	730.00
12:30	47.60	63.80	62.20	58.00	56.30	40.50	60.80	37.00	6.00	750.00
13:00	48.20	64.90	63.10	59.20	58.40	41.00	61.40	37.70	6.00	750.00
13:30	48.10	64.40	62.90	59.30	59.00	41.00	60.60	38.35	6.00	720.00
14:00	48.30	65.00	63.80	58.80	58.00	41.80	61.20	38.40	6.00	710.00
14:30	48.40	64.70	64.00	57.80	56.90	42.50	61.00	39.00	6.00	675.00
15:00	47.90	63.30	63.60	57.90	53.80	43.10	60.10	39.23	6.00	620.00
15:30	47.10	60.80	61.90	56.10	53.50	42.80	57.30	39.30	6.00	528.00
16:00	46.80	57.70	59.50	54.30	51.10	42.50	54.50	39.10	6.00	430.00
16:30	45.70	54.50	57.50	53.00	49.50	41.70	52.90	39.14	6.00	322.00
17:00	44.80	52.40	55.90	52.50	48.00	41.50	50.00	39.40	6.00	220.00
17:30	43.20	49.80	53.20	49.20	47.00	40.50	47.50	39.20	6.00	50.00
18:00	41.90	47.40	50.80	46.50	44.00	39.80	45.00	38.80	6.00	0.00
18:30	41.50	44.80	48.20	43.40	40.00	39.00	42.00	38.00	6.00	0.00

Table A.2. Experimental Observation Date: 19/04/2015

Time	Glass Temp(°C)	T_2 (°C)	T_3 (°C)	T_4(°C)	T_5 (°C)	Inlet Air Temp	Outlet Air Temp(°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	44.70	60.30	57.50	50.40	49.80	37.20	52.50	34.00	6.00	550.00
10:30	45.60	62.20	61.60	52.40	52.00	37.50	55.00	34.70	6.00	640.00
11:00	48.00	62.90	62.10	54.80	53.90	38.00	57.50	35.70	6.00	700.00
11:30	49.30	64.10	63.90	56.40	55.70	39.00	59.40	36.60	6.00	730.00
12:00	49.80	66.20	65.60	57.70	57.10	39.80	60.90	37.20	6.00	750.00
12:30	50.00	69.10	68.30	59.80	58.70	41.30	63.50	37.77	6.00	788.00
13:00	50.00	70.20	69.10	61.20	60.40	42.10	63.90	38.31	6.00	771.00
13:30	49.80	68.90	67.60	60.90	59.10	42.10	63.10	39.30	6.00	742.00
14:00	50.20	67.20	66.00	59.20	58.60	42.10	62.50	39.68	6.00	710.00
14:30	49.80	66.20	65.40	59.30	58.50	43.10	61.90	40.58	6.00	655.00
15:00	48.00	64.90	62.30	56.80	55.60	42.10	59.70	40.53	6.00	595.00
15:30	47.00	62.10	61.60	56.10	55.00	42.00	57.90	40.46	6.00	530.00
16:00	45.90	57.90	59.20	53.70	51.10	41.90	54.60	40.44	6.00	403.00
16:30	43.90	56.40	57.20	51.20	49.20	41.80	52.10	40.20	6.00	200.00
17:00	43.20	54.20	53.20	48.10	46.90	41.50	49.70	40.00	6.00	150.00
17:30	42.80	50.00	51.30	46.30	44.90	41.20	46.70	39.00	6.00	0.00
18:00	42.40	49.30	48.40	43.20	42.80	39.50	44.50	38.42	6.00	0.00
18:30	40.00	47.20	46.70	41.20	41.00	39.00	43.00	38.00	6.00	0.00

Table A.3 Experimental Observation Date: 20/04/2015

Time	Glass Temp(°C)	T_2 (°C)	T_3 (°C)	T_4(°C)	T_5 (°C)	Inlet Air Temp	Outlet Air Temp(°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	46.10	64.00	63.10	57.40	55.20	39.70	55.00	36.35	6.00	540.00
10:30	47.50	65.60	65.20	58.00	56.10	40.00	56.70	37.70	6.00	660.00
11:00	48.40	67.80	67.10	58.70	56.70	39.90	59.10	38.40	6.00	740.00
11:30	49.70	69.30	68.10	61.60	58.00	41.80	61.90	39.20	6.00	770.00
12:00	51.20	69.20	68.30	62.90	59.00	42.40	63.70	40.00	6.00	784.00
12:30	52.60	70.50	70.00	63.00	60.20	43.20	65.20	40.50	6.00	803.00
13:00	51.00	70.10	70.00	61.00	59.00	44.10	65.80	41.20	6.00	790.00
13:30	50.40	70.00	69.40	62.00	61.00	44.20	65.40	42.00	6.00	770.00
14:00	50.00	69.50	69.10	62.90	60.70	44.90	65.00	41.90	6.00	720.00
14:30	49.70	68.00	68.40	62.60	60.10	44.90	64.00	41.60	6.00	655.00
15:00	48.70	66.60	67.40	62.10	59.30	44.50	62.70	41.20	6.00	570.00
15:30	47.90	65.00	66.10	61.90	58.80	43.10	60.50	41.00	6.00	520.00
16:00	46.80	64.00	65.60	56.00	55.00	42.70	55.00	39.80	6.00	380.00
16:30	45.70	60.30	62.40	54.30	52.70	41.70	53.70	39.50	6.00	360.00
17:00	44.90	56.10	59.30	51.50	49.00	40.90	50.40	39.20	6.00	200.00
17:30	44.00	53.00	56.00	48.80	46.00	40.20	48.40	39.10	6.00	0.00

Table A.4. Experimental Observation Date: 21/04/2015

Time	Glass Temp (°C)	T2 (°C)	T3 (°C)	T4 (°C)	T5 (°C)	Inlet Air Temp(°C)	Outlet Air Temp (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	43.20	56.50	55.90	49.20	48.50	38.00	14.30	34.27	9.00	598.00
10:30	44.10	57.50	56.90	50.20	49.60	38.80	12.70	35.61	9.00	640.00
11:00	44.70	60.20	58.50	51.00	50.20	39.00	14.10	36.20	9.00	710.00
11:30	45.80	61.00	60.40	53.00	51.90	40.10	15.50	36.40	9.00	750.00
12:00	46.00	61.60	61.00	54.20	52.00	40.30	15.80	36.59	9.00	750.00
12:30	47.00	63.00	61.70	55.00	54.50	40.50	16.70	36.91	9.00	790.00
13:00	48.20	63.30	62.80	55.90	54.90	41.10	16.90	37.34	9.00	788.00
13:30	47.60	63.10	62.40	54.40	53.20	41.50	16.00	37.73	9.00	740.00
14:00	46.90	62.50	62.80	54.20	52.60	41.90	15.60	38.11	9.00	720.00
14:30	46.10	60.20	61.00	53.00	51.50	42.00	14.40	38.16	9.00	650.00
15:00	45.80	59.40	60.00	52.10	50.50	41.50	12.60	38.49	9.00	545.00
15:30	44.70	56.00	57.50	50.00	48.50	40.60	12.20	38.20	9.00	520.00
16:00	44.10	54.00	54.30	49.30	47.50	40.20	10.10	38.25	9.00	430.00
16:30	43.50	53.20	53.20	47.00	46.10	40.00	8.30	37.96	9.00	310.00
17:00	43.00	51.60	50.90	46.20	45.60	40.00	6.10	37.62	9.00	200.00
17:30	42.50	48.30	49.00	44.20	44.50	39.00	6.00	37.56	9.00	58.00
18:00	42.00	46.90	48.20	43.40	43.60	38.50	6.00	37.16	9.00	0.00
18:30	41.10	45.20	45.50	42.10	42.50	38.20	4.00	36.37	9.00	0.00

Table A.5. Experimental Observation Date: 22/04/2015

Time	Glass Temp (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Inlet Air Temp(°C)	Outlet Air Temp (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	41.20	55.50	55.20	48.80	47.00	37.10	52.80	34.29	9.00	575.00
10:30	42.80	58.70	57.30	49.30	48.20	37.60	51.80	34.33	9.00	637.00
11:00	43.60	59.30	58.20	52.00	51.20	38.00	53.60	34.69	9.00	700.00
11:30	44.90	61.30	60.40	52.70	52.00	38.60	54.90	35.22	9.00	730.00
12:00	45.70	63.00	60.90	53.50	53.00	39.00	57.00	35.77	9.00	810.00
12:30	48.00	64.70	62.90	54.90	54.00	40.00	58.40	37.51	9.00	825.00
13:00	48.60	65.60	64.20	55.20	54.40	40.70	59.30	37.44	9.00	831.00
13:30	47.90	63.60	63.50	55.40	54.20	41.00	59.00	37.52	9.00	800.00
14:00	47.30	62.70	63.30	52.40	52.10	41.40	58.30	38.20	9.00	745.00
14:30	47.30	60.70	61.50	53.00	51.00	41.30	57.70	38.28	9.00	720.00
15:00	46.20	59.90	60.60	52.10	50.00	42.00	55.70	39.48	9.00	610.00
15:30	45.10	56.50	57.90	50.00	48.00	41.70	54.50	39.02	9.00	560.00
16:00	44.40	54.50	55.90	49.30	48.70	41.60	51.90	38.61	9.00	400.00
16:30	43.50	52.70	55.20	48.90	48.00	41.40	50.70	38.70	9.00	320.00
17:00	42.80	51.60	50.90	46.20	45.60	40.00	6.10	37.62	9.00	200.00
17:30	41.70	48.30	49.00	44.20	44.50	39.00	6.00	37.56	9.00	58.00
18:00	41.20	46.90	48.20	43.40	43.60	38.50	6.00	37.16	9.00	0.00
18:30	41.00	45.20	45.50	42.10	42.50	38.20	4.00	36.37	9.00	0.00

Table A.6. Experimental Observation Date: 23/04/2015

Time	Glass Temp (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Inlet Air Temp(°C)	Outlet Air Temp (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	43.70	60.70	59.10	52.10	52.00	38.00	55.00	34.56	9.00	620.00
10:30	44.80	61.40	60.20	51.00	50.90	39.30	54.00	35.39	9.00	680.00
11:00	45.90	62.70	61.70	52.70	51.80	39.50	55.20	35.82	9.00	720.00
11:30	46.90	64.00	63.20	53.60	52.90	39.60	56.20	35.94	9.00	750.00
12:00	47.90	64.60	63.70	54.40	54.10	39.90	57.20	36.72	9.00	780.00
12:30	50.00	64.00	63.70	55.10	54.70	40.10	57.50	37.90	9.00	782.00
13:00	49.90	65.20	64.40	55.50	55.20	40.50	58.30	37.96	9.00	799.00
13:30	49.60	65.40	65.00	55.80	55.40	40.90	58.50	38.31	9.00	788.00
14:00	49.30	64.80	64.10	56.00	55.10	41.00	58.30	38.41	9.00	790.00
14:30	49.30	64.00	63.80	54.80	53.90	41.70	57.50	38.77	9.00	680.00
15:00	48.10	62.80	61.50	53.40	51.60	41.20	55.80	38.33	9.00	610.00
15:30	46.10	59.00	59.60	50.70	49.30	40.50	53.10	38.69	9.00	525.00
16:00	45.20	57.20	58.20	47.90	47.00	40.10	51.20	38.57	9.00	465.00
16:30	43.20	56.00	56.40	46.30	45.40	39.80	50.10	38.32	9.00	340.00
17:00	41.50	54.20	54.40	47.70	44.90	39.60	48.70	38.66	9.00	225.00
17:30	40.90	52.20	53.00	45.90	43.20	39.00	47.20	38.06	9.00	50.00
18:00	40.00	50.30	51.90	43.80	40.70	38.80	45.90	37.43	9.00	0.00
18:30	38.70	49.40	49.00	41.50	40.00	38.50	44.10	37.08	9.00	0.00

Table A.7. Experimental Observation Date: 27/04/2015

Time	Glass Temp (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Inlet Air Temp(°C)	Outlet Air Temp (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
11:00	42.90	59.60	58.10	52.40	53.30	35.20	49.00	32.50	6.00	688.00
11:30	43.90	60.40	59.00	53.30	51.30	36.50	48.20	33.52	6.00	730.00
12:00	44.60	63.60	61.40	55.50	54.60	37.40	50.00	34.44	6.00	760.00
12:30	47.20	63.80	63.70	57.20	56.90	38.00	51.00	36.50	6.00	775.00
13:00	48.20	64.20	63.90	58.10	57.80	39.50	52.60	37.19	6.00	778.00
13:30	48.80	62.70	63.20	57.00	57.40	40.80	53.00	38.01	6.00	720.00
14:00	48.40	62.10	62.90	56.30	57.10	40.90	52.80	38.60	6.00	690.00
14:30	48.00	62.00	62.60	56.20	56.40	41.80	52.90	38.88	6.00	640.00
15:00	47.90	59.80	60.90	54.90	55.30	42.30	52.70	39.63	6.00	593.00
15:30	47.00	58.70	59.50	53.40	52.70	41.70	50.40	39.00	6.00	490.00
16:00	46.70	56.00	57.10	52.00	51.60	41.00	50.20	38.70	6.00	465.00
16:30	46.20	55.00	55.80	50.60	51.00	41.00	49.20	38.50	6.00	290.00
17:00	46.10	53.00	53.90	51.60	45.80	40.70	48.50	38.50	6.00	200.00
17:30	45.20	50.10	50.90	48.20	47.10	40.10	47.00	38.10	6.00	0.00
18:00	43.70	47.20	48.70	46.00	45.30	39.70	44.20	38.00	6.00	0.00

Table A.8. Experimental Observation of Single Pass Solar Air Heater with Thermal Energy Storage (DATE-29-04-2015)

Time	Glass Temp (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Inlet Air Temp(°C)	Outlet Air Temp (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	43.20	62.90	62.90	54.40	54.20	35.90	47.60	32.00	6.00	600.00
10:30	44.50	62.00	62.20	55.90	56.00	36.20	47.30	33.00	6.00	650.00
11:00	45.30	63.80	63.30	57.70	57.00	37.50	50.20	34.00	6.00	688.00
11:30	46.50	65.00	64.60	58.40	58.80	38.50	51.70	35.00	6.00	730.00
12:00	47.10	65.40	65.00	59.10	59.20	39.00	52.80	36.00	6.00	760.00
12:30	47.20	66.10	65.80	60.00	60.80	40.20	54.30	36.00	6.00	775.00
13:00	48.00	66.70	66.90	60.40	61.00	40.90	55.40	37.00	6.00	778.00
13:30	47.70	65.70	66.20	58.80	59.60	41.40	54.80	37.50	6.00	720.00
14:00	47.40	65.00	65.40	57.90	58.60	41.80	52.90	38.00	6.00	690.00
14:30	47.30	64.40	65.20	57.70	58.20	42.40	53.30	39.00	6.00	640.00
15:00	47.00	63.40	64.00	57.80	56.20	42.60	53.30	40.00	6.00	593.00
15:30	46.70	62.50	63.10	56.40	55.80	41.50	53.00	39.50	6.00	490.00
16:00	46.00	61.10	61.80	54.40	55.00	40.90	51.00	39.20	6.00	465.00
16:30	45.70	59.40	59.80	52.80	53.80	40.70	50.60	39.00	6.00	290.00
17:00	45.10	57.20	57.60	51.00	51.90	40.50	49.00	38.50	6.00	200.00
17:30	44.40	55.50	56.00	50.40	50.00	39.80	45.90	38.00	6.00	0.00
18:00	42.80	53.20	54.00	48.00	46.50	39.00	43.80	37.40	6.00	0.00

Table A.9 Experimental Observation of Single Pass Solar Air Heater with Thermal Energy Storage (DATE-30-04-2015)

Time	Glass Temp (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Inlet Air Temp(°C)	Outlet Air Temp (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	41.20	51.50	52.90	48.30	47.90	36.50	44.60	32.71	9.00	560.00
10:30	43.20	55.40	54.30	49.20	48.90	38.20	46.10	33.78	9.00	610.00
11:00	45.30	56.70	58.00	52.10	52.20	38.80	48.50	34.96	9.00	698.00
11:30	47.80	59.30	58.90	54.20	53.10	39.40	50.80	36.43	9.00	728.00
12:00	49.40	61.10	59.80	55.60	55.20	40.50	52.60	37.69	9.00	747.00
12:30	50.00	62.20	63.20	56.90	58.40	41.00	54.00	38.41	9.00	760.00
13:00	51.00	63.80	64.30	57.60	60.00	41.50	54.80	38.97	9.00	772.00
13:30	51.80	64.70	64.90	57.80	60.20	42.50	56.10	39.99	9.00	782.00
14:00	50.70	63.60	64.00	57.20	59.40	42.90	55.70	40.18	9.00	735.00
14:30	49.90	62.90	63.40	56.90	58.20	43.60	55.00	41.15	9.00	650.00
15:00	49.80	61.60	62.60	56.60	57.80	44.10	54.10	41.58	9.00	560.00
15:30	48.80	60.20	61.30	55.70	56.20	44.50	53.70	41.67	9.00	510.00
16:00	47.50	59.50	59.00	54.00	55.10	43.20	51.50	40.87	9.00	444.00
16:30	46.10	57.80	56.90	53.30	53.20	42.10	49.40	40.00	9.00	350.00
17:00	44.70	55.20	55.60	51.10	51.00	41.10	47.20	38.80	9.00	197.00
17:30	42.30	53.20	52.90	50.10	49.00	40.10	45.80	38.60	9.00	0.00
18:00	40.90	50.10	50.90	47.50	48.00	39.20	45.00	38.10	9.00	0.00
18:30	41.20	51.50	52.90	48.30	47.90	36.50	44.60	32.71	9.00	560.00

Table A.10 Experimental Observation of Single Pass Solar Air Heater with Thermal Energy Storage (DATE-01-05-2015)

Time	Glass Temp (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Inlet Air Temp(°C)	Outlet Air Temp (°C)	T_{amb} (°C)	V_{air} (m/s)	I_T (W/m^2)
10:00	40.00	53.60	53.90	48.10	48.00	34.70	43.50	31.44	9.00	600.00
10:30	41.70	55.00	54.40	49.00	48.80	35.40	44.80	32.01	9.00	680.00
11:00	43.30	55.90	56.10	50.40	50.10	36.00	46.40	33.00	9.00	745.00
11:30	45.30	57.20	57.70	51.30	51.00	37.10	47.90	35.12	9.00	770.00
12:00	46.60	58.00	59.10	53.70	53.60	38.10	50.00	35.22	9.00	790.00
12:30	47.70	59.80	61.80	55.00	54.80	39.00	52.00	36.83	9.00	830.00
13:00	48.50	60.80	61.00	55.70	55.50	39.90	52.60	37.07	9.00	800.00
13:30	48.30	60.30	60.80	55.70	55.00	40.10	52.60	37.35	9.00	780.00
14:00	47.30	59.80	60.20	55.60	54.80	40.20	51.90	38.42	9.00	720.00
14:30	46.50	58.90	59.60	55.40	53.80	40.50	51.40	38.20	9.00	670.00
15:00	45.80	57.20	58.10	55.30	51.30	41.20	50.70	38.72	9.00	590.00
15:30	45.00	55.50	56.00	53.00	49.50	40.80	49.40	38.53	9.00	520.00
16:00	44.30	54.70	55.50	52.50	49.40	41.00	48.40	38.58	9.00	400.00
16:30	43.80	52.80	53.20	50.40	47.30	41.30	47.20	38.47	9.00	280.00
17:00	42.20	51.00	51.20	48.00	46.00	40.30	45.20	38.36	9.00	210.00
17:30	41.20	48.80	50.00	46.60	44.90	39.50	44.00	38.20	9.00	50.00
18:00	40.50	46.90	47.70	43.30	42.20	38.70	42.00	37.56	9.00	0.00