rate of 0.003 kg/sec. The maximum average overall efficiency of PV/T was found to be 67.16% for the mass flow rate of 0.003 kg/sec. The exergy efficiency of PV/T varies from 5% to 13% for the mass flow rate of 0.002 kg/sec. The maximum average exergy efficiency of PV/T was found to be 11.26% for the mass flow rate of 0.002 kg/sec. With increase in mass flow rate of water, average electrical efficiency of solar PV/T system increases as compared with solar PV system. This is because of the increase in mass flow rate of water increases the cooling rate of panel. Exergy analysis of solar PV/T system was also carried out for different mass flow rate of water and it was found that with increase in mass flow rate of water the exergy efficiency of solar PV/T system decreases. PV/T application can offer sustainable solution for maximizing the solar energy output from building integrated photovoltaic system. This kind of PV/T system is especially suitable for low temperature applications like pre-heating of domestic water.

Nomenclature

η_f	Energy Saving Efficiency	%
η_{th}	Thermal Efficiency	%
η_e	Electrical Efficiency	%
η_o	Overall Efficiency	%
V_{oc}	Open circuit voltage	V
V	Voltage	V
V_{mp}	Voltage at maximum power point	V
I_{mp}	Current at maximum power point	A
I_{sc}	Short circuit current	A
I	Current	A
FF	Fill factor	No units
m	Mass flow rate	Kg/sec
A	Surface area of the module	m^2
G	Global irradiance	W/m^2
K	Boltzmann constant	J/K
P_{el}	Electrical power	W
P_{max}	Maximum power	W
T	Temperature	K
T_a	Ambient temperature	K
T_m	Module temperature	K
NOCT	Nominal operating cell temperature	^oC

References

[1] V.V. Tyagi, S.C. Kaushik, S.K. Tyagi, "Advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology", Renewable and Sustainable Energy Reviews 16 (2012) 1383– 1398
[2] Wei He et. al. " Hybrid photovoltaic and thermal solar collector designed for natural circulation of water" Applied energy 83(2006) 199-210
[3] Boddaert S, Caccavelli D. Hybrid PVTh Panel optimisation using a Femlab/ Matlab/Simulink approach. Environment Identities and Mediterranean Area, ISEIMA'06. In: First international Symposium on 2006. 2006. p. 121–6.
[4] Tiwari A, Sodha MS. Performance evaluation of hybrid PV/thermal water/air heating system: a parametric study. Renewable Energy 2006;31:2460–74.
[5] Zondag HA, de Vries DW, van Helden WGJ, van Zolingen RJC, van Steenhoven AA. The yield of different combined PV-thermal collector designs. Solar Energy 2003;74:253–69.
[6] Fraisse G, Me´ne´zo C, Johannes K. Energy performance of water hybrid PV/T collectors applied to combisystems of Direct Solar Floor type. Solar Energy 2007;81(11):1426–38.
[7] Sandnes B, Rekstad J. A photovoltaic/thermal (PV/T) collector with a polymer absorber plate. Experimental study and analytical model. Solar Energy 2002;72:63–73.
[8] Ji Jie, Chow Tin-Tai, He Wei. Dynamic performance of hybrid photovoltaic/ thermal collector wall in Hong Kong. Build Environ 2003;38:1327–34.
[9] Vokas G, Christandonis N, Skittides. Hybrid photovoltaic-thermal systems for domestic heating and cooling – a theoretical approach. Sol Energy 2006;80:607–15.
[10] Duffie, J. A, Beckman, W. A, 1991. Solar Engineering of Thermal Processes, 2nd ed., John Wiley and Sons, New York, USA.
[11] Wong, K.F.V., 2000. Thermodynamics for engineers. University of M iami, CRC Press LLC.
[12] A. Hepbasli, A key review on exergetic analysis and assessment of renewable energy resources for a sustainable future,Renewable Sustainable Energy Rev., 12 (2008) 593–661.
[13] Bejan, A., 1998. Advanced engineering thermodynamics. John W iley & Sons Ltd., Chichester, UK.
[14] Kotas, T.J., 1995. The exergy method of thermal plant analysis. M alabar, FL: Krieger Publish Company.
[15] Petela, R., 2003. Exergy of undiluted thermal radiation. Solar Energy, 74: 469-488.
[16] Wei He et. al. " Hybrid photovoltaic and thermal solar collector designed for natural circulation of water" Applied energy 83(2006) 199-210.
[17] Huang BJ et. al. Performance evaluation of solar photovoltaic/thermal systems. Sol Energy 2001;70;443-8.
[18] Huang BJ et. al. A performance test method for solar thermosyphon systems. ASME J Sol Energy 1991; 113; 172-9.
[19] P.G. Charalambous et.al. "Photovoltaic thermal (PV/T) collectors: A review". Applied Thermal Engineering 27 (2007) 275–286.
[20] S.A. Kalogirou and Y. Tripanagnostopoulos, "Hybrid PV/T solar systems for domestic hot water and electricity production". Energy Conversion and Management 47 (2006) 3368–3382
[21] Kumar S, Tiwari A. An experimental study of hybrid photovoltaic thermal (PV/T)-active solar still. International Journal of Energy Research 2008;32(9):847–58.
[22] Tripanagnostopoulos Y. Aspects and improvements of hybrid photovoltaic/ thermal solar energy systems. Solar Energy 2007;81:1117–31.
[23] Deffeyes KS. Hubbert's peak: the impending world oil shortage. Princeton, NJ: Springer Netherlands; 2002.

[24] Bardi U. Peak oil: the four stages of a new idea. Energy 2009; 34:323–6.
[25] Sadorsky P. Oil price shocks and stock market activity. Energy Economics 1999; 21:449–69.
[26] Pareto VEIV, Pareto MP. The urban component of the energy crisis. SSRN; 2008.
[27] Constatntinos A, Bouroussis FVT. Optimization of potential and autonomy of a photovoltaic system for street lighting. WSEAS Transactions on Circuits and Systems 2004; 3.
[28] Hoffmann W. PV solar electricity industry: market growth and perspective. Solar Energy Materials and Solar Cells 2006;90:3285–311.
[29] Zondag HA. Flat-plate PV-thermal collectors and systems: a review. Renewable and Sustainable Energy Reviews 2008;12:891–959.
[30] Prakash J. Transient analysis of a photovoltaic-thermal solar collector for cogeneration of electricity & hot air/water. Energy Conversion Management 1994;35(11):967–72.
[31] Bhargava AK, Garg HP, Agarwal RK. Study of a hybrid solar system—solar air heater combined with solar cells. Energy Conversion and Management 1991;31:471–9.
[32] Bakker M, Zondag HA, Elswijk MJ, Strootman KJ, Jong MJM. Performance and costs of a roof-sized PV/thermal array combined with a ground coupled heat pump. Solar Energy 2005; 78:331–9.
[33] Bazilian MD. Photovoltaic cogeneration in the built environment. Fuel and Energy Abstracts 2002;43. 269.
[34] Charalambous PG, Maidment GG, Kalogirou SA, Yiakoumetti K. Photovoltaic thermal (PV/T) collectors: a review. Applied Thermal Engineering 2007;27: 275–86.
[35] Chow TT. A review on photovoltaic/thermal hybrid solar technology. Applied Energy 2009;87:365–79.
[36] Pratish Rawat, Mary Debbarma, Saurabh Mehrotra, K.Sudhakar, Prakash Sahu, “Performance Evaluation of Solar Photovoltaic/Thermal Hybrid Water Collector” Impending Power Demand and Innovative Energy Paths, ISBN: 978-93-83083-84-8, 278-285.
[37] Pratish Rawat, Mary Debbarma, Saurabh Mehrotra, K.Sudhakar “Design, Development and Experimental Investigation Of Solar Photovoltaic/Thermal (Pv/T) Water Collector System”, International Journal of Science, Environment and Technology, Vol. 3, No 3, 2014, 1173 – 1183

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Author Profile

Mr. Pratish Rawat is currently working as an Assistant Professor in Department of Mechanical Engineering in Poornima University, Jaipur. He obtained his B.E. in Mechanical Engineering from R.G.P.V. Bhopal and MTech in Renewable Energy from Maulana Azad National Institute of Technology, Bhopal. His major research area includes: Energy Management and Audit, Climate Change, Hybrid System, Solar Thermal & PV Systems, Wind Energy and Energy Conservation. He has published number of research papers in national and international journals. He also published book on solar PV/T with LAP lambert academic publishing.