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Energy Payback Time Calculation for a Building Integrated Semitransparent Thermal (BISPVT) System with Air Duct

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Abstract - This paper evaluates the energy payback time (EPBT) of building integrated photovoltaic thermal (BISPVT) system for Srinagar, India. Three different photovoltaic (PV) modules namely mono crystalline silicon (m-Si), poly crystalline silicon (p-Si), and amorphous silicon (a-Si) have been considered for calculation of EPBT. It is found that, the EPBT is lowest in m-Si. Hence, integration of m-Si PV modules on the roof of a room is economical.

Index Terms - Embodied energy, Energy payback time, Photovoltaic

1. INTRODUCTION

Development in the design and manufacture of photovoltaic cells has been very rapid over the last few years because they are now predicted to become a major renewable energy source. The embodied energy payback time is important for renewable technologies as their use makes no sense if the energy used in their manufacture is more than they can save in their life-time. Energy payback time (EPBT) of a PV module is defined as the ratio of energy consumed to produce the PV system to annual energy generated from the PV system by using solar energy. Slesser and Houman [1] have been reported that the energy payback time (EPBT) of a PV module is 40 years. Aulich et al. [2] have evaluated the energy payback time of 8 years for a crystalline silicon module. The energy payback time for a crystalline silicon solar cell module under Indian climatic condition for annual peak load duration is about 4 years, Prakash and Bansal [3]. Keolein and Lewis [4] have predicted the energy payback time (EPBT) of 7.4 years for an amorphous silicon (a-Si) solar cell module for the climatic conditions of Detroit, USA.

Yamada et al. [5] have evaluated the energy payback time (EPBT) for both polycrystalline and amorphous silicon solar cell and reported the energy payback time of 5.7 and 6.3 years respectively at annual power production rate of 0.01 GW/y. Battisti and Corrado [6] have investigated the energy payback time (EPBT) for a conventional multi-crystalline building integrated system, retrofitted on an inclined roof, located in Rome (Italy); with yearly global insolation on a horizontal plane was taken as 1530 kWh/m^2y. They have concluded that energy payback time (EPBT) gets reduced from 3.3 years to 2.8 years. In this paper, energy payback time (EPBT) based on overall thermal energy and exergy output from BISPVT system with duct, for Srinagar, India has been evaluated.

2. EMBODIED ENERGY

Embodied energy is defined as: "the quantity of energy required by all of the activities associated with a production process, including the relative proportions consumed in all activities upstream to the acquisition of natural resources and the share of energy used in making equipments and in other supporting functions i.e. direct energy plus indirect energy", Treloa

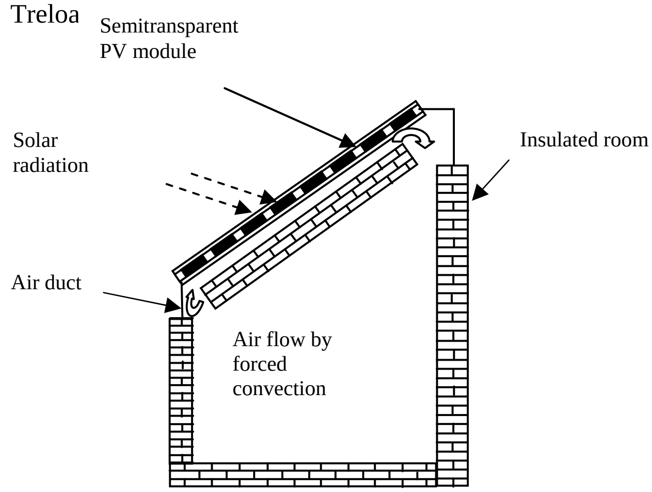

Figure 1: Cross section view of building integrated photovoltaic thermal (BISPVT) system integrated to roof with air duct.

Thus embodied energy analysis is quantifying the amount of energy used to manufacture a material or component. This involves the assessment of the overall expenditure of energy required to extract the raw material, manufacture product or components, installation and maintain the component element whichever is being assessed. For the embodied energy analysis of BISPVT system integrated to roof with air duct (shown in Fig. 1), the total energy requirement for individual components with their manufacturing energy needs to be evaluated. The break up of embodied energy of each component of BISPVT system has been tabulated in Table 1. BISPVT system consists of building materials, DC fan, different PV materials, battery, inverter, PV frame and charge controller.

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3. ENERGY PAY BACK TIME (EPBT)

The EPBT depends upon the energy spent to prepare the materials used for fabrication of the system and its components, i.e. embodied energy and the annual energy yield (output) obtained from such systems. To evaluate embodied energy of various components of systems, the energy densities of different materials are required. It is the total time period required to recover the total energy spent to prepare the materials (embodied energy) used for fabrication of BISPVT system. It is defined as the time necessary for a system to generate the energy equivalent to that used to produce, install and decommission. Mathematically,

$$EPBT = \frac{\text{Total energy input in manufacturing, installation and decommission}}{\text{Annual energy output from the system}} = \frac{E_{in}}{E_{aout}} \quad (1)$$

$$T_{epb} = \frac{\text{Embodied energy } (E_{in})}{\text{Annual energy output } (E_{aout})} \quad (2)$$

EPBT for the BISPVT system with air duct can be expressed as,

$$EPBT = \frac{E_{building} + E_{support} + E_{BISPVT} + E_{inverter} + E_{inst+M\&O} + E_{dec}}{E_{aout}} \quad (3)$$

where, $E_{building}$, $E_{support}$, E_{BISPVT}, $E_{inverter}$, $E_{inst+M\&O}$, E_{dec} are the embodied energy of the building, support for the BISPVT system, BISPVT system, inverter, battery, installation maintenance and operation and decommissioning respectively.

Building construction material	Specific energy content (MJ/ kg)		Quantity used	Embodied energy (MJ)
	Range	Assigned		
Clay bricks ($23\times11\times7.5\ cm^3$) (for foundation)	2-7	4.5	1632 kg (510 Nos.)	7344
Clay bricks ($23\times11\times7.5\ cm^3$) (for floor)	2-7	4.5	1600 kg (500 Nos.)	7200
Clay bricks ($23\times11\times7.5\ cm^3$) (for walls)	2-7	4.5	4896 kg (1530 Nos.)	22032
Cement sand concrete (for foundation, roof and walls)0	4-8 < 0.5 0.8-1.5	6 0.2 1.15	750 kg(15 bags) 646 kg 1294 kg	4500 129.2 1488.1
Lime (for white wash Mild steel (for roof)	3-5 30-60	4 45	0.5 kg 78 kg	2 3510
Paint (for doors) Plywood (for one door) Straw fibre	80-150 8-12	115 10 0.28	0.5 kg 9 kg 5 kg	57.5 90 1.45 46354.15 MJ 12876.15 kWh

Table 1(a).Embodied energy of the building materials used for BISPVT system with air duct (Agrawal [8]).

DC fan (Exhaust fan)	Specific energy content (kWh/ kg)	Quantity used	Embodied energy (kWh)
Aluminium Iron Plastic Copper wire	32.39 8.89 19.44 19.61	0.39 kg 0.22 kg 0.12 kg 0.05 kg	12.63 1.95 2.33 0.98
Fittings			
Hinges Door lock Hooks Nut and Bolt with washer, steel, screw & rivets	32.39 32.39 32.39 9.67	0.2 kg 0.025 kg 0.1 kg 1.0 kg	6.47 0.80 3.23 9.67 38.09 kWh

Table 1 (b): Embodied energy used for operating the DC fan for forced circulation of air used in BISPVT system with duct (Tiwari and Barnwal [9]).

Type of PV module	Expected life	Specific energy content (kWh/ m^2)		Quantity (No.)	Area of PV (m^2)	Embodied energy (kWh)
		Range	Assigned			
m-Si	30	1120-1260	1190	9	0.605	6479.55
p-Si	30	840-980	910	9	0.605	4954.95
a-Si	20	308-448	378	9	0.605	2058.21

Table 1 (c): Embodied energy for different PV materials (Agrawal [8]).

	Specific energy content, (kWh)	Quantity used	Embodied energy (kWh)
Battery	46	6	276
Inverter	1703	1	1703
M&O	59.5	-	59.5
PV frame	32.39 kWh/ kg	4.5 kg	145.75
Charge controller	100	1	100
Miscellaneous	200	-	200
			2484.25

Table 1 (d): Embodied energy for battery, inverter, PV frame and charge controller. (Agrawal [8]).

4. RESULTS AND DISCUSSION

Annual overall thermal energy and exergy gain of BISPVT system for different PV material for Srinagar, India (considering a, b, c, and d type weather) have been shown in Fig. 2. The basic heat transfer equations derived by Vats et al. [10] have been used to compute the overall energy and exergy for different type of PV materials.

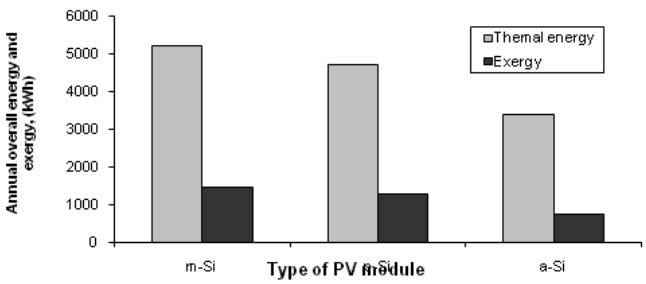

Figure 2: Type of PV Module

The values of energy and exergy observed from the Fig. 2 for BISPVT system with air duct have been tabulated in Table 2. The annual solar radiation (E_{sol}) falling on inclined roof, which is equal to the latitude of Srinagar (34 ^{o}) is calculated as 10465 kWh.

S. No.	Different types of PV materials	Annual overall thermal energy output (kWh),	Annual overall exergy output (kWh), $E_{aout,ex}$
1.	m-Si	5204	1479
2.	p-Si	4715	1285
3.	a-Si	3393	762

Table 2: Annual overall thermal energy and overall exergy for different type of PV materials, for a BISPVT system integrated to roof with duct.

The calculated values of EPBT for BISPVT system on energy and exergy basis have been shown in Table 3.From the table, it is found that the energy payback time in BISPVT system integrated to roof with air duct is lowest in m-Si on thermal (4.26 years)and exergy (15.00 years) basis. Hence, EPBT point of view, use of m-Si in BISPVT system with duct is most suitable.

S. No.	Different types of PV materials	Embodied Energy (kWh), (E_{in})	Annual overall thermal energy output (kWh) $E_{aout,th}$	Annual overall exergy output (kWh), $E_{aout,ex}$	$(T_{epb})_{energy}$ (yrs.)	$(T_{epb})_{exergy}$ (yrs.)
1.	m-Si	21877	5204	1479	4.26	15.00
2.	p-Si	20352	4715	1285	4.38	16.00
3.	a-Si	17456	3393	762	5.26	23.00

Table 3: Calculations of energy payback time for different types of PV materials, for a BISPVT system integrated to roof with duct.

5. CONCLUSION

1. EPBT is lowest in m-Si PV modules integration as compared to p-Si and a-Si PV modules integration.
2. Use of m-Si PV on BISPVT system is economical as EPBT is lowest.

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