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AN OVERALL ENERGY AND EXERGY ANALYSIS OF COPPER/ALUMINIUM (CU/AL) BASE PHOTOVOLTAIC THERMAL (PVT) COLLECTOR

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Abstract— **In this paper, an electrical performance of glass, tedlar (Te), copper/aluminium (Cu/Al) base PV module have been analyzed. On the basis of its electrical performance, it has been observed that glass base PV modules gives better performance due to low operating temperature, hence the analyses of glass base and copper/aluminium (Cu/Al) base photovoltaic thermal (PVT) collector have been done in terms of electrical efficiency. Effect of mass flow rate on the performance copper/aluminium (Cu/Al) base PVT water collector has also been studied. Based on the numerical computation, it has been found that glass and copper/aluminium (Cu/Al) base PVT gives similar performance at mass flow rate of 0.017 kg/sec. The thermal and exergy efficiency of copper/aluminium (Cu/Al) base PVT collector will be 61.05% and 13.35% considering the climatic conditions of New Delhi. The Cu/Al base PVT water collector produced 785.05kWh of thermal energy and 106.67kWh of exergy annually.**

Keywords—**Photovoltaic thermal (PVT), Copper base, Exergy, Thermal efficiency**

I. INTRODUCTION

With the growing awareness on solar energy utilization amongst users in highly populated developing nations such as India, cost effective efficient solar energy systems are needed to reduce the dependence of fossil fuel reserves. Various researches since two decades have been performed in order to achieve the higher efficiency of the solar energy system by building an efficient solar collector. The search for an efficient solar collector will give rise to photovoltaic thermal (PVT) collectors which converts the solar energy into heat and electricity.

The photovoltaic thermal system has been introduced by Wolf and the analysis has also been performed using the Hottel-Whillier model (Wolf M. (1976), Florschuetz L.W.(1979)). Generally the working fluid used to extract the thermal energy from the PVT module is water, air and Nano fluids. Many researchers have performed the thermal modelling of PVT systems using the air as the mode of operation (Bhargava et al.(1991), Tiwari A and Sodha M.S(2006), Cartmell et al.(2004), Hegazy A.A(2000), Kamthania et al.(2011)) and many have researched using water as working fluid (Tiwari A and Sodha M.S(2006), He et al. (2006), Radziemska E. (2009), Gaur A., Tiwari G.N.(2014)). The two fluids have also been reviewed by Chow T.T.(2010) and he suggested that the PVT air collector is best for the space heating and PVT water collector can be best used for pre heating services. The applications of the hybrid photovoltaic/thermal (PVT) technology is reviewed by Brahim T. and Jemni A.(2017) and he suggested that there is a need of a cost effective and energy efficient PVT systems. To build an effective PVT solar collector the material used in the absorber plays a very important role in order to increase the efficiency of the system. Various substances such as glass, fiber imposed plastic, tedlar etc. have been used by the researchers to achieve the higher efficiency. Joshi et al. (2009) have compared the performance of glass to glass and glass to tedlar PVT system and the electrical efficiency of glass to glass PVT system is reported higher than that of glass to tedlar PVT system. The glass to glass PV panel have been reported with higher overall efficiency than glass to tedlar PV panels by Sophien et al.(1996). Jaiganesh and Duraswamy (2013) analyzed the effect of ambient temperature and solar radiation on the glass to glass and glass to tedlar PV panels and the efficiency of glass to glass PV panels are reported to be higher. Glass to glass and glass to back sheet structure has also been compared using bifacial silicon solar cell and glass to glass module is recommended to be used because of its higher efficiency (Singh et al.(2015)). A sheet and tube absorber have been developed which shows the effect of number of glass cover used in the PVT system, the results shows that the thermal efficiency PVT collector increases on increasing the number of glazing while the electrical efficiency decreases due to increased fluid temperature and optical losses (Guarracino et al. (2016)).A 68.4% of the overall efficiency have been achieved with the spiral flow design of the PVT water collector (Fudholi et al. (2014)).A aluminium absorber attached PVT collector has been reported with high output density in comparison to a unit PV module (Fujisawa T. and

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Tani T. (1997)).The four types of absorber, namely aluminium with fin, aluminium without fin, tedlar and black painted glazing absorbers have been compared and aluminium with fin produced higher overall efficiency (Ziapour et al. (2014)).A 5% improvement in electrical efficiency with additional 65% of thermal efficiency have been reported with PV panel retrofitted with a thermal absorber (Xu et al. (2015)). Zondag H.A. (2008) reviewed that the high thermal resistance between the different layers of a PV module minimizes heat transfer from the top glass cover to fluid. A high overall efficiency of 87.52% has been achieved with the copper sheet laminated PV integrated to a single water channel (Michael J.J. et al.(2016), Michael J.J. and Selvarasan I. (2017)).

The main objective of this paper is to study the performance of photovoltaic (PV) laminated with glass, tedlar (Te), copper/aluminium (Cu/Al) as a base for the composite climate of New Delhi, India. The comparison of the three bases (glass, Te, Cu/Al) have been done on the basis of their electrical efficiencies. The effect of mass flow rate on energy and exergy of copper/aluminium (Cu/Al) base PVT water collector has been analyzed. The daily energy and exergy of the copper/aluminium (Cu/Al) base PVT water collector has been analyzed. Further, the analysis has been carried out for annual useful overall thermal energy and exergy gain. The analysis have been done for the climatic conditions of New Delhi, India. The motive of this study to achieve higher thermal and electrical gain for the copper/aluminium (Cu/Al) base PVT water collector.

II. SYSTEM DESCRIPTION

Case I. Glass base photovoltaic (PV) module –

In this case, solar cell is encapsulated under the two glass covers as shown in Fig. 1(a). No flow of fluid (air/water) has been considered below the photovoltaic module. The electrical gain is observed for the glass to glass semi-transparent PV module.

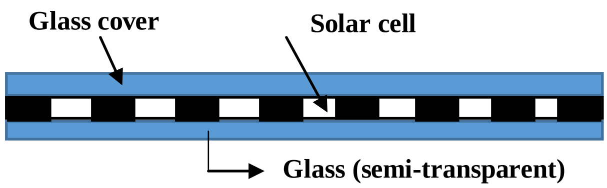

Fig. 1(a). Cut sectional view of semi-transparent PV collector

Case II: Te base photovoltaic (PV) module

In this case, there is no flow of fluid (air/water) has been considered below the photovoltaic collector. PV modules have been made by adhering the tedlar (Te) just below the solar cell as shown in Fig. 1(b).

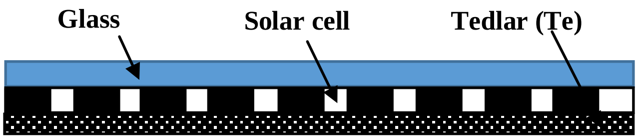

Fig. 1(b). Cut sectional view of opaque PV collector

Case III: Cu/Al base photovoltaic (PV) module

In this case, there is no flow of fluid (air/water) has been considered below the photovoltaic collector. PV modules have been made by adhering the copper/aluminium (Cu/Al) sheet just below the solar cell as shown in Fig. 1(c).

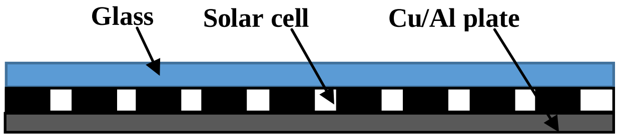

Fig. 1(c). Cut sectional view of opaque PV collector

Case IV: Cu/Al base photovoltaic thermal water (PVT) collector

In this case, water has been chosen as a working fluid in the copper/aluminium (Cu/Al) base PVT collector as shown in Fig. 1(d). In the proposed PVT collector glass has been used at the top to restrict the long wave radiation and to get maximum efficiency. The solar radiation incident on the collector passes through the glass cover and from the non-packing area of the solar cell. The solar radiation is then absorbed by the copper/aluminium (Cu/Al) plate. Due to high thermal conductivity of the copper (401 W/mK) and aluminium (207 W/mK) which much higher than that of glass (0.816 W/mK) and tedlar (0.033 W/mK), more heat is transferred from the back of the solar cell to the riser tubes by reducing the thermal resistance.

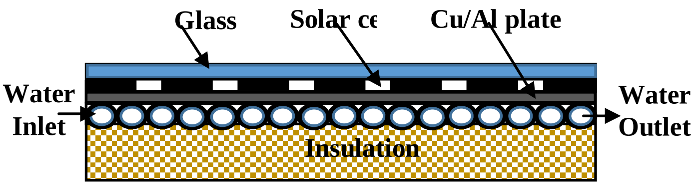

Fig.1d. Cut sectional view of Cu/Al base PVT water collector

The thermal circuit diagram corresponding to Case IV have been shown in Fig.2 and the design parameter of the proposed Cu/Al base PVT water collector has been given in Table. 1.

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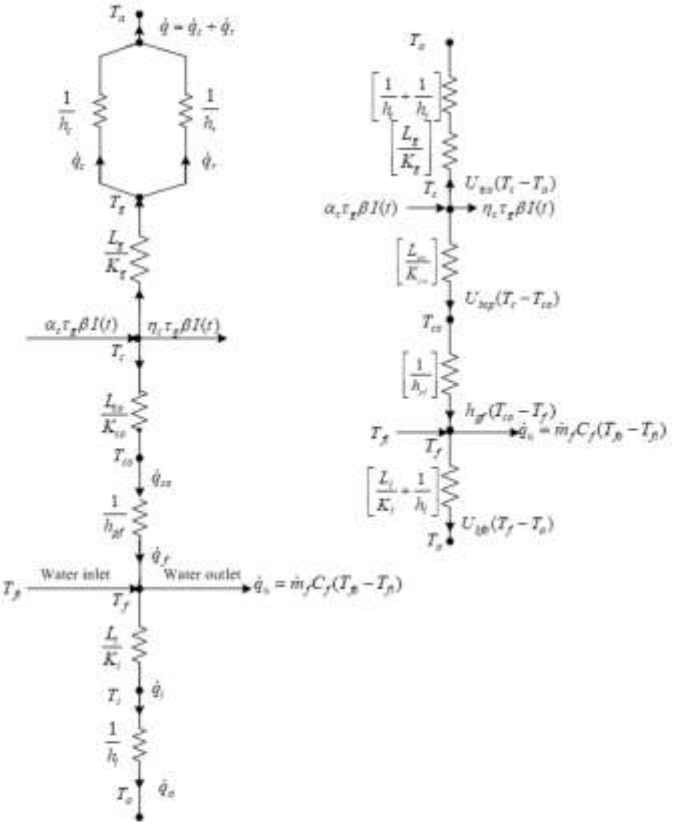

Fig. 2. Thermal circuit diagram of Cu/Al base PVT water collector

Table 1: Design parameters of copper/aluminium (Cu/Al) base PVT water collector

Parameters	Values	Parameters	Values
α_c	0.9	τ_g	0.95
β	0.89	η_o	0.15
α_p	0.93	$h_{i'}$	5.8
h_o	9.5	L_g	0.004
K_g	1	L_i	0.0001
K_i	1.8	L_c	0.0001
K_{co}	401	L_{al}	0.0002
K_{al}	207	C_f	4190
K_t	0.033	β_o	0.0045
L_t	0.0005	A_m	2
F'	0.895	h_{pf}	100
$\dot{m}_f$	0.017	U_{tk}	0.6

III. THERMAL MODELLING

The energy balance equations have been written for each component of the copper/aluminium (Cu/Al) base PVT collector using following assumptions.

1. The glass to copper/aluminium (Cu/Al) PVT system is in quasi-steady state
2. There are negligible ohmic losses
3. The heat capacity of the glass, copper materials and insulationof PVT collectors is neglected
4. Only one dimensional heat flow is considered
5. There is no stratification in water temperatire in the insulated tank

The energy balance equation for all the three cases following (Tiwari A. and Sodha M.S. (2006), Joshi et al. (2009)) have been given below:

Case I: Glass base photovoltaic (PV) module

$$\alpha_c\tau_g\beta I(t)Wdx = U_{t,ca}(T_{cg}-T_a)Wdx + U_{b,cpg}(T_{cg}-T_a)Wdx + \eta_c\tau_g\beta I(t)Wdx \quad (1)$$

$$T_{cg} = T_a + \frac{(\alpha\tau)_{1,eff}\, I(t)}{U_{Lm,water}} \quad (2)$$

where $\alpha_c\tau_g\beta I(t)Wdx$ is the rate of solar energy achieved by the solar cell after transmission, $U_{t,ca}(T_{cg}-T_a)Wdx$ is the rate of heat loss from the solar cell to ambient for glass base PV module, $U_{b,cpg}(T_{cg}-T_a)Wdx$ is the rate of heat transfer between cell to absorbing glass (semi-transparent) plate, $\eta_c\tau_g\beta I(t)Wdx$ is the electrical energy from the solar cell.

Case II: Tedlar base photovoltaic (PV) module

$$\alpha_c\tau_g\beta I(t)Wdx = U_{t,ca}(T_{ct}-T_a)Wdx + U_{b,cpt}(T_{ct}-T_t)Wdx + \eta_c\tau_g\beta I(t)Wdx \quad (3)$$

$$T_{ct} = \frac{(\alpha\tau)_{eff} + (U_{t,efft}\times T_a)}{U_{t,efft}} \quad (4)$$

where $\alpha_c\tau_g\beta I(t)Wdx$ is the rate of solar energy achieved by the solar cell after transmission, $U_{t,ca}(T_{ct}-T_a)Wdx$ is the rate of heat loss from the solar cell to ambient for the case of tedlar (Te) as a base, $U_{b,cpt}(T_{ct}-T_t)Wdx$ is the rate of heat transfer between cell to tedlar, $\eta_c\tau_g\beta I(t)Wdx$ is the electrical energy from the solar cell .

Case III: Cu/Al base photovoltaic (PV) module

$$\alpha_c\tau_g\beta I(t)Wdx = U_{t,ca}(T_{ccu}-T_a)Wdx + U_{b,cpcu}(T_{ccu}-T_{cu})Wdx + \eta_c\tau_g\beta I(t)Wdx \quad (5)$$

$$T_{ccu} = \frac{(\alpha\tau)_{eff} + (U_{t,effcu}\times T_a)}{U_{t,effcu}} \quad (6)$$

$$\alpha_c\tau_g\beta I(t)Wdx = U_{t,ca}(T_{cal}-T_a)Wdx + U_{b,cpal}(T_{cal}-T_{al})Wdx + \eta_c\tau_g\beta I(t)Wdx \quad (7)$$

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$$T_{cal} = \frac{(\alpha\tau)_{eff} + (U_{t,effal} \times T_a)}{U_{t,effal}} \quad (8)$$

where $\alpha_c \tau_g \beta I(t) W dx$ is the rate of solar energy achieved by the solar cell after transmission, $U_{t,ca}(T_{ccu} - T_a)Wdx$ and $U_{t,ca}(T_{cal} - T_a)Wdx$ are the rate of heat loss from the solar cell to ambient for the case of copper/aluminium (Cu/Al) as a base, $U_{b,cpcu}(T_{ccu} - T_{cu})Wdx$ and $U_{b,cpal}(T_{cal} - T_{al})Wdx$ are the rate of heat transfer between cell to absorbing copper/aluminium (Cu/Al) plate, $\eta_c \tau_g \beta I(t) W dx$ is the electrical energy obtained from the solar cell .

Case IV: Cu/Al base photovoltaic thermal (PVT) water collector

- For PV module

$$\alpha_c \tau_g \beta I(t) W dx = U_{t,ca}(T_c - T_a)Wdx + U_{b,ccu}(T_c - T_{cu})Wdx + \eta_c \tau_g \beta I(t) W dx \quad (9)$$

[The rate of solar radiation received at solar cell] [The rate of heat loss from solar cell to ambient through top glass cover] [The rate of heat transfer from solar cell to copper plate] [The rate of electrical energy produced from the solar cell]

- For copper plate

$$\alpha_p (1-\beta) \tau_g I(t) W dx + U_{bccu}(T_c - T_{cu})Wdx = F' h_{pf}(T_{cu} - T_f)Wdx \quad (10)$$

[The rate of solar energy received at copper plate from solar cell through non-packing area] [The rate of heat transfer from solar cell to copper plate] [The rate of heat transfer from solar cell to flowing water]

- For water below absorber plate

$$F' h_{pf}(T_{cu} - T_f)Wdx = \dot{m}_f C_f \frac{dT_f}{dx} dx + U_{bfa}(T_f - T_a)Wdx \quad (11)$$

[The rate of thermal energy received by flowing water copper absorbing plate] [The rate of heat carried away with the flowing water] [The rate of heat loss from flowing water to ambient through bottom insulation]

$$T_c = \frac{[(\alpha\tau)_{1,eff} + (U_{tca} \times T_a) + (U_{bcp} \times T_{co})]}{(U_{tca} + U_{bcp})} \quad (12)$$

$$T_{cu} = \frac{[(\alpha\tau)_{m,eff} + (U_{L1} \times T_a) + (F' h_{pf} \times T_f)]}{(U_{L1} + F' h_{pf})} \quad (13)$$

and hence, the outlet water temperature obtained from at the end of the copper/aluminium (Cu/Al) base PVT water collector is as follows:

$$T_{fo,water} = T_f|_{x=L} = \left(\frac{PF_2 \alpha\tau_{m,effwater} I(t)}{U_{Lm}} + T_a\right)\left(1 - e^{\frac{-F' U_{Lm} A_m}{\dot{m}_f C_f}}\right) + T_{fi} e^{\frac{-F' U_{Lm} A_m}{\dot{m}_f C_f}} \quad (14)$$

$$\dot{Q}_{u,water} = A_m F_{Rm,water}(PF_2(\alpha\tau_{m,effwater} I(t)) - U_{Lm,water}(T_{fi} - T_a) \quad (15)$$

where, $\dot{Q}_{u,water}$ is the rate of thermal energy available at the end of copper/aluminium (Cu/Al) base water collector.

Energy and Exergy calculations

The expression for the instantaneous thermal efficiency can be given as

$$\eta_i = \frac{\bar{Q}_u}{A_c I(t)} \quad (16)$$

An expression for electrical efficiency of a PV module can be calculated as

$$\eta_c = \eta_o [1 - 0.0045(T_c - T_0)] \quad (17)$$

The rate of useful thermal energy can be evaluated from

$$\dot{E}e_{thermal} = \dot{m}_f C_f (T_{fo} - T_{fi}) \quad (18)$$

The useful electrical gain can be eveluated as

$$\dot{Q}_{electrical} = \dot{E}x_{electrical} = A_m \times \eta_m \times I(t) \quad (19)$$

The rate of useful thermal exergy can be obtained as

$$\dot{E}x_{thermal} = \dot{m}_f c_f (T_{fo} - T_{fi}) - \dot{m}_f c_f (T_a + 273) \ln \frac{(T_{fo} + 273)}{(T_{fi} + 273)} \quad (20)$$

The expression for hourly overall thermal energy yield based on the first law of thermodynamics can be defined as

$$\sum \dot{E}e_{overall} = \sum \dot{E}e_{thermal} + \frac{\sum \dot{E}x_{electrical}}{0.38} \quad (21)$$

where $\dot{Q}_{thermal} = \dot{Q}_u$

and the expression for overall exergy will be based on second law of thermodynamics is given by

$$\dot{E}x_{overall} = \dot{E}x_{thermal} + \dot{E}x_{electrical} \quad (22)$$

IV. METHODOLOGY

The analysis of Cu/Al base PVT water collector have been done in order to obtain the annual energy and exergy gains.The methodology flow chart has been given in Fig. 4. The input data for the solar radiation and ambient air temperature has been taken from the India Meterological Deparatment (IMD), Pune, India.

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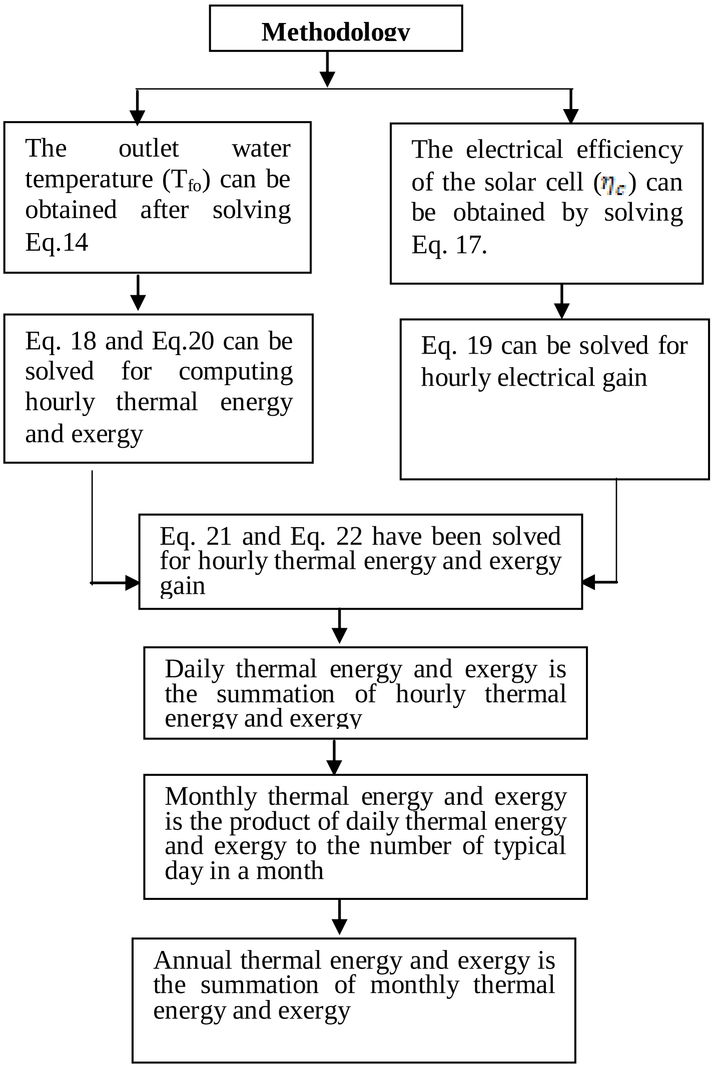

Fig.4 Methodolgy flow chart for the analysis of Cu/Al base PVT water collector

V. RESULT AND DISCUSSION

In copper/aluminium (Cu/Al) base PVT water collector, due to the higher thermal conductivity of the copper (401 W/mK) and aluminium (207 W/mK), heat is tranfers at a higher rate in comparision to glass and tedlar base PV module.Hence more thermal energy can be obtained in Case III (Cu/Al base PV module) due to low thermal resistance between different layers of the PV module.The bottom heat loss coefficient observed from solar cell to copper plate ($U_{b,cpcu}$) is 5.7 W/m^2K and solar cell to aluminium plate ($U_{b,cpal}$) is also 5.7 W/m^2K . Hence both the copper and aluminium plate gives similar performance in terms of energy and exergy.

The performance of the Cu/Al base PVT water collector has been studied for the climatic conditions of New Delhi, India. The data for the hourly variation of global solar radiation (I_t) and ambient air temperature (T_a) has been taken from the Indian Metrological Department (IMD) Pune, India is shown in Fig. 4.

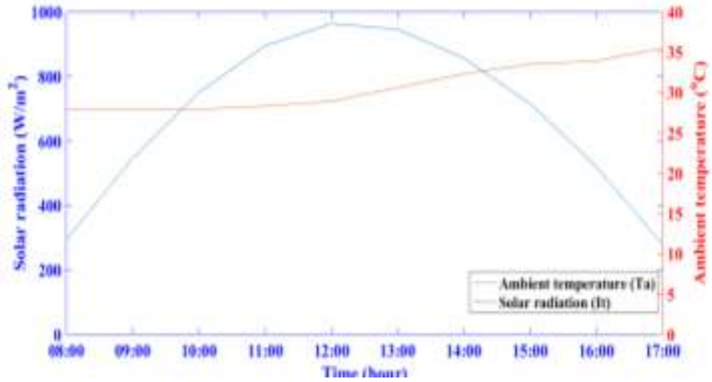

Fig. 4. Hourly variation of solar radiation and ambient air temperature.

The electrical efficiency of the PVT collector will depend upon the incident solar radiation and operating temperature of the solar cell. The electrical efficiency and average solar cell temperature for Case I (glass), Case II (Te) and Case III (Cu/Al) have been evaluated with the help of Eq. 13 as shown in Fig.5. The electrical efficiency of Case I (glass) has been reported higher than that of Case II (Te) and Case III (Cu/Al) PV modules because of higher transmissivity and lower operating temperature achieved in glass.

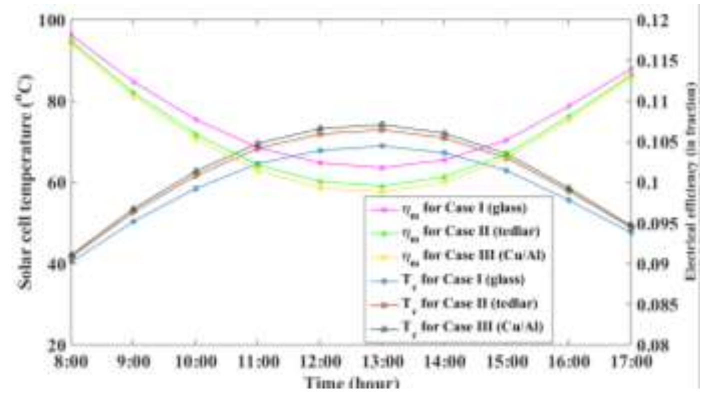

Fig. 5. Hourly variation of solar cell temperature and electrical efficiency

In order to achieve higher electrical efficiency equivalent to Case I (glass) in a Cu/Al base PVT water collector, the heat removal from the back of the PV module should be optimized. Hence, the electrical efficiency of the Cu/Al base PVT water collector has been studied under different mass flow rates. The result suggests that at the mass

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flow rate of 0.017kg/sec, the electrical efficiency of Case I is similar to Case IV as shown in Fig. 6.

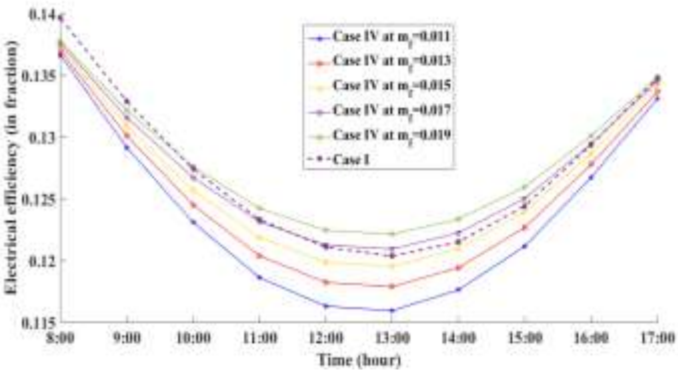

Fig. 6. Hourly variation of electrical efficiency at different mass flow rates

The hourly variation of thermal energy of the aluminium/copper base PVT collector has been evaluated with water as a working fluid. The instantaneous thermal (characteristic curve) efficiency and exergy are shown in Fig. 7a & Fig. 7b.

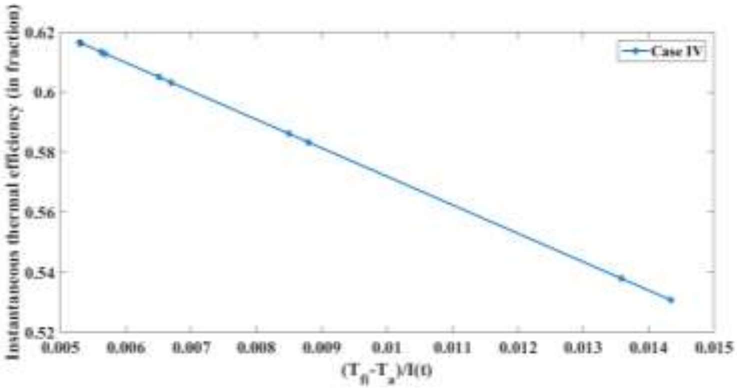

Fig. 7a Hourly variation of thermal energy of Cu/Al base PVT water collector

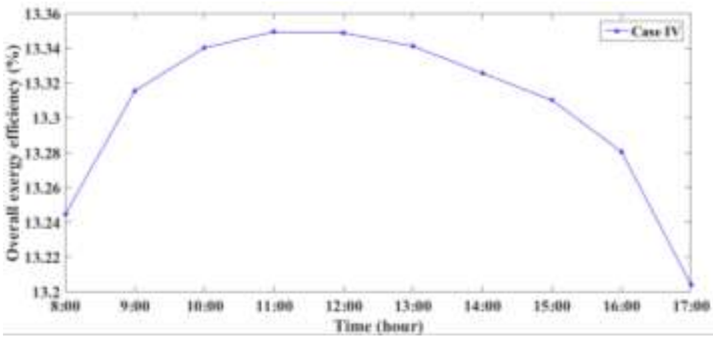

Fig. 7b Hourly variation of exergy of Cu/Al base PVT water collector.

The monthly yield in thermal energy and exergy yield at constant mass flow rate of 0.017 kg/s are shown in Fig. 8a & Fig. 8b. The monthly overall yield will depend upon the number of clear days. The number of clear days in different weather condition (A, B, C and D) for New Delhi weather station is given in Table. 2. The maximum thermal energy and exergy is attained for the month of June for "C" type weather condition as number of clear days is maximum in "C" type weather condition.

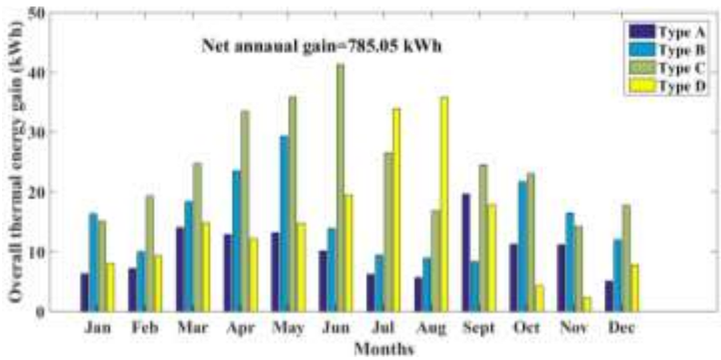

Fig. 8a Monthly variation of thermal energy yield for A,B,C, D type weather condition for New Delhi.

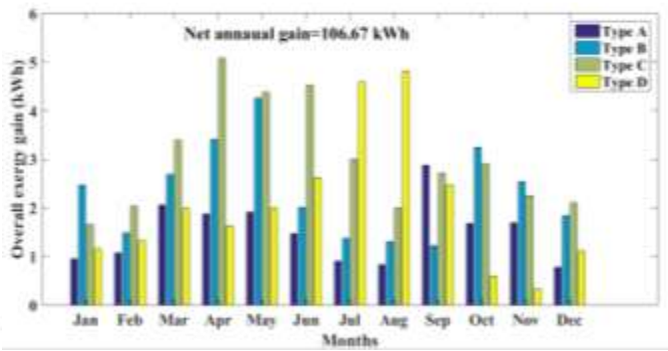

Fig.8b. Monthly variation of exergy yield for A, B, C, and D type weather condition for New Delhi.

Table 2. Number of clear days for New Delhi climatic conditions

Weather condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	3	3	5	4	4	3	2	2	7	5	6	3
B	8	4	6	7	9	4	3	3	3	10	10	7
C	11	12	12	14	12	14	10	7	10	13	12	13
D	9	9	8	5	6	9	17	19	10	3	2	8

VI. CONCLUSIONS

This study emphasizes on optimizing the performance of copper base PVT water heating system. The glass base, tedlar (Te) base and copper/aluminium (Cu/Al) base photovoltaics (PV) are analyzed without the flow of water in order to find the best configuration of the PV module. Several conclusions can be drawn from the results obtained from the analysis Case I, Case II, Case III and Case IV

i. The electrical efficiency of Case I (glass) PV is higher than that of Case II (Te) and Case III (Cu/Al) PV modules because of the higher operating temperature achieved in Case II and Case III.

ii. At mass flow rate of 0.017kg/sec the electrical efficiency of the Case IV (Cu/Al base PVT water collector) is nearly equal to the electrical efficiency of Case I (glass).

iii. The hourly thermal and exergy efficiency of the Case IV (Cu/Al) PVT water collector are 61.65 % and 13.35%.

iv. The net annual thermal energy and exergy gain obtained as 785.05 kWh and 106.67 kWh.

v. On the basis of present study, it is clear that copper/aluminium (Cu/Al) base PVT water collector is best designed system for the thermal and electrical needs.

Appendix

The relations used in the thermal modelling of the copper/aluminium (Cu/Al) base photovoltaic thermal (PVT) water collector system is given as follows:

$$(\alpha\tau_{1,eff}) = (\alpha_c - \eta_c)\tau_g \beta \text{ and } (\alpha\tau_{2,eff}) = \alpha_p (1-\beta)\tau_g$$

$$U_{tca} = \left[\frac{1}{h_o} + \frac{L_g}{K_g}\right]^{-1}$$

$$U_{b,cpcu} = \left[\frac{1}{h_i} + \frac{L_{cu}}{K_{cu}}\right]^{-1} or, U_{b,cpal} = \left[\frac{1}{h_i} + \frac{L_{al}}{K_{al}}\right]^{-1}$$

$$U_{b,cpg} = \left[\frac{1}{h_i} + \frac{L_g}{K_g}\right]^{-1} \text{ and } U_{b,cpt} = \left[\frac{1}{h_i} + \frac{L_t}{K_t}\right]^{-1}$$

$$(\alpha\tau_{m,eff}) = (\alpha\tau_{1,eff}) + PF_1(\alpha\tau_{2,eff})$$

$$PF_1 = \frac{U_{b,cp}}{U_{t,ca} + U_{b,cp}} \text{ and } PF_2 = \frac{F'h_{pf}}{F'h_{pf} + U_{L2}}$$

$$U_{L1} = \frac{U_{t,ca} \times U_{b,cp}}{U_{t,ca} + U_{b,cp}} \text{ and } U_{bfa} = \left[\frac{1}{h_i} + \frac{L_i}{K_i}\right]^{-1}$$

$$U_{L2} = U_{bfa} - U_{L1} * PF_2$$

Nomenclature

A	area (m^2)	T_{fi}	Inlet water temperature of the collector (^oC)
W	breadth (m)	T_{fo}	Outlet water temperature at the end of collector (^oC)
Dx	elemental length	h_o	Heat transfer coefficient between PVT collector and ambient (W/m^2K)
α_c	apsorbtivity of the photovoltaic cell	$U_{t,ca}$	Overall heat transfer coefficient from cell to the ambient (W/m^2K)
ζ_g	transmittivity of the glass	$U_{b,cpg}$	Overall heat transfer coefficient from photovoltaic cell to absorption plate (W/m^2K) in Case I (glass base PV module)
T_{cg}	Solar cell temperature for glass base PV module	T_{ct}	Solar cell temperature for tedlar base PV module.
T_{ccu}	Solar cell temperature for Cu/Al base PV module	$U_{b,cpt}$	Overall heat transfer coefficient from photovoltaic cell to absorption plate (W/m^2K) in Case II (tedlar base PV module)

$U_{b,cp}$	Overall heat transfer coefficient from photovoltaic cell to absorption plate (W/m^2K) in Case IV (Cu/Al base PVT collector)	$U_{b,cpc}$	Overall heat transfer coefficient from photovoltaic cell to absorption plate (W/m^2K) in Case III (Cu/Al base PV module)
β	packing factor of the photovoltaic cell	h_{pf}	Heat transfer coefficient from copper absorption plate to the ambient (W/m^2K)
η_c	efficiency of solar cell	T_t	Temperature of tedlar (^oC)
α_p	absorbtivity of the copper absorbing plate	C_w	Specific heat of water (J/kgK)
ε	emissivity of the fluid	F`	Flat plate collector efficiency factor
C_f	specific heat of the water (J/kgK)	U_{bfa}	Overall heat tranfer coefficient from fluid to ambient (W/m^2K)
$\dot{m}_f$	mass flow rate of water(kg/s)	PF_1	Penalty factor due to glass cover of the PV module
L_g	thickness of glass cover (m)	T_{cu}	Temperature of copper plate (^oC)
K_g	thermal conductivity a of glass(W/mK)	T_{cg}	Temperature of the solar cell (^oC) with glass base PV module
L_i	Thickness of insulation (m)	I(t)	Solar intensity (W/m^2)
K_i	Thermal conductivity of insulation (W/mK)	T_a	Ambient temperature (^oC)
L_c	Thickness of solar cell (m)	K_t	Thermal conductivity of tedlar (W/mK)
K_c	Thermal conductivity of solar cell (W/mK)	L_c	Thickness of tedlar (m)
L_{co}	Thickness of copper absorbing plate (m)	$(\alpha\zeta)_{eff}$	Effective transmittance-absorbtance product
K_{co}	Thermal conductivity of copper absorbing plate (W/mK)	U_{tk}	Overall heat transfer coefficient from storage water tank to ambient (W/m^2K)
A_c	Area of the solar collector (m^2)		

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