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## Energy, Economic and Environmental Analysis of Semi-Transparent PVT Solar Dryer Integrated with Kitchen Chimney



**Abstract:** - In this paper, an effort has been made to assess the annual low exergy (thermal Energy) and high exergy (electrical energy) performance for a semi-transparent PVT solar dryer integrated with a kitchen chimney. The values of annual thermal energy, electrical energy for all weather conditions namely a, b, c, and d type have been obtained by comparing the different packing factors at different chimney temperatures for Delhi climatic conditions. The embodied energy of the above dryer is calculated and the same has been used for evaluation of CO<sub>2</sub> emission and mitigation and carbon credit earned. From the results, it has been observed that CO<sub>2</sub> mitigation also increases as the kitchen chimney outlet temperature increases. Energy matrices of hybrid dryer have also been evaluated and it has been observed that hybrid dryer along with integration with kitchen chimney is more feasible and practical from an overall thermal energy point of view.

**Keywords:** Exergy, embodied energy, CO<sub>2</sub> mitigation, carbon credit, solar dryer

### INTRODUCTION:

Finding solutions for today's environmental problem requires multiple efforts in the direction of sustainable development in the long run. Renewable energy resources; especially solar energy is one of the best-suited solutions towards global energy requirements while balancing environmental concerns [1]. One of the most basic solar energy application is solar drying. For generations, solar energy has been used to preserve agricultural and marine products all over the world. Various types of dryers have been designed and developed to improve the performance of the dryer and food quality. Generally, solar dryers are classified into four types; (i) direct, (ii) indirect, (iii) mixed-mode and (iv) hybrid solar dryers. The solar dryer has been designed with a flat-plate solar air heater mounted with solar cells and a plane booster. The performance of this system has been evaluated for various combinations of boosters and it is found that the minimum required solar cell area decreases with the use of boosters [2]. A double pass photovoltaic thermal solar collector has also been used for drying applications and it is found that the temperature varies proportionally with the change in global solar radiation [3]. A hybrid PVT greenhouse dryer has been developed to dry the grapes for forced mode convection and it is concluded that moisture evaporation with natural convection is better than forced convection [4]. Performance analysis for different air mass flow rate has been carried out for a hybrid PVT solar dryer, which is equipped with a heat pump system. It has been observed that drying time and energy consumption decreases with an increase in air mass flow rate and drying air temperature [5]. A hybrid system has been designed with solar collector support a dryer system and also provide consumptive hot water for the domestic purpose with optimally dried vegetables [6]. A hybrid solar dryer has been designed with paraffin wax as a phase change material which has contributed significantly to improve overall thermal efficiency of the system and it is reported that the air temperature is increased up to 30°C above the ambient temperature at the outlet of the solar panel [7]. Overall energy and exergy of PVT mixed-mode greenhouse dryer by considering different parameters namely crop, greenhouse and solar cell temperatures, etc have been calculated and the problem of de-colouration has been minimized with better food quality [8]. The performance of a PVT collector integrated greenhouse has been evaluated. It has been found that the annual exergy and exergy efficiency for PVT integrated greenhouse has been obtained to be 12.8 kWh and is 4% respectively

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[9]. A solar dryer integrated with a photovoltaic powered DC fan has been designed and developed for performance analysis with forced mode under the no-load condition in different climates of India. It is observed that for installing a mixed-mode dryer, the best place is where the climate has maximum solar intensity [10]. A simple mathematical model has been developed to study the effectiveness of PVT and earth air heat exchanger (EAHE) integrated with the greenhouse. The result reported that when the system is operated with PVT coupled with EAHE at night, the greenhouse air temperature can be increased by 7°C to 8°C during the winter season [11], [12]. Energy and exergy analysis has been carried out for hybrid micro-channel PVT module in terms of design and climatic parameters under a constant mass flow rate of air and it is concluded that there is an increase of overall annual thermal energy and exergy by 70.62% and 60.19% respectively for all types of climatic conditions [13]. Energy and exergy of a semi-transparent PVT double pass air collector and single-pass air collector have been compared for different weather conditions of five different cities. It is observed that due to the low extraction of heat the outlet air temperature of a double pass air collector is around 3°C to 4°C higher than a single-pass air collector. Hence, the double pass air collector is more efficient than a single-pass air collector and found the best place for installing a hybrid PVT double pass air collector [14]. The performance has been evaluated for a hybrid PVT double pass facade for space heating. It is concluded that room air temperature increases by 5 to 6°C than the ambient air temperature for a typical winter day [15]. An exergo-economic analysis is carried out in terms of energy-saving by using a glazed hybrid PVT module air collector compared to a PV module. It has been observed that for cold climatic conditions, glazed hybrid PVT module air collectors are very useful for electricity generation as well as for space heating. [16]. In an enviro-economic analysis, energy payback time (EPBT), energy production factor (EPF), life cycle conversion efficiency (LCCE) and inflation based on annual overall thermal energy and exergy gain of glazed hybrid photovoltaic thermal (PVT) module air collector have been done for specific climatic conditions. It has been observed that in terms of thermal energy and exergy, energy payback time is 1.8 and 7.8 years respectively for glazed hybrid PVT module air collector and annualized uniform cost/kWh for thermal energy (3.6 Rs./kWh) is lower than exergy (15.7 Rs./kWh), if its lifetime is 30 years [17]. A hybrid PVT ultraviolet (UV)-stabilized polyethylene greenhouse dryer has been developed by considering various silicon and non-silicon based PV modules [18]. It is concluded that net annual electrical energy savings, annual thermal energy and annual exergy, energy payback factor, life cycle conversion efficiency, CO<sub>2</sub> mitigations and carbon credits obtained for c-Si type PV module have been calculated to be maximum due to the highest module efficiency and highest expected life [19]. Performance analysis in terms of carbon credit earned on annualized uniform cost of glazed hybrid PVT air collector has been done in the climatic condition of New Delhi. The effect of interest rates on annualized uniform cost for the lifetime (30 years), the carbon emission reduction based on overall thermal energy and exergy comes to Rs.1,09,242 and Rs.25275.6 [20]. A newer approach on cash flow diagram to investigate the effect of energy payback time and earned carbon credits on life cycle cost of different PVT array systems namely opaque type PVT array, solar cell tile array, and the semi-transparent array is proposed. It has also been observed that in terms of energy and exergy semi-transparent array type configuration is a better performer among all the cases [21]. The economic analysis of the drying process has been done using a hybrid PVT integrated indirect type solar dryer which is coupled with a solar heater under forced air circulation without any external power supply. Under load condition, test is performed on cauliflower and it is concluded that the total energy output and total energy payback period of the dryer has been calculated as 222.15kWh and 5.6 years respectively [22].

In this communication, an attempt has been made to evaluate CO<sub>2</sub> mitigation and energy matrices based on overall thermal energy and exergy of a hybrid solar dryer for Delhi climatic conditions. Numerical computations have been carried out by using energy balance equations for the proposed system as a function of design and climatic parameters.

### 1. Working Principle:

An indirect hybrid semi-transparent PVT solar dryer which comprises a semi-transparent PVT air collector unit and a drying chamber has been designed. The PVT air collector unit consists of a flat plate collector and semi-transparent PV module, which is integrated with the outlet of the kitchen chimney. The air entering into the collector unit is preheated by solar radiation received by the absorber below the semi-transparent PV module through the non-packing factor area. Hot air from the kitchen chimney forces itself towards the drying chamber unit through the semi-transparent PVT air collector and gets further heated by the heat trapped by the absorber

unit. This hot air absorbs moisture from the food to be dried which is kept on wire mesh trays while flowing in the upward direction in the drying chamber. Two exhaust fans of 12 W each, are provided at top of the drying chamber in the east and west walls. The duct of dimensions 2.2m x 0.65m x 0.05m and 50W semi-transparent PV module are attached to it. PVT air collector unit is kept at an angle of 30° with the horizontal to receive maximum solar radiation for Delhi climatic condition. The schematic diagram of the hybrid PVT dryer integrated with the kitchen chimney is shown in Fig. 1. The solar intensity and ambient temperature values with respect to time have been taken for the analysis under no-load conditions. Analysis of dryer has been carried out under no-load condition for four different chimney outlet temperatures i.e. 37°C, 47°C, 57°C and 72°C, whose values are always greater than the ambient temperature. The design parameters of the hybrid system are given in Table 1. The embodied energy of semi-transparent PVT solar dryer as shown in Fig.1 has been given in Table 2 along with the energy density of each component. The average monthly solar radiation and ambient air temperatures are given in Table 3a for Delhi's climate.

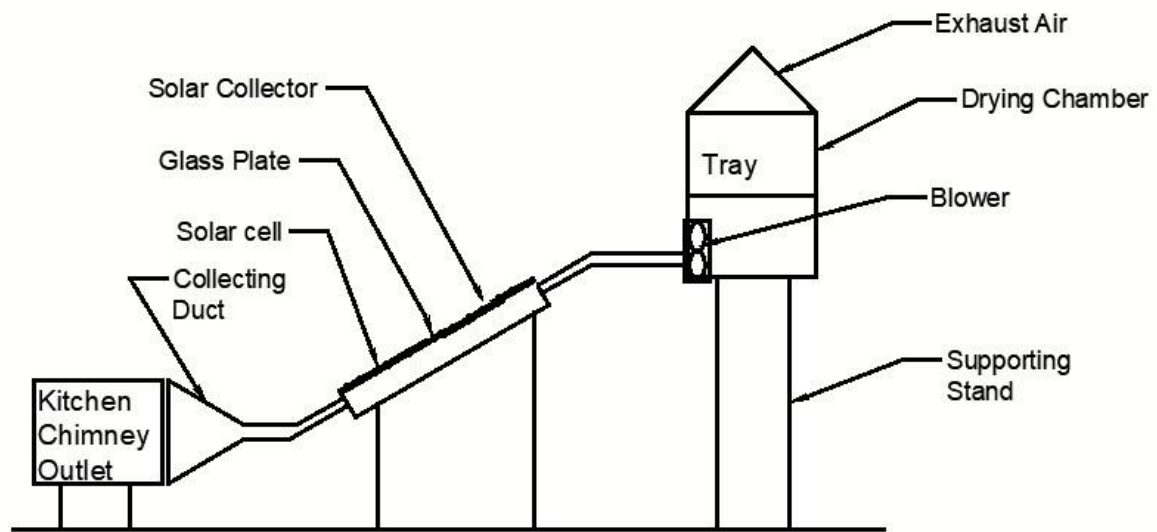


Fig. 1 Schematic diagram of indirect semi-transparent PVT Solar Dryer integrated with kitchen chimney

Table 1. Design Parameters values for the proposed semi-transparent PVT Dryer

Design Parameters	Values
$A_c$	1.07m <sup>2</sup>
$A_m$	0.357m <sup>2</sup>
$C_a$	1005J/kg K
$F_{Rm}$	1.0
$h_{p,f}$	14.82W/m <sup>2</sup> K
$\dot{m}$	0.078kg/s
$U_{bp,a}$	0.68 W/m <sup>2</sup> K
$U_{L,m}$	3.58 W/m <sup>2</sup> K
$U_{tc,a}$	9.5 W/m <sup>2</sup> K
$U_{tc,f}$	5.7 W/m <sup>2</sup> K
$\alpha_c$	0.9
$\beta_c$	0.22-0.83
$\eta_o$	0.12
$\alpha_p$	0.8
$\tau_g$	0.95

**Table 2:** Embodied energy ( $E_{in}$ ) calculation for semi-transparent PVT dryer

Sr. No.	Items used	Weight (kg)	Embodied energy (kWh/kg)	Embodied energy (kWh)
1	Glass	16	7.28	116.48
2	Steel Sheet	12	8.89	106.68
3	Black Paint	1	25.22	25.22
4	Plastic Sheets & Rubber Parts	1	25.64	25.64
5	Fasteners	1	8.89	8.89
6	Aluminium Sheet	15	55.28	829.2
7	Wood	22	2.89	63.58
8	Photovoltaic module	1	369.5	369.5
9	DC Fan	1.5	26.83	40.245
	<b>Grand Total</b>			<b>1585.4</b>

**Table 3a.** Monthly variation of solar Intensity

Month	No. of days in different climate types				Monthly solar intensity in four climate types (in W/m <sup>2</sup> )				
	type A	type B	type C	type D	type A	type B	type C	type D	Total
Jan	3	8	11	9	33660	75400	63855	42570	<b>215485</b>
Feb	3	4	12	9	33660	37700	69660	42570	<b>183590</b>
Mar	5	6	12	8	56100	56550	69660	37840	<b>220150</b>
Apr	4	7	14	5	44880	65975	81270	23650	<b>215775</b>
May	4	9	12	6	44880	84825	69660	28380	<b>227745</b>
Jun	3	4	14	9	33660	37700	81270	42570	<b>195200</b>
Jul	2	3	10	16	22440	28275	58050	75680	<b>184445</b>
Aug	2	3	7	19	22440	28275	40635	89870	<b>181220</b>
Sep	7	3	10	10	78540	28275	58050	47300	<b>212165</b>
Oct	5	10	13	3	56100	94250	75465	14190	<b>240005</b>
Nov	6	10	12	2	67320	94250	69660	9460	<b>240690</b>
Dec	3	7	13	8	33660	65975	75465	37840	<b>212940</b>
<b>Annual solar intensity</b>					<b>527340</b>	<b>697450</b>	<b>812700</b>	<b>491920</b>	<b>2529410</b>

**Table 3b:** Variation of ambient air temperature in four different climate types

Time	Ambient air temperature in four different climate types (in °C)			
	Type A	Type B	Type C	Type D
9:00 AM	30	27	15.5	11
9:30 AM	32	27.5	18	12
10:00 AM	33	28	19	13
10:30 AM	34	28	21	14
11:00 AM	35	29	23.5	15
11:30 AM	36	29.5	25	16
12:00 PM	37	30	28	17
12:30 PM	38	30.9	30	18

1:00 PM	39	32	31	19
1:30 PM	40	32	29	18
2:00 PM	39	31	28	17
2:30 PM	38	30.8	27	15
3:00 PM	37	30	25	13
3:30 PM	36	30	23	11
4:00 PM	35	29.5	21	10

**2. Thermal Modelling for a hybrid PVT hybrid Integrated with Kitchen Chimney:**

Following assumptions are made to write the energy balance equations for the proposed hybrid semi-transparent indirect PVT dryer:

- (i) Quasi-steady state condition has been considered for the proposed system.
- (ii) The transmissivity is considered as 100% for Ethyl Vinyl Acetate (EVA).
- (iii) The temperature variation is neglected along with the thickness and width.
- (iv) Resistance losses between two solar cells of semi-transparent PV modules have been neglected.

Using the first law of thermodynamics, energy balance equations for the proposed dryer have been written as:

**(a) For semi-transparent PV module:**

The energy balance equation for solar cells of a semi-transparent PV module can be written as[23],

$$\alpha_c \tau_g \beta_c I(t) b dx = [U_{tc,a}(T_c - T_a) + U_{tc,f}(T_c - T_f)] b dx + \tau_g \eta_c \alpha_c \beta_c I(t) b dx \tag{1}$$

**(b) For blackened absorber plate**

The energy balance equation for the absorber plate is given by,

$$[\alpha_p(1 - \beta_c)\tau_g^2 I(t)] b dx = [h_{p,f}(T_p - T_f) + U_{bp,a}(T_p - T_a)] b dx \tag{2}$$

**(c) For the air flowing through the duct**

The energy balance equation for the air which is flowing through the absorber plate can be written as,

$$\dot{m}_a C_a \frac{dT_f}{dx} dx = [h_{p,f}(T_p - T_f) + U_{Tc,f}(T_c - T_f)] b dx \tag{3}$$

For the boundary condition, x=0, T<sub>f</sub>=T<sub>ch</sub> and at x=L, T<sub>f</sub>=T<sub>fo</sub>, Eq (5) can give the following expression

$$T_{fo} = \left[ \frac{(\alpha\tau)m_{eff}I(t)}{U_{L,m}} + T_a \right] \left[ 1 - \exp\left(-\frac{bU_{L,m}L}{\dot{m}_a C_a}\right) \right] + T_{ch} \left[ \exp\left(-\frac{bU_{L,m}L}{\dot{m}_a C_a}\right) \right] \tag{4}$$

Where, T<sub>ch</sub> the outlet temperature at the exit of the kitchen.

**3.1 Thermal energy and exergy [24]**

At the end of the semi-transparent PVT collector, the rate of thermal energy and exergy available can be evaluated as,

$$\dot{Q}_{u,m} = \dot{m}_a C_a (T_{fo} - T_{ch}) \tag{5}$$

and,

$$\dot{Q}_{u,m,ex} = \dot{m}_a C_a \left[ (T_{fo} - T_{ch}) - (T_a + 273) \ln \frac{T_{fo} + 273}{T_{ch} + 273} \right] \quad (6)$$

### 3.2 Electrical efficiency and energy

For the known average temperature of fluid from Eq. 4, average  $T_c$  can be obtained from Eq (1). Then an electrical efficiency can be obtained as

$$\eta_{el} = \eta_o [1 - 0.0045(T_c - 25)] \quad (7a)$$

The hourly electrical energy produced by the solar panel of a hybrid dryer can be obtained by

$$E_{el} = \frac{\eta_{el} \times I(t) \times A_m \times N_{cl}}{1000} \quad (7b)$$

Eqs. 5, 6 and 7a & b have been used to compute the hourly variation of thermal, thermal exergy and electrical energy [24]. The obtained hourly results for thermal, thermal exergy and electrical energy have been converted into daily after adding the hourly data for each weather and after multiply with the number of days for particular weather, one gets monthly results.

The overall thermal energy and exergy of hybrid solar dryer have been computed as follows:

$$\text{Overall monthly thermal energy} = \text{Monthly thermal energy gain} + \frac{\text{Monthly electrical energy}}{\gamma} \quad (8)$$

where  $\gamma$  is the conversion factor of the thermal power plant and it is considered as 0.37 for best coal[25].

and,

$$\text{Overall monthly exergy} = \text{Monthly thermal exergy gain} + \text{Monthly electrical energy} \quad (9)$$

### 3.3 Methodology:

From India Meteorological Department, Delhi, India, the average hourly solar Intensity data in  $W/m^2$  (on a flat surface), the number of days under different weather types (A, B, C and D type) of various weather stations and the average ambient temperature in  $^{\circ}C$  of these weather types have been obtained and used for calculations. The four types of weather conditions such as ‘A’ type, ‘B’ type, ‘C’ type, ‘D’ type have been described as Clear day, Hazy day (fully), Hazy and cloudy (partially) and Cloudy day (fully) respectively. If the duration of sunshine hour is more than or equal to 9 h, then it is considered as A type or Clear day. If the sunshine hour is between 7 and 9 h. then it is described as ‘B’ type or Hazy day (fully). If the sunshine hour is between 5 and 7 h, then it is ‘C’ type or Hazy and cloudy (partially). If the sunshine hour is less than 5 h, then it is ‘D’ type or Cloudy day (fully). Amount of diffused radiation is also increased as the sunshine hours decreased in different weathers types. An average number of days of each type of weather for every month are as shown in Table 3b.[11]

## 3. RESULTS AND DISCUSSION

### 4.1 Thermal energy and exergy

By using Eqs. 8 and 9, numerical computation has been done for design and climatic parameters of Tables 1 and 3 respectively for a different exit air temperature of the kitchen. The results for overall thermal energy and exergy are given in Tables 4 and 5 respectively. It can be seen that overall thermal energy is maximum in all cases for May, October and November. It may due to high solar intensity, low ambient air temperature and more clear days (Table 3a). However, it decreases with the increase of exit air temperature due to more heat losses from the top of the semi-transparent photo-voltaic thermal (SPVT) air collector. Further, there is not much variation in overall exergy with the month of the year but an overall exergy increase with the increase of exit air temperature from

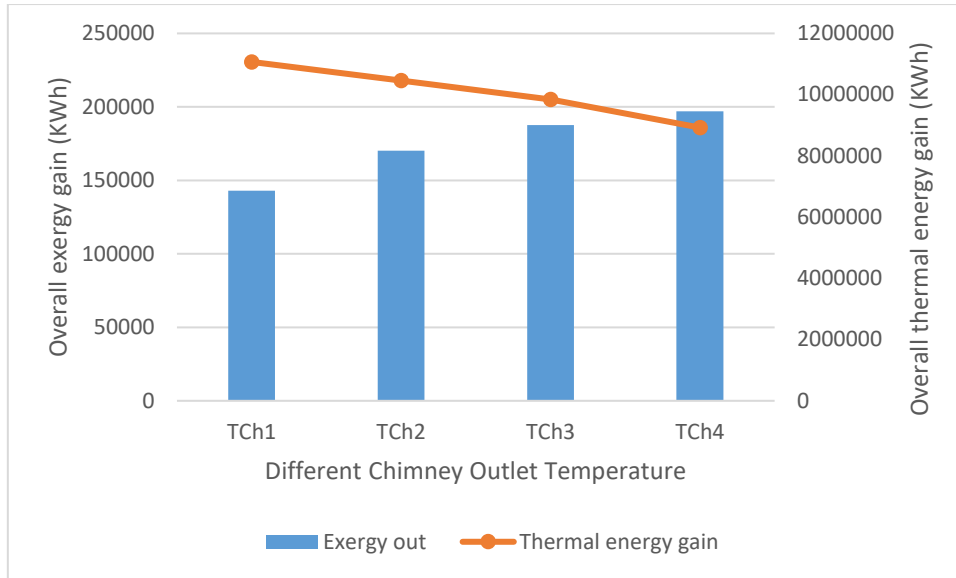
the kitchen as expected, unlike overall thermal energy. The comparison of annual exergy gain and thermal energy gain at different chimney outlet temperature for  $\beta=0.83$  indicated the same finding in graphical form (Fig. 2).

**Table 4.** Annual overall thermal energy gain for four different chimney outlet temperatures

Month	Monthly thermal energy gain for Tch1 (in KWh)	Monthly thermal energy gain for Tch2 (in KWh)	Monthly thermal energy gain for Tch3 (in KWh)	Monthly thermal energy gain for Tch4 (in KWh)
Jan	942960	890863	838766	760620
Feb	801891	755356	708821	639020
Mar	964378	912061	859744	781268
Apr	948384	897625	846867	770730
May	1000257	947581	894906	815893
Jun	853236	803448	753661	678980
Jul	798312	747679	697047	621098
Aug	780837	730357	679876	604156
Sep	926636	876049	825460	749579
Oct	1057554	1004300	951046	871165
Nov	1061516	1009582	957648	879748
Dec	932772	880795	828818	750853
<b>Annual Thermal Energy Gain (KWh)</b>	<b>11068734</b>	<b>10455696</b>	<b>9842660</b>	<b>8923112</b>

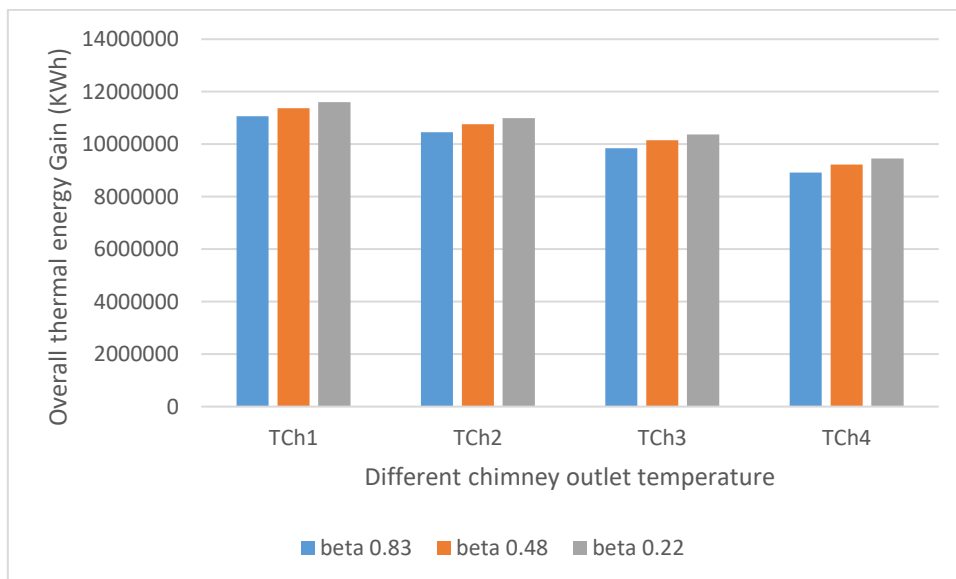
**Table 5.** Annual overall exergy out for four different chimney outlet temperatures

Month	Monthly exergy gain for Tch1 (in KWh)	Monthly exergy gain for Tch2 (in KWh)	Monthly exergy gain for Tch3 (in KWh)	Monthly exergy gain for Tch4 (in KWh)
Jan	12299	14608	16080	16871
Feb	10632	12481	13586	13990
Mar	12234	14680	16280	17251
Apr	11972	14439	16081	17150
May	12614	15242	17013	18222
Jun	11334	13294	14459	14866
Jul	11306	12837	13577	13351
Aug	11257	12665	13288	12899
Sep	11617	13946	15459	16349
Oct	12929	15875	17946	19572
Nov	12707	15760	17954	19791
Dec	12162	14439	15880	16630
<b>Annual Exergy Gain (KWh)</b>	<b>143063</b>	<b>170267</b>	<b>187602</b>	<b>196943</b>

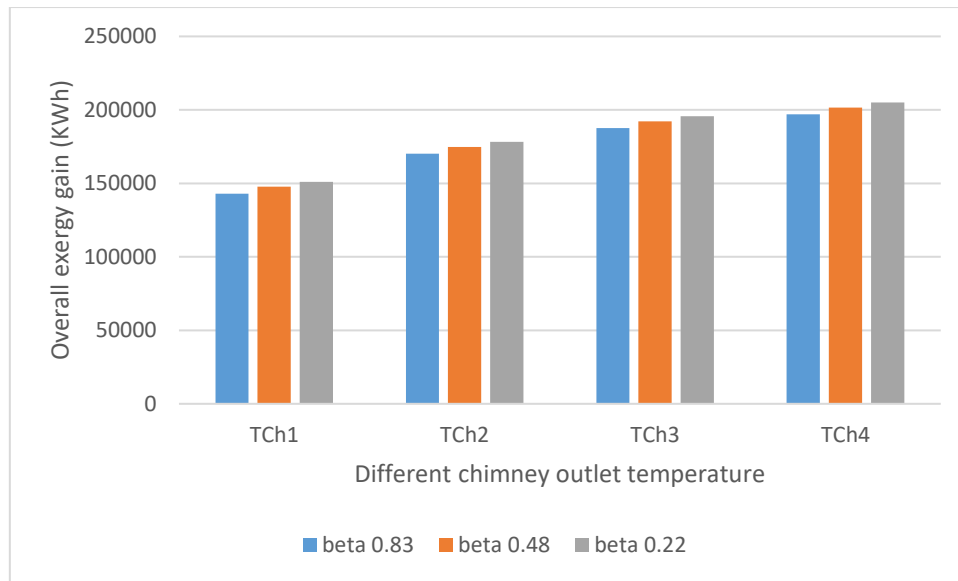


**Fig.2: Comparison of annual exergy gain and thermal energy gain at different chimney outlet temperature for  $\beta=0.83$**

The effect of the packing factor of the semi-transparent photo-voltaic module on the overall thermal and exergy of the system has been shown in Figs.3 for a different exit air temperature of the kitchen. This indicates that overall thermal energy and exergy increases with the decrease of packing factor due to the increase of direct gain (Fig. 3a). However, an overall thermal energy decrease with the increase of exit air temperature of kitchen, unlike exergy as explained earlier.



**Fig.3a: Annual thermal energy gain comparison for different packing factor at a different chimney outlet temperature**



**Fig.3b Annual exergy out the comparison for different packing factor at a different chimney outlet temperature**

**3.2 CO<sub>2</sub> emissions**

The CO<sub>2</sub> emission per year can be evaluated as

$$\text{CO}_2 \text{ emission per year} = \frac{E_{in}}{\text{Life Time}} \times 0.98 \text{ Kg} \tag{10}$$

where, E<sub>in</sub> = Embodied energy of hybrid dryer (Table 2). The life of the system has been considered as 20 years.

In India, if the losses due to poor domestic appliances and transmission are considered to be 20% and 40% respectively then the factor 0.98 increases to 1.58 and the CO<sub>2</sub> emission per year will be:

$$\text{CO}_2 \text{ emission per year} = \frac{E_{in}}{\text{Life Time}} \times 1.58 \text{ Kg} \tag{11}$$

The CO<sub>2</sub> emission over lifetime of the system can be obtained as

$$\text{CO}_2 \text{ emission over lifetime of the system} = E_{in} \times 1.58 = 2505 \text{ Kg} \tag{12}$$

**4.3 CO<sub>2</sub> mitigation**

The CO<sub>2</sub> mitigation per year can be evaluated as

$$\text{CO}_2 \text{ mitigation per year} = E_{aout} \times 1.58 \tag{13}$$

$$\text{CO}_2 \text{ mitigation over lifetime of the system} = E_{aout} \times \text{total life span} \times 1.58 \text{ kg} \tag{14}$$

$$\text{The net CO}_2 \text{ mitigation over the lifetime of the system} = \text{Total CO}_2 \text{ mitigation} - \text{Total CO}_2 \text{ emission} = (E_{aout} \times \text{total life span} - E_{in}) \times 1.58 \text{ kg} \tag{15}$$

$$\text{The net CO}_2 \text{ mitigation over the lifetime of the system in tonnes of CO}_2 \text{ is given by} = (E_{aout} \times \text{total life span} - E_{in}) \times 1.58 \times 10^{-3} \text{ tonnes} \tag{16}$$

where, E<sub>aout</sub> is the overall exergy gain, Eq. 9 which is the sum of the electrical exergy and thermal exergy, Table 3b. CO<sub>2</sub> mitigation calculations for different chimney outlet temperatures considering the total life span of 20 years have been shown in Table 5. It is observed that as kitchen chimney outlet temperature increases, CO<sub>2</sub> mitigation also increases due to the utilization of co-generation.

**Table 5: CO<sub>2</sub> mitigation for four different chimney outlet temperatures**

	<b>Exergy gain (KWh)</b>	<b>CO<sub>2</sub> mitigation (in tonnes)</b>
<b>For Tch1</b>	143063	4516.83
<b>For Tch2</b>	170267	5376.47
<b>For Tch3</b>	187602	5924.26
<b>For Tch4</b>	196943	6219.44

#### 4.4 Energy Matrices

Energy matrices of any system determine the feasibility of the success of the technology. For this following parameters have been computed:

- (a) **Energy payback time (EPBT):** This determines the period to recover invested energy to develop a hybrid dryer. It should be as minimum as possible and it is evaluated as

$$EPBT = \frac{E_{in}}{\text{Annual energy}} \tag{17}$$

Here annual energy can be either thermal or exergy.

By using the data of annual thermal energy and exergy from Table 2 and 3, one gets

$$EPBT \text{ (thermal energy based)} = \frac{1585.4}{11068734} = 0.00014 \text{ years} = 0.05 \text{ day} \ll 1$$

(Which is negligible for chimney 1)  
and,

$$EPBT \text{ (exergy based)} = \frac{1585.4}{143063} = 0.011 \text{ years} = 4.04 \text{ day} \ll 1$$

(Which is negligible for chimney 1)

This indicated that the use of exit hot chimney air is most economical from an energy as well exergy point of view. Similar calculations and conclusions can be made for other chimneys.

- (b) **Energy production factor (EPF):** It is a factor which determines how many time energy is obtained from any system in comparison with embodied energy and it can be expressed as

$$EPF = \frac{\text{annual energy} \times \text{life time}}{E_{in}} \tag{18}$$

The EPF can be obtained by using the data of Tables 2 and 3 as

$$EPF \text{ (Thermal energy base)} = \frac{11068734 \times 20}{1585.4} = 139633.33 \gg 1$$

and,

$$EPF \text{ (Exergy basis)} = \frac{143063 \times 20}{1585.4} = 1804.76 \gg 1$$

- (c) **Life cycle conversion efficiency (LCCE):** It is a ratio of effective energy obtained and available solar energy in the lifetime of the system and it is defined as

$$LCCE = \frac{\text{Annual energy} \times \text{Life of system} - E_{in}}{\text{Annual solar radiation} \times \text{area of collector} \times \text{Life of system}} < 1 \tag{19}$$

where annual solar radiation is 2529410 W/m<sup>2</sup>

Further by using the data of Table 2 and 3, one has

$$LCCE \text{ (Thermal energy base)} = \frac{11068734 \times 20 - 1585.4}{2529410 \times 20} = 0.21$$

and,

$$LCCE(\text{Exergy basis}) = \frac{143063 \times 20 - 1585.4}{2529410 \times 20} = 0.0028$$

In both cases, the numerical values are less than one and hence the system is more effective from a thermal exergy point of view as per our expectation because solar dryer should be designed from the thermal point of view. Such a system is also a self-sustained system without any grid power requirement.

#### 4. CONCLUSIONS:

The following conclusions have been drawn from the proposed solar SPVT dryer:

- (i) Exit air temperature from the kitchen act as a co-generation of thermal energy to the solar dryer which may reduce the drying time
- (ii) It is predictable from EPBT, EPF and LCCE from view
- (iii) Annual exergy gain and annual thermal energy gain increases as the packing factor decreases
- (iv) CO<sub>2</sub> mitigation also increases as the kitchen chimney outlet temperature increases.

#### Nomenclature:

A	= area in m <sup>2</sup>
b	= width in m
C	= specific heat in J/kg °C
F <sub>R</sub>	= heat removal factor
h	= heat transfer coefficient in W/m <sup>2</sup> °C
hp1, hp2	= penalty factor due to the glass cover of PV module
I(t)	= incident solar intensity in W/m <sup>2</sup>
L	= length in m
m	= rate of flow of air in kg/s
N	= number of values
T	= temperature in °C
U <sub>tc,a</sub>	= overall heat transfer coefficient from solar cell to ambient in W/m <sup>2</sup> °C
U <sub>tc,f</sub>	= overall heat transfer coefficient from solar cell to flowing air in W/m <sup>2</sup> °C
U <sub>b</sub>	= overall back loss coefficient from flowing air to ambient in W/m <sup>2</sup> °C
U <sub>L</sub>	= overall heat transfer coefficient in W/m <sup>2</sup> °C
V	= air velocity in m/s

#### Subscripts

1	= kitchen chimney outlet temperature 37 °C
2	= kitchen chimney outlet temperature 47 °C
3	= kitchen chimney outlet temperature 57 °C
4	= kitchen chimney outlet temperature 72 °C
a	= ambient
c	= solar cell
cal	= calculated value
ch	= kitchen chimney exhaust
cl	= clear hour in a day
el	= electrical
f	= flowing air
fi	= inlet flowing air
fo	= outgoing flowing air
g	= glass
m	= module
p	= blackened plate
s	= sun
th	= thermal

**Greek letters**

$\alpha$	= absorptivity
$(\alpha\tau)_{\text{eff}}$	= product of effective absorptivity and transmittivity
$\beta$	= packing factor
$\zeta$ -power	= electric power generation efficiency = 0.38 for a conventional power plant
$\eta_0$	= efficiency at standard condition at $I(t) = 1000 \text{ W/m}^2$ and $T_a = 25 \text{ }^\circ\text{C}$
$\tau$	= transmittivity

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