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Carbon Payback Period and Energy Payback Period for Solar Water Heater

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Abstract

The solar water heater system is compared with electric water to quantify the environmental and energy benefit of the system using life cycle assessment. In this paper consider the 100 lpd solar water heater available at Chennai, Tamilnadu. LCA has done as a three life cycle stages like manufacturing stage, operation and maintenance stages and product disposal stage. Based on the available data and calculated data life cycle inventory has been made for the solar water heater system. Material inventory, energy inventory and carbon inventory has done for the system to predict the environmental impact. Based on the life cycle inventory data Energy and Carbon intensity has been estimated for the solar flat plate collector. Then compared with electric water heater Energy and Carbon Payback Period has been estimated.

Keywords: Solar water heater, life cycle assessment, energy payback period, carbon payback period.

Introduction

The continuous growth of population and economic development is lead to the energy demand in the world. Also, fossil fuels consumption are being increasing, even though availability of resource is limited. The fossil fuels consumption are increasing the global warming and environmental pollution. We are in the position to accelerate the development of advance clean energy technology in order to address the global challenges of energy security. Power being produce from the natural resource (renewable energy) is the one of the alternative method. Different method of energy conservation has been available for various system such as energy conservation in building.

Electric Water heating system is a one of the major energy consumer in the building around the world. Water heating system is share the major energy in total residential building, it's contributing about 32% in South Africa[1], 29% in Mexico[2], 27% in China[3], 25% in Australia[4], 22% in Canada[5], 14% in Europe[6], 11% in USA[7], etc. They comparison of various water heating systems is useful to choice the proper system among them. Also, can use those data for the new design. It can save the energy, Environment and cost.

Renewable energy from the solar is one of the key technology option to reduce the energy consumption and reduce environmental pollution. Solar water heater is one of the renewable energy technology which can reduce the energy consumption in the building. In the solar water heater carbon emission is associated with manufacturing and disposal, due to raw material manufacturing for the product formation. Also some amount of energy and carbon emitting in the disposal and recycling of the system at the end of the life cycle. The indirect environmental impact has been calculated based on the life cycle assessment of the solar water heater system.

Some of the studies has been done in the review of domestic hot water production system. Hepbasli and Kalinci done a review in terms of energetic and exegetic on heat pump water heating system[8]. Jaisankar et al. presented a review on solar water heaters system using different techniques to improve the thermal efficiency[9]. Shukla et al. done a review on performance solar water heater system based on the different phase change material used as a thermal storage media[10]. Chow conducted a review on thermal – photovoltaic hybrid solar system. This study discusses about the life cycle assessment of solar water heater[11]. Separate collector and storage tank type sola water heater has been taken for this study (figure 1). There are various components and materials used for manufacturing the solar water heater.

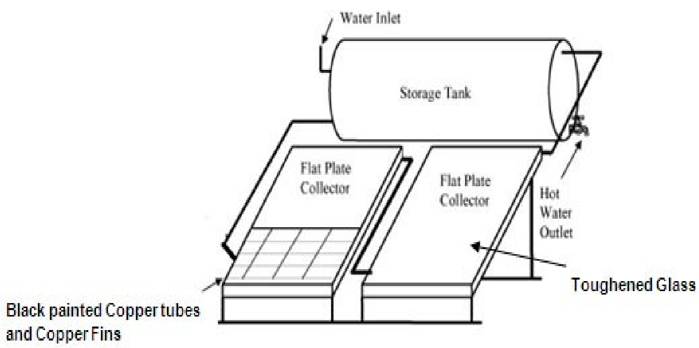

Figure-1
Domestic Solar water heater system

A typical solar water heater is consist of flat plate solar collector and storage tank. The flat plat collector is includes the absorber plate which have good thermal conductivity properties. The absorbed solar radiation is converted in to heat. The absorber plate is coated with black paint to maximize heat absorbance. Then the heat is transferred to the water flowing through the pipe. The absorber are insulated with thermal insulating material which can be used to reduce heat loss from the absorber and pipes are commonly used. The cover plate are used in the top side of the collector. The function of cover plates are to transmit maximum solar energy to the absorber plate, to minimize upward heat loss from the absorber plat to the environment and to shield the absorber plate from direct exposure to weathering. Copper, aluminium, steel, glass and various plastics are used for the manufacturing the flat plat collector. The storage tank is placed at a certain height (30-60cm) relatively to the top of the collector to prevent the reverse circulation during off-sun shine hours. The storage tank is made up of with stainless steel which have less corrosive properties. The storage tank is insulated with low thermal conductivity and high temperature stability material.

Methodology

LCA is a concept and a methodology to evaluate the environmental effects of a product or activity holistically by analyzing the entire life cycle of a particular product, process, or activity. Principally, LCA is applied to address input of energy and resources and output of the environmental impacts of product system. Life Cycle Assessment (LCA) is a tool which can be used to predict environmental impacts associated with material consumption and energy consumption for the manufacturing of the solar water heater. After the prediction or quantification of the impacts which can be used to improve the manufacturing process of raw material used in the solar water heart. The results of the assessment can be combined and used to make a database for solar water heater and for the future development of an environmental labeling regulation[12]. The figure 2 clearly indicate the LCA of solar water heater system. Many LCA of renewable energy system is available in the literature, but some of them refer to solar water heater[13-18]. Among them, some of author studied about the different type of solar system in environmental point of view[16, 17]. Some of the author has analyses the solar system in term of net energy analysis[18]. In this paper, LCA of solar water heater is performed for 100lpd system and is compared with the electrical water heater in terms of EPBP and CPBP.

System Description: In this paper consider the flat plate solar water heater with storage tank mounted in the roof of the building. The system has manufactured based on the Bureau of Indian Standards (BIS)[19]. The detailed description of the system is given in the table 1.

Life cycle Assessment: Based on the LCA of 100 lpd solar water heater, the result has been discussed as three categories: Manufacturing stage, Operation and Maintenance stage and Decommissioning stage. Then the manufacturing stage is divided into three categories: Material inventory, Energy inventory and Carbon inventory. Regarding the solar water heater, the foremost important environmental impact will arise during manufacturing of the flat plate collector. On the other hand, the operational stage does not contribute significantly to the environmental impacts. Several life cycle studies exist for the solar water heater of various capacities. The available studies are differing in their scope and climatic condition; however show the dominant influence of the material production on the environmental performance of solar water heater.

Table-1
Description of the system

Capacity	100lpd at 60^{o}C
Standard	Bureau of Indian Standards
Insulation	Glass wool
Glazing	Toughened glass (4mm thick)
Riser tube	0.5" dia , 10nos of Copper tubes
Header tube	1" dia , 2 nos of copper tubes
Absorber plate	Aluminium (0.71mm thick)
Absorber plate	Copper
Storage Tank	Stainless steel
Cladding	Aluminium
Flat Plate Collector	Aluminium
Life time	15 years

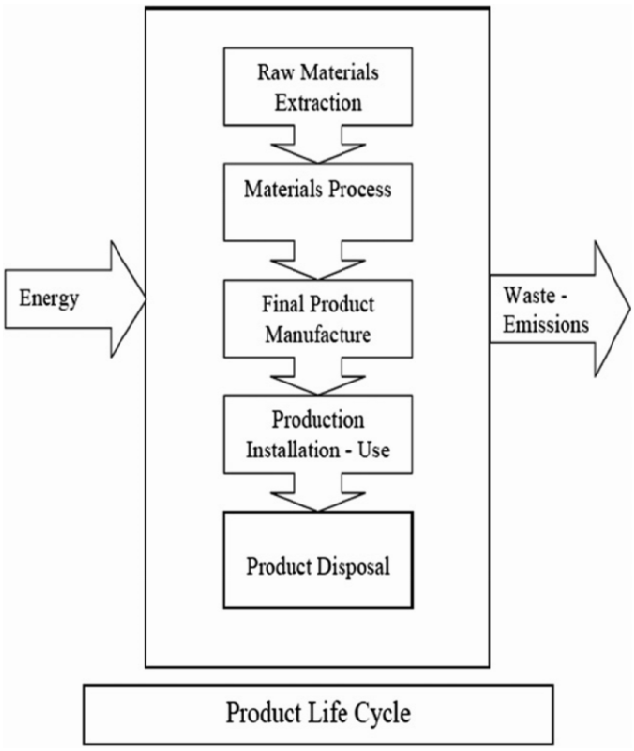

Figure-2
Life Cycle assessment of solar water heater

Manufacturing stage: Based on the available manufacturing data, the material inventory, energy inventory and carbon inventory has been calculated for solar water heater system. The system has been divided into four components: Flat plate collector, Storage tank, Supporting stand and Pipe line. Table 2 shows the data, in which Flat plate collector is consuming more amount of material and energy. Due to that, more amount of carbon has been emitted to the environment[20].

Operation and Maintenance: The system efficiency has been reduced by the long time running of the solar water heater. So, in order to improve the system performance, some of the materials have been replaced. Energy has been consumed and carbon has been emitted due to the manufacturing of materials which are used for replacement. Table clearly indicates the material consumption and energy consumption and carbon emission.

Table-2
Life cycle inventory for the manufacturing stage

Components	Material	Martial Inventory (Kg)	Energy Inventory (KWh)	Carbon Inventory (kg)
Flat Plate Collector				
Sectional Frame (100mmX25mm)	Aluminium	4.25	299.89	7.01
Sheet for back of the box (24 swg)	Aluminium	4.50	317.53	7.43
Angle of Box (1"X1"X16swg)	Aluminium	1.50	105.84	2.48
Foil for heat reflection (0.5mm)	Aluminium	1.50	105.84	2.48
Neelpoop rivets (60nos)	Aluminium	0.03	2.12	0.05
Steel tapping screw	Aluminium	0.50	6.95	0.83
Insulation	Glass wool	1.80	15.85	0.13
Glazing (4mm thick)	Toughened glass	35.00	291.69	7.35
0.5" dia riser tube (24 swg 10nos)	Copper	4.00	147.79	2.04
1" diaheder tube (22 swg 2 nos)	Copper	2.25	83.13	1.31
Flanges (4 nos. 80mm OD)	Brass	0.80	29.56	1.32
Beading for glass sealing	Rubber	1.50	54.17	1.05
Black Paint		0.50	10.00	1.70
Absorber plate (0.71mm thick)	Aluminium	4.46	61.95	7.36
Absorber plate (34 swg)	Copper	4.25	157.03	1.79
Total		**66.84**	**1689.32**	**44.30**
Storage tank				
Tank	Stainless steel	12.50	173.63	18.25
Insulation	Glass wool	8.25	72.65	0.59
Cladding	Aluminium	1.50	105.84	2.48
Total		**22.25**	**352.12**	**21.31**
Supporting Stand				
Angle	Steel	12.00	166.68	13.46
Paint		0.60	12.00	4.00
Total		**12.60**	**178.68**	**17.46**
Pipeline				
Pipe	GI	20.00	277.80	29.20
Insulation	Glass wool	2.10	18.49	0.15
Cladding	Aluminium	0.80	56.45	1.32
Total		**22.90**	**352.74**	**30.67**
Carbon emission based on the energy Consumption				**2421.07**
Grand Total		**124.59**	**2572.87**	**2534.81**

Table-3
Life cycle inventory for the Operation and Maintenance stage

Material replacement	Quantity (kg)	Frequency of replacement (Year)	Energy intensity (MJ/kg)	Energy consumption (kWh)	Carbon intensity (kg/kg)	Carbon emission (kg)
Glass	35.00	10	30.00	291.69	0.21	7.35
Rubber	1.50	10	130.00	54.17	0.70	1.05
Paint	1.00	7	72.00	20.00	3.40	6.80
Insulation	9.72	10	31.70	85.60	0.07	0.69
Total	**47.22**			**451.46**	0.94	**440.26**
Maintenance Energy				308.40	0.94	290.20
Grand Total				**1211.32**		**746.36**

Decommissioning: Table 4 shows the assumption for the recycle of material[21]. Aluminium, copper, steel and glass are the major materials which have recycling potential. Based on the quantity of the material, energy and carbon emission saving has been calculated.

Table-4
Assumption for the recycle of material

Material	Recyclability
Aluminium	90% recycled;1 0% landfilled
Copper	41% recycled; 59%landfilled
Steel	62% recycled; 38%landfilled
Glass	90% recycled; 10% landfilled

Results and Discussion

The summary of the life cycle inventory and the life cycle assessment data is given in table 5 and the figure 3 shows the comparison of life cycle stage data with respect to the inventory data. From that, 50% of the material can be recycled for the reuse. The corresponding amount of energy and carbon has been saved. Based on this data, energy payback period and carbon payback period has been estimated for the 100lpd solar water heater system and is compared with the electrical water heater system. The energy consumption for the electrical water heater system has been calculated based on the average temperature of Chennai.

Table-5
Combined data for the Life cycle assessment

Life Cycle Inventory	Material Consumption	Energy Consumption	Carbon Emission
Manufacturing	124.69	2572.87	2564.91
Operation and Maintenance	42.22	1211.32	746.36
Decommission ing	-80.53	-627.29	-667.93
Total	**86.38**	**3156.89**	**2643.34**

Energy payback period: The energy consumption of 100lpd solar water heater is 3156.89 KWh. This is nothing but the energy consumed in the life cycle of solar water heater. The energy intensity of the 100lpd of solar heater is 5.77 KWh/m^3 of hot water. The energy intensity of the electric water heater is 37.56 KWh/m^3. This is six times higher than the energy intensity of solar water heater. The energy payback period for the above capacity solar water heater is 2.3 years when compared with electrical water heater (table 6). The energy payback period can be calculated using the equation (2).

$$Energy\ Intensity = \frac{Total\ Input\ Energy\ (kWh)}{Life\ Time\ Hot\ water\ production\ (m^3)} \quad (1)$$

$$EPBP = \frac{Life\ Cycle\ Energy\ Consumption\ (KWh)}{Energy\ Saved\ by\ Solar\ Water\ Heater\ per\ year\ (KWh)} \quad (2)$$

Table-6
Energy intensity and EPBP for 100 lpd solar water heater

Life cycle energy consumption per solar heater (KWh)	Life cycle hot water production (m^3)	Energy Intensity (kWh/m^3)	Energy saved per year based on electric water heater (KWh)	EPBP (Year)
3156.89	547.50	5.77	1370.97	2.30

Carbon Payback Period: Carbon intensity is nothing but, the carbon emission associated with the manufacturing, operation and decommissioning of the solar water heater per unit of hot water production over the life time. The simplified equation is given below.

$$CO_2 intensity = \frac{\text{Life Cycle } CO_2 \text{ emission (Kg of } CO_2)}{\text{Life Time Hot water production } (m^3)} \quad (3)$$

Carbon Pay Back Period is nothing but, a measure of how long a CO_2 mitigating process needs to run to compensate the CO_2 emitted to the atmosphere during the life cycle stage. The carbon intensity of the solar water heater is 4.83 kg/m^3. The carbon intensity of the electric water heater is 35.34 KWh/m^3. This is six times higher than the carbon intensity of solar water heater. CPBP for the 100lpdsolar water heater is 2.21 years (table 7).

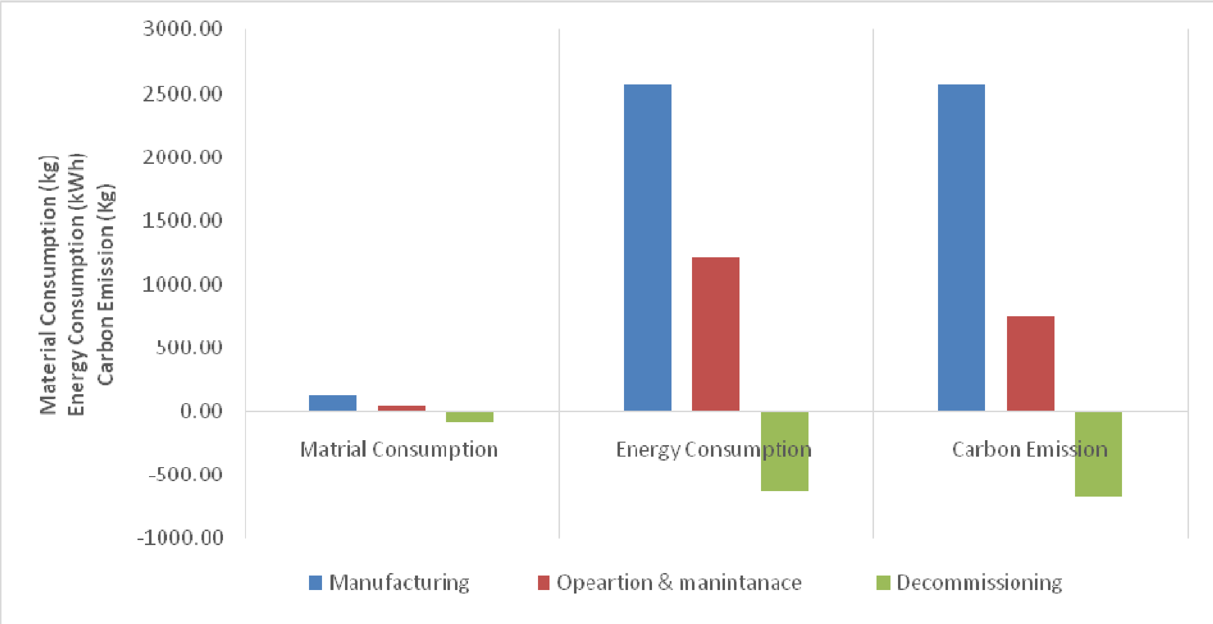

Figure-3
Comparison of life cycle assessment stages

Table-7
Carbon intensity and CPBP for 100 lpd solar water heater

Life cycle carbon emission per solar heater (kg)	Life cycle hot water production (m^3)	Carbon Intensity (kg/m^3)	Energy saved per year based on electric water heater (KWh)	Carbon emission based on convention method (kg)	CPBP (Year)
2643.34	547.50	4.83	1273.34	1198.22	2.21

$$CPBP = \frac{\text{Life Cycle } CO_2 \text{ emission}}{\text{Gross } CO_2 \text{ emission avoided per Year}} \quad (4)$$

Conclusion

The Energy Payback Period and the Carbon Payback Period for the 100lpd solar water heater system has been estimated. The total energy consumed in the LCA is recovered in 2.3 years of operation. The energy intensity and the carbon intensity of the system are 5.77 KWh/m^3 and 4.83kg/m^3 respectively. This is six times lower than the carbon intensity and energy intensity of electric water heater. The carbon emission for the total life cycle has beenestimated as 2643.34 kg. Based on the above data, it has been arrived that the carbon payback period for the solar water heater is 2.21 years.

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