ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

*An ISO 3297: 2007 Certified Organization, Volume 2, Special Issue 1, December 2013*

**Proceedings of International Conference on Energy and Environment-2013 (ICEE 2013)**

**On 12th to 14th December Organized by**

**Department of Civil Engineering and Mechanical Engineering of Rajiv Gandhi Institute of Technology, Kottayam, Kerala, India**

# GREEN HOUSE SAVING POTENTIAL OF A PHOTOVOLTAIC THERMAL HYBRID SOLAR SYSTEM FOR RESIDENTIAL APPLICATIONS

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## ABSTRACT

Global warming is a problem in which the combustion of coal, oil and other fossil fuels causes the atmospheric concentrations of GHGs such as carbon dioxide to increase. Solar energy is one of the most promising renewable sources of energy for present needs. Solar Photovoltaic Thermal (PVT) system is a hybrid system to produce both thermal and electrical energy. This paper presents the $CO_2$ savings potential of a hybrid system of 4 $m^2$ PV module area to produce about 3 kWh per day electrical energy and a flat plate solar collector of 2 $m^2$ area to deliver about 100 LPD of hot water at about 80°C. In this paper the yearly $CO_2$ saving potential of different systems used for residential applications are calculated and analysed. The $CO_2$ annual saving potential is found to vary from 0.4 to 2.7 ton.

**Keywords**: Flat plate collector, Green house gases, Hybrid, Photovoltaic, Solar water heater

## NOMENCLATURE

a area ($m^2$)
c specific heat of collector fluid (J/kg K)
$F'$ collector efficiency factor
$F_R$ collector heat removal factor
G solar insolation ($W/m^2$)
S solar flux on a tilted surface
h heat transfer coefficient ($W/m^2$ K)
K thermal conductivity (W/m K
L the length of PVT water collector,

thickness (m)

$\dot{m}$ mass flow rate of air (kg/s)

p penalty factor

## 1. INTRODUCTION

. Energy is an essential factor for human life. Every energy generation and transmission method affects the environment. About 90% of the world energy supplies are provided by fossil fuels, with the associated emissions causing local, regional, and global environmental problems. In the context of greenhouse gas emissions and fossil and fissile resources depletion, solar energy is one of the most promising sources of power. Energy crisis and $CO_2$ pollutions are the major threat facing the mankind today. In developing countries, residential energy use plays a dominant role in energy-related sustainability issues.

The major component of any solar system is the solar collector, which absorbs the incoming solar radiation into heat and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The production of hot water using solar water heater represents one of the most important applications of the solar energy. There are lots of initiatives taken by different countries and organizations like United Nations Framework Convention on Climate Change (UNFCCC), United Nations Environment Programme (UNEP) and Intergovernmental Panel on Climate Change (IPCC), in mitigating and adapting to the global climate change. Vijay Venkata Raman et al.[1] reviewed on climate change, mitigation and adaptation and reported that the most important mitigation measures include carbon sequestration (maintenance of optimum $CO_2$ level in the atmosphere); clean development mechanism, joint implementation and most importantly use of renewable and non-polluting sources of energy like solar, wind and geothermal energy sources.

Raghuvanshi et al. [2] reported that combustion of coal is currently responsible for over 60% of the enhanced greenhouse effect. Mathews [3] highlighted that world needs to reduce global carbon dioxide emissions by 70% by 2050 and is explained seven steps to curb global warming. Chel et al. [4] calculated the carbon credit potential of PV system on the basis of total amount of $CO_2$ emissions from life time of the system. Recently many studies are going on the building integrated photovoltaic (BIPV) on the rooftops suitable for solar panels and could jointly generate enough energy to meet building's demand for electricity at peak periods and also reduce the GHG emissions Zhang et al. [5].

Energy is important not only for the economic growth of the country but also to meet the increased demand due to the population growth. The urban development is one of the major factors for increased usage of energy in any society. Renewable energies are going to be main substitute for fossil fuels in the coming years for their clean quality. The global needs for energy savings require the usage of renewable sources in many applications. PVT systems in residential applications can contribute to the reduction of energy consumption for heating, cooling and the same time minimizing the total surface area of the system. It works on noiseless environment and do not produce any unwanted waste like radioactive materials. Low maintenance cost with life span of 20-30 years is the attractive features for the house-hold applications. The use of conventional electrical energy can be avoided if combination of both types of thermal collector and photovoltaic collector is hybrid in one unit named hybrid collector or photovoltaic-thermal collector (PVT).

From the literature review, it is apparent that use of renewable source of energy is a good option for reducing the GHG emissions.

## 2.METHODOLOGY

Both thermal and electrical energy are required for the residential applications. A typical simple house requires about 2 to 4 kWh of electrical energy per day. A PV system of about 4 m2 module area can produce about 3 kWh per day. A flat plate solar collector of 2 m2 area can deliver about 100 LPD of hot water at about 80oC. A combination of PVT system of 4 square meter area and Solar Flat plate collector of 2 square meter area, arranged as shown in Fig.1 can meet the thermal and electrical requirements of a typical house. For this analysis, a PVT module in combination with water heat extraction units made from copper sheet and pipes is taken for analysis. The module is also assumed to have glazing covers of 4 mm thickness to achieve satisfactory thermal output. The three major parameters for coal fire quantification are the amount of coal burning [tons of coal], the amount of energy released [mega-watts], and the amount of GHGs emitted [tons of $CO_2$].$CO_2$ emission per unit energy production from coal plants is highest among all fuels. $CO_2$ emission from combustion of coal depends on the quantity of coal consumed, the average carbon content of the coal, a small percentage of unoxidised carbon and heating value of the coal. It is important to point out that the amount of carbon emitted by the thermoelectric power plants depends on the type of fuel used and on the combustion effiency of the fuel, being that 1 kg of carbon leads to the release of 3.67 kg of $CO_2$. India will be adding over 220,000 MW of coal and Natural Gas based thermal power generation capacity from 2010 to 2030.

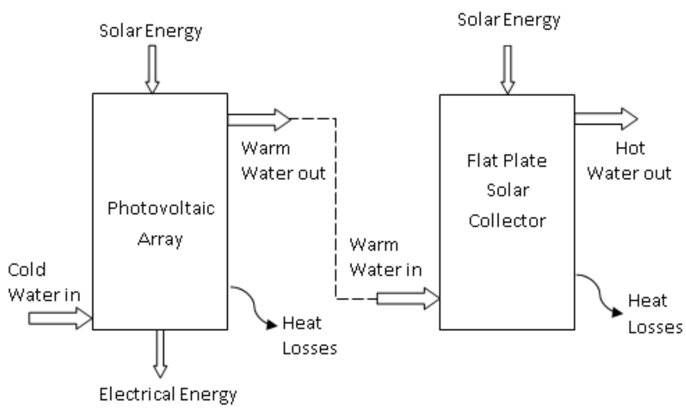


FIG.1. SCHEMATIC DIAGRAM OF PVT AND FPC CONNECTED IN SERIES

Specific carbon emission in thermoelectric power plants, the data of Table I was used. Parameters used for calculating the $CO_2$ emission listed in Table II.

TABLE 1. EMISSION OF CARBON FOR SEVERAL THERMOELECTRIC POWER PLANTS

| Technology | Specific emission(kg carbon / MWh) |
|---|---|
| Coal –Vapour Cycle (CVC) | 360 |
| Fuel Oil – Vapour Cycle (FOVC) | 238 |
| Natural Gas-Combined Cycle (NGCC) | 110 |

TABLE 2. EMISSION PARAMETERS USEDFOR CALCULATING THE $CO_2$ EMISSION

| Items | Particulars |
|---|---|
| Coal Based Power Plants to produce electrical energy: | |
| Mass percentage of carbon in fuel | 40 kg |
| Heating value of coal | 16 MJ/kg |
| Overall efficiency of the plant | 30 % |
| LPG Gas Stove to produce hot water: | |
| Heating value of coal | 44 MJ/kg |
| Gas Stove efficiency | 60 % |
| Electrical Geyser to produce hot water: | |
| Specific heat of water | |
| Geyser efficiency | 4.2 kJ/kg K |
| Electrical transmission efficiency | 90 % |
| Power plant efficiency | 80 % |
| It is also assumed that the water is heated from 30°C to 80°C. | 30 % |

Source: Taborianski and Prado[6]

## 2. HYBRID PVT WATER COLLECTOR

In a combined system as shown in Fig.1, an expression for water outlet temperature from the absorber of PVT module can be calculated with the boundary condition [Tf]x=0,Tf=Tfi and at [Tf]x=L, Tf = $T_{f'}$

$$T_{f'} = \left(T_a + (p_1 p_2 (\alpha\tau)_{pvt} G/U_{L1})\right)\left(1\text{-}\exp\left(\text{-}F'A_{pvt} U_{L1}/\dot{m}c_w\right)\right) + T_{fi}\left(\exp\left(\text{-}F'A_{pvt}U_{L1}/\dot{m}c_w\right)\right) \quad 1$$

The rate of useful thermal energy from PVT collector is given as,

$$\dot{Q}_{u_1} = \dot{m}c_w(T_{f'} - T_{fi}) = A_{pvt}F_{R_1}\left(p_1p_2(\alpha\tau)_{pvt}\right)G - U_{L1}\left(T_{fi} - T_a\right) \quad 2$$

Similarly, an expression of outlet water temperature at the end of flat plate collector can be written as a function of the inlet water temperature $T_{f'}$.

$$T_{fo} = \left(T_a + (\alpha\tau)_{fpc}G/U_{L2}\right)\left(1\text{-}\exp\left(\text{-}F'A_{fpc}U_{L2}/\dot{m}c_w\right)\right) + T_{f'}\exp\left(\text{-}F'A_{fpc}U_{L2}/\dot{m}c_w\right) \quad 3$$

The rate of useful thermal energy obtained from FPC system is given as

$$\dot{Q}_{u2} = \dot{m}c_w(T_{fo} - T_{f'}) = A_{fpc}F_{R_2}(\alpha\tau)_{fpc}G - U_{L2}\left(T_{f'} - T_a\right) \quad 4$$

The useful heat output of the combination of PVT and FPC is,

$$\dot{Q}_u = \dot{Q}_{u1} + \dot{Q}_{u2}$$

$$= \left[ A_{pvt} F_{R_1} \left( p_1 p_2 (\alpha\tau)_{pvt} \right) \left( 1 - \frac{A_{fpc} F_{R_2} U_{L2}}{\dot{m} c_w} \right) + A_{fpc} F_{R_2} (\alpha\tau)_{fpc} \right] G$$

$$- \left[ A_{pvt} F_{R_1} U_{L1} \left( 1 - \frac{A_{fpc} F_{R_2} U_{L2}}{\dot{m} c_w} \right) + A_{fpc} F_{R_2} U_{L2} \right] \left( T_{fi} - T_a \right) \quad 5$$

An instantaneous thermal efficiency can be obtained from the above equation as,

$$\eta_{thermal} = (\alpha\tau)_{overall} - (UA)_{overall} \frac{(T_{fi} - T_a)}{G} \quad 6$$

Here,

$$(\alpha\tau)_{overall} = \left[ A_{pvt} F_{R_1} \left( p_1 p_2 (\alpha\tau)_{pvt} \right) C + A_{fpc} F_{R_2} (\alpha\tau)_{fpc} \right] \Big/ A_{pvt} + A_{fpc};$$

$$(UA)_{overall} = \left[ A_{pvt} F_{R_1} U_{L_1} C + A_{fpc} F_{R_2} U_{L_2} \right] \Big/ A_{pvt} + A_{fpc};$$

$$C = \left( 1 - \frac{A_{fpc} F_{R_2} U_{L_2}}{\dot{m} c_w} \right)$$

An expression for temperature dependent electrical efficiency of a PV module Zondag [7] is given as

$$\eta_{electrical} = \eta_{e0} [1 - 0.0045 (T_c - T_{a0})] \quad 7$$

Temperature coefficient ($0.0045^oC^{-1}$), ηe0 is the reference efficiency of the PV module (12%) and Ta0 is the reference temperature (25°C) under standard test conditions.

Overall thermal and exergy efficiency

An expression for thermal efficiency of a system can be obtained as,

$$\eta_{thermal} = \frac{\dot{Q}_u}{A \cdot G} \text{ where } (A = A_{pvt} + A_{fpc}) \quad 8$$

For the thermal analysis, an overall thermal efficiency of the system has been calculated.

$$\eta_{overall\ thermal} = \eta_{thermal} + \frac{\eta_{electrical}}{C_f} \quad 9$$

Electrical efficiency has been converted to equivalent of thermal efficiency using electric power generation efficiency for a conventional power plant. The value of $C_f$ varies between 0.20 and 0.40. Then the overall exergy efficiency can be given as,

$$\eta_{overall\ exergy} = \eta_{electrical} + \eta_{thermal} \left[ 1 - \frac{T_a}{T_{fo}} \right] \quad 10$$

## 3. RESULTS AND DISCUSSION

The variation of solar intensity and ambient temperature for a typical day in the month of May in Chennai is shown in Fig.2. The reading has been taken from the weather station installed at Anna university campus.

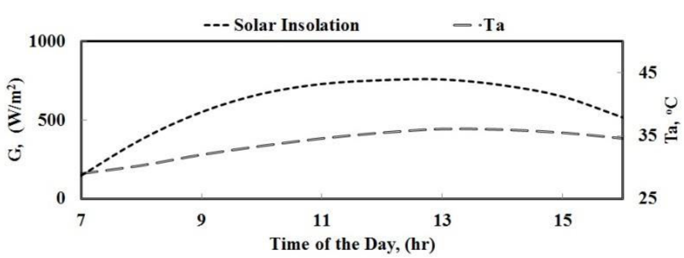


FIG. 2. HOURLY VARIATIONS OF SOLAR INSOLATION AND AMBIENT TEMPERATURE.

The variation of cell temperature and electrical efficiency is shown in Fig.3, where it is seen that the solar cell temperature increases with solar intensity and it clearly shows that the increase in cell temperature decreases the electrical efficiency. Also during the local time of 11.00 hr -15.00 hr the variation of electrical efficiency is significant because of the cell temperature variation. The average solar cell temperature is 47oC, while its maximum temperature is about 55oC. The electrical efficiency is found to vary from 10.4 to 11.6 %, efficiency being low at high temperature.

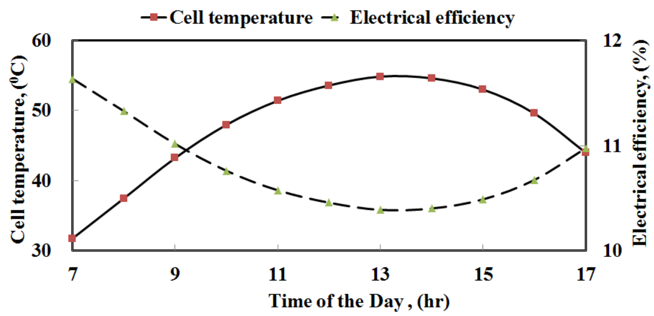


FIG. 3. HOURLY VARIATIONS OF CELL TEMPERATURE AND CELL EFFICIENCY

Scientists project that excessive $CO_2$ emissions into the atmosphere will increase the earth's surface temperature approximately 1.5 – 4oC in the next 30–40 years. India is the world's fourth largest economy and has a fast growing energy market. India's current power capacity is 30% short of demand. Coal and petroleum are the primary sources of energy. The share of $CO_2$ in warming is expected to rise from slightly more than half today to around 3/4th by 2100 and further stated that the average global surface temperature would be raised more during the 20th century than during any other century in the last 1000 years. High ash content in Indian coal and inefficient combustion technologies contribute to India's emission of air particulate matter and other trace gases are responsible for the greenhouse effect.

The processes of construction and operation of the buildings were responsible for one-third of the total consumption of energy in 1992, 26% of this amount was due to fossil fuel burn. In this context, the study of the environmental impact of the water heating systems is essential, since they are one of the activities that account for most energy consumption in buildings.

For every ton of fossil fuels burned, at least three quarters of a tone of carbon is released as $CO_2$. It has been found that 0.8–0.9 kg/kWh $CO_2$ is emitted in Indian power plants. $CO_2$ saving potential is calculated for different residential water heating systems such as LPG, geyser, flat plate collector and PVT hybrid systems. A PVT hybrid system to produce 4 kWh of electricity and 100 LPD of hot water at 80$^o$C is compared with various options and the results are plotted in Fig 4.

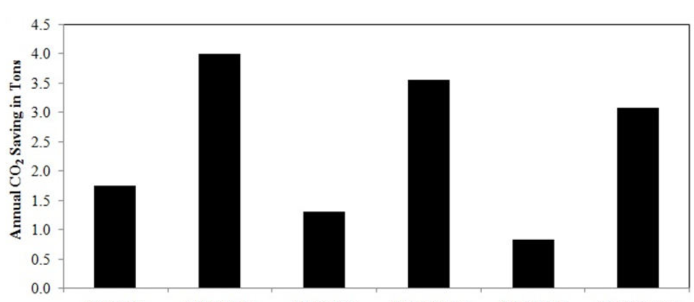


FIG 4. ANNUAL $CO_2$ SAVINGS POTENTIAL OF PVT SYSTEM IN COMPARISON WITH VARIOUS OPTIONS

The $CO_2$ saving potential is found varies from 0.85 to 4 Ton per year. The saving is the highest for coal vapour cycle (CVC) and geyser combination, since both have low overall efficiency. The same is low for natural gas combined cycle (NGCC) and LPG gas stove option. The fuel oil vapour cycle (FOVC) has intermediate savings in the rage of 1.3 to 3.6 ton per year.

4. CONCLUSION

The combined system of photovoltaic thermal (PVT) solar water heater presented in this study is a self-sustainable system, suitable for standalone applications. This system can be installed at remote areas for fulfillment of hot water requirements and the electrical energy produced by this system can be utilized for other purposes. Moreover it works noiselessly, with no toxic residues or unwanted waste such as radioactive materials. It has high reliability with expected life span of 20 and 30 years and very low maintenance cost. The $CO_2$ saving can lead to sustainable development and the energy payback period obtained from the present system analysis is about 4 - 6 years depending on the unit cost of electricity and it can be easily integrated with the buildings to make it self-sustainable and such system can be a preferable option for achieving goals of green buildings.

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