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Research Article

A sensitivity study for n similar partly enclosed with photovoltaic thermal flat plate collectors having series connection

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ABSTRACT

A sensitivity study for N similar partly enclosed with photovoltaic thermal flat plate collectors with a series connection (N-PVT-FPCs) has been carried out in this research study. The analysis has been done for a typical day of May, wherein data for the ambient conditions of New Delhi (India) has been received from the India metrological department (IMD), Pune, India. In addition, further computational work has been carried out on the MATLAB programme for the daily heat gain of N-PVT-FPCs. One-at-a-time (OAT) methodology has been used for the sensitivity analysis. From the sensitivity analysis, it has been found that the heat gain from the proposed system is more sensitive with respect to the number of collectors (N) followed by inclination angle, mass flow rate (MFR) and packing factor (PF). The sensitivity figure has been found to be 0.08, 0.17, 0.25 and 0.94 for daily heat gain of N-PVT-FPCs with respect to PF, MFR, inclination angle and N, respectively.

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INTRODUCTION

The recent industrial and domestic developments and restrictions are being made by different country's governments to emit greenhouse gases. Renewable energies are being used rapidly to fulfil the energy demand due to the industrial and domestic developments. Solar energy is one of the cleanest and abundantly free energies that can be

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converted either into heat or electricity depending upon the application using the collectors or solar cells. A solar collector works on the principle of a heat exchanger works; the heat is captured from the solar radiation and transferred to the working fluids (water, air, oil, etc.). A photovoltaic thermal (PVT) collector can generate electricity and heat simultaneously; compared to the photovoltaic (PV) module, a PVT can generate more electricity. The solar collectors viz. flat plate collectors (FPC), parabolic trough collectors (PTC), evacuated tube collectors (ETC) and PVT collectors can also be used to fulfil the demand for the freshwater by incorporating them with the solar stills for the remote areas where the conventional sources of energy are not readily available. Solar collectors also being used for drying applications and assisting solar desalination units. Currently, solar collectors are being developed for space heating, industrial products, seasoning of timber, etc.[1–6].

The use of FPC in the present era of evolving technology is because of its efficient incident solar radiation capturing, lesser complexity, and lesser maintenance of the FPC. The operating temperature of FPC is relatively low compared to other solar collectors; therefore, the efficiency of such collectors is sub-optimal. The solar collector's efficiency decreases as the wind speed increases; this is because of the increase in convective heat loss to the environment. However, the collector's efficiency depends upon the tilt angle, temperature and flow rates apart from the wind velocity [7,8]. The various researchers have proposed different methods that can be used for increasing the efficiency of such collectors. The nanoparticles inclusion in heat transfer fluids (HTFs) is an important interest in the recent year's development of FPC. The nanofluid enhances the thermal behaviour of the HTFs, which ultimately enhances the thermal efficiency of collectors. Apart from the nanoparticle, the HTF's mass flow rate (MFR), collector's area and operating temperature also affect the efficiency of the FPC [9–11]. Many researchers have reported the different methods for improving efficiency and performance by changing the different HTFs and some modifications in collectors (size, shape and orientations). Verma and Tiwari [12] reviewed the nanofluid application. They concluded that the nanofluids' specific heat increases as the volume fraction decreases, and it strongly depends upon the base fluid. The use of nanofluids increases efficiency and lowers the sensitivity of collectors. The use of nanoparticles to base fluids are more efficient at the higher MFR, and the collector efficiency is directly proportional to the concentration of nanofluids [13]. Said et al. [11] studied the FPCs with the treated nanofluids; the MFR of the nanofluids has been varied in the experimentation and have found the exergy and energy efficiency of the collector both increasing with an increase in MFR of nanofluids. Ji et al. [10] investigated the performance of hybrid PVT with the variations in MFR and packing factor (PF) and reported that MFR increases are beneficial for the PV cooling, but after certain MFR, the thermal efficiency of the collector starts decreasing. It has also been reported that there is a substantial drop in the thermal efficiency of the collector with an increase in PF. Increase in MFR; the peak outlet temperature reduces as more solar energy is required to heat the same water quantity [14]. Michael and Selvarasan [15] studied PV and PVT systems to analyze the environmental effect and economic analysis. The overall efficiency found higher by them for the PVT system. Cooper has studied the effect of inclination angle on heat loss from the FPC. He found that the total heat loss coefficient increased as the inclination increased at a slower rate till 60˚and the heat loss coefficient increased rapidly beyond the inclination of 60˚[16].

Tiwari et al. [17] reported the PVT-FPC integrated with double slope solar still and concluded that it could be an effective solution for fulfilling the daily freshwater demand and electrical supply. Singh [18] done the computational analysis of N-PVT-FPC with integrating to double slope solar still. He reported the four collectors are optimum for the climatic condition of Delhi, India. A further study by Singh et al. [19] investigated the effect of the N similar partly enclosed with photovoltaic thermal flat plate collectors having a series connection on the performance of the single-slope solar still. Raju and Narayana [20] experimentally investigated the effect of the number of FPCs connected in series on the performance of the solar still. The results indicate that the two collectors give optimum results compared to the three collectors in the series.

The contemporary literature survey shows that the sensitive analysis of N similar partly enclosed with photovoltaic thermal flat plate collectors having a series connection (N-PVT-FPCs) shown in Figure 1 has not been reported by any researcher yet. Therefore, the present work is focused on the effect of MFR, inclination angle with the horizontal, PF, ambient temperature, wind speed on the output of the N-PVT-FPCs. The following are the foremost aims of the present work:

i. To explore the effect of MFR variations in the heat gain of N-PVT-FPCs connected in series, keeping remaining input parameters constant.
ii. To study the effect of heat gain via N-PVT-FPCs by changing the enclosed area keeping the remaining input parameters constant.
iii. To investigate the heat gain of N-PVT-FPCs by varying PF keeping remaining input parameters constant.
iv. To investigate the dissimilarities of the inclination angle of collectors with the horizontal on the daily heat gain of the proposed system. For this analysis, the global solar radiation data has been used to correspond to different angles while all other parameters are kept constant.

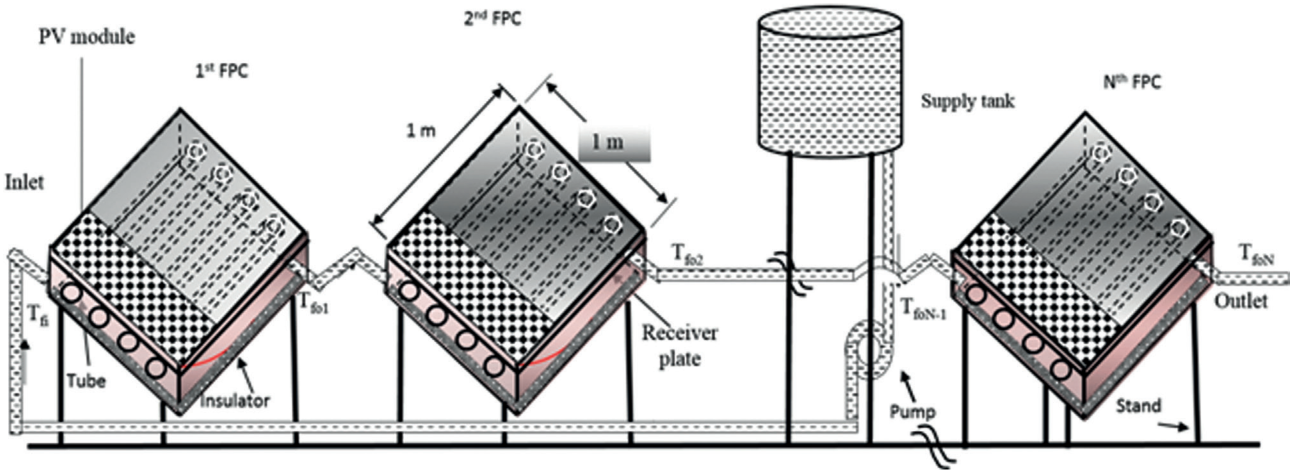


Figure 1. N similar partly enclosed with photovoltaic thermal flat plate collectors having series connection.

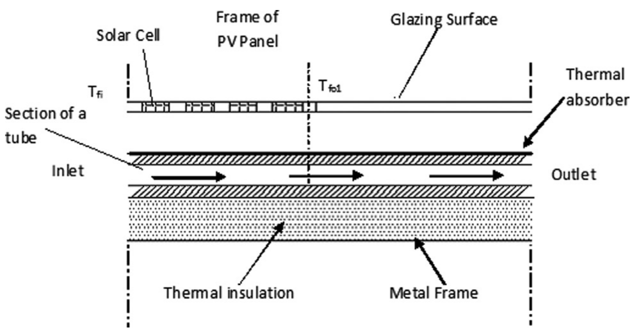


Figure 2. Sectional side view of a PV coupled (bottom portion) single glaze FPC.

SYSTEM DESCRIPTION AND MATHEMATICAL MODEL

Figure 1 illustrates the geometrical reorientations of N similar partly enclosed with photovoltaic thermal flat plate collectors with a series connection (N-PVT-FPCs). The in-series linking has been chosen because it provides high temperature (such as solar desalination units, biogas plants etc.) at lower discharge. However, the parallel connection may use for low-temperature applications (domestic use, laboratory etc.) with high discharge. Sometimes the mixed connection is chosen for medium temperature applications (such as water heating, air heating etc.). The output of the 1^{st}collector is the input to the 2^{nd} collector and so on up to the N^{th} collector. The present study focuses on the collectors connected in series to obtain the higher heat gain. Table 1 displays the specifications of N similar partly enclosed with photovoltaic thermal flat plate collectors having a series connection.

The mathematical modelling of N-PVT-FPC means to write different system component equations of N-PVT-FPC by equating input heat to output heat for the particular component followed by solving these equations to find the expression for unknown parameters by way of some known parameters like solar intensity, the surrounding temperature, heat transfer coefficients and some known constants. The equations further can be written as by equating input heat to output heat:

For Solar Cells of Semitransparent PV Module*:*

A semitransparent PV module covers the bottom part of the absorber of FPC, and the higher part is covered by a glass cover, as shown in Figure 2. Therefore, the equation by the method of equating input heat to output heat for a solar cell of PV can be written as:

$$\alpha_c \tau_g \beta_c I(t) W dx = [U_{tc,a}(T_c - T_a) + U_{tc,p}(T_c - T_p)] W dx + \eta_c \tau_g \beta_c I(t) W dx \quad (1)$$

It should be noted in equation (1) that the electrical efficiency of the semitransparent PV module is

$$\eta_m = \eta_c \tau_g \beta_c \quad (2)$$

The expression for solar cell temperature from equation (1) can be found as

$$T_c = \frac{(\alpha\tau)_{1,eff} I(t) + U_{tc,a} T_a + U_{tc,p} T_p}{U_{tc,a} T_a + U_{tc,p}} \quad (3)$$

The electrical efficiency of the cell can be written as:

$$\eta_c = \eta_0 \{1 - \beta_0 (T_c - T_0)\} = \frac{\eta_0 \left[1 - \beta_0 \left\{T_a - T_0 + \frac{\alpha_c \tau_g \beta_c I(t) + U_{tc,p}(T_p - T_a)}{U_{tc,a} + U_{tc,p}}\right\}\right]}{1 + \frac{\beta_c \beta_0 \tau_g I(t)}{U_{tc,a} + U_{tc,p}}} \quad (4)$$

Table 1. Specification of N similar partly enclosed with photovoltaic thermal flat plate collectors having series connection

PVT-FPC collector			
Particular	**Specification**	**Particular**	**Specification**
Number of collector/Type	N/Tube in plate type	Module area	0.25 m × 1.0 m
Receiver Area (solar water collector)	1.0 m × 1.0 m	Collector area	0.75 m × 1.0 m
The thickness of collector plates	0.002m	F'	0.968
Copper tube thickness	0.00056 m	ρ	0.84
Length of each Copper Tubes	1.0 m	τ_g	0.95
Insulation thickness	0.1 m	α_c	0.9
Toughened glass thickness (on FPC)	0.004 m	β_c	0.89
FPC Angle (with Horizontal)	30°	α_p	0.8
Diameter of pipe	0.0125 m	FF	0.8
Collector effective area under glass	0.75 m^2	Collector area (under PV module)	0.25 m^2
DC motor rating	12 V, 24W		

For Blackened Absorber Plate of FPC:

The equation based on equating input heat to output heat for absorber plate of FPC can be written as:

$$\alpha_p(1-\beta_c)\tau_g^2 I(t)Wdx + U_{tc,p}(T_c - T_p) Wdx = F'h_{p,f}(T_p - T_f)Wdx \quad (5)$$

From equation (5), the expression for plate temperature can be expressed as:

$$T_p = \frac{(\alpha\tau)_{2,eff}I(t) + PF_1(\alpha\tau)_{1,eff}I(t) + U_{L1}T_a + F'h_{p,f}T_f}{U_{L1} + F'h_{p,f}} \quad (6)$$

For an Absorber Pipe Water Flow:

When PV is coupled at the lower part of the collector, the direction of water flow is shown in Figure. 1. The equation by equating input heat to output heat for absorber pipe of FPC can be written as:

$$\dot{m}_f C_f \frac{dT_f}{dx} dx = F'h_{p,f}(T_p - T_f)Wdx \quad (7)$$

Using equation (6), the equation (7) can be expressed as,

$$\dot{m}_f C_f \frac{dT_f}{dx} dx = F'[PF_2(\alpha\tau)_{m,eff}I(t) - U_{L,m}(T_f - T_a)]Wdx \quad (8)$$

By reshuffling and both side integration of equation (8) along with taking boundary conditions, namely, at $T_{f|x=0} = T_{fi}$ and at $T_{f|x=L} \bullet = T_{fo}$, one gets,

$$T_{fo} = \left[\frac{PF_2(\alpha\tau)_{m,eff}I(t)}{U_{L,m}} + T_a\right] \left[1-\exp\left(-\frac{F'A_m U_{L,m}}{\dot{m}_f C_f}\right)\right] + T_{fi}\exp\left(-\frac{F'A_m U_{L,m}}{\dot{m}_f C_f}\right) \quad (9)$$

Here, the exit of water at the end of the PV module-absorber arrangement becomes inlet to glass-absorber arrangement. Such a collector has referred to as a photovoltaic thermal (PVT) water collector, and T_{fo1} is the final exit temperature of water from the PVT water collector.

Water Outlet Temperature at The Exit of Collector:

Adapting Duffie and Beckman [21] and Tiwari [22], the equation for water outlet temperature at the exit of conventional FPC can be written as,

$$T_{fo1} = \left[\frac{(\alpha\tau)_{c1,eff}I(t)}{U_{L,c1}} + T_a\right] \left[1-\exp\left(-\frac{F'A_{c1}U_{L,c1}}{\dot{m}_f C_f}\right)\right] + T_{fi1}\exp\left(-\frac{F'A_{c1}U_{L,c1}}{\dot{m}_f C_f}\right) \quad (10)$$

Here, $T_{fi1} = T_{fo}$, the equation for final exit temperature from the first PVT hybrid flat plate collector can be written as,

$$T_{fo1} = \left[\frac{(\alpha\tau)_{c1,eff}I(t)}{U_{L,c1}} + T_a\right]\left[1-\exp\left(-\frac{F'A_{c1}U_{L,c1}}{\dot{m}_f C_f}\right)\right] + \left[\begin{array}{l}\left[\frac{PF_2(\alpha\tau)_{m,eff}I(t)}{U_{L,m}} + T_a\right]\left[1-\exp\left(-\frac{F'A_m U_{L,m}}{\dot{m}_f C_f}\right)\right] \\ + T_{fi}\exp\left(-\frac{F'A_m U_{L,m}}{\dot{m}_f C_f}\right)\end{array}\right] \exp\left(-\frac{F'A_{c1}U_{L,c1}}{\dot{m}_f C_f}\right) \quad (11)$$

Equation (11) can be rearranged as

$$T_{fo1} = \frac{\left(AF_R\left(\alpha\tau\right)\right)_1}{\dot{m}_f C_f} I(t) + \frac{\left(AF_R U_L\right)_1}{\dot{m}_f C_f} T_a + T_{fi}\left(1 - \frac{\left(AF_R U_L\right)_1}{\dot{m}_f C_f}\right) \quad (12)$$

Similarly, the exit water temperature at the exit of the second PVT hybrid collector can be written as,

$$T_{fo2} = \frac{\left(AF_R\left(\alpha\tau\right)\right)_2}{\dot{m}_f C_f} I(t) + \frac{\left(AF_R U_L\right)_2}{\dot{m}_f C_f} T_a + T_{fi2}\left(1 - \frac{\left(AF_R U_L\right)_2}{\dot{m}_f C_f}\right) \quad (13)$$

Here $T_{fi2} = T_{fo1}$; therefore, equation (13) can be rearranged as

$$T_{fo2} = \frac{(AF_R(\alpha\tau))_1}{\dot{m}_f C_f} I_{(t)}(1 + K_k) + \frac{(AF_R U_L)_1}{\dot{m}_f C_f} T_{(a)}\ (1 + K_k) + T_{fi} K_k^2 \quad (14)$$

Similarly, the outlet water temperature at the exit of the N[th] PVT hybrid collector can be represented as,

$$T_{foN} = \frac{\{AF_R(\alpha\tau)\}_1}{\dot{m}_f C_f}\left(\frac{1-K_K^N}{1-K_k}\right) I(t) + \frac{\{AF_R U_L\}_1}{\dot{m}_f C_f}\left(\frac{1-K_K^N}{1-K_k}\right) T_a + T_{fi} K_K^{\ N} \quad (15)$$

Expressions for $(A\,F_R\,U_L)_1$, $(A\,F_R\,(\alpha\tau))_1$ and K_k have been given in appendix-A

The rate at which useful heat output from an in series connected N-alike photovoltaic thermal (PVT) hybrid flat plate collector can be written as,

$$Q_{u,N} = \dot{m}_f C_f (T_{foN} - T_{fi}) \quad (16)$$

Putting the value of T_{foN} from equation (15) into equation (16) and rearranging, one can express $\dot{Q}_{u,N}$ as:

$$\dot{Q}_{u,N} = [(\alpha\tau)_{eff,N} I(t) - U_{L,N}(T_{fi} - T_a)](A_m + A_c)N \quad (17)$$

SENSITIVITY ANALYSIS

The input parameters (PF, collector area, mass flow rate, inclination angle) on the output parameter by keeping certain assumptions have been analyzed. The main aim of the study is to understand the relationship between input and output parameters. Sensitivity usually defined in terms of the percentage change in output parameter to the percentage change in input parameter, which is the ratio of output to the input. Several techniques are available for the sensitivity analysis of a system, but here we have chosen a simplified technique for the study; this analysis involves the changing parameters one-at-a-time (OTA) to see the effects of changing parameters [23]. The output parameter of N-PVT-FPCs has been calculated by varying a parameter while letting the remaining parameters constant. Several input parameters, out of which the solar intensity, wind speed, and ambient temperatures, are extremely reliant on the weather, so these cannot be supervised; apart from these, other parameters are monitored. Therefore, variation in output with respect to variation in input (say PF) while all remaining parameters are keeping as constant. In this manner, all others monitored input parameters effect has been computed and plotted.

METHODOLOGY

The sensitivity analysis of N-PVT-FPCs connected in series has been done by employing the subsequent stepwise methodology:

Step-: I: The initial input parameter such as solar flux intensity, ambient temperature, wind speed from the climatic condition of New Delhi has been obtained from the Indian Meteorological Department (IMD), Pune, India. The solar flux intensity for the 30° northern latitude has been computed by Liu and Jordan (1960) [24]; this formula has been further incorporated in MATLAB for solar flux intensity computation.

Step-II: The $(\alpha\tau)_{eff,N}$ and $U_{L,N}$ have calculated from equation (2) and then hourly and total heat gain values computed from equation (1).

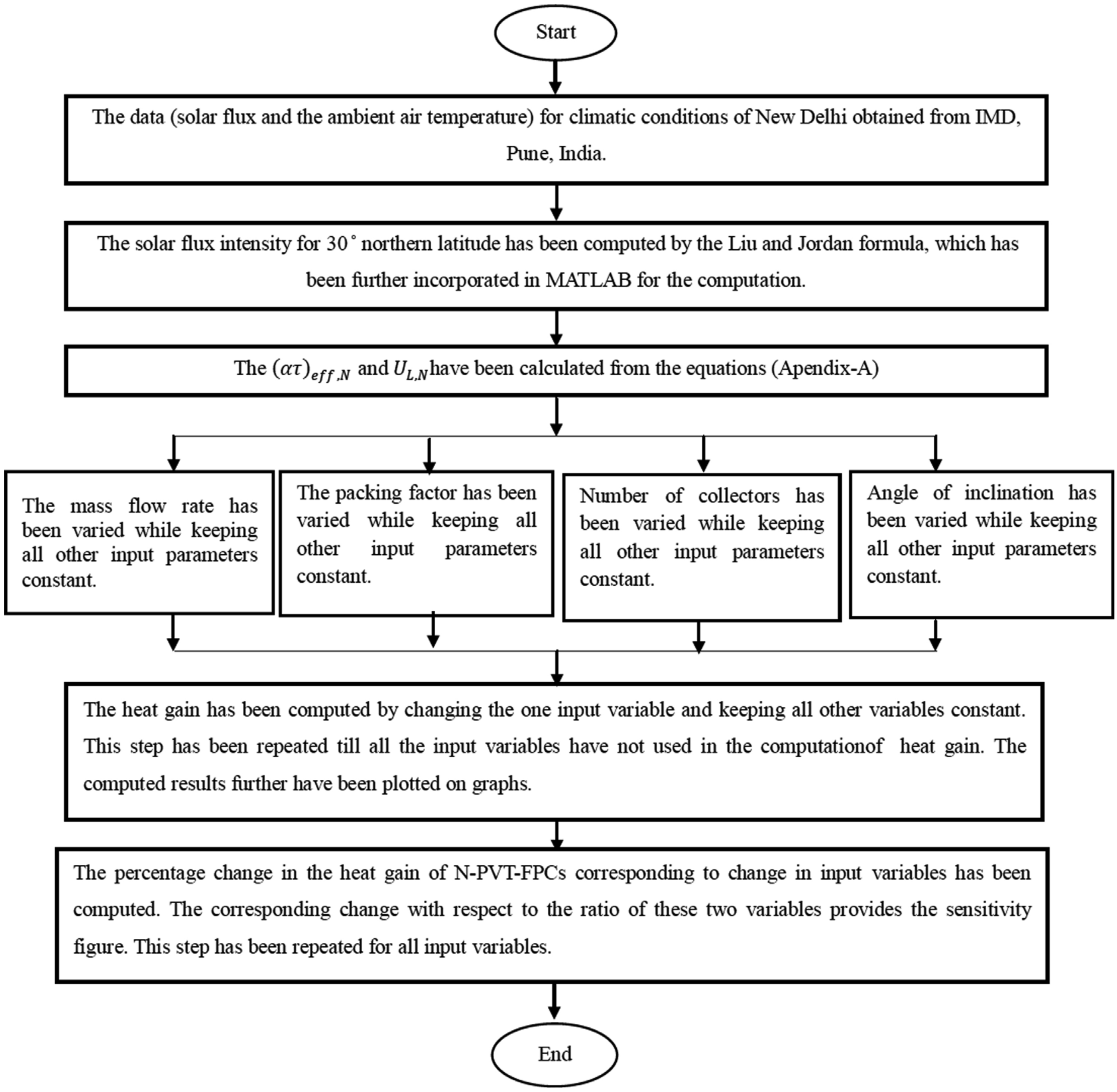
Step-III: The heat gain computed by changing the one input variable and keeping all other variables constant. The computed results have been further being plotted on the graph.

Step-IV: Step III has been repeated by varying all the input variables (OAT), except the solar flux intensity and ambient temperature, as they are dependent on the weather.

Step-V: The percentage change in the heat gain of N-PVT-FPCs corresponding to change in input variables has been computed. The corresponding change in the ratio of these two variables gives the sensitivity figure.

Step-VI: Step V has been repeated for all the input variables, and the results, which have been obtained, are plotted.

The following flow chart can help for a better understanding of the methodology as well as the sensitivity analysis, which have been carried out in the present study:



RESULTS AND DISCUSSION

The sensitivity analysis has been carried out by feeding the different input parameters into the MATLAB software. OTA method has been used throughout the analysis for the projected system. The solar flux intensity and ambient temperature have been taken from the IMD Pune, India, for the typical day of May, which shown in Figure 3. The results obtained in the present study have been plotted in Figures 4 to 12. The sensitivity figure of daily heat gain of N-PVT-FPCs with respect to PF, MFR, N and inclination of FPC with horizontal has been shown in Table 2.

Figure 4 shows the variation of daily heat gain of N-PVT-FPCs for the constant values of N=10 and MFR=0.06 kg/s. It can be seen from Figure 4 that the daily heat gain of the proposed system starts decreasing with the increase in PF, but at a prolonged rate, this is happening because lesser module surface area selected in the proposed system. Figure 5 shows the sensitivity with respect to PF for the daily heat gain of N-PVT-FPCs. It is evident from Figure 5 that the proposed system is having significantly less sensitivity with respect to the PF.

The variation in the daily heat gain with respect to MFR for fixed values of PF=0.8 and N=10 has been plotted on

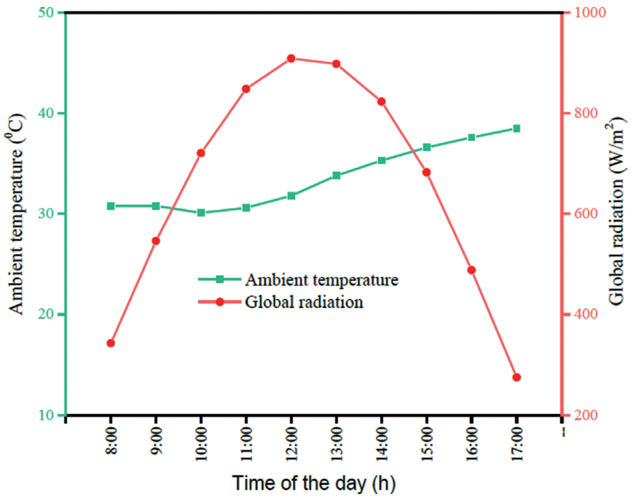


Figure 3. Hourly variation of global radiation and ambient air temperature for a typical day in the month of May.

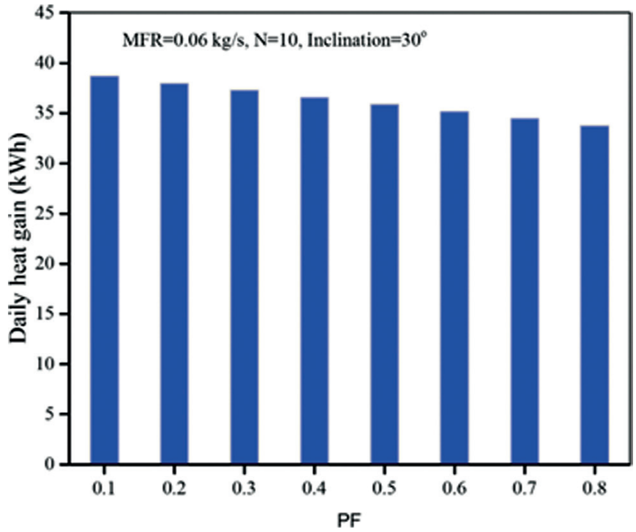


Figure 4. Variation in daily heat gain of N-PVT-FPCs with PF.

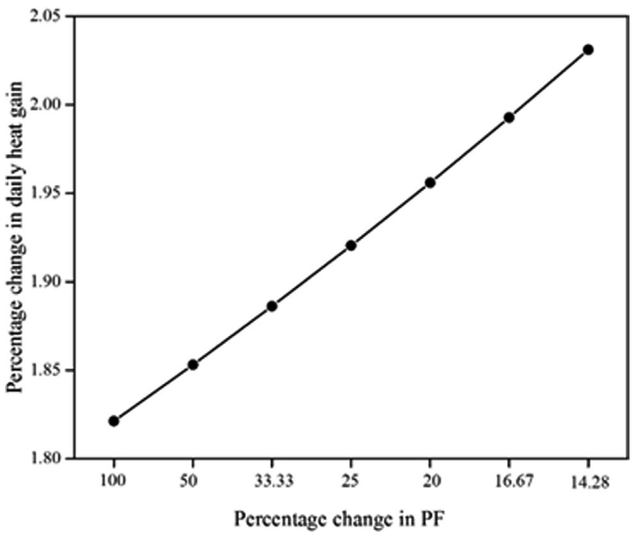


Figure 5. Sensitivity with respect to PF for the daily heat gain.

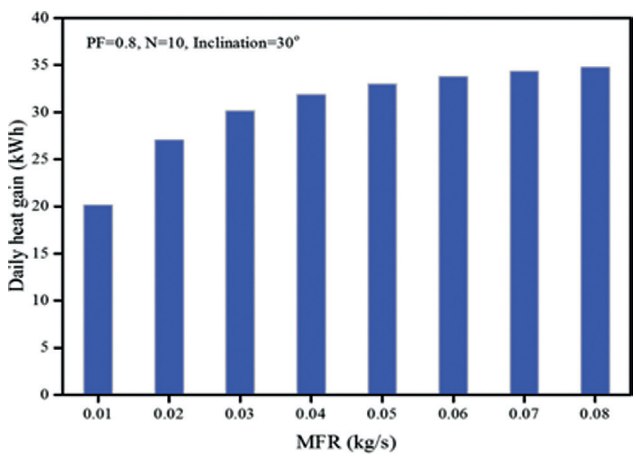


Figure 6. Variation in daily heat gain of N-PVT-FPCs with MFR.

the graph and shown in Figure 6. The heat gain increases as the MFR of fluid increases in the proposed system; this is because MFR is directly proportional to the heat gain; henceforth, the heat gain by the collector increases. The sensitivity of the MFR has been represented in Figure 7 and can be understood from this plot; the heat gain of N-PVT-FPCs is more sensitive when the system is at a lower MFR and vice versa. This is because, at lower MFR, the fluid has enough time to absorb the heat from the absorber plate; therefore, the fluid temperature increases instead of increasing the collector heat gain. After a certain value of MFR, i.e. 0.06 kg/s, the collector's heat gain increment becomes insignificant because of the steady-state achieved between the absorber plate and fluid flow.

For the constant value of MFR=0.06 kg/s and PF=0.8, Figure 8 shows the variation of N on the heat gain of the N-PVT-FPCs. As the number of collectors increases the heat gain increase because of the increase in the heat collection area. However, when the numbers of collectors increase, the system's cost also increases; such consideration should be taken into account while designing and installing said systems. The sensitivity of the proposed system is higher for the lesser values of N and lower for higher values of N, and can be seen in Figure 9. It is because of the lower values of N, the difference of temperature between the absorber plate of the PVT-FPCs collectors and the flowing fluid is higher; however, the temperature of each collector is the same because of the identical collectors, which leads to higher temperature

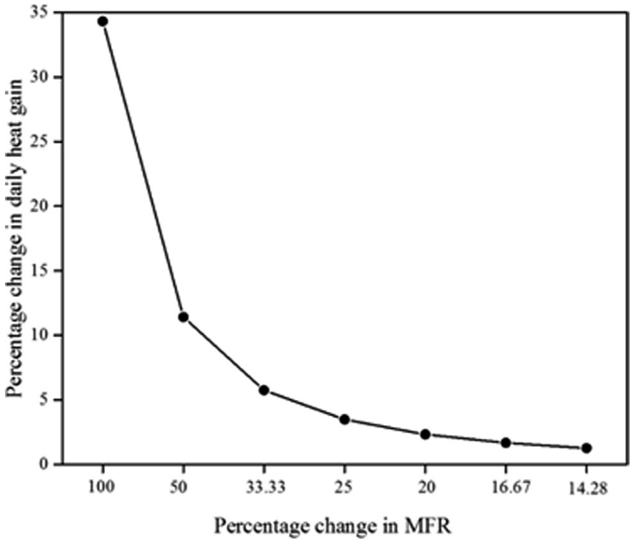


Figure 7. Sensitivity with respect to MFR for the daily heat gain

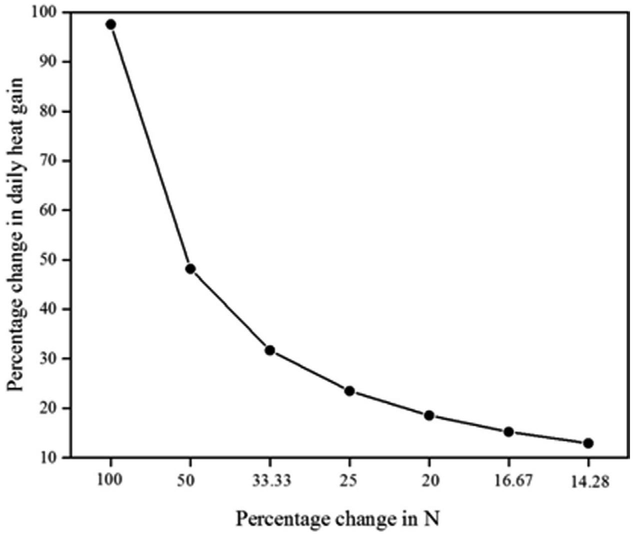


Figure 9. Sensitivity with respect to N for the daily heat gain.

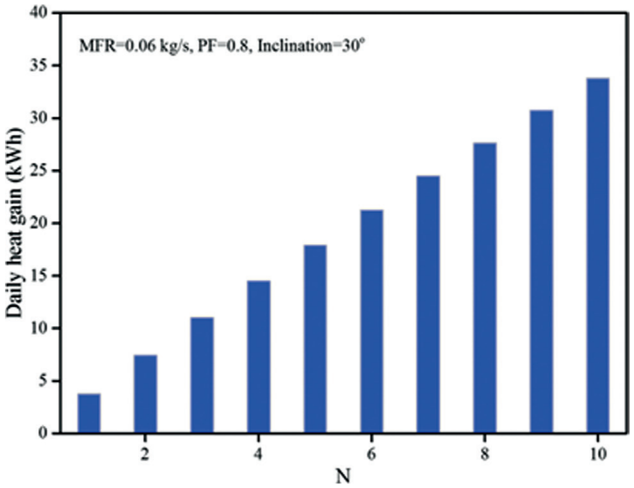


Figure 8. Variation in daily heat gain of N-PVT-FPCs with N.

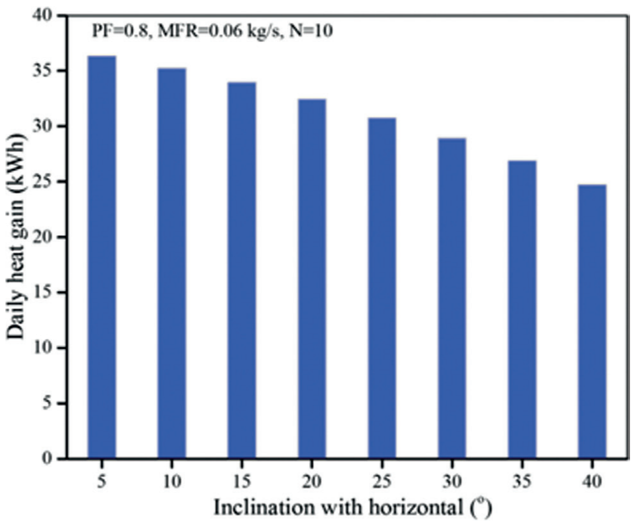


Figure 10. Variation in daily heat gain of N-PVT-FPCs with inclination angle.

difference at lower N values and vice versa for higher values of N.

The dissimilarity in daily heat gain with respect to the inclination angle of FPCs for the constant PF, MFR and N has been shown in Figure 10. It can be seen from Figure 10 that as the inclination angle from the horizontal increases, the daily heat gain of the proposed system decreases this is because of the total decrease in global solar radiation falling over the N-PVT-FPCs surface. However, the daily heat gain decreases with the inclination angle, but the inclination angle should be equal to the latitude of the place where the system has been installed. For this inclination angle, the system will receive maximum solar radiation throughout the year [25-27]. As our analysis, the latitude of the place (New Delhi) is around 28.61˚; therefore, in this analysis (except the effect of inclination), the inclination angle has been chosen of 30˚. Figure 11 represents the sensitivity of the proposed system with respect to inclination angle; the system shows less sensitivity at higher inclination compared to lower one this is due to the fact that solar radiation received by the system is higher at the lower inclination while it comes to higher inclination the radiation received by the system has fewer variations.

The comparative study of the proposed N-PVT-FPCs system has been shown in Figure 12. The sensitivity has been plotted by changing one of these viz: PF, MFR and

Table 2: Computation of sensitivity figure of daily heat gain of N-PVT-FPCs with respect to PF, MFR, N and inclination angle

% change in the input variable	% change in daily heat gain w.r.t. PF	Sensitivity figure for daily heat gain w.r.t. PF	% change in daily heat gain w.r.t. MFR	Sensitivity figure for daily heat gain w.r.t. MFR	% change in daily heat gain w.r.t. N	Sensitivity figure for daily heat gain w.r.t. N	% change in daily heat gain w.r.t. inclination angle	Sensitivity figure for daily heat gain w.r.t. inclination angle
100	1.82	0.02	34.32	0.34	97.55	0.98	2.99	0.03
50	1.85	0.04	11.42	0.23	48.17	0.96	3.68	0.07
33.33	1.89	0.06	5.75	0.17	31.71	0.95	4.41	0.13
25	1.92	0.08	3.48	0.14	23.49	0.94	5.19	0.20
20	1.96	0.10	2.33	0.12	18.56	0.93	6.04	0.30
16.67	1.99	0.12	1.67	0.10	15.27	0.92	6.99	0.42
14.28	2.03	0.14	1.26	0.09	12.92	0.90	8.06	0.56
	The average value of sensitivity figure for daily heat gain w.r.t. PF	**0.08**	The average value of sensitivity figure for daily heat gain w.r.t. MFR	**0.17**	The average value of sensitivity figure for daily heat gain w.r.t. N	**0.94**	The average value of sensitivity figure for daily heat gain w.r.t. inclination angle	**0.25**

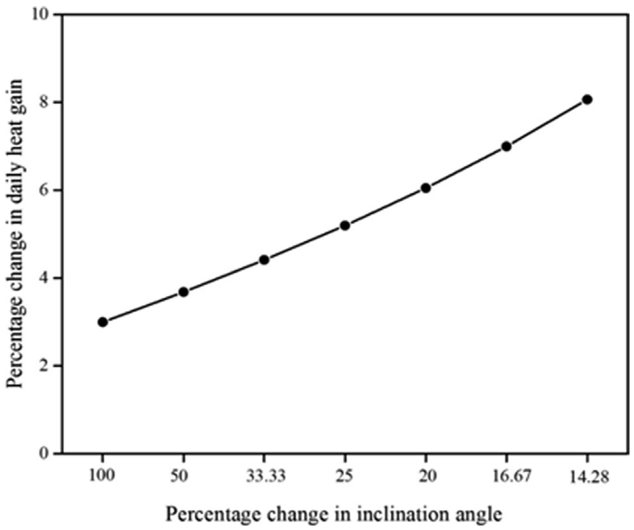


Figure 11. Sensitivity with respect to inclination angle for the daily heat gain.

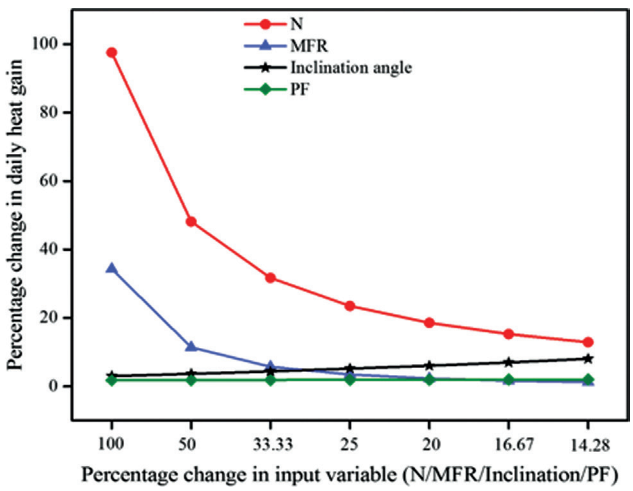


Figure 12. Comparative sensitivity of N-PVT-FPCs with respect to input variables (PF/MFR/N/Inclination).

N as per OAT. The sensitivity analysis found that the number of collectors is more sensitive, followed by the MFR and PF. Therefore, selecting the number of collectors is the most important parameter while choosing the N-PVT-FPCs for installation. Therefore, one should take care of these points while designing such a system for collector heat gain. The slope of the curve provides the sensitivity figure, which has been represented in Table 2 of the proposed system with respects to PF, MFR and N. The average value of the sensitivity figure has been found 0.08, 0.17, 0.25 and 0.94 for daily heat gain w.r.t. PF, MFR, inclination angle and N respectively. The higher value of the slope represents the higher sensitiveness of the system.

CONCLUSIONS

The sensitivity analysis of N identical partly covered collectors (attached in series) have been performed in this study. The obtainable conclusions from the study are as follows:

i. The daily heat gain of N-PVT-FPCs decreases as the PF factor increases, but the rate of decrement is lesser.
ii. The daily heat gain of the N-PVT-FPCs starts increasing when the MFR increases, but beyond the MFR of 0.06 kg/s, the increment in the heat gain is not very significant.
iii. With the increase in the numbers of collectors, the heat gain of the proposed system increases.
iv. With the increase in the angle of inclination, the daily heart gain decreases of the proposed system.
v. The sensitivity analysis of the N-PVT-FPCs indicates that the system is more sensitive w.r.t. N followed by inclination, MFR and PF. The average value of the sensitivity figure has been found to be 0.94, 0.25, 0.17 and 0.08 w.r.t. N, MFR and PF, respectively.

Abbreviations

PVT	photovoltaic thermal
PV	photovoltaic
FPC	flat plate collectors
PTC	parabolic trough collectors
ETC	evacuated tube collectors
HTFs	heat transfer fluids
MFR	mass flow rate
N-PVT-FPCs	N identical partly covered flat plate collectors
N	Numbers of collector
PF	packing factor
OTA	one-at-a-time

Nomenclature

A_m	Module area, m^2
A_c	Collector area, m^2
F'	Efficiency factor (flat plate collector), dimensionless
F_R	Heat removal factor, dimensionless
PF_1	Penalty factor first(dimensionless)
PF_2	Penalty factor second(dimensionless)
I(t)	Incident solar intensity, W/m^2
$I_c(t)$	Incident solar intensity on collector, W/m^2
K	Thermal conductivity, W/m-K
$\dot{m}_f$	Rate of flow of water mass in the collector, kg/s
L_g	Thickness of glass cover, m
c_f	specific heat of water
T	Inlet water temperature
Q_u	Rate of useful energy transfer, kW
U_{tca}	Total heat transfer coefficient from the solar cell to ambient (via glass cover), W/m^2-K
$U_{tc,p}$	Total heat transfer coefficient from the solar cell to plate (via glass cover), W/m^2-K
$U_{L,m}$	An overall heat transfer coefficient from blackened surface to ambient, W/m^2-K

Subscripts

a	Ambient
c	Solar cell
eff	Effective
w	Water in solar still
g	Glass
f	Water in flat plate collector
fi	Water at Inlet of FPC
fo	Water at the outlet of FPC
m	Module
N	Number of collectors

Greek Letters

α	Absorptivity
$(\alpha\tau)_{eff}$	Product of effective absorptivity and transmittivity
β	Packing factor
η	Efficiency
τ	Transmittivity

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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APPENDIX-A

Expressions for different terms used in equations (1) to (17) are as follows.

$(\alpha\tau)_{1,eff} = \tau_g(\alpha_c - \eta_c)\,\beta_c$; $(\alpha\tau)_{2,eff} = \alpha_p(1 - \beta c)\,\tau_g^2$; $PF_1 =$

$$\frac{U_{tc.p}}{U_{tc,a}+U_{tc,p}}$$

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

$$h_o=5.7+3.8V,\,Wm^{-2}K^{-1};V=1ms^{-1};$$

$$h_i=5.7;Wm^{-2}K^{-1};$$

$$\frac{(AF_R(\alpha\tau))_1}{(A_m+A_c)}\left[\frac{1-(1-K_{K,A})^N}{NK_{K,A}}\right],$$

$$\cdots U_{L,N}=\frac{(AF_RU_L)_1}{(A_m+A_c)}\left[\frac{1-(1-K_{K,A})^N}{NK_{K,A}}\right];$$

$$K_{K,A}=\frac{(AF_RU_L)_1}{\dot{m}_f c_f}$$

$$\frac{h_{p,f}}{U_{L1}+h_{p,f}}$$

$$(AF_R(\alpha\tau))_1=\left[A_mF_{Rm}PF_2(\alpha\tau)_{m,eff}\left(1-\frac{A_cF_{Rc}U_{L,c}}{\dot{m}_fC_f}\right)+A_cF_{Rc}(\alpha\tau)_{c,eff}\right]$$

$$(AF_RU_L)_1=\left[A_mF_{Rm}PF_2(\alpha\tau)_{m,eff}\left(1-\frac{A_cF_{Rc}U_{L,c}}{\dot{m}_fC_f}\right)+A_cF_{Rc}U_{L,c}\right]$$

$$A_mF_{Rm}=\frac{\dot{m}_fC_f}{U_{L,m}}\left[1-\exp\left(\frac{F'A_mU_{L,m}}{\dot{m}_fC_f}\right)\right]$$

$$A_cF_{Rc}=\frac{\dot{m}_fC_f}{U_{L,c}}\left[1-\exp\left(\frac{F'A_cU_{L,c}}{\dot{m}_fC_f}\right)\right]$$

$$U_{Lm}=\frac{U_{L1}h_{p,f}}{U_{L1}+F'h_{p,f}}$$

$$U_{L1}=\frac{U_{tc,a}U_{tc,p}}{U_{tc,a}+U_{tc,p}}$$

$$\left(AF_R\left(\alpha\tau\right)\right)_1=\left(AF_R\left(\alpha\tau\right)\right)_2\,and\left(AF_RU_L\right)_1=\left(AF_RU_L\right)_2$$