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Comparative Experimental Performance Study of Different Types of Solar Water Heating Systems in a Typical Climate

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Abstract: This paper present the concept of saving the energy in domestic heating system. In this paper we compare the three different types of domestic solar water heating system with different collectors are flat plate collector without heat exchanger (FPC), flat plate collector with heat exchanger (FPCHE) and evacuated tube type collector (ETC). The first system consists of FPC (2.07m^2) connected to a 100 liters of storage tank. The other system consists of FPCHE having an area of (1.836m^2) and the ETC having an area of (1.358m^2) are both connected to 100 liters of storage tank, corresponding to several nice sunny days at Solar Energy Centre. The average temperature in the tank of FPC reached to a maximum of 58^{o}C starting from an initial temperature of 25^{o}C in the morning, while the average tank temperature in the FPCHE is 48^{o}C starting from the same initial temperature. Similarly in the ETC the average temperature in the tank is 49^{o}C with the same initial temperature. The efficiency of the FPC was observed to be around 40% and for FPCHE, it was observed to be around 48% while it was observed to be around 51% for the ETC.

Keywords: Flat plate collector without heat exchanger, flat plate collector with heat exchanger, evacuated tube collector, efficiency.

I. INTRODUCTION

Solar water heater system is renewable source of energy. Several types of solar collectors exist according to the different methods collecting the solar energy from incident radiation. There are collectors are used in modern domestic solar water heating systems are:

- Flat plate collector without heat exchanger
- Flat plate collector with heat exchanger
- Evacuated tube collector.

A. Flat plate collector without heat exchanger

The FPCs are composed by these parallel metal absorbers, the joined copper pipes on the back of the absorber strips, the covering transparent glass, the insulator and the coating. There are two types of FPCs depending on the medium between the covering glass and the absorber. The simpler one is fulfilled by air which has significant thermal lost as a result of convective heat transfer. This thermal lost energy can be decreased by evacuating the air from the collector frame [1].

B. Flat Plate Collector with Heat Exchanger

It consists of a plastic or glass cover on top and a dark-colored absorber plate on the bottom. The sides and bottom of the collector are usually insulated to minimize heat loss. Sunlight passes through the glazing and strikes the absorber plate, which heats up, converting solar energy into heat energy. The heat is transferred to liquid flowing through pipes joined to the absorber plate. Absorber plates are commonly painted with coatings which absorb and retain heat better than ordinary black paint. [2-7].

C. Evacuated Tube Collector

Evacuated solar collectors are made up of series of modular tubes, mounted in parallel, whose number can be added to or reduced as hot water delivery needs change. This type of Evacuated solar collector consists of rows of parallel transparent tubes, each of which contains an absorber tube (in place of the absorber plate to which metal tubes are attached in FPC). The tubes are covered with a light modulating coating. In an evacuated tube collector, sunlight passing through an outer glass tube heats the absorber tube contained within it. The absorber can either consists of copper or specially coating glass tubing [8-25].

II. EXPERIMENTAL SET AND MEASURING TECHNIQUE

In order to evaluate the thermal performance of solar water heating system, we need the following parameters are Ambient temperature, temperature of water kept inside tank, total global solar radiation, wind velocity, temperature of collector plates. Various sensors used to measure the temperature of water inside the tank and the temperature of water inside the collector plates are measurement of solar radiation, measurement of ambient temperature, temperature of top of collector plate (TC), temperature of bottom of collector plate (BC), temperature of top of water tank (TT), temperature of bottom of water tank (BT). For the following consideration, no water is withdrawn from the tank. All the experimental measurements were averaged over an interval of 10 minutes, corresponding to fairly good summer days at Solar Energy Center, Gurgaon, India. The time variation of various temperatures in the system and the variation of the incident solar radiation of flat plate collector without heat exchanger are shown in figure 1(a-l) with date. The time variation of various temperatures in the system and the variation of the incident solar radiation of flat plate

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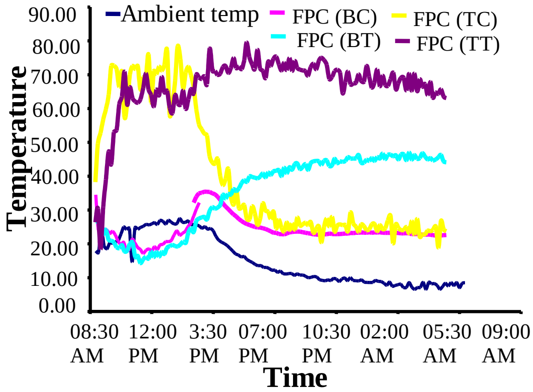
collector with heat exchanger are shown in figure 2(a-l) with date. The time variation of various temperatures in the system and the variation of the incident solar radiation of evacuated tube collector are shown in figure 3(a-l) with date.



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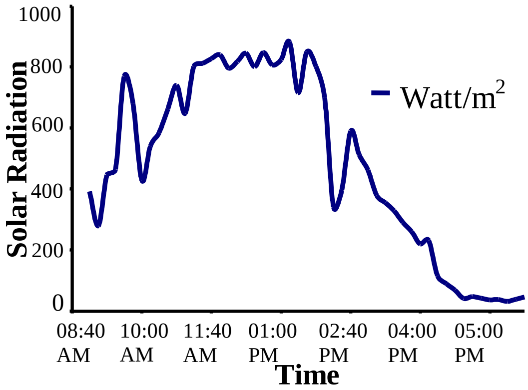

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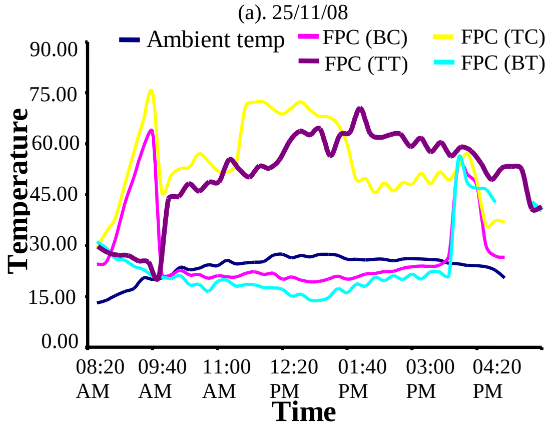

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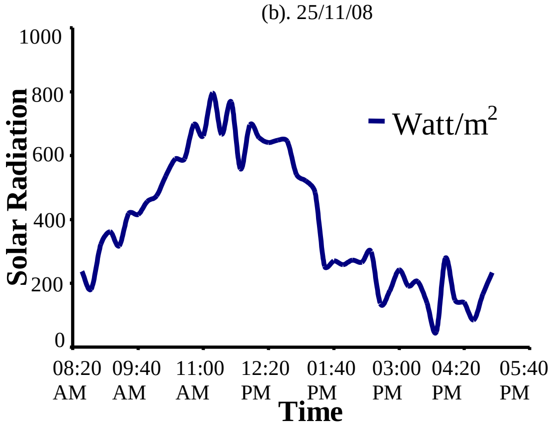

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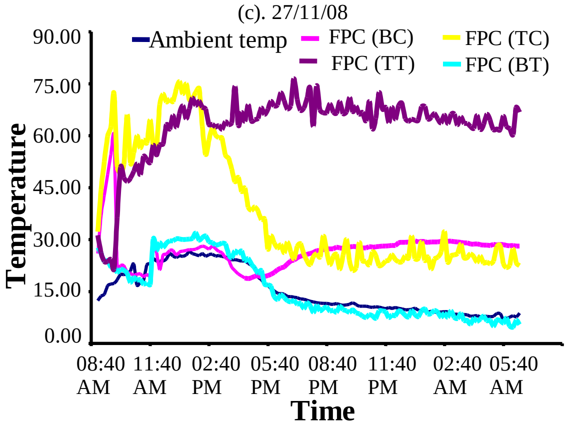

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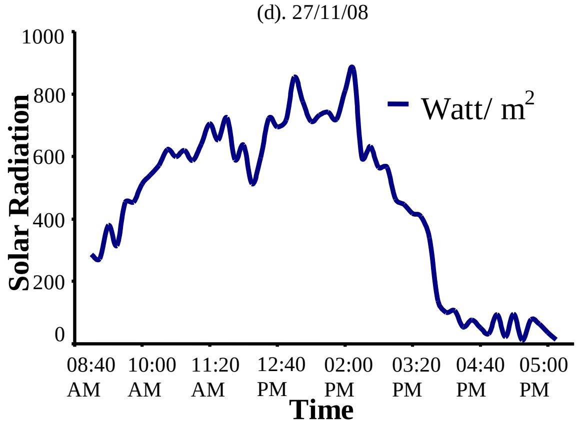

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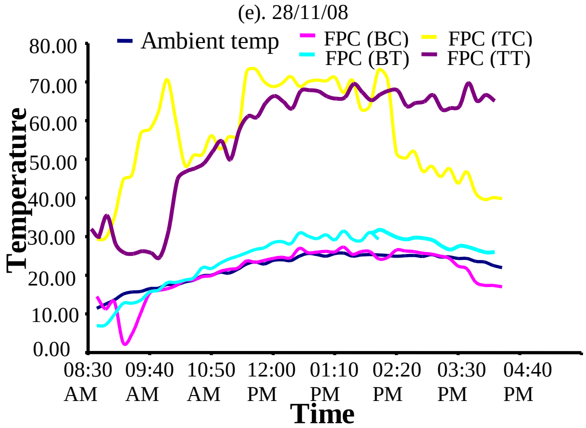

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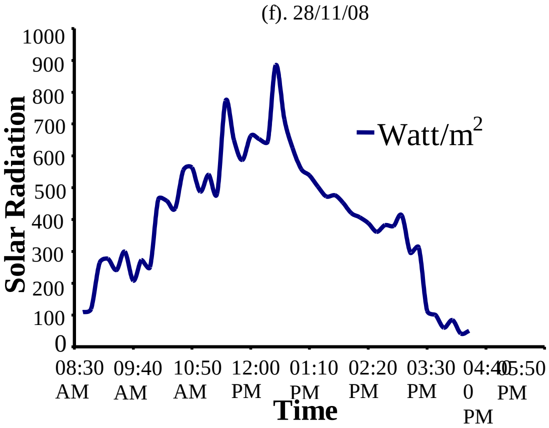

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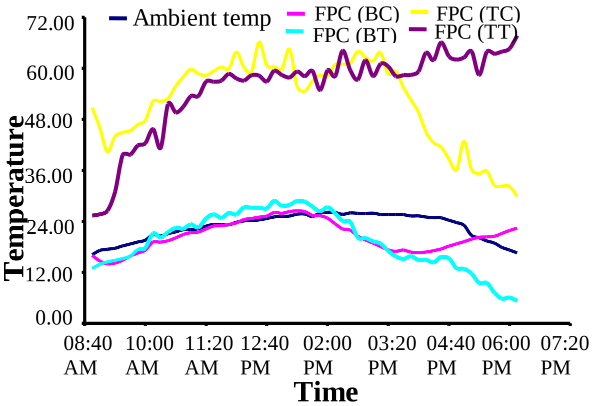

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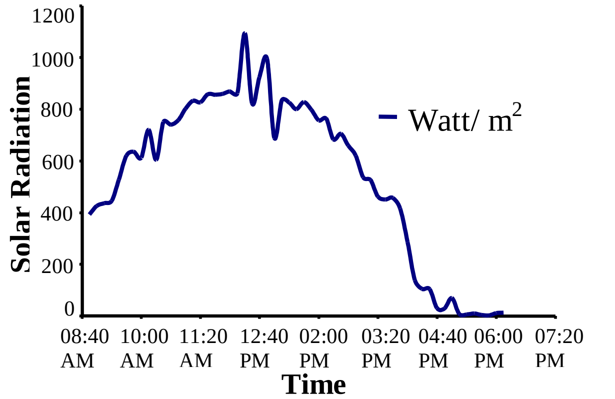

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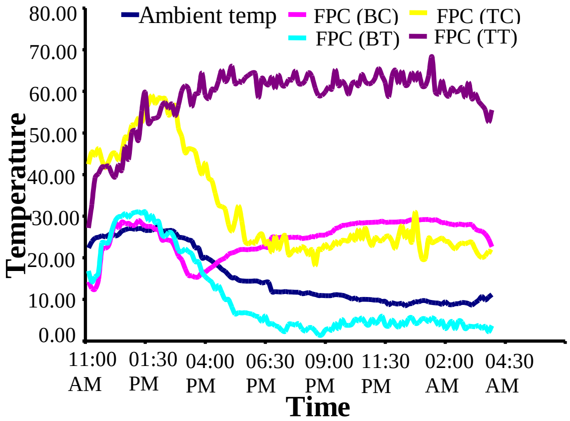

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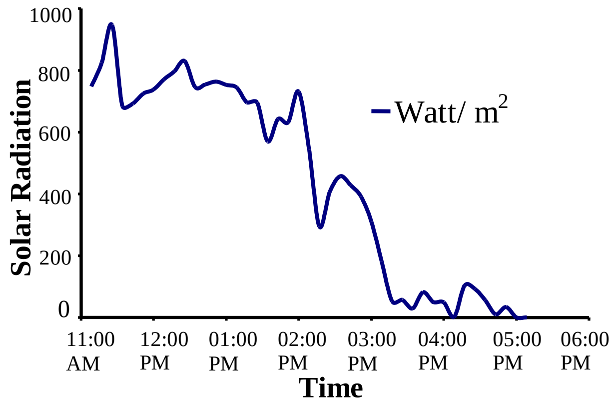

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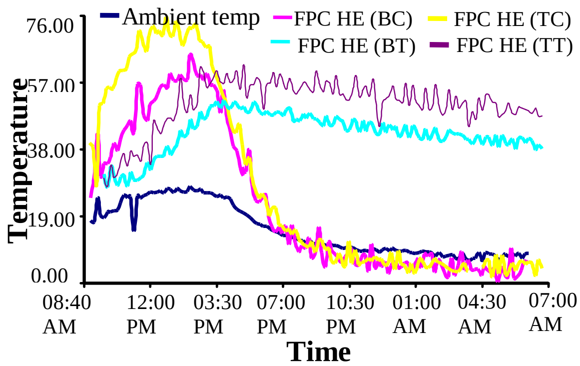
Fig. 1 (a-l) Time variations of various temperatures in the system and the variation of the incident solar radiation of flat plate collector without heat exchanger



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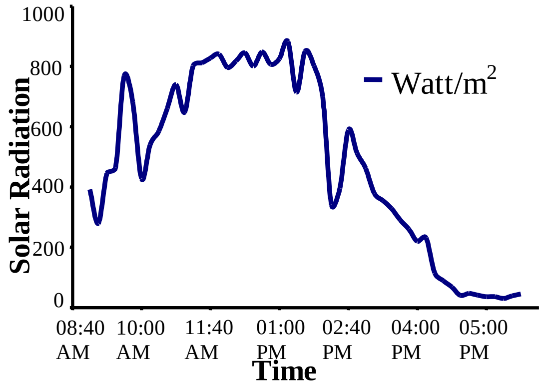

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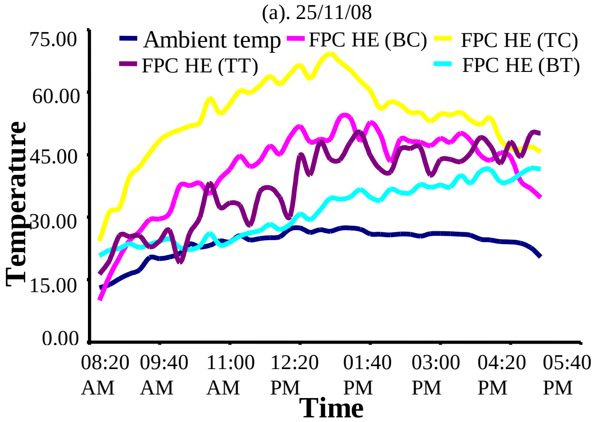

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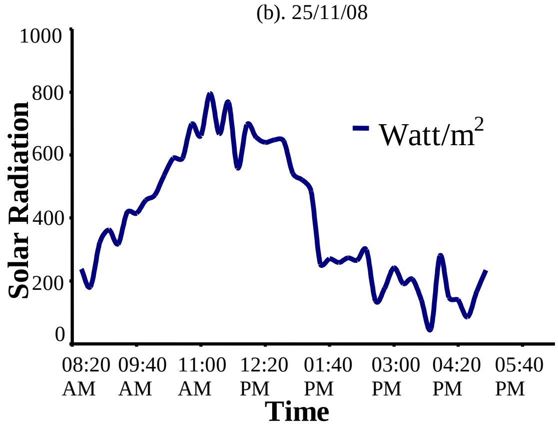

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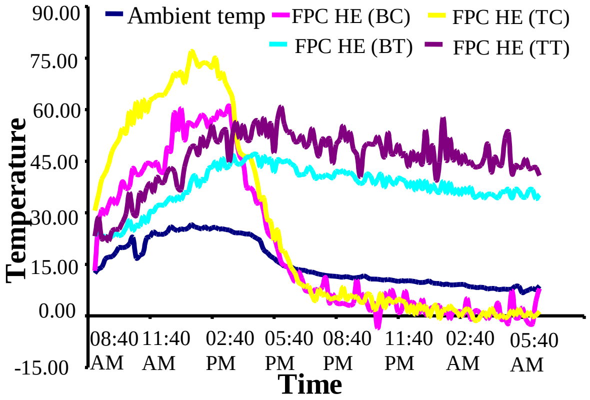

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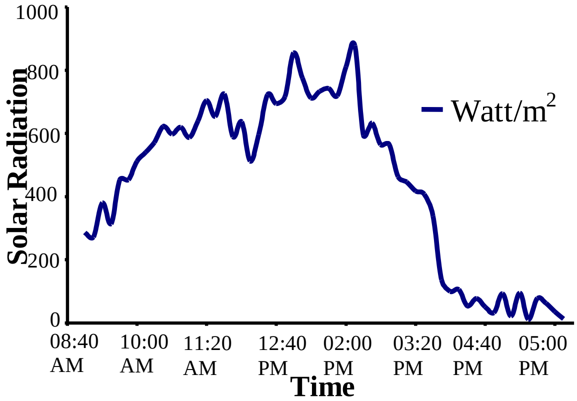

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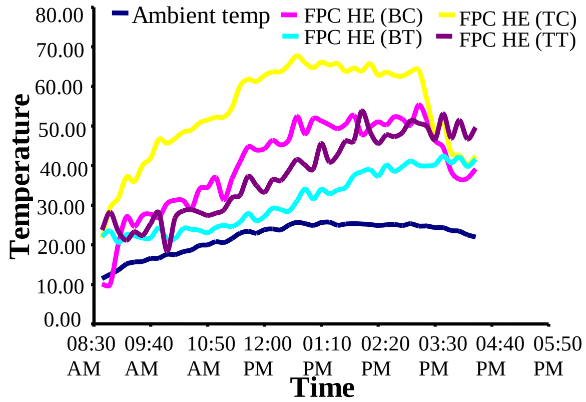

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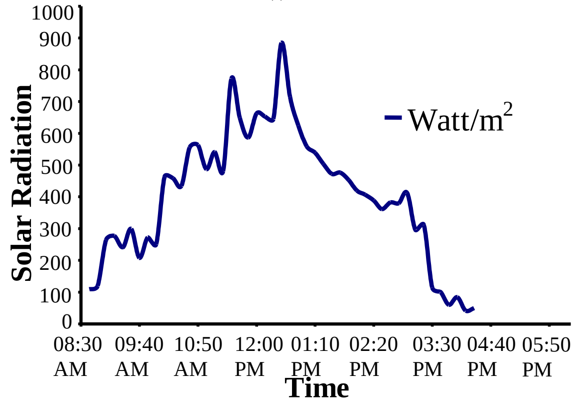

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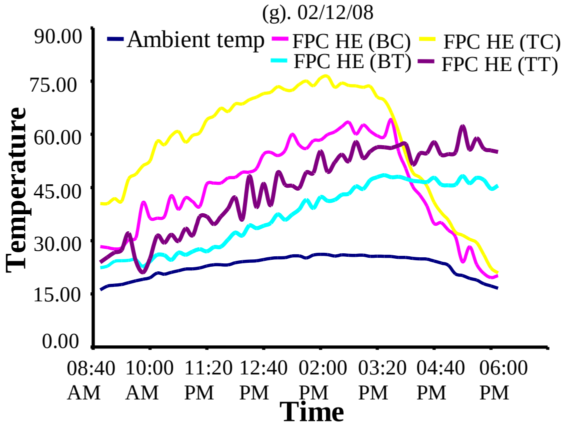

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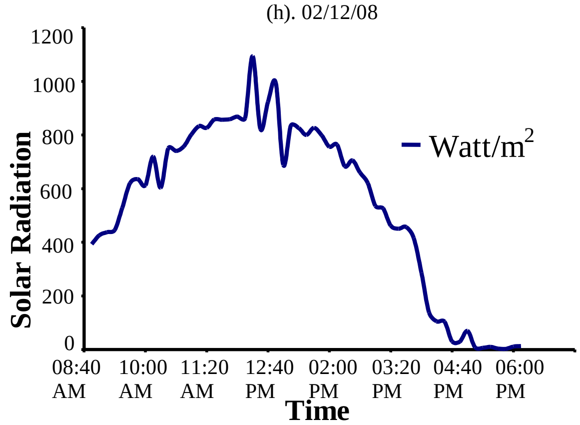

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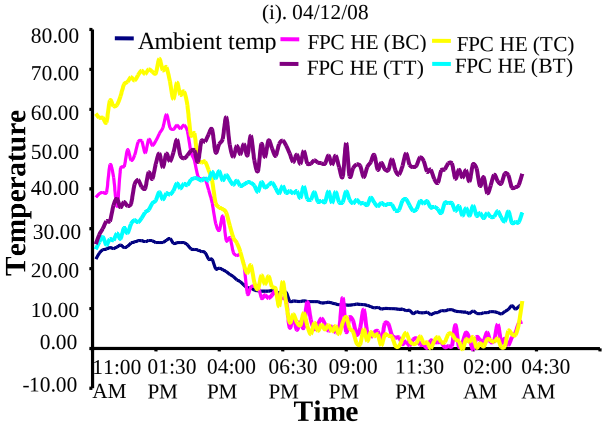

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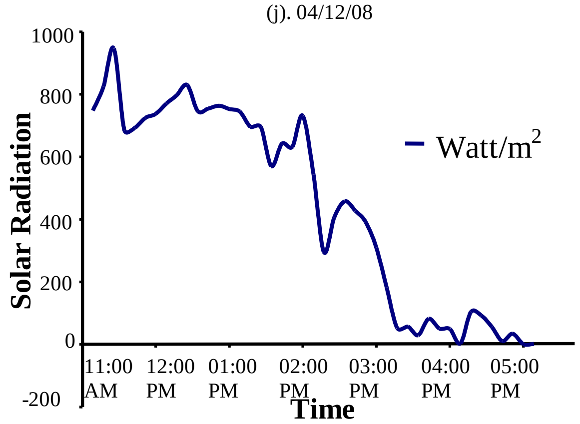

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Fig. 2 (a-l) Time variations of various temperatures in the system and the variation of the incident solar radiation of flat plate collector with heat exchanger

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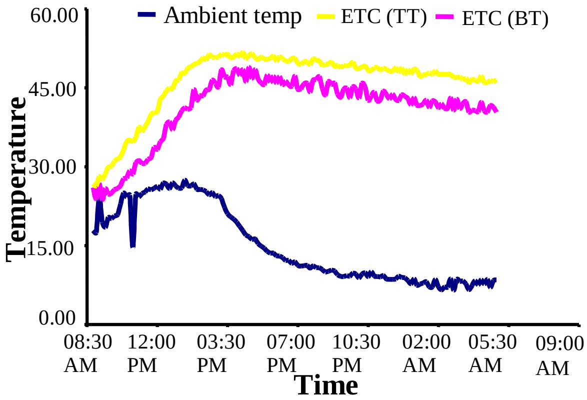

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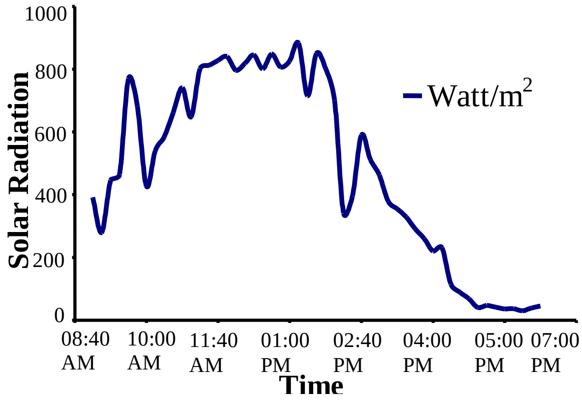

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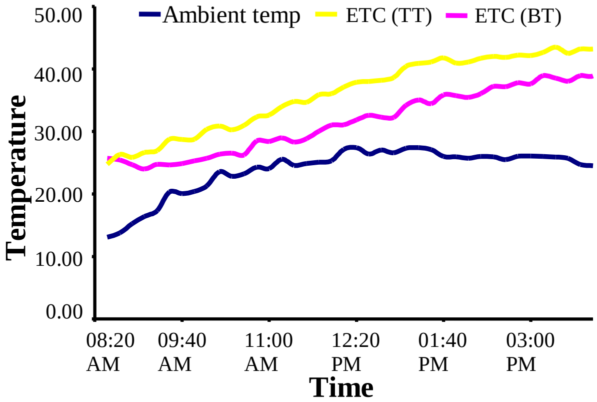

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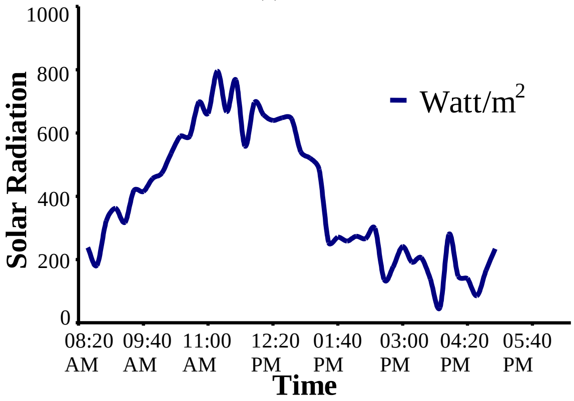

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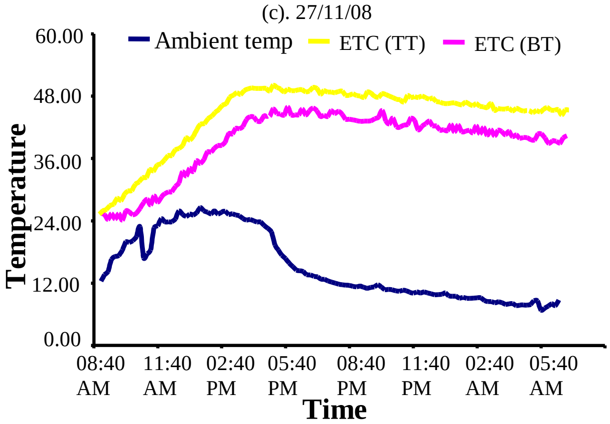

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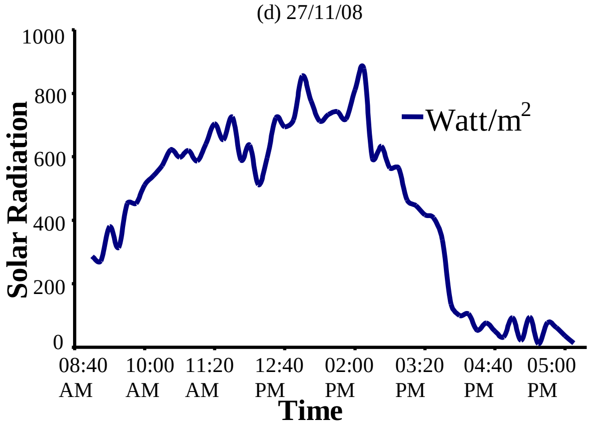

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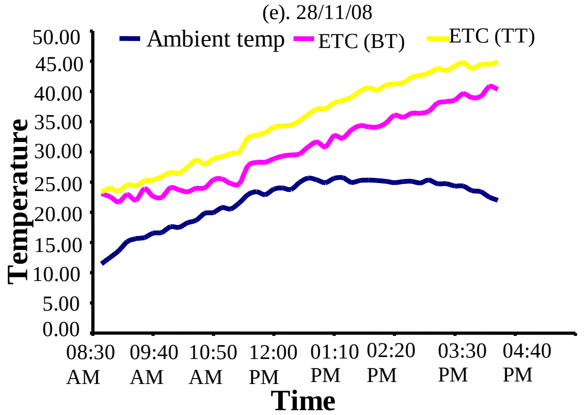

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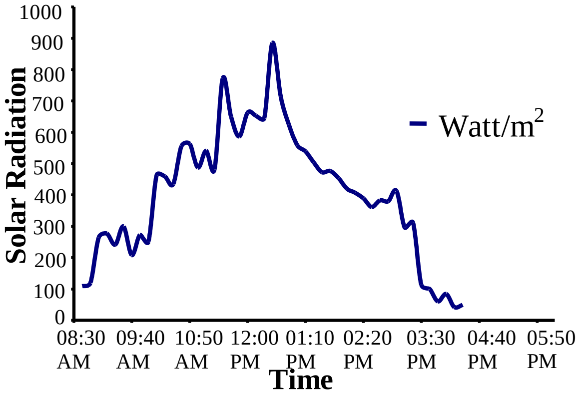

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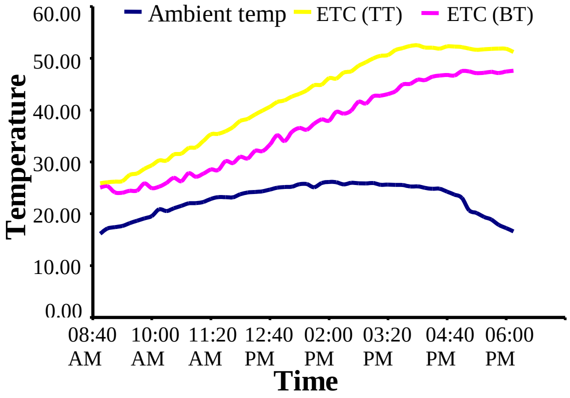

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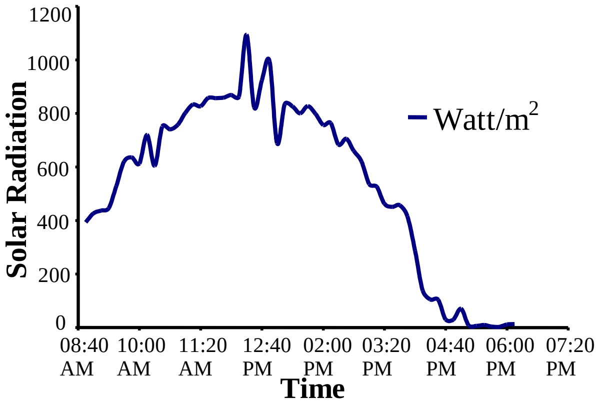

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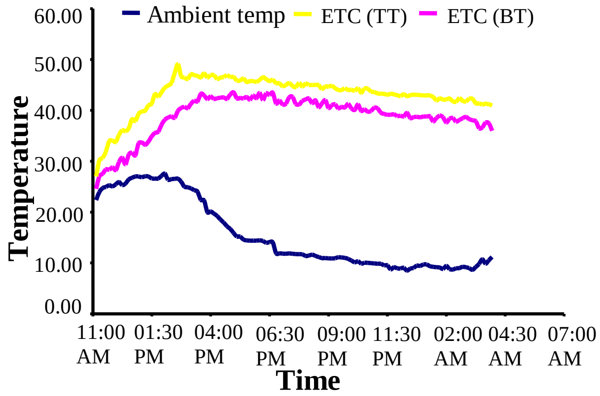

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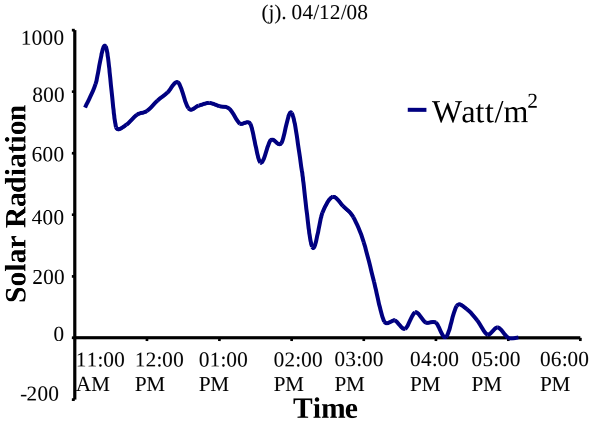

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Fig. 3 (a-l) Time variations of various temperatures in the system and the variation of the incident solar radiations of evacuated tube collector

III. PERFORMANCE ANALYSIS OF FLAT PLATE COLLECTOR WITHOUT HEAT EXCHANGER

Calculations for Thermal efficiency of the system for 24 hours (with night losses): For 25th to 26th November 2008:

Capacity of the tank = 100 Liter (ltr)
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:
From the Overhead Tank = 23.0°C
From the Overflow Tube = 24.0°C
Average (T_c) = (23.0+24.0)/2 = 23.5°C
Hot Water taken out on 26th Nov. 2008 at 7:30 AM
Temperature at 1st Bucket = 61°C
Temperature at 2nd Bucket = 62°C
Temperature at 3rd Bucket = 63°C
Average (T_h) = (61+62+63)/3 = 62°C
Net Delivered Useful Energy= Q_{use}

$Q_{use} = \{M\,C_p\,(T_h\text{-}T_c)\}/3.6\times10^6$ kWh
$= \{100\times4180\times(62\text{-}23.5)\}/3.6\times10^6 = 4.47$ KWh

Total Solar Radiation over the Test Period
$G_{total} = 4.394$ KWh/m^2

Efficiency $\eta = Q_{use}/(A_c\times G_{total}) = 4.47/(2.07\times4.394)$
$= 49.17$ %

where C_p is the heat capacitance of water, M is the amount of water, T_h is the average hot water, T_c is the average cold water and A_c is collector area.

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 27th November 2008:

Filling of the Cold Water at 8:22 AM
Cold Water Temperature:

From the Overhead Tank = 23°C
From the Overflow Tube = 24°C
Average = (29.2+30.2)/2 = 23.5°C
Recording of the Hot Water Temperature at 4:24 PM
Temperature of Top of Tank = 41.37
Temperature of Bottom of Tank = 40.32
Avg. Temperature of Tank = 40.845
Net Delivered Useful Energy

$Q_{use} = \{M\,C_p\,(T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times(40.845\text{-}23.5)\}/3.6\times10^6 = 2.0139$KWh

Total Solar Radiation over the Test Period
$G_{total} = 3.068$ KWh/m^2

Efficiency $\eta = Q_{use}/(A_c\times G_{total}) = 2.0139/(2.07\times3.068)$
$= 31.7$ %

Calculations for Thermal efficiency of the system for 24 hours (with night losses): For 28th to 29th November 2008:

Capacity of the tank = 100 ltr
Filling of the Cold Water at 8:37 AM
Cold Water Temperature:
From the Overhead Tank = 23.0°C
From the Overflow Tube = 24.0°C
Average = (23.0+24.0)/2 = 23.5°C
Hot Water taken out on 29th Nov. 2008 At 7:16 AM
Temperature at 1st Bucket = 62°C
Temperature at 2nd Bucket = 64°C
Temperature at 3rd Bucket = 66°C
Average = (62+64+66)/3 = 64°C
Net Delivered Useful Energy

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$Q_{use} = \{M\ C_p\ (T_h - T_c)\}/3.6\times10^6$
$= \{100\times4180\times (64-23.5)\}/3.6\times10^6 = 4.70$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 4.276$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 4.70 / (2.07\times4.276)$
$= 53.10$ %

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 30th November 2008:
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:
From the Overhead Tank = 23°C
From the Overflow Tube = 24°C
Average = (29.2+30.2)/2 = 23.5°C
Recording of the Hot Water Temperature at 4:00 PM
Temperature of Top of Tank = 56.42
Temperature of Bottom of Tank = 21.38
Avg. Temperature of Tank = 38.9
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h - T_c)\}/3.6\times10^6$
$= \{100\times4180\times (38.9-23.5)\}/3.6\times10^6 = 1.788$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 2.728$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 1.788 / (2.07\times2.728)$
$= 31.66$ %

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 2nd December 2008:
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:
From the Overhead Tank = 23°C
From the Overflow Tube = 24°C
Average = (29.2+30.2)/2 = 23.5°C
Recording of the Hot Water Temperature at 4:00 PM
Temperature of Top of Tank = 63.41
Temperature of Bottom of Tank = 24.31
Avg. Temperature of Tank = 43.86
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h - T_c)\}/3.6\times10^6$
$= \{100\times4180\times (43.86-23.5)\}/3.6\times10^6 = 2.364$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 3.347$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 2.364 / (2.07\times3.347)$
$= 34.12$%

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 4Th December 2008:
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:
From the Overhead Tank = 23°C
From the Overflow Tube = 24°C
Average = (29.2+30.2)/2 = 23.5°C
Recording of the Hot Water Temperature at 6:00 PM
Temperature of Top of Tank = 67.69
Temperature of Bottom of Tank = 45.31
Avg. Temperature of Tank = 56.5
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h - T_c)\}/3.6\times10^6$
$= \{100\times4180\times (56.5-23.5)\}/3.6\times10^6 = 3.83$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 5.122$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 3.83 / (2.07\times5.122)$
$= 36.13$%

Calculations for Thermal efficiency of the system for 24 hours (with night losses): For 5th to 6th December 2008:
Capacity of the tank = 100 ltr
Filling of the Cold Water at 11:00 AM
Cold Water Temperature:
From the Overhead Tank = 23.0°C
From the Overflow Tube = 24.0°C
Average = (23.0+24.0)/2 = 23.5°C
Hot Water taken out on 6th Dec. 2008: At 8:00 AM
Temperature at 1st Bucket = 53°C
Temperature at 2nd Bucket = 54°C
Temperature at 3rd Bucket = 55°C
Average = (53+54+55)/3 = 54°C
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h - T_c)\}/3.6\times10^6$
$= \{100\times4180\times (54-23.5)\}/3.6\times10^6 = 3.54$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 3.124$ KWh
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 3.54 / (2.07\times3.124)$
$= 54.74$ %

IV. PERFORMANCE ANALYSIS OF FLAT PLATE COLLECTOR WITH HEAT EXCHANGER

Calculations for Thermal efficiency of the system for 24 hours (with night losses): For 25th to 26th November 2008:
Capacity of the tank = 100 ltr
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:
From the Overhead Tank = 23.0°C
From the Overflow Tube = 24.0°C
Average = (23.0+24.0)/2 = 23.5°C
Hot Water taken out on 26th Nov. 2008 at 7:30 AM
Temperature at 1st Bucket = 44°C
Temperature at 2nd Bucket = 45.5°C
Temperature at 3rd Bucket = 46.5°C
Average = (44+45.5+46.5)/3 = 45.33°C
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h - T_c)\}/3.6\times10^6$
$= \{100\times4180\times (45.33-23.5)\}/3.6\times10^6 = 2.534$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 4.39$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 2.534 / (1.836\times4.39)$
$= 31.43$ %

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 27th November 2008:
Filling of the Cold Water at 8:22 AM
Cold Water Temperature:
From the Overhead Tank = 23°C
From the Overflow Tube = 24°C
Average = (29.2+30.2)/2 = 23.5°C
Recording of the Hot Water Temperature: At 4:24 PM

Temperature of Top of Tank = 50.15
Temperature of Bottom of Tank = 41.54
Avg. Temperature of Tank = 45.845
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (45.845\text{-}23.5)\}/3.6\times10^6 = 2.59$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 4.394$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 2.59 / (1.836\times4.394)$
$= 32.10$ %

Calculations for Thermal efficiency of the system for 24 hours (with night losses): For 28th to 29th November 2008:
Capacity of the tank = 100 ltr
Filling of the Cold Water at 8:37 AM
Cold Water Temperature:
From the Overhead Tank = 23.0^{o}C
From the Overflow Tube = 24.0^{o}C
Average = (23.0+24.0)/2 = 23.5^{o}C
Hot Water taken out on 29th Nov. 2008: At 7:16 AM
Temperature at 1st Bucket = 40^{o}C
Temperature at 2nd Bucket = 41^{o}C
Temperature at 3rd Bucket = 42^{o}C
Average = (40+41+42)/3 = 41^{o}C
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (41\text{-}23.5)\}/3.6\times10^6 = 2.03$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 4.276$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 2.03 / (1.836\times4.276)$
$= 25.85$ %

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 30th November 2008
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:
From the Overhead Tank = 23^{o}C
From the Overflow Tube = 24^{o}C
Average = (29.2+30.2)/2 = 23.5^{o}C
Recording of the Hot Water Temperature: At 4:00 PM
Temperature of Top of Tank = 46.55
Temperature of Bottom of Tank = 39.14
Avg. Temperature of Tank = 42.845
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (42.845\text{-}23.5)\}/3.6\times10^6 = 2.246$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 2.728$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c\times G_{total}) = 2.246/ (1.836\times2.728)$
$= 44.84$ %

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 2nd December 2008:
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:
From the Overhead Tank = 23^{o}C
From the Overflow Tube = 24^{o}C
Average = (29.2+30.2)/2 = 23.5^{o}C
Recording of the Hot Water Temperature: At 4:00 PM
Temperature of Top of Tank = 49.64
Temperature of Bottom of Tank = 41.57
Avg. Temperature of Tank = 45.60
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (45.60\text{-}23.5)\}/3.6\times10^6 = 2.566$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 3.347$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c\times G_{total}) = 2.566 / (1.836\times3.347)$
$= 41.75$%

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 4Th December 2008:
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:
From the Overhead Tank = 23^{o}C
From the Overflow Tube = 24^{o}C
Average = (29.2+30.2)/2 = 23.5^{o}C
Recording of the Hot Water Temperature: at 6:00 PM
Temperature of Top of Tank = 54.97
Temperature of Bottom of Tank = 45.47
Avg. Temperature of Tank = 50.22
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (50.22\text{-}23.5)\}/3.6\times10^6 = 3.102$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 5.122$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c\times G_{total}) = 3.102 / (1.836\times5.122)$
$= 32.98$%

Calculations for Thermal efficiency of the system for 24 hours (with night losses): For 5th to 6th December 2008:
Capacity of the tank = 100 ltr
Filling of the Cold Water at 11:00 AM
Cold Water Temperature:
From the Overhead Tank = 23.0^{o}C
From the Overflow Tube = 24.0^{o}C
Average = (23.0+24.0)/2 = 23.5^{o}C
Hot Water taken out on 6th Dec. 2008: At 8:00 AM
Temperature at 1st Bucket = 41^{o}C
Temperature at 2nd Bucket = 42^{o}C
Temperature at 3rd Bucket = 43^{o}C
Average = (41+42+43)/3 = 42^{o}C
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (42\text{-}23.5)\}/3.6\times10^6 = 2.148$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 3.124$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 2.148 / (1.836\times3.124)$
$= 37.45$ %

V. PERFORMANCE ANALYSIS OF EVACUATED TUBE COLLECTOR

Calculations for Thermal efficiency of the system for 24 hours (with night losses): For 25th to 26th November 2008:
Capacity of the tank = 100 ltr
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:

From the Overhead Tank = 23.0°C
From the Overflow Tube = 24.0°C
Average = (23.0+24.0)/2 = 23.5°C
Hot Water taken out on 26th Nov. 2008: At 7:30 AM
Temperature at 1st Bucket = 45°C
Temperature at 2nd Bucket = 45.5°C
Temperature at 3rd Bucket = 46.5°C
Average = (45+45.5+46.5)/3 = 45.5°C
Net Delivered Useful Energy
$Q_{use} = \{M\, C_p\, (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (45.5\text{-}23.5)\}/3.6\times10^6 = 2.554$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 4.394$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 2.554\ (1.358\times4.394) = 42.80$ %

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 27th November 2008:
Filling of the Cold Water at 8:22 AM
Cold Water Temperature:
From the Overhead Tank = 23°C
From the Overflow Tube = 24°C
Average = (29.2+30.2)/2 = 23.5°C
Recording of the Hot Water Temperature: at 4:24 PM
Temperature of Top of Tank = 40.78
Temperature of Bottom of Tank = 39.44
Avg. Temperature of Tank = 40.11
Net Delivered Useful Energy
$Q_{use} = \{M\, C_p\, (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (40.11\text{-}23.5)\}/3.6\times10^6 = 1.9286$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 3.068$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c\times G_{total}) = 1.9286/ (1.358\times3.068) = 46.29$ %

Calculations for Thermal efficiency of the system for 24 hours (with night losses): For 28th to 29th November 2008:
Capacity of the tank = 100 ltr
Filling of the Cold Water at 8:37 AM
Cold Water Temperature:
From the Overhead Tank = 23.0°C
From the Overflow Tube = 24.0°C
Average = (23.0+24.0)/2 = 23.5°C
Hot Water taken out on 29th Nov. 2008: At 7:16 AM
Temperature at 1st Bucket = 43°C
Temperature at 2nd Bucket = 44°C
Temperature at 3rd Bucket = 45°C
Average = (43+44+45)/3 = 44°C
Net Delivered Useful Energy
$Q_{use} = \{M\, C_p\, (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (44\text{-}23.5)\}/3.6\times10^6 = 2.38$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 4.276$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 2.38 / (1.358\times4.276) = 40.99$ %

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 30th November 2008:
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:
From the Overhead Tank = 23°C
From the Overflow Tube = 24°C
Average = (29.2+30.2)/2 = 23.5°C
Recording of the Hot Water Temperature: at 4:00 PM
Temperature of Top of Tank = 44.07
Temperature of Bottom of Tank = 40.07
Avg. Temperature of Tank = 42.07
Net Delivered Useful Energy
$Q_{use} = \{M\, C_p\, (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (42.07\text{-}23.5)\}/3.6\times10^6 = 2.156$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 2.728$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c\times G_{total}) = 2.156 / (1.358\times2.728) = 58.20$ %

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 2nd December 2008:
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:
From the Overhead Tank = 23°C
From the Overflow Tube = 24°C
Average = (29.2+30.2)/2 = 23.5°C
Recording of the Hot Water Temperature: at 4:00 PM
Temperature of Top of Tank = 44.89
Temperature of Bottom of Tank = 40.36
Avg. Temperature of Tank = 42.62
Net Delivered Useful Energy
$Q_{use} = \{M\, C_p\, (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (42.62\text{-}23.5)\}/3.6\times10^6 = 2.22$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 3.347$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 2.22 / (1.358\times3.347) = 48.84$%

Calculations for Thermal efficiency of the system for daytime only (without night losses): On 4Th December 2008
Filling of the Cold Water at 8:40 AM
Cold Water Temperature:
From the Overhead Tank = 23°C
From the Overflow Tube = 24°C
Average = (29.2+30.2)/2 = 23.5°C
Recording of the Hot Water Temperature: at 6:00 PM
Temperature of Top of Tank = 51.22
Temperature of Bottom of Tank = 47.60
Avg. Temperature of Tank = 49.41
Net Delivered Useful Energy
$Q_{use} = \{M\, C_p\, (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (49.41\text{-}23.5)\}/3.6\times10^6 = 3.008$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 5.122$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c\times G_{total}) = 3.008 / (1.358\times5.122) = 43.24$%

Calculations for Thermal efficiency of the system for 24 hours (with night losses): For 5th to 6th December 2008:
Capacity of the tank = 100 ltr

Filling of the Cold Water at 11:00 AM
Cold Water Temperature:
From the Overhead Tank = 23.0^{o}C
From the Overflow Tube = 24.0^{o}C
Average = (23.0+24.0)/2 = 23.5^{o}C
Hot Water taken out on 6th Dec. 2008: At 8:00 AM
Temperature at 1st Bucket = 40^{o}C
Temperature at 2nd Bucket = 41^{o}C
Temperature at 3rd Bucket = 42^{o}C
Average = (40+41+42)/3 = 41^{o}C
Net Delivered Useful Energy
$Q_{use} = \{M\ C_p\ (T_h\text{-}T_c)\}/3.6\times10^6$
$= \{100\times4180\times (41\text{-}23.5)\}/3.6\times10^6 = 2.031$ KWh
Total Solar Radiation over the Test Period
$G_{total} = 3.124$ KWh/m^2
Efficiency $\eta = Q_{use} / (A_c \times G_{total}) = 2.031 / (1.358\times3.124)$
$= 47.87$ %

VI. CONCLUSION

The Comparative Experimental Study Shows that Thermosyphon system gives the higher average temperature of water in the tank and lower heat loss of the tank. The experimental study that we have performed on the three systems for 20 days shows that the avg. efficiency of the FPC system without heat exchanger is 40%, similarly the avg. efficiency of the FPC system with heat exchanger is 48% and the avg. efficiency of the ETC system is 51 %.

On the above basis the ETC system is better to install in households for domestic purposes. Economic comparison shows that thermosyphon system can compete with warm water system, The reason for this being the fact that for conventional system, though cheaper in investment than solar system, the total demand of capital inclusive of interest for fuel and electricity over the life time plays the dominant role.

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