Study of Hybrid Photovoltaic Solar Thermal Systems During Summer Months in Bangladesh

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Abstract

A hybrid photovoltaic (PVT) solar system combines simultaneous conversion of the absorbed solar radiation into electricity and heat. In this study the design of an experimental PVT/dual system, both air and water circulation with modifications in the air channel is presented. A thin metallic sheet (TMS) inside the air channel and painted black ribbed surfaces at the bottom of the air channel are placed. For observing the variations of heat transmittance with change of the shape of the ribs four experimental setups with a Trapezoidal, a Saw tooth forward, a Saw tooth backward ribbed surfaces and a flat plate have been used, Natural convection is applied instead of forced convection to increase the system net electrical output & thereby the overall system efficiency. All setups are of the same capacity, projected area and water heat extraction method and average depth. Performance study is carried out during the months of March to June, 2012 at IUT campus, Gazipur, Bangladesh. Significant performance has been obtained with the above stated modifications. Natural convection is allowed to take place instead of fluid convection. Results obtained in this study have been compared with available information in the literature.

Keywords: Hybrid Thermal System, Solar Energy, Thin Metallic Sheet (Tms), Painted Black Ribbed Surfaces.

1.0. Introduction

The need for alternative energy sources is getting urgent, hence, the development of renewable energy is moving fast. Nationally and internationally various individuals and research companies are creating new and exciting energy systems. Some of these apparatuses are great works and need improving for massive use. Politician's world-wide are drafting policies and are making agreements to make greater use of these energy sources.

A wide use of fossil fuels today is very harmful for the environment. In the early seventies and eighties there were people and even scientists who preach otherwise, but today the negative effects are showing. The earth is warming up and climates are changing. There are parts in the world where there will be more rain and sunshine and others parts will become dryer than they already are. Another negative effect is that the ozone layer is getting thinner which also leads to a warming up of the earth. These two effects complement each other and make it even more crucial to make another step in a different direction. This step will lead us to the use of renewable energy.

Renewable energy is derived from an energy source that is rapidly replaced, or renewed by a natural process. It is the energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable in nature. Some of the renewable energy are solar energy, Wind and Wave energy, Hydropower, Bio-mass, geothermal energy etc. Solar energy is an important clean, cheap and abundantly available renewable energy. The earth receives an incredible supply of solar energy.

There is a good prospect of harnessing solar power in Bangladesh. In a recent study conducted by Renewable Energy Research Centre, it is found that average solar radiation varies between 4 to 6.5 $kWhm^{-2}$ day^{-1}. Maximum amounts of radiation are available in the month of March-April and minimum in December-January.

Mainly there are two ways to collect solar energy: Natural collection and Technological collection.

There are also two methods for technological collection of solar energy.

i. Photovoltaic conversion method
ii. Thermal conversion method

Different photovoltaic cell convert only 5-15% of the incoming solar radiation into electricity, with the greater percentage converted into heat. The solar radiation converted into heat increases the temperature of the PV modules, resulting in the drop of their electrical efficiency. This undesirable effect can be partially avoided by applying a suitable heat extraction mode with a fluid circulation, keeping the electrical efficiency at a satisfactory level. Furthermore, this extracted heat can be utilized for heating air and/or water. For this purpose, the concept of hybrid photovoltaic/thermal (PV/T or PVT) solar systems have been developed.

From the above discussion, it is found that a number of survey works have been carried out in hybrid PVT solar systems using air and water as heat carrier's fluid. But only a few works have been carried out on PVT/dual (both air and water) system. However, both air and water are used as heat carriers.

2.0. Experimental setup & test procedures

2.1. Experimental setup

Four experimental setups are fabricated with similar design and dimensions except the shape of the ribs. The whole setup is constructed in a wooden box. PV panels are set at the top of the box. Thin Metallic Sheet (TMS) is placed at the middle part of the box on top of which pipes are set for water circulation. Air channel of 0.1m height is kept under the water heat exchanger. Different ribbed plates (Trapezoidal, Saw tooth forward, Saw tooth backward and Flat plate) of same height and dimension are placed on opposite wall of the air channel. The whole inner portion of the box is insulated. TMS and Ribbed plates are painted black for better heat absorption. Fig. 1 shows the schematic diagram of each experimental setup with different ribbed surfaces. Photograph of the installed setup at IUT campus, shows in Fig. 2.

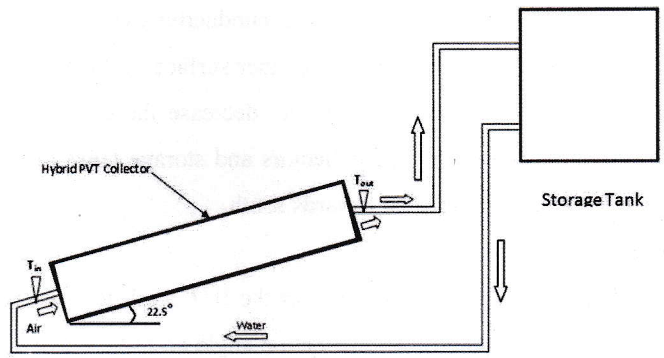


Fig. 1. Schematic diagram of each experimental setup.

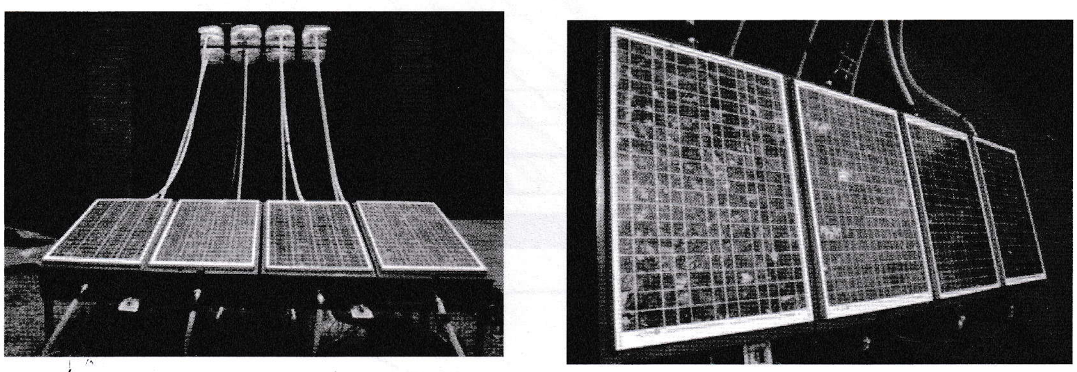


Fig. 2. Photograph of the installed setup at IUT campus.

The main components of each setup consist of a PV panel, a wooden box, a water heat exchanger (WHX), a TMS and the absorber plate, ribbed plates at the opposite of air channel, water storage tank, insulation, steel frame and stand. For this project, Polycrystalline-Silicon (pc-Si) PV panels are used with a rating of 50 watts and 0.45m^2 aperture area having approximate dimensions of (839 ×

537 × 50) mm. For circulating water copper tubes were used in this project, as copper has got higher thermal conductivity which is a necessary requirement of the project. The optimum diameter 1.25 cm (½″) is selected to facilitate the high rate of heat transfer and sufficient rate of flow.

For the header portion, copper pipe of diameter 3.8 cm (1.5") is used. The diameter of the header is found by calculating the cross-sectional area of the copper tubes corresponding to header cross-sectional area to maintain a uniform flow rate through all the tubes. For water flow to and from the storage tank nylon tube of diameter 2.5 cm is used. Nylon tubes are flexible and don't bend to interrupt the flow.

Glass wool is used as insulation for its low conductivity (K) of 0.04 W/mK, and of moderate cost. Insulation of 2.5 cm height is applied at the inner surface of the wooden box to avoid any kind of heat transfer to and from the setup which may decrease the efficiency of the PVT system. A supporting steel structure is made for the collectors and storage tanks. The collectors are set at an inclination angle of (β) 23.5^0 and directed towards south.

3.3. Test Procedures

All the collectors are installed in front of the IUT workshop where there is no obstacle to sunshine and faced towards south with an inclination angle of 23.5^0 which is the best angle to collect as much as available radiation. Photograph of which are shown in Fig. 2. All storage tanks are filled

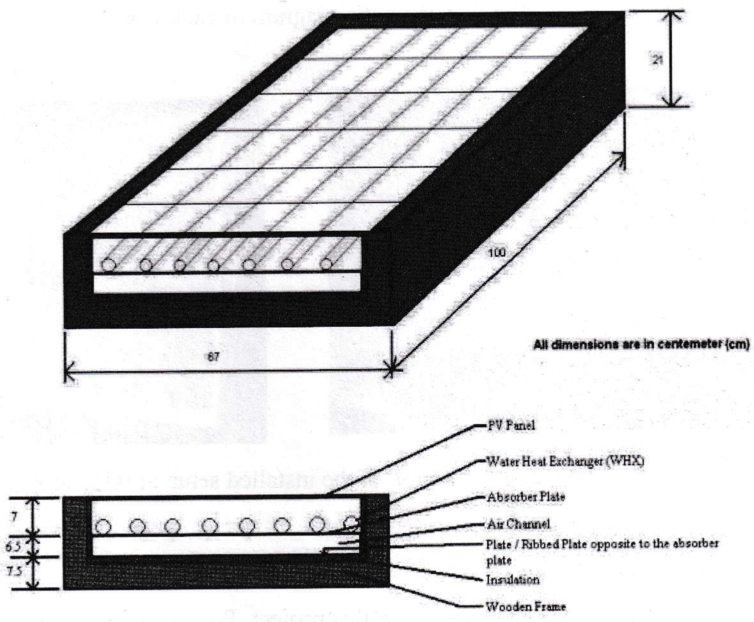


Fig. 3. Details of Hybrid Collector (All dimensions are in cm).

early in the morning with fresh water. Temperatures are measured for PV panel (T_{PV}), Water heat exchanger (T_{WHX}), Inlet and Outlet of water (T_i and T_O), Air in the channel (T_{air}) and the rib temperature (T_{rib}) in air channel by using seven 36 S.W.G. Chromel-Alumel thermocouples. Selector switches are used to switch among the thermocouples.

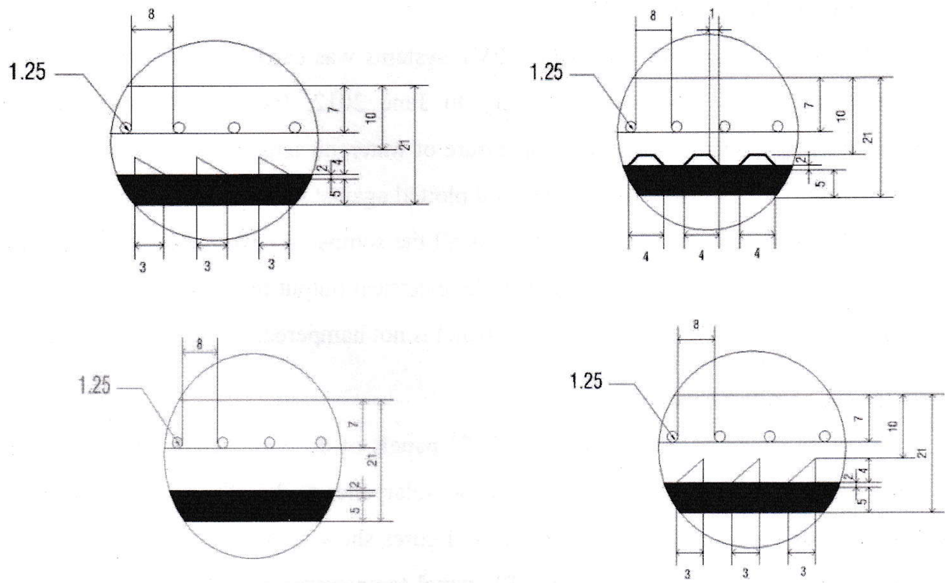


Fig. 4. Test specimens (a) Trapezoidal rib; (b) Saw tooth forward rib; (c) Saw tooth backward rib; (d) Flat plate (All dimensions are in mm).

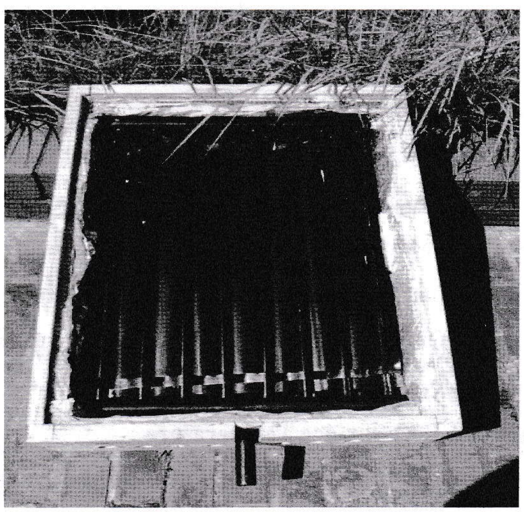


Fig. 5. Photograph of the Interior view showing the TMS with water heat exchanger.

Ambient temperature (T_{amb}), solar radiation (G) are recorded hourly every day from at 8 AM up to 6 PM. All readings are recorded in data sheets. Details of hybrid collector and test specimens used in this study are shown in Fig. 3. and in Fig. 4. Photograph of the Interior view showing the TMS with water heat exchanger shows in Fig. 5.

4.0. Results and Discussions

Performance study of four hybrid PVT systems was carried out in IUT Campus, Gazipur, Bangladesh during the months of February to June 2012. PV panel temperature, water heat exchanger surface temperature, outlet temperature of water, air temperature in the air channel and rib temperature in the air channel are recorded and plotted against time. These are presented from Fig. 6. to Fig. 22. Thermal efficiency is calculated for all the setups and average values are plotted in Fig. 23. Thermal output is emphasized more than the electrical output in this study. As no electrical load is used as a part of the setup, output from PV panel is not hampered.

4.1. PV panel Temperature

Typical temperature distributions of PV panels of different setups with time are shown in Fig. 6 to Fig. 8. As the PV panel receives the solar energy directly on top of the setup, panel temperature rises very quickly with time. These figures show similar patterns of temperature survey with slight difference among four setups. PV panel temperature rises from 8:00 am to 12:00 noon and then decreases after 2:00 pm rapidly. In an intense sunny day of 15March2012, the maximum temperature of PV panel is found to be 62°C for flat plate, 56°C for trapezoidal, 57°C for Saw tooth forward and 59°C for Saw tooth backward plate. In a sunny day of 30/April/2012, the maximum temperature of PV panel is found to be 61°C for Flat plate, 54°C for trapezoidal, 56°C for Saw tooth forward and 59°C for saw tooth backward plate. In a rainy day of 30/May/2012, the maximum temperature of PV panel is found to be 40°C for flat plate, 41°C for trapezoidal, 40°C for saw tooth forward and 39°C for saw tooth backward plate.

Setup with saw tooth forward and saw tooth backward ribs setups give lower temperature of the panel which shows better cooling of PV. Trapezoidal ribbed plate gives moderate cooling better than that of flat plate setup. In flat plate setup PV temperature is found always high, which shows inadequate heat transfer for PV cooling.

4.2. Water Heat Exchanger (WHX) Surface Temperature

Typical water heat exchanger surface temperature distributions of different setups with time are shown in Fig. 9 to Fig. 11. Water heat exchanger with TMS is placed below the PV panel at the middle section of the setup. Heat energy is absorbed here from the PV rear surface and water is heated flowing through it. It is evident from these figures that the temperature of this heat exchanger also rises with time from 8:00 am to 12:00 noon and then decreases after 2:00 pm rapidly. In a sunny day of 30/March/2012, the maximum temperature of WHX is found to be 48°C for Flat plate, 46°C for Trapezoidal, 49°C for saw tooth forward and 48°C for Saw tooth backward plate. In a sunny day of 30/April/2012, the maximum temperature of WHX is found to be 49°C for flat plate, 47°C for trapezoidal, 51°C for saw tooth forward and 49°C for saw tooth backward plate. In a rainy day of 30/May/2012, the maximum temperature of WHX is found to be 34°C for flat plate, 37°C for trapezoidal, 36°C for saw tooth forward and 35°C for saw tooth backward plate. Average good temperature is found in case of setup with saw tooth forward rib. Average temperature difference between PV panel and WHX is around 10-12°C.

4.3. Water outlet Temperature

Typical distribution of Water outlet temperatures of different setups with time are shown from Fig. 12 to Fig. 14. Water is one of the heat removal fluids of these hybrid PVT systems and is also important for meeting thermal needs. Water temperature is raised by taking absorbed heat from heat exchanger. On intense sunny day of 15/March/2012, the maximum temperature of water is found to be 39°C for Flat plate, 41°C for trapezoidal, 40°C for saw tooth forward and 59°C for Saw tooth backward plate. On sunny day of 15 April 2012, the maximum temperature of water is found to be 40°C for flat plate, 43°C for Trapezoidal, 42°C for saw tooth forward and 41°C for saw tooth backward plate. On a rainy day of 30May2012, the maximum temperature of water outlet is found to be 35°C for flat plate, 37°C for trapezoidal, 36°C for saw tooth forward and 35°C for saw tooth backward plate.

Temperature of the water in supply lines varies between 23°C to 26°C. The maximum temperature rise is found to be 43 ° C using hybrid PVT systems. Average temperature of water is found to be around 40°C. Water at this temperature is very much suitable for household activities, in kitchens, in bathrooms for washing purpose and for taking bath etc. This water also can be used as pre-heated water in many chemical industries.

4.4. Air temperature in the air channel

Typical distributions of air temperature in the air channel of different setups with time are shown from Fig. 15 to Fig. 17. Air is one of the heat removal fluids of these hybrid PVT systems. As natural circulation of air is preferred, air flows inside the channel are found to be insufficient for heat extraction. As a result, the air temperature inside the channel is found to be only a few degrees above the ambient temperature and sometimes remains same. On a sunny day of 30/March/2012, the maximum temperature of air is found 32°C for Flat plate, 37°C for Trapezoidal, 36°C for Saw tooth forward and 35°C for Saw tooth backward plate. On a sunny day of 30 April 2012, the maximum temperature of air is found to be 33°C for flat plate, 36°C for Trapezoidal, 35°C for Saw tooth forward and 35°C for saw tooth backward plate. In a rainy day of 30/May/2012, the maximum temperature of Air channel is found 33°C for flat plate, 35°C for trapezoidal, 34°C for saw tooth forward and 34°C for saw tooth backward plate.

Maximum air temperature in the air channel is found to be maximum 4°C to 5°C higher than the ambient temperature. Although this temperature rise is much lower than water, air as heat removal fluids of hybrid PVT system can be used for natural ventilation of buildings. In winter when the inside/room temperature.

4.5. Ribbed Surface Temperature

Variations of ribbed surface temperature with time for different setups with time are typically shown from Fig. 18 to Fig. 20. Ribbed surface is placed at the bottom of the setup in the air channel. It receives heat from the WHX. Temperature on the ribbed surface gives idea about heat transfer to air in the channel. On an intense sunny day of 15 March 2012, the maximum temperature of rib surface is found 33°C for flat plate, 36°C for Trapezoidal, 35°C for Saw tooth forward and 34°C for Saw tooth backward plate. On a sunny day of 30 March 2012, the maximum temperature of rib surface is found to be 34°C for Flat plate, 37°C for Trapezoidal, 36°C for Saw tooth forward and 35°C for Saw tooth backward plate. On a sunny day of 15/April/2012, the maximum temperature of rib surface is found to be 35°C for flat plate, 38°C for Trapezoidal, 37°C for Saw tooth forward and 36°C for saw tooth backward plate. In a partly cloudy day of 15 May 2012, the maximum temperature of ribbed surface is found to be 33°C for Flat plate, 36°C for trapezoidal, 34°C for saw tooth forward and 34°C for Saw tooth backward plate at 02:00 PM. Maximum air temperature in the ribbed surface is found to be maximum 3°C to 4°C higher than the ambient temperature.

4.6. Temperature Distribution

A hybrid PVT/dual system has several heat exchanging surfaces. PV panel, WHX, water, air and rib temperature varies accordingly. Fig. 21 to Fig. 22 show typical temperature distributions in four hybrid PVT systems with ambient temperature. It is found from these figures that temperature of the PV panel is highest as it receives heat from PV rear surface and temperature is found to be 36 °C -48 °C in this region. Water acts as a heat carrier fluid here and the temperature of water is rises with rising of WHX temperature. Water temperature is found to be within 34 °C to 50 °C. After WHX, air in the channel is receiving heat from TMS and WHX. Air temperature varies in between 35 °C to 45

°C. The last portion is the ribbed surfaces placed at the bottom of air channel of the setup. Temperature of ribbed surface varies in between 32 °C to 39 °C.

4.7. Thermal Efficiency Comparison

Thermal efficiency regarding water is compared as a function of $\Delta T/G$ ($KW^{-1}m^2$). ΔT is the temperature difference between input fluid and the ambient temperature. Efficiency of all four setups are compared along with the work of Tripangnostopoulos et al. (2007) and Karim et al. (2011) in Fig. 18 for comparison. Tripangnostopoulos et al. (2007) studied a hybrid PVT/dual system having corrugated rib on opposite air channel with WHX placed just under the PV panel in 2007 at the University of Patras, Greece. Karim et al. (2011) studied hybrid photovoltaic thermal solar system using three different ribbed surfaces (Triangular, Semicircular, Square) and flat plate in 2011 at IUT, Bangladesh.

In the present study, a hybrid photovoltaic solar thermal system using three different ribbed surfaces (Trapezoidal, saw tooth forward, saw tooth backward) and a flat plate have been carried out from March to June in 2012. The efficiency of Trapezoidal is 36% to 73%, Saw tooth forward is 37% to 70%, Saw tooth backward is 36% to 67% and Flat plate is 33% to 59%. Tripangnostopoulos et al. (2007) PVT system is found to vary from 45% to 62% and Karim et al. (2011) is found to vary from 35% to 70%. The average efficiency from all calculated values is found to be 67% for Trapezoidal, 62% for Saw tooth forward, 61% for Saw tooth backward and 54% for flat plate setup.

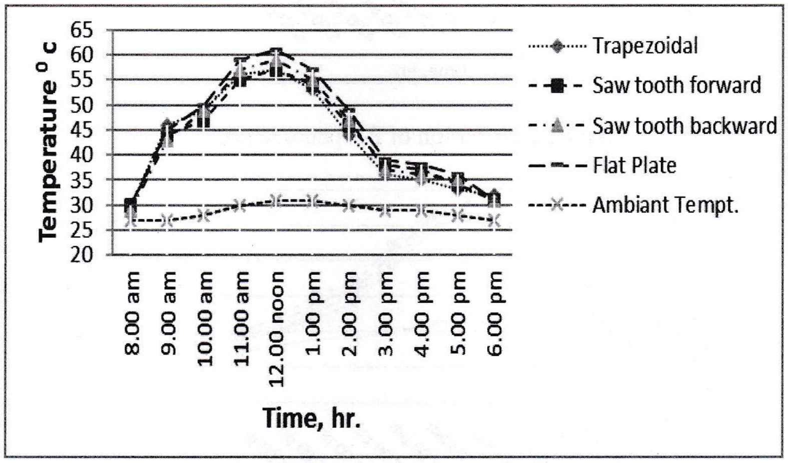


Fig. 6. Temperature distribution of PV panel temperature on 15/03/2012.

The range of efficiency varies with the operating temperature of the system. The thermal efficiency of PVT/dual system for water heat extraction is extended in negative $\Delta T/G$ axis, as some experiments were performed for ambient temperature being higher than the water temperature at system input. Data taken for comparisons of setups are similar with ΔT/G values, to make the comparison more correct.

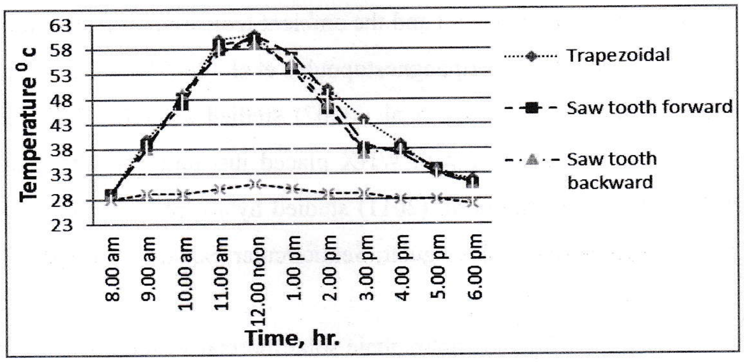


Fig. 7. Temperature distribution of PV panel temperature on 30/04/2012.

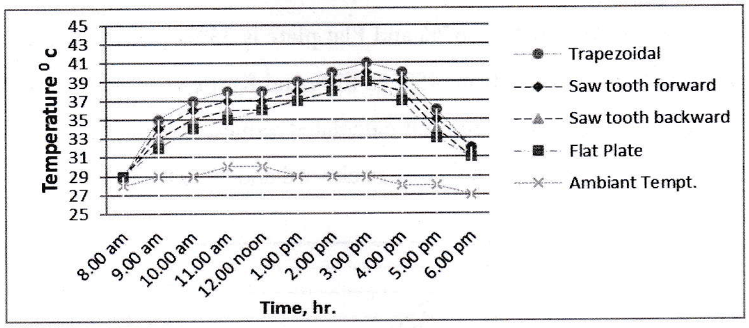


Fig. 8. Temperature distribution of PV panel temperature on 30/05/2012.

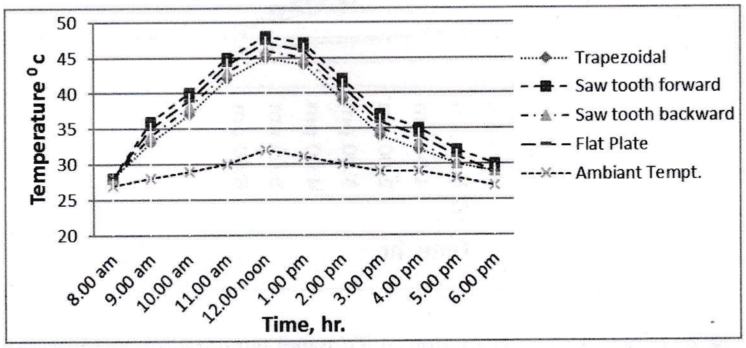


Fig. 9. Temperature distribution of water heat exchanger temperature on 30/03/2012.

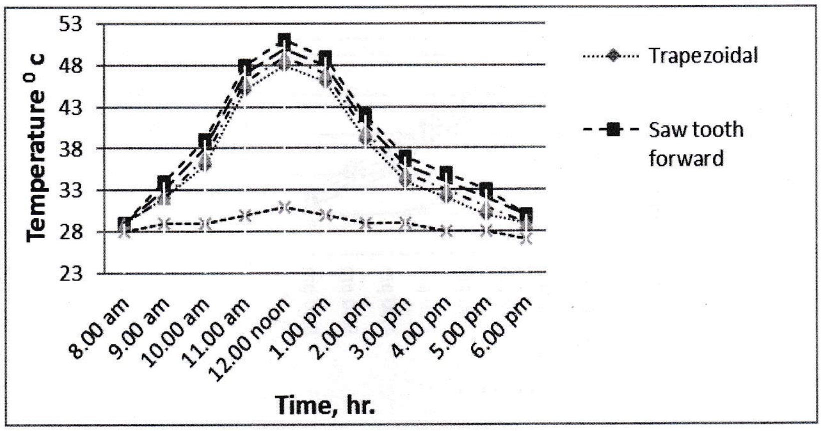


Fig. 10. Temperature distribution of water heat exchanger temperature on 30/04/2012.

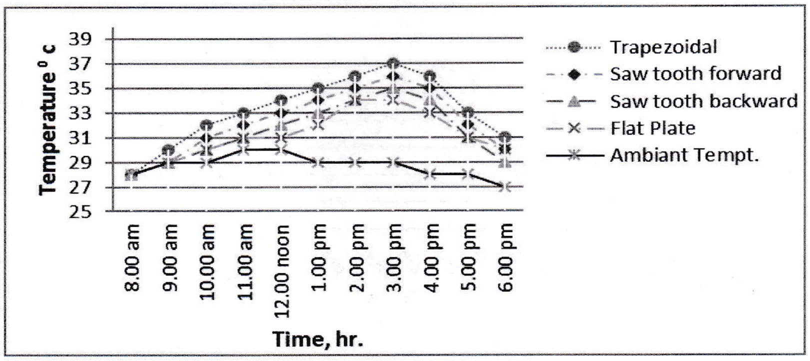


Fig. 11. Temperature distribution of water heat exchanger temperature on 30/05/2012.

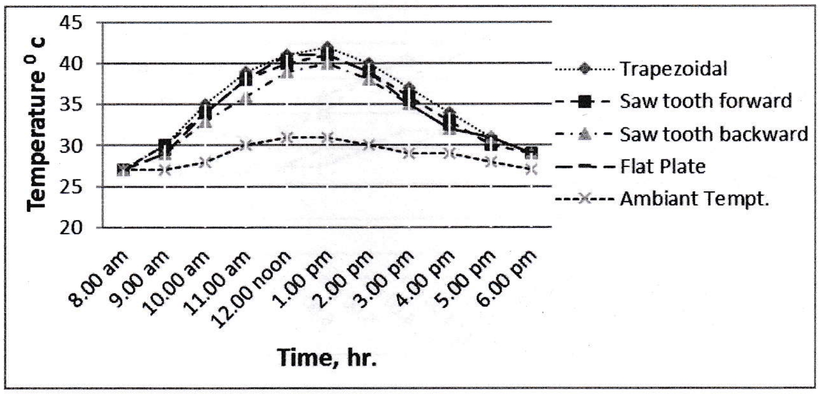


Fig. 12. Temperature distribution of water outlet temperature on 15/03/2012.

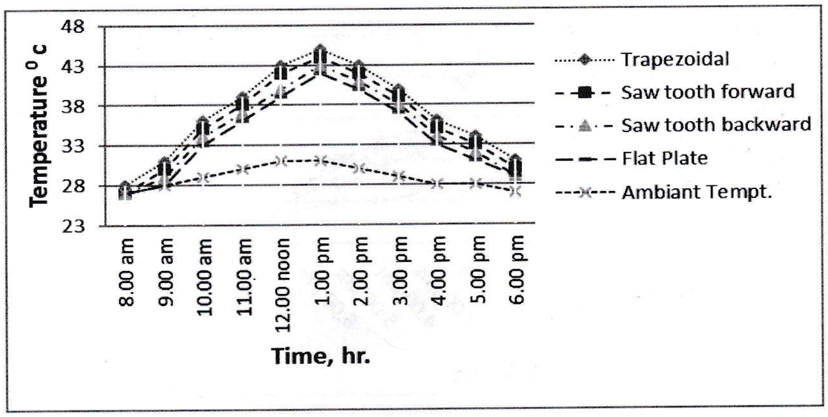


Fig. 13. Temperature distribution of water outlet temperature on 15/04/2012.

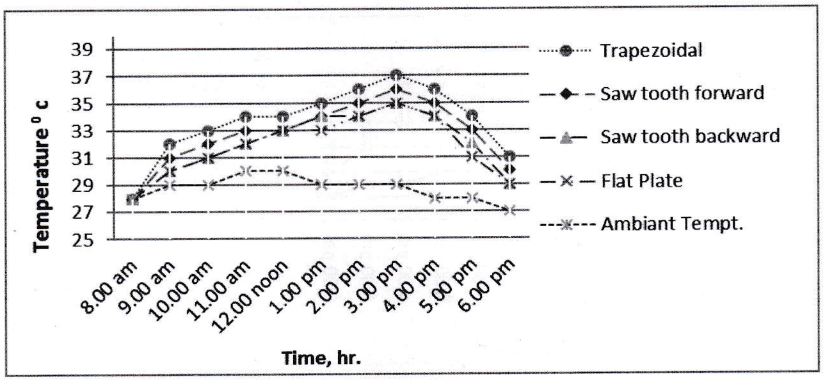


Fig. 14. Temperature distribution of water outlet temperature on 30/05/2012.

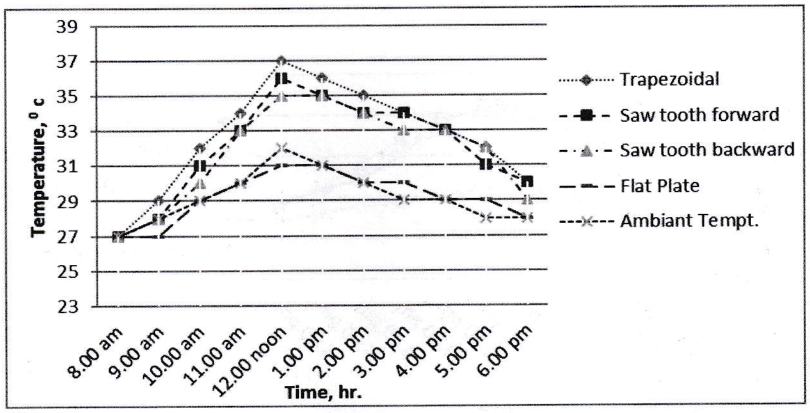


Fig. 15. Temperature distribution of Air Channel temperature on 30/03/2012.

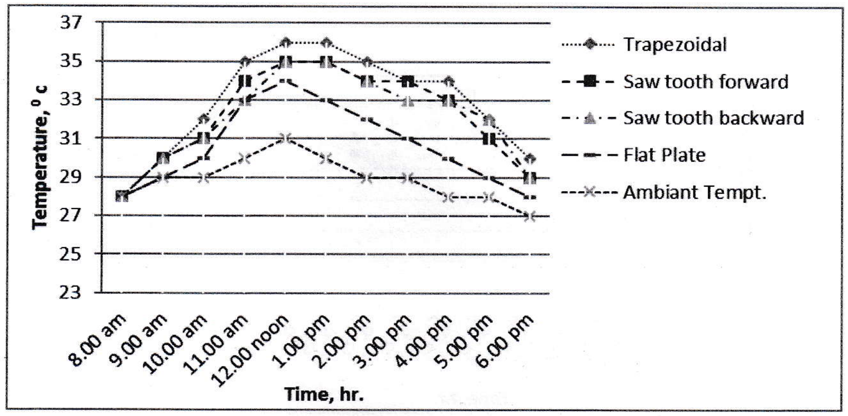


Fig. 16. Temperature distribution of Air Channel temperature on 30/04/2012.

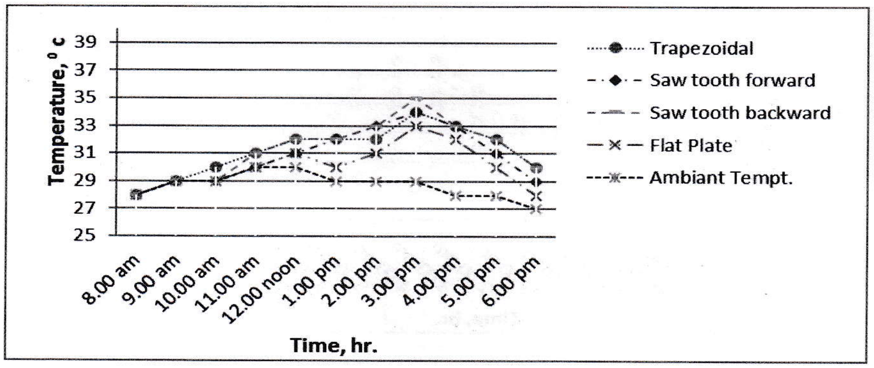


Fig. 17. Temperature distribution of Air Channel temperature on 30/05/2012.

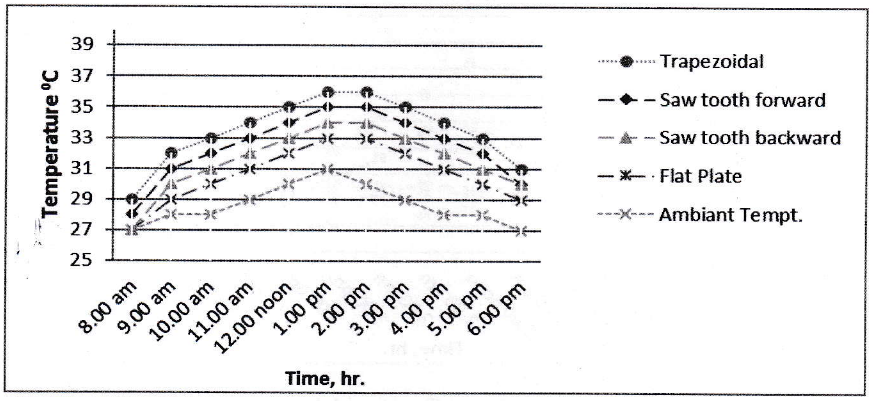


Fig. 18. Temperature distribution of Ribbed surface temperature on 15/03/2012.

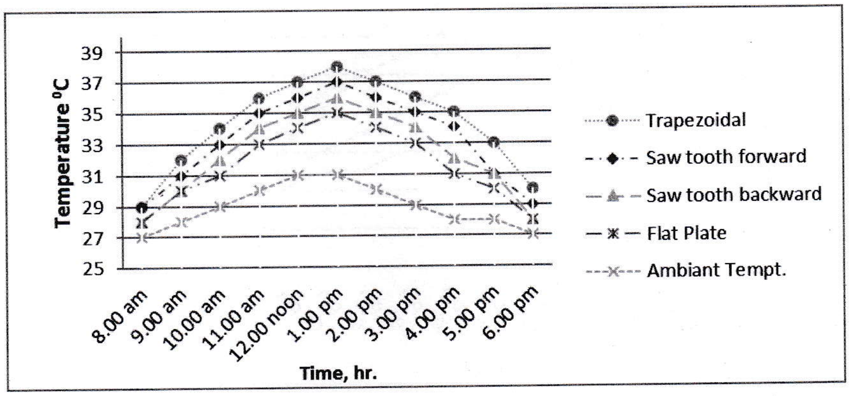


Fig. 19. Temperature distribution of Ribbed surface temperature on 15/04/2012.

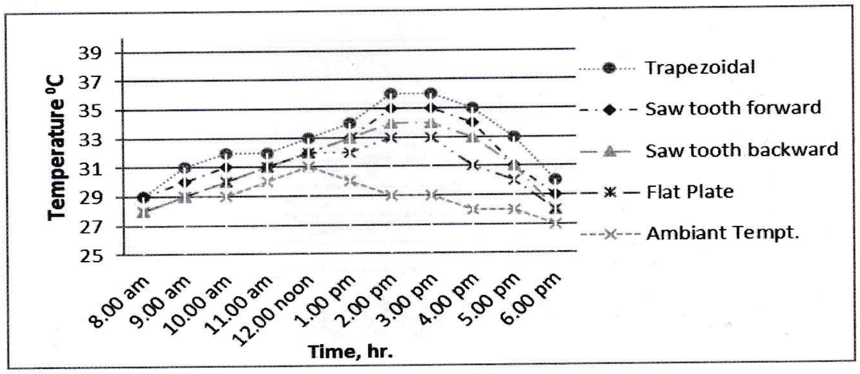


Fig. 20 Temperature distribution of Ribbed surface temperature on 15/05/2012.

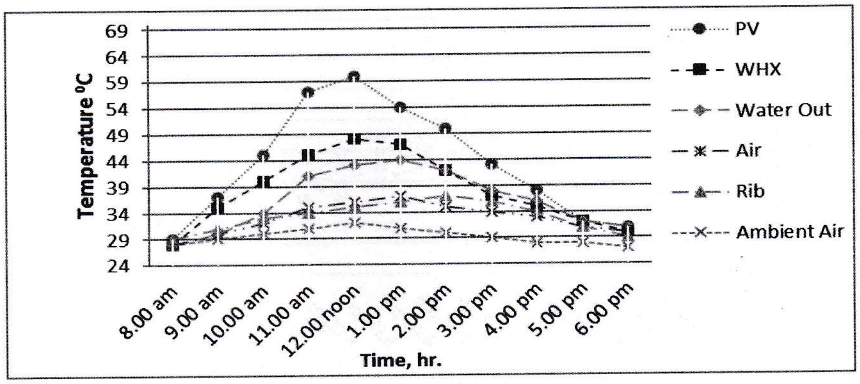
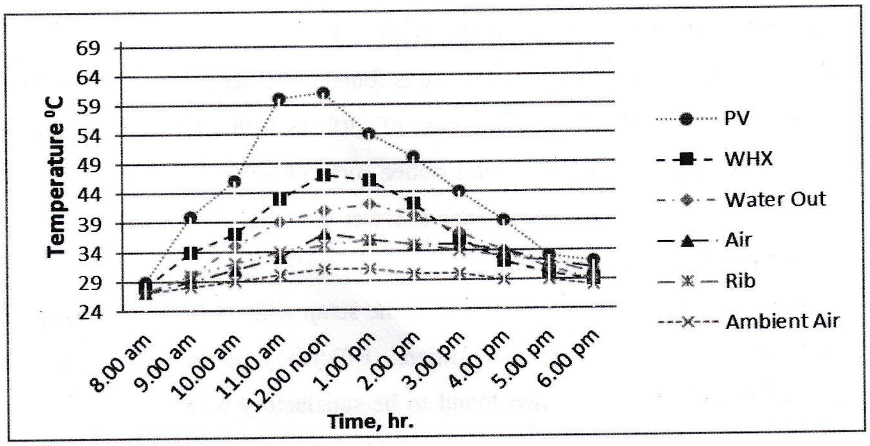


Fig. 21. Temperature distribution in Trapezoidal ribbed setup in March,2012.



22. Temperature distribution in Saw tooth backward ribbed setup in April, 2012.

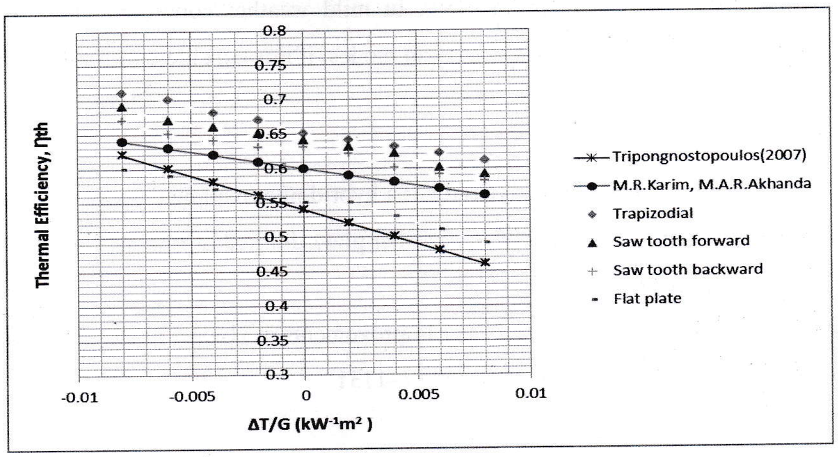


Fig. 23. Comparison of Thermal efficiencies of all four systems.

5.0. Conclusions

From this experimental study the following conclusions may be drawn:

i. With increasing of PV panel temperature, the water and air temperatures also increase and reach a maximum value at a maximum PV temperature around noon. Water and air temperature then decrease slowly with the ambient temperature also.

ii. The energy absorbed in the system from 8AM to 12 Noon is faster than that absorbed in the afternoon for all systems, tested in this study.

iii. Average water and air temperatures rise is found to be better in a Trapezoidal and in a Saw tooth forward ribbed surfaces then those of surfaces with a Saw tooth backward and a Flat plate. Setup with Saw tooth forward ribbed surfaces shows better performance than that of Flat plate but its average performance is lower than that of setup with a Trapezoidal and a Saw tooth forward ribbed surface.

iv. Thermal efficiency is found to be best in the setup with Trapezoidal ribs among all setups, applying similar experimental conditions. Efficiency of Saw tooth forward, saw tooth backward and flat plate is also found to be satisfactory within the range of experimental conditions.

v. PVT/dual system can be used either to heat water or to heat air depending on the weather conditions and building needs. The water heat extraction part could operate mainly during periods of higher ambient temperature and the air heat extraction part to operate mainly when the ambient temperature low. In mild weather conditions (like Bangladesh) it is possible to operate both heat extraction modes, if it is considered useful for the application.

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