ISSN 2229-5518

Performance of semi-transparent photovoltaic systems integrated with buildings on exergy basis: A review.

Neha Gupta*

Abstract: In this communication, a review has been done to understand the performance of semi-transparent photovoltaic system integrated with roof top of a building based on exergy analysis. Analytical expressions for calculating the thermal exergy based on both low and high operating temperatures, total exergy, output and input exergy and exergy efficiency have been written. Based on which, graphical representations of a proposed roof top integrated with semi-transparent photovoltaic module of a room have been plotted. Impact of number of air changes has also been reviewed on exergy analysis of BiSPVT system.

Index Terms: BiSPVT system, Exergy efficiency, Input exergy, Number of air changes, Output exergy.

1 INTRODUCTION

As stated by second law of thermodynamics, we can neither create energy nor destroy it. The second law of thermodynamics functions for higher operating temperature range (≫ 400 ℃). This law gives rise to the concept of exergy. Exergy may be expressed as the maximum output work as it reached in equilibrium with its surroundings. The numeric value of exergy will be equal to zero for the system in equilibrium with its surroundings.

The concept of exergy can be further explained by taking a simple example of a water fall. With fall of water from the height, potential energy is transformed into kinetic energy. Lastly, this kinetic energy is converted into thermal energy. The energy is conserved during this process since it is converted from one form to another. At the same time, no work is produced during the process, thus either energy is destroyed or lost. This lost energy is referred as exergy.

The quality of energy is more significant than the quantity. Exergy has been explained as a qualitative aspect of energy by Saloux et al. [1]. Exergy study is a strong instrument to assess the system that involves several sources of energy. Both first and second law of thermodynamics are used to determine the exergy of a system and thus helps to classify the main source of exergy losses [2], [3], [4]. The exergy analysis helps us to identify the sources of irreversibility and inefficiencies so that the losses can be reduced, ultimately maximum resource, efficiency and capital savings may be achieved. Thus, to achieve the same, a careful selection of technology, design optimization shall be done.

Photovoltaic systems when integrated with the building as a part of the façade, roof top, or any other element of the structure is known as Building integrated Photovoltaic Thermal (BiPVT) systems [5], [6], [7]. When the module chosen for integration is semi-transparent, the system is referred to as Building integrated Semi-transparent Photovoltaic (BiSPVT) system [8], [9], [10]. Various literatures are available to understand the performance of BiSPVT system on the basis of energy matrices [11], energy and exergy performances [12], [13], [14], [15]. It is important to analyze the said systems on the basis of exergy because different forms of energy are involved and to conclude the actual performance, exergy analysis acts as an important tool.

As discussed, the energy output from solar technologies can be broadly classified into low-grade and high-grade energy.

- First law of thermodynamics gives the basis of low-grade energy. An example of the same is the thermal energy obtained from back side of the photovoltaic module or the thermal energy available to the room from floor.
- Second law of thermodynamic gives the basis of high-grade energy which is referred as

* ar.nehagupta@gmail.com

exergy analysis. The electrical energy output of a PV system is an example for high grade energy.

Application of both high-grade (electrical energy) and low-grade (thermal energy) can be seen in Photovoltaic Thermal (PVT) systems. To assess the overall potential of the proposed system, either electrical energy should be converted to low-grade energy [4] or thermal energy should be converted to high-grade energy with the help of Carnot's efficiency concept.

The source of thermal energy (low-grade energy) that is available to the room under consideration is from the back side of the SPV modules and the solar radiation absorbed from non-packing area of SPV modules by the floor to the room which is integrated with Semi-transparent Photovoltaic (SPV) modules at roof top. Thus, it is important to convert this low-grade energy into thermal exergy to assess the overall exergy. (Refer Fig. 1)

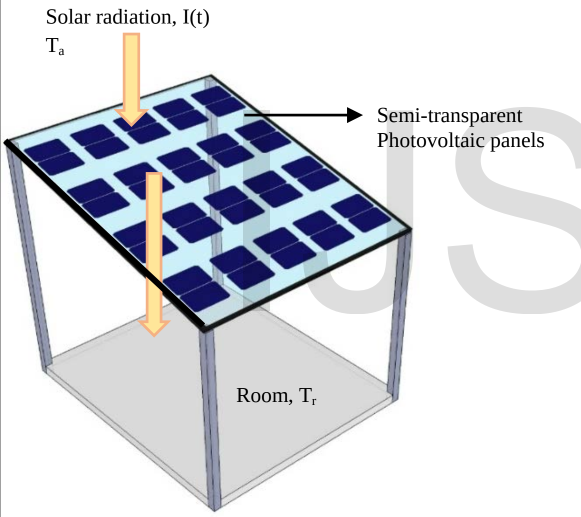

Fig.1. Roof top of a room integrated with semi-transparent photovoltaic modules.

2 THERMAL MODELLING

Exergy analysis for the proposed system integrated with semi-transparent photovoltaic modules are based on the following equations.

The rate of thermal exergy can be determined as explained below [16], [17], [18], [19]:

Case (i) For high operating temperature (second law of thermodynamics)

- From floor to room

$$\dot{E}x_{thf(i)} = Q_f\left(1 - \frac{T_a}{T_f}\right), \quad (1a)$$

where,

$$Q_f = A_f h_c (T_f - T_r)$$

- From rear side of SPV module to room:

$$\dot{E}x_{thc(i)} = Q_f\left(1 - \frac{T_a}{T_c}\right), \quad (1b)$$

where,

$$Q_f = A_R h_c (T_c - T_r)$$

- Total hourly thermal exergy is the sum of above thermal exergies and can be expressed as:

- $\dot{E}x_{th(i)} = \dot{E}x_{thf(i)} + \dot{E}x_{thc(i)}$ (1c)

Case (ii) For low operating temperature (first law of thermodynamics),

- From floor to room:

$$\dot{E}x_{thf(ii)} = A_f h_c\left[(T_f - T_r) - (T_a + 273)ln\frac{T_f + 273}{T_r + 273}\right] \quad (2a)$$

- From rear side of SPV module to room:
-

$$\dot{E}x_{thc(ii)} = A_R h_c\left[(T_c - T_r) - (T_a + 273)ln\frac{T_c + 273}{T_r + 273}\right] \quad (2b)$$

- Total hourly thermal exergy is the sum of bove exergies and can be expressed as:

$$\dot{E}x_{th(ii)} = \dot{E}x_{thf(ii)} + \dot{E}x_{thc(ii)} \quad (2c)$$

2.1 Output exergy

The output exergy can be calculated by summing up electrical power ($\dot{E}_e$) [20], thermal energy (either Eq. 1c or 2 c) and day light savings ($\dot{E}x_{sun,daylight}$) [21] and is given by:

Net output exergy = $\dot{E}_e + \dot{E}x_{th(ii)} + \dot{E}x_{sun,daylight}$

2.2 Input exergy

The net input exergy can be defined as the exergy of solar radiation on SPV modules [22], [18]

$$\dot{E}x_{sun} = \{A_m \ I(t)\}\left[1-\frac{4}{3}\left(\frac{T_a}{T_s}\right)+\frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right] \quad (3)$$

where, the temperatures in Eq. 3 are in Kelvin.

2.3 Exergy efficiency

An overall exergy efficiency ($\eta_{o,ex}$) and thermal exergy efficiency ($\eta_{th,ex}$) and of BiSPVT can be calculated as follows:

- An overall exergy efficiency is given by:

$$\eta_{o,ex} = \frac{\dot{E}_e+\dot{E}x_{th(ii)}+\dot{E}x_{sun,daylight}}{\dot{E}x_{sun}} \quad (4a)$$

- Using Eqs. 2c and 3, thermal exergy efficiency is given by:

$$\eta_{th,ex} = \frac{\dot{E}x_{th(ii)}}{\dot{E}x_{sun}} \quad (4b)$$

Using above equations, design parameters [13], climatic conditions (Fig. 2) of a typical day of Varanasi, India for the month of January, Fig. 3. gives thermal exergy of the proposed room (of 9.18 m^2, Fig. 1.) where Semi-transparent Photovoltaic (SPV) modules are integrated at the roof top for high and low operating temperatures with number of air changes, $N_1 = 2$. Hourly variation of thermal exergy based on low operating temperature is plotted in Fig. 4 for different number of air changes.

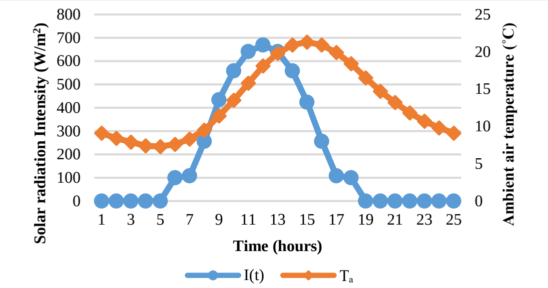

Fig. 2. Solar radiation intensity and ambient temperature.

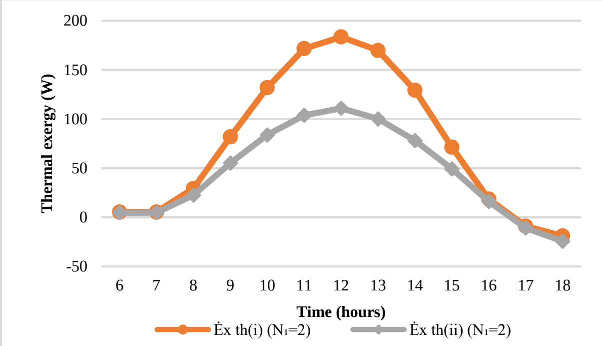

Fig. 3. Thermal exergy on high ($\dot{E}x_{th(i)}$) and low operating temperature ($\dot{E}x_{th(ii)}$).

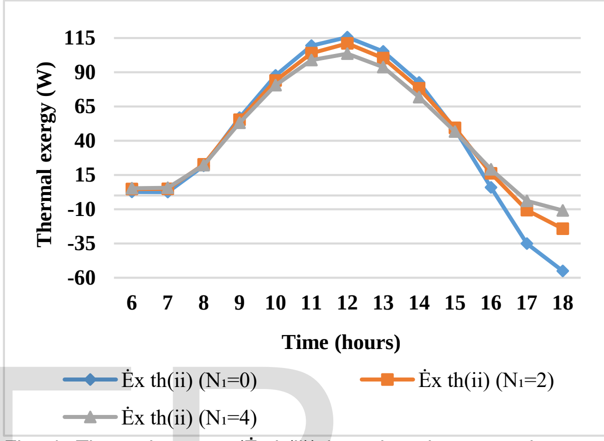

Fig. 4. Thermal exergy (Ėxth(ii)) based on low operating temperature.

Fig. 5 gives an overall hourly variation of exergy for different air changes. Due to dominance of electrical and day light savings, overall exergy achieved at noon hours for N_1=4 is 1281 Wh. No significant impact of air changes can be seen on total thermal exergy due to variation in number of air changes. With increase in the air changes from 0 to 4, about 1.15 % increase in overall daily exergy can be noticed.

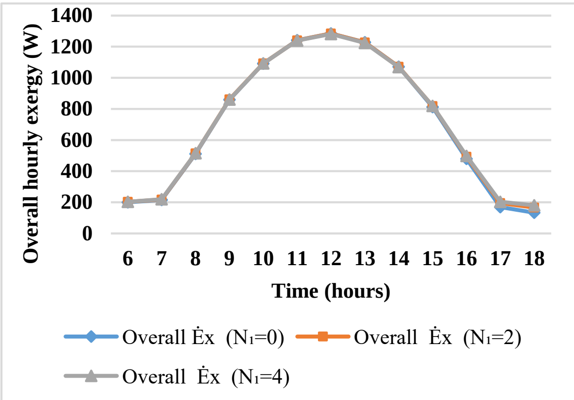

Fig. 5. Overall hourly exergy.

3 CONCLUSION:

Impact of air changes has been studied on exergy analysis of BiSPVT system. It has been found with increase in air changes from 0 to 4, daily thermal exergy drops by 6.28 % and overall thermal exergy increases by 1.15 %.

ACKNOWLEDGEMENT

Author would like to thank IJSER to partly fund the paper.

NOMENCLATURE

A	Area		m^2
$\dot{E}_e$	Electrical power		W
$\dot{E}x_{th}$	Total thermal exergy		W
$\dot{E}x_{thf}$	Rate of thermal exergy from floor to room		W
$\dot{E}x_{thc}$	Rate of thermal exergy from PV module to room		W
h_c	Convective heat transfer coefficient		W/m^2 K
I(t)	Solar intensity		W/m^2
N_1	Number of air changes per hour		-
T	Temperature		°C
T_s	Sun surface temperature		K
Subscript			
(i)	Case (i)	f	Floor of room
(ii)	Case (ii)	m	PV module
a	Ambient air	r	Room
c	Solar cell	R	Roof

REFERENCES

[1] E. Saloux, A. Teyssedou and M. Sorin, "Analyysis of photovoltaic (PV) and photovoltaic/thermal (PV/T) systems using the exergy method.," Energy and Buildings, vol. 67, pp. 272-285, 2013.

[2] A. Joshi, I. Dincer and B. Reddy, "Thermodynamic assessment of photovoltaic systems.," Solar Energy, vol. 83, pp. 1139-1149, 2009.

[3] A. Sahin, I. Dincer and M. Rosen, "Thermodynamic analysis of solar photovoltaic cell systems.," Solar Energy Materials and Solar Cells, vol. 91, pp. 153-159, 2007.

[4] N. Gupta, A. Tiwari and G. Tiwari, "Exergy analysis of building integrated semitransparent photovoltaic thermal (BiSPVT) system.," Engineering Science and Technology, an International Journal, 2016.

[5] N. Gupta, "Exploring passive cooling potentials in Indian vernacular architecture.," Journal of Buildings and Sustainability, vol. 1, no. 2, 2017.

[6] N. Gupta and G. N. Tiwari, "Review of passive heating/cooling systems of buildings.," Energy Science & Engineering, September 2016.

[7] N. Gupta and G. Tiwari, "A thermal model of hybrid cooling systems for building integrated semitransparent photovoltaic thermal system.," Solar Energy, vol. 153, pp. 486-498, 2017.

[8] G.N.Tiwari, H. Saini, A. Tiwari, a. Deo, N. Gupta and P. S. Saini, "Periodic theory of building integrated photovoltaic thermal (BiPVT) system.," Solar Energy, vol. 125, pp. 373-380, February 2016.

[9] S. Baljit, H.-Y. Chan and K. Sopian, "Review of building integrated applications of photovoltaic and solar thermal systems.," Journal of cleaner production, vol. 137, pp. 677-689, 2016.

[10] N. Gupta and G. N. Tiwari, "Parametric study to understand the effect of various passive cooling concepts on building integrated semitransparent photovoltaic thermal system.," Solar Energy, vol. 180, pp. 391-400, 2019.

[11] N. Gupta and G. Tiwari, "Energy matrices of Building integrated Photovoltaic Thermal Systems: A case study.," Journal of Architectural Engineering., 2017b.

[12] N. Gupta and G. Tiwari, "Effect of heat capacity on monthly and yearly exergy performance of building integrated semitransparent photovoltaic thermal system.," Journal of Renewable and Sustainable Energy., vol. 9, 2017a.

[13] N. Gupta, A. Tiwari and G. Tiwari, "Exergy analysis of building integrated semitransparent photovoltaic thermal (BiSPVT) system.," Engineering Science and Technology, an International Journal, pp. 41-50, 2016.

[14] K. Vats and G. Tiwari, "Energy and exergy analysis of a building integrated semitransparent photovoltaic thermal (BISPVT) system.," Applied Energy, vol. 96, pp. 409-416, 2012.

[15] A. S. Joshi, I. Dincer and B. V. Reddy, "Performance analysis of photovoltaic systems: A review," Renewable and Sustainable Energy Reviews, vol. 13, no. 8, pp. 1884-1897, October 2009.

[16] M. Hedayatizadeh, F. Sarhaddi, A. Safavinejad, F. Ranjbar and H. Chaji, "Exergy loss- based efficiency optimization of a double- pass/ glazed v-corrugated plate solar air heater.," Energy, vol. 94, pp. 799-810, 2016.

[17] J. Yazdanpanahi, F. Sarhaddi and M. M. Adeli, "Experimental investigation of exergy efficiency of asolar photovoltaic thermal (PVT) water collector based on exergy losses.," Solar Energy, vol. 118, pp. 197-208, 2015.

[18] A. Bejan, "General criterion for rating heat-exchanger performance.," Heat mass transfer, vol. 21, pp. 655-658, 1978.

[19] C. Yunus and B. Micheal, Thermodynamic by Engineering Approach, 5th edition., McGrawHill, 2008.

[20] N. Gupta, G. N. Tiwari, A. Tiwari and V. S. Gupta, "New model for building- integrated semitransparent photovoltaic thermal system.," Journal of Renewable and Sustainable Energy, vol. 9, 2017.

[21] N. Gupta and G. Tiwari, "Effect of water flow on building

integrated semitransparent photovoltaic thermal system with heat capacity.," Sustainable cities and Society, vol. 39, pp. 708-718, 2018.

[22] R. Petela, "Exergy of undiluted thermal radiation.," Solar Energy, vol. 74, pp. 469-488, 2003.