Energetic Feasibility Analysis of Low Temperature Solar Thermal Applications

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I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no materials previously published or written by another person nor any materials presented for the award of any degree or diploma of Delhi Technological University or any other institution of higher learning. Any contribution made to this research by others is explicitly acknowledged in the dissertation.

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CERTIFICATE

This is to certify that the work presented in this dissertation "***Energetic Analysis of Low Temperature Solar Thermal Applications***" *by Sudhanshu Shekhar*, Roll No. 2K20/THE/21, is a record of original research carried out by him under my supervision and guidance in partial fulfillment of the requirements for the degree of *Master of Technology* (*Thermal Engineering)*. Neither this dissertation nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

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It is a matter of great pleasure for me to present my dissertation report on **“Energetic Feasibility Analysis of Low Temperature Solar Thermal Applications”.**

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Finally, and most importantly, I would like to thank my family members , friends and seniors for their help, encouragement and prayers through all these months. I dedicate my work to them.

Place: Delhi

Date: 31/05/2022

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ABSTARCT

Owing to the dwindling supplies of conventional sources of energy, their rising cost and adverse impacts on the environment, the efforts towards developing new and renewable sources of energy have found impetus. The energetic feasibility criterion should necessarily be taken care of in the case of renewable energy technologies because there is no point in promoting a technology which consumes more energy in its production, installation ,operation and maintenance than it delivers in its entire lifetime. It is therefore quite important to undertake studies on energetic feasibility of renewable energy technologies.

An attempt to analyze the energetic feasibility of low temperature solar thermal applications has been done in this work. The systems under consideration can be briefly classified as solar thermal system and solar PV system. Of all the other factors Embodied Energy , Energy Payback Time and Carbon Credit are mainly under consideration for this analysis.

The systems under analysis are solar cooker, solar dryer ,solar collector, solar space and water heater, solar desalination, solar irrigation and hybrid solar collector respectively. It was found that as the size of system was increasing embodied energy was also increasing. Energy payback time was also dependant on the net output energy provided by the system apart from the embodied energy. Difference of net output energy and net input energy influenced the net carbon credit of a system.

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CHAPTER 1

INTRODUCTION

1.1 Energy

A physical activity of any kind in this world requires energy or energy flow in either one form or the other whether it is carried out by human beings or nature. Any kind of work can be done with the help of energy only. For better understanding there is a Greek word named ‘en-ergon’ which means 'in-work’ or ‘work content’. For economic growth of a country and also for its development the basic or the most basic infrastructure is energy. The dependence on manual and animal labour was abolished after the industrial revolution. The energy consumption accelerated as the standard of living of human beings developed and increased. A nations energy consumption can be broadly classified or divided into four sub sectors namely domestic sector, transportation sector, agriculture sector and industry sector. The dependence for energy can be of conventional type or non-conventional types. Based on the origin conventional and non-conventional sources of energy can be classified as fossil fuel, nuclear, hydro, solar, tidal, wind, biomass, geothermal, ocean thermal and ocean wave energy. Energy as in of conventional type has its certain advantages and disadvantages as well. The very first is related to cost only. Conventional sources are cheaper than non-conventional sources.so this is an advantage of conventional over non-conventional. Apart from this from security and convenience point of view also conventional is better than non-conventional. Now coming to the disadvantage part, conventional source of energy like fossil fuels create pollution. It generate pollutants which are very hazardous for health. Carbon monoxide (CO), carbon dioxide (CO_2), Oxides of Nitrogen (NO_x), Oxides of Sulpher ($SO_{x)}$, are few to name. Not only they cause health hazards but they also destroy or damage the environment. The main responsible thing for global warming is carbon dioxide. In the same there are some merits and demerits of non-conventional sources of energy. We also know that Non-conventional sources of energy are available in abundance and creates almost no harm to the environment. As it is freely available in nature it is inexhaustible. Now talking about demerits, they are available freely in nature but harnessing them is costly. This is a major setback for them. Another setback is availability part. There availability is uncertain. It depends upon various natural phenomena which is beyond control of any human. Solar energy is one such kind of energy which is dependent on availability of sun. Talking about

India perspective, it receives solar energy in the order of or over 5000 trillion kWh per year, considerably more than is consumed on a yearly basis. In the most part of India sunshine hours is around 2300-3200 and 5 kWh per sq.m per day is the figure for daily global. As mentioned above that availability is a problem or setback for solar energy or any non-conventional source of energy, due to technological revolution it is now possible to reliably harness low energy density and non -continuous solar energy by converting to usable heat or by directly generating electricity. The heat harnessed is called solar thermal energy and electricity harnessed is called solar PV or photovoltaics. Solar thermal energy can be used for cooking , drying, water heating and space heating as well using various schemes. Solar PV energy can be used for street-lighting, irrigation, home-lighting and grid as well. Now a days both solar thermal and solar PV are used simultaneously and together they are called PVT or PV/T system.

1.2 Energetic Feasibility

Global energy demand is continuously increasing for economic growth and improvement in quality of human life. In view of depleting sources of conventional sources of energy, their adverse impacts on the environment and their rising costs there is a global interest in the development and use of renewable sources of energy. Renewable sources of energy will find sustained use only when it is (i) based on locally available resources(ii) technologically appropriate (iii) financially viable (iv) environmentally sustainable (v) socio-culturally acceptable and (vi) energetically feasible.

Energetic feasibility demands that a renewable energy system is a net energy producer. Alternatively, it should produce sufficiently more energy in its entire lifetime than the total input energy required in its fabrication, insatallation, operation and maintenance. As per the energetic feasibility criteria the energy yield ratio(EYR; the ratio of the total output to the total input energy) must be greater than unity. In other words the energy payback period (the period in which the energy output of the system is paid off by the input energy) must be much less than the useful lifetime of the system. It is essential for any renewable energy resource technology combination to be energetically feasible because economic feasibility does not necessarily mean energetic feasibility as prices are liable to be influenced by various other factors. The tool that is used for evaluating the energetic feasibility is called energy analysis or energetics.

1.3 Energy analysis and Embodied Energy

The energy fluxes involved in the production of commodities and services are determined through energy analysis. Some authors attribute the origin of energy analysis to the realization of the adverse impacts on the environment caused by the industries and to the dwindling supplies of conventional fossil fuels available from the earth.

One of the primary aims of energy analysis is to analyse energy flows in industries and find measures to reduce energy consumption. The materials industries was identified as one of the major energy consuming sectors energy analysis has been used to determine the effect of materials recycling substitution of less energy intensive materials for intensive ones etc. for saving fuels in materials production.

Food production in industrialized countries is mainly reliant on fossil fuel energy inputs.Such inputs with a special focus on U.K. Energy conservation measures to reduce energy consumption in food production sectors has been emphasized.The primary energy input required to produce a variety of fuels and concluded that serious considerations should be given to the increased development of renewable energy technologies has also been studied. So one of the major interests of the recent energy analysis has been that of energy supply options .

Any renewable energy system must create more energy throughout its entire lifetime than the energy necessary for energy installation, operation, and maintenance.Discussion of the concept of a breeder and mathematics for analyzing the viability of renewable energy technologies has been done.Determination of the energy payback period of photovoltaic installation in U.K has been done.Study the energetic of household biogas plants in India in which three popular designs of biogas palnts have also been done and Study of the energetic of a box type solar cooker has also been done. It can be summarized that energy analysis can help

i) Test the energetic viability of new sources of energy
ii) Compare the energy costs associated with alternative energy production technologies
iii) Identify process changes that may lead to decreased energy consumption

iv) Measure the impact of a particular policy measure on overall energy consumption

Embodied energy is the whole energy required to create any item, thing, or service (EE). It is a variable that is frequently utilised while conducting an environmental study. It aids in calculating the amount of energy required to produce a unit of system. It can be done by taking into account the amount of energy used in extracting, processing, manufacturing and transporting the materials.Since energy is consumed in the above mentioned things that means it can correlate to carbon dioxide production which eventually contribute to greenhouse gas emission. So if any material is ultimately utilised for producing electricity,embodied energy analysis offers a tool for assessing the cost of thermal energy production for that produced electricity. The technique for calculating embodied energy is by multiplying mass value of different materials with their respective embodied energy coefficients.Embodied energy coefficient is usually expressed in MJ/kg. Embodied energy of some selected materials are shown in table 1.

Table 1: Embodied energy of some selected materials(Hammond & Jones, 2008)(Prakash et al., 2017)

Materials	Energy (MJ/ Kg)	C (Kg /Kg)	Density (Kg/m^3)
Aggregate	0.083	0.0048	2240
1:1.5:3 Concrete	1.11	0.159	2400
Common Bricks	3	0.24	1700
Medium density Concrete block	0.67	0.073	1450
Aerated block	3.5	0.3	750
Limestone block	0.85	–	2180
Marble	2	0.116	2500
1:3 Cement mortar	1.33	0.208	
general, av. recycled content Steel	20.1	1.37	7800
Stainless steel	56.7	6.15	7850
Timber	8.5	0.46	480–720
Glue laminated timber	12	0.87	–
Loose fill Cellulose insulation	0.94–3.3	–	43
Cork insulation	26	–	160
Glass fibre insulation	28	1.35	12
Flax insulation	39.5	1.7	30
Rockwool (slab)	16.8	1.05	24
Expanded Polystyrene insulation	88.6	2.55	15–30
Polyurethane insulation (rigid foam)	101.5	3.48	30
Recycled Wool insulation	20.9	–	25
Straw bale	0.91	–	100–110

1.4 Techniques of Energy Analysis

1.4.1 Energy Intensity Method

In this method the input energy to the system can be determined by multiplying the cost incurred with the prevailing figure of primary energy consumption per unit monetary worth.This figure is normally obtained by dividing the net primary energy consumption of the economy by the GDP.The drawbak of this method is that the overall economy involving all manufacturing sectors is considered in the evaluation(MJ/Rs).Practically energy intensity values of different goods produced and services provided in the economy may be quite different from each other.

1.4.2 Input-Output method based energy accounting

The much used method of input-output analysis depends on the use of national input-output tables which record monetary transactions between an array of industrial and commercial sectors as purchasers and the same array as sellers.Energy industries are also recorded.The coefficients of the input-output table depend on technology.With the advancement or change in the process it is possible to change the values i.e the gross output could be different for a given final demand.One goal of energy analysis is to indicate where reductions in the energy requirements for total processes could be made the pressure points for technological change.This method has for example been used by Wright[12] to estimate the energy costs of all commodities in the U.S using U.S government input-output tables which divided the economy into 363 industries.Main drawbacks of input-output table based energy accounting include:

(a) High degree of aggregation so that individual products and inputs can be separated
(b) Incomplete coverage of all relevant industries and services
(c) The exclusion(in many cases) of capital purchases by industries

1.4.3 Process Analysis

This method is considered most reliable as all outputs and inputs are traced individually through the entire processes leading from the finished goods to the required material and energy input.Process analysis involves three stages.The first is to identify the network of processes which contribute to a final product.Next each process within the network has to be analysed in order to identify the inputs,in the form of equipment,materials and energy.Finally an energy value has to be assigned to each input. Several levels of regression are considered.The first level considers the direct energy input(labour,fuel,electricity etc.) supplied to the process while the second level of regression considers the direct energy requirement to produce the materials required in regression level one and so on.It is recommended that to the extent possible ,the analysis be carried back to a level at which the contributions are comparable with the uncertainities in the contribution from the previous level.There are two problems with this method.The first is choosing appropriate subsystem,Chapman[13] has given examples and shown clearly how choosing different subsystems for the same process can lead to totally different results.The other problem is attaching energy values to particular inputs.

1.5 Present Work

An attempt to analyse the energetic feasibility of low temperature solar thermal application has been made in the present work. These include solar cooker, solar dryer ,solar collector, solar space and water heater, solar desalination, solar irrigation and hybrid solar collector respectively. The embodied energy, energy payback time and carbon credit are mainly analysed for the systems under consideration.The detailed comparison for the respective parameters has been presented individually in their respective chapter.

CHAPTER 2

SOLAR COOKER

Cooking energy accounts for a significant portion of total energy use, particularly in rural areas. To meet the requirements, a variety of fuels such as coal, kerosene, cooking gas, firewood, dung cakes, and agricultural wastes are employed. Fossil fuels are a finite resource that must be conserved. Cooking with firewood deforests the environment, but cow dung, agricultural waste, and other trash could be better employed as fertilisers. Fossil fuels are a finite resource that must be protected. Cooking with firewood deforests the environment, but cow dung, agricultural waste, and other waste products might be used as fertilisers instead.

Box-Type Solar Cooker

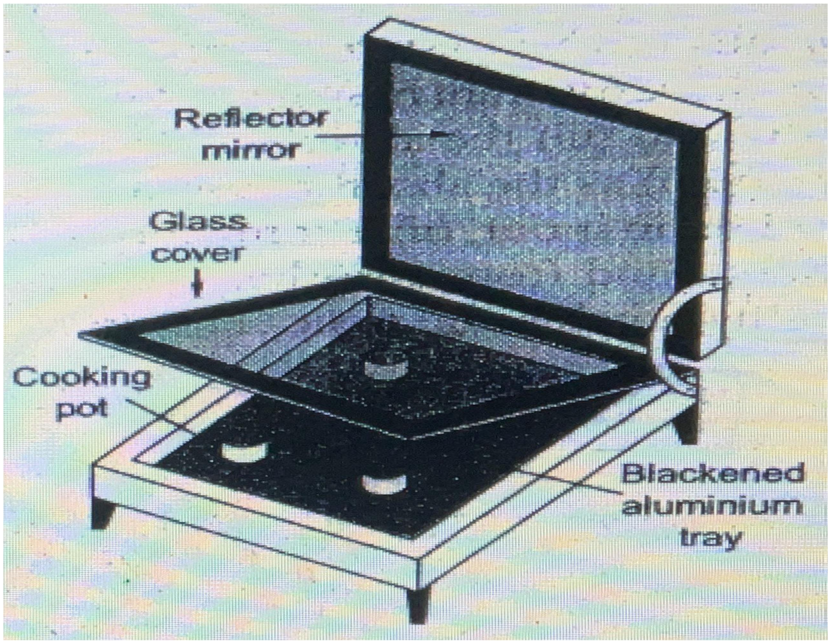


Fig 2.1: Box type solar cooker

The construction of the most common box-type solar cooker is schematically shown in Fig 2.1. The external dimensions of a typical family-size (4 dishes) box-type cooker are 60 cm X 60 cm X 20 cm. This cooker is simple in construction and operation. The utensils packed with food are kept in an insulated box made of blackened aluminium. A reflector mirror installed on the inside surface of the box lid attached to one side of the box provides direct and reflected radiation to the box. The reflector's angle can be modified as needed. The box door is a glass cover made up of two layers of clear-window glass sheets. Because of the greenhouse effect, the glass cover traps heat. Inside the box, the maximum air temperature is roughly 140-160°C. This is plenty to slowly cook boiling-type foods in roughly 2-3 hours. It can cook up to 2 kg of food and save up to 3-4 LPG cylinders of fuel every year. Some designs have an electrical backup for usage during non-sunny hours. Its price ranges from Rs 1800 to Rs 2,800 in 2008, depending on the kind, size, quality, and availability of an electrical backup system. A more cheap, folding-type kind of solar cooker has also been built out of cardboard. A solar cooker must be able to receive variable intensity energy from the sun and transfer it to the food in order to prepare food. The heat provided to the pot must be adequate to raise the temperature of raw food to the required cooking temperature, as well as to maintain that temperature until the food is fully cooked. Boiling, frying, baking, and grilling are examples of thermal cooking methods. However, they can be separated into two groups based on the cooking temperature necessary for each of these operations. The first category includes all procedures that require only enough heat to bring water to its boiling point. The substance must then be stored at a specific temperature for a specified period of time. Due to the high water content in most foods prepared by this procedure, the energy required to bring the item to cooking temperature is around 4.2 kJ/kg°C. As long as the supply of thermal energy is equivalent to thermal losses from the utensils, the speed of cooking is almost independent of heat input rate after the cooking temperature is attained. The second group, which includes frying, baking, roasting, and grilling, requires a steady source of heat at a temperature over the boiling point of water. Only the first series of procedures (boiling) are suitable for a box-type solar cooker.

In India, (Nouni et al., 2008) tried an energy analysis for the use of box style solar cookers. The process analysis method was used to evaluate the energy input necessary for the production of a box-type solar cooker. For many bodies, embodied energy was discovered. Fiber reinforced plastic, aluminium, and galvanised iron were the materials used. FRP, Al, and GI are the abbreviations for these terms. The energy payback time for the bodies described was also discovered. FRP, Al, and the GI body have embodied energy of 1585.56 MJ, 1309.38 MJ, and 966.58 MJ, respectively. The variance in embodied energy is caused by variations in material density. The average energy payback time for FRP, Al, and GI was 2.24, 2.06, and 1.78 years, respectively. The energy payback period varies depending on the system's energy output.

A lifecycle analysis and embodied energy evaluation for an aluminium body double mirror reflector box type solar cooker as shown in fig 2.2 was completed by (Chakma et al., 2021). The total embodied energy discovered was 2376.316 MJ, with a payback time of 4.13 years. This demonstrates that if additional material is used in the fabrication of a system, the embodied energy will rise, and if the power output is not increased to match, the energy payback time will rise as well. However,the authors make no mention of the system's net carbon mitigation or carbon credit.

Fig 2.2: Photograph of double reflector box-type solar cooker

Table 2: Embodied energy and energy payback time of solar cookers

Ref.	System	Embodied Energy(MJ)	Energy Payback Time(EPBT)(years)	Carbon Credit(USD)
(Chakma et al., 2021)	Double Mirror Reflector Box Type Solar Cooker	2376.316	4.13	-
(Nouni et al., 2008)	Box Type Solar Cooker	FRP-1585.56 Aluminium-1309.38 GI-966.58	FRP-2.24(avg.) Aluminium-2.06(avg.) GI-1.78(avg.)	-

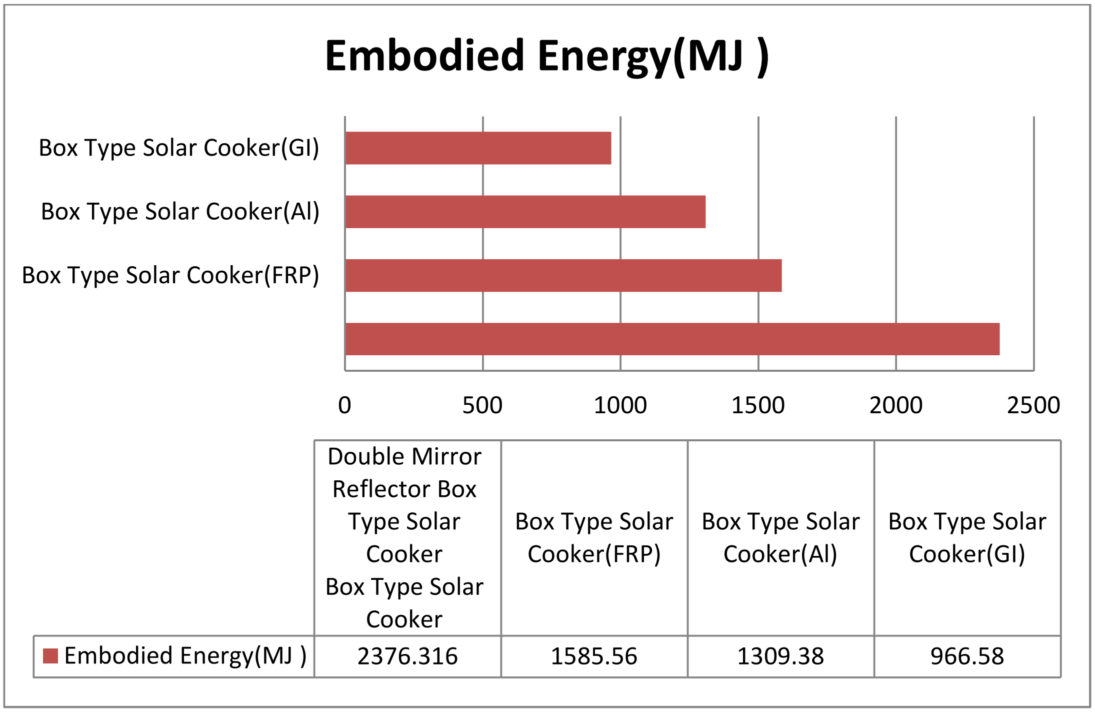


Fig 2.3: Embodied energy comparison of solar cookers

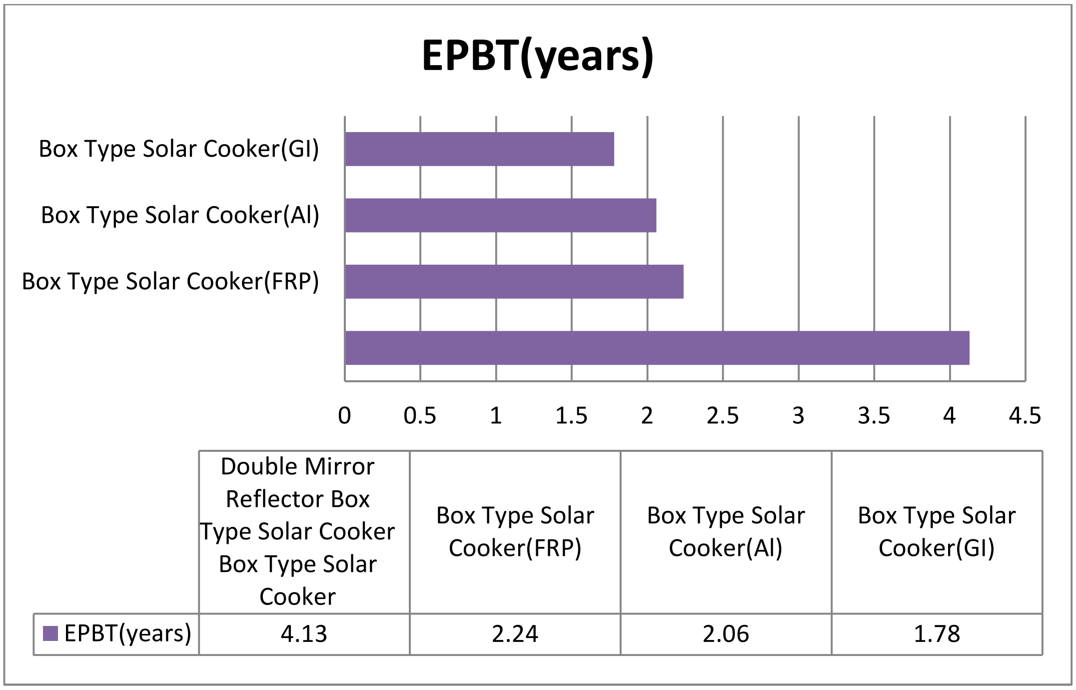


Fig 2.4: Energy payback time comparison of solar cookers

CHAPTER 3

SOLAR DRYER

The drying process removes moisture from a product and aids in its preservation. Sun crop drying is one of the oldest and most common direct uses of solar energy. The traditional method is to spread the item to be dried on the ground in a thin layer. The downsides of this strategy are as follows:

(1) the procedure is slow;
(2) the product is susceptible to insect attack
(3) dust is mixed in with the product.

These drawbacks can be mitigated by using a solar dryer. Furthermore, drying might be made a more efficient and regulated process, resulting in a higher-quality product.

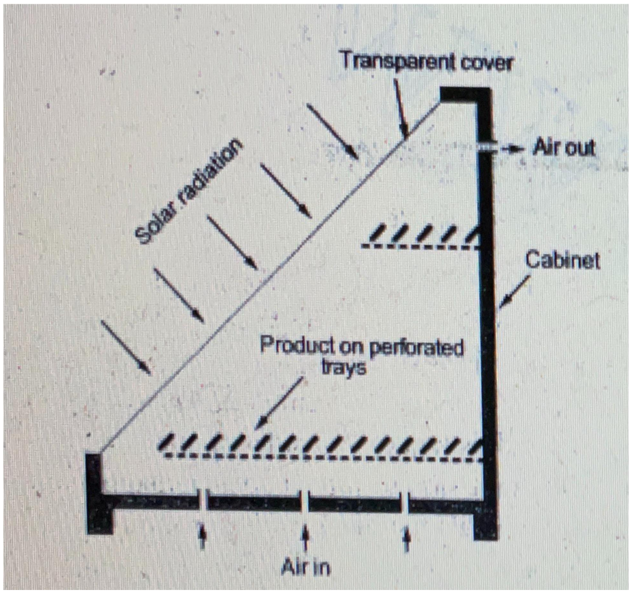


Fig 3.1:Solar Cabinet Dryer

Figure 3.1 depicts a modest cabinet-style solar dryer. It's a greenhouse-style enclosure with a transparent cover. On perforated trays, the material to be dried is inserted. Solar radiation enters the enclosure and is absorbed by both the product and the enclosure's inside surfaces, raising the temperature. The temperature of the inner air rises to between 50 and 80 degrees Celsius. By creating adequate holes at the bottom and top, natural air circulation is guaranteed. The moisture in the product is removed by the circulating air.

A blower can be used to create forced air circulation for large-scale drying. Controlled temperature drying, also known as kal drying, can be utilised in the case of green timber, when direct sunlight causes curling and wrapping, or for products where direct sunlight is insufficient. The air is heated separately in an array of solar air heaters before being routed to the chamber where the dried product is kept. Food grains, as well as items like tea and tobacco, can be dried in these dryers. Solar dryers are categorised in a number of ways.

One of the way is on the basis of air flow. If it is a forced convection system then it is called as active dryer but if natural convection process is used for drying then it is called passive drying .In active drying a fan is used. This will eventually increase the embodied energy of the system. A lot of studies has been done in the past to calculate the embodied energy, energy payback time and carbon credit ofsolar dryers.

(Prakash et al., 2016) had done the energy and exergy analysis, annual performance and environomical analysis of a modified green house dryer with thermal energy storage working under active and passive mode as shown in the fig 3.2 . Thermal storage was applied on the ground in three different ways which was barren floor, black coated and floor covered with black PVC sheet. The dryers frame was of aluminium enveloped with transparent polycarbonate sheet except north wall which had an opaque mirror. Length, width and side height dimensions were 1.5 m, 1.0 m and 0.5 m respectively. The embodied energy found for active mode was 2263.128 MJ while for passive mode it was 1728.997 MJ. The increase in active mode is due to the exhaust fan being used. The energy payback time for active and passive made is 1.3 and 1.04 years respectively. This is because the primary energy consumed is more in active dryer.The carbon credit earned in USD for active and passive mode was 393 and 375.

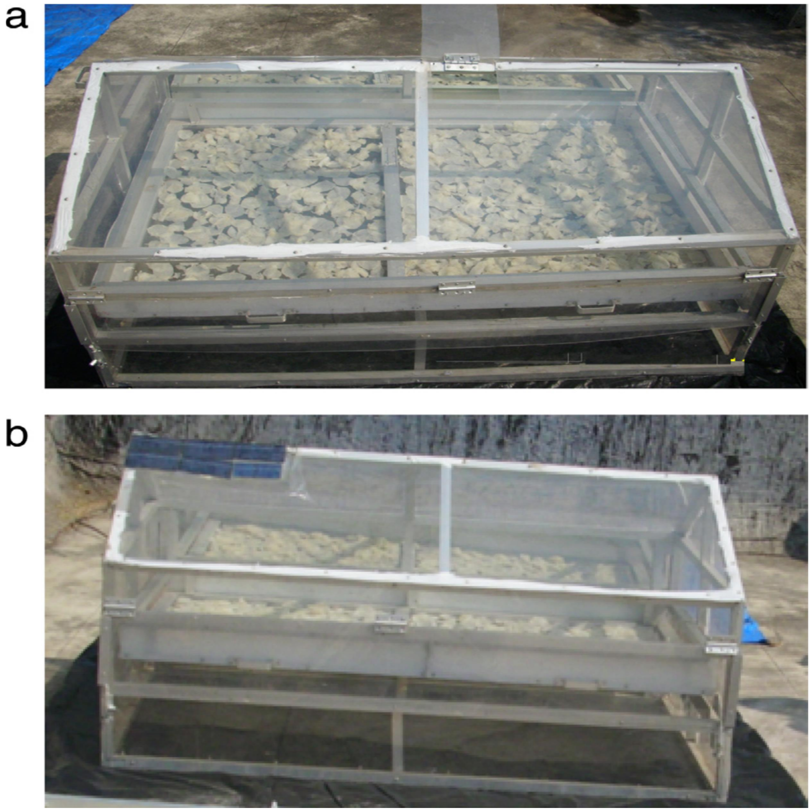


Fig 3.2: Photograph of modified green house dryer for potato chips drying under

a) Passive mode b)Active mode (Prakash et al., 2016)

(Prakash & Kumar, 2014) in their study did an environmental and performance analysis as well as mathematical modelling of an active modified greenhouse dryer used for tomato flakes drying as shown in fig 3.3. The dimension of the dryer used was 1.5 X 1.0 X 0.712 m^3 and an exhaust fan of diameter 127mm was used. The embodied energy found was 2263.423 MJ and the energy pay back time was 1.14 years. The carbon credit earned was ranging from 176-706 USD.

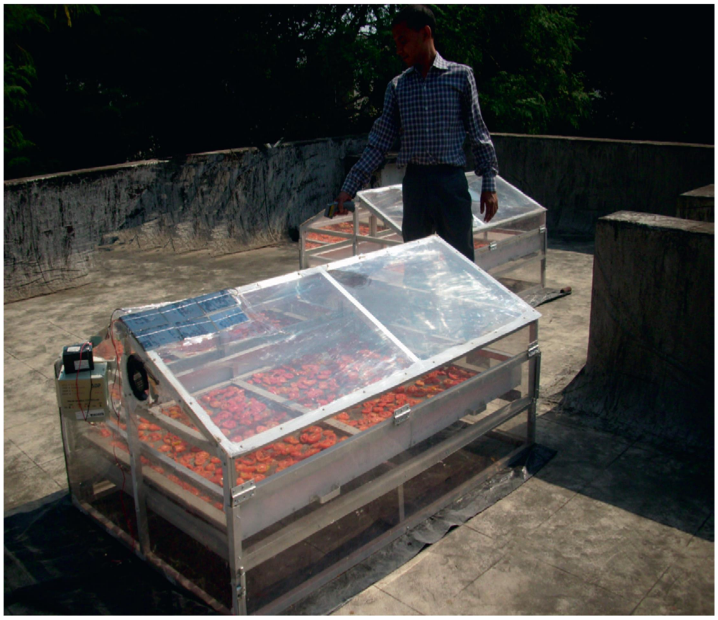


Fig 3.3 : Photograph of active modified greenhouse dryer used for tomato flakes drying(Prakash & Kumar, 2014)

(Shrivastava & Kumar, 2017) analysed the embodied energy, energy payback time, CO_2 emission and the carbon credit earned of indirect solar drying unit. The indirect solar dryer as shown in fig 3.4 consisted of air supplying unit with 12V DC fan, solar air heater and a drying chamber consisting two steel wire mesh tray with 0.91mx 0.76m x 0.76m as the dimension of drying chamber. The embodied energy found was 3894.48 MJ and the energy payback time was 4.36 years. The carbon credit earned was ranging from 660-2061 USD.It means this system is more environment friendly than the above mentioned work of solar dryer systems.

Fig 3.4 : Photograph of indirect solar drying unit(Shrivastava & Kumar, 2017)

Table 3: Embodied energy, energy payback time and carbon credit values of solar dryers

Ref.	System	Embodied Energy(MJ)	Energy Payback Time(EPBT)(years)	Carbon Credit(USD)
(Prakash et al., 2016)	Modified greenhouse dryer with thermal energy storage	Active- 2263.428 Passive-1728.997	Active – 1.3 Passive – 1.04	Active-393 Passive-375
(Prakash & Kumar, 2014)	Modified greenhouse dryer under active mode	2263.423	1.14	176-706
(Shrivastava & Kumar, 2017)	Indirect solar dryer	3894.48	4.36	660 – 2061

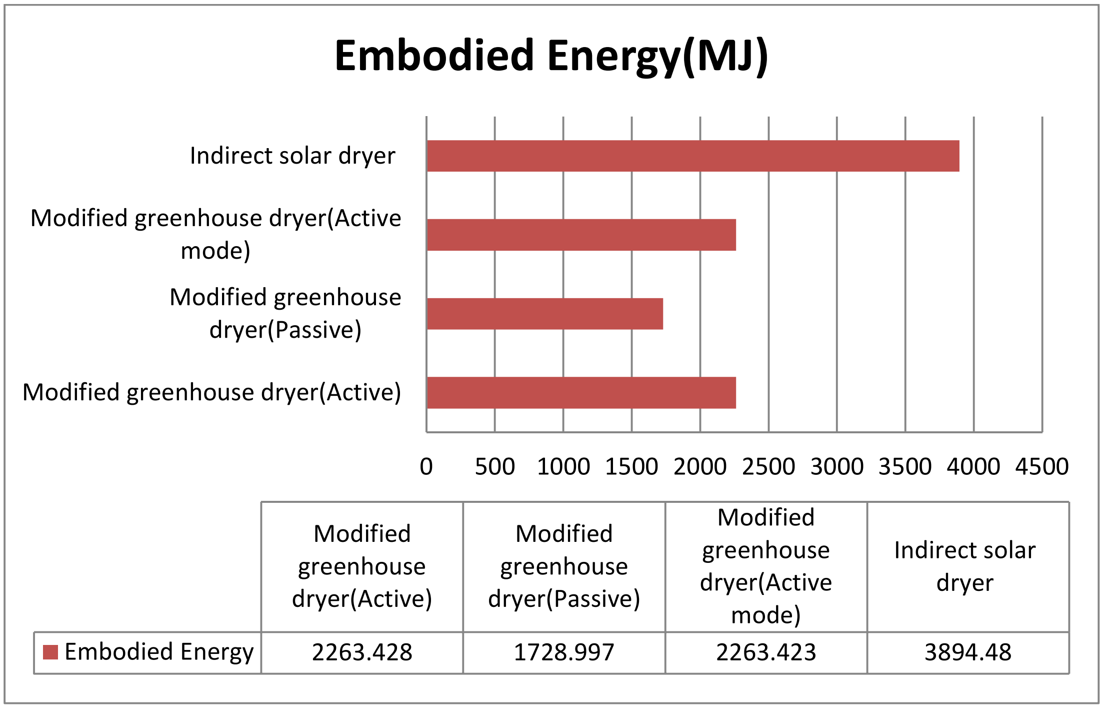


Fig 3.5: Embodied energy comparison of solar dryers

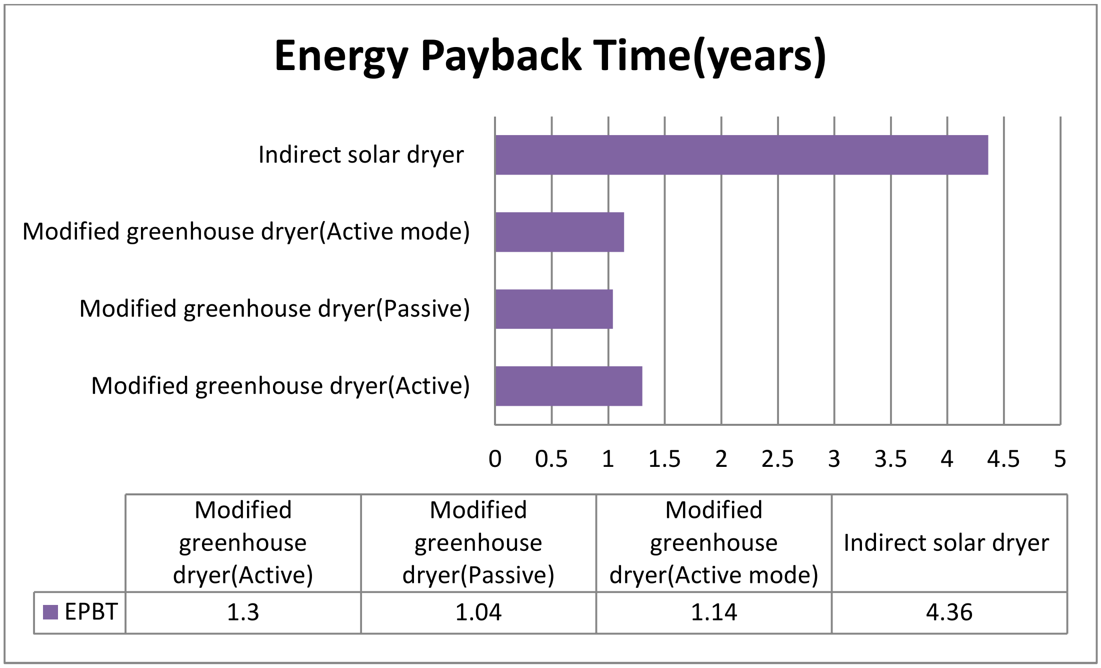


Fig 3.6: Energy payback time comparison of solar dryers

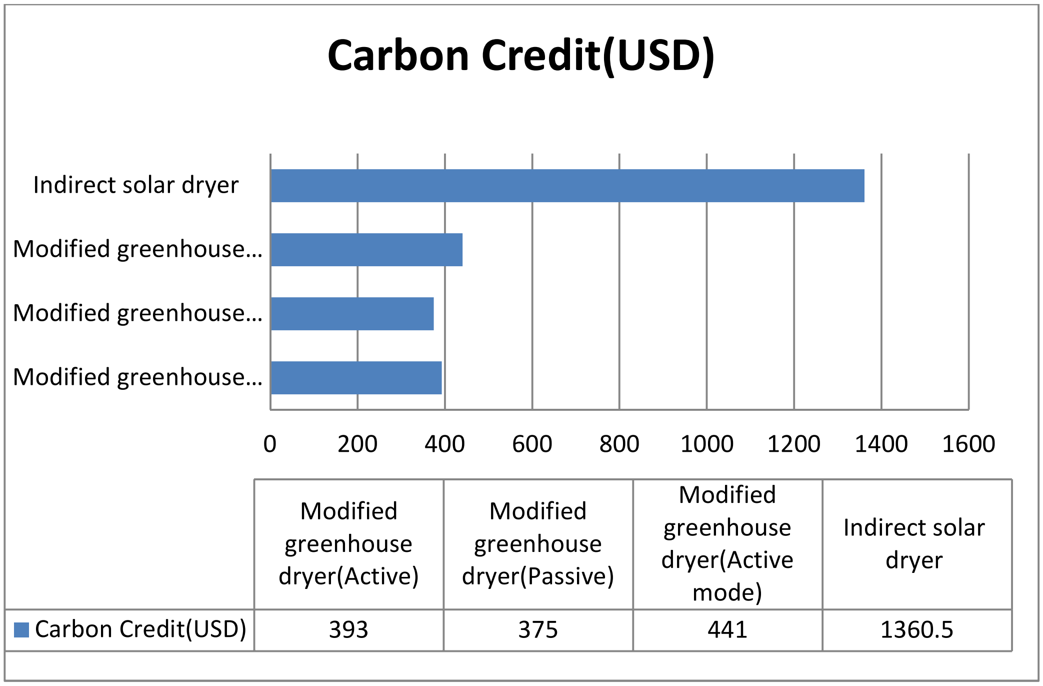


Fig 3.7: Carbon credit comparison of solar dryers

CHAPTER 4

SOLAR COLLECTOR

Solar power has a low density per square meter (1 to 0.1 kW/sq. m.). As a result, solar thermal collectors are used to cover a wide area of the ground. A solar thermal collector is the basic building block of a solar thermal system. It efficiently collects solar energy as heat and transfers it to the heat transport fluid. The heat-transport fluid transports the heat to a thermal storage tank/boiler/heat exchanger, where it will be used in the system's later stages.

Figure 4.1 depicts the overall classification of solar collectors into categories and subcategories. The way they collect solar light determines their classification. The non-concentrating type absorbs radiation as it strikes the collector's surface, but the concentrating type raises radiation concentration per unit area before absorbing it. The concentrating type is further split into focus and non-focus types based on the techniques used for radiation concentration. Depending on the focusing mechanism, the focus type is further split into line or point focus.

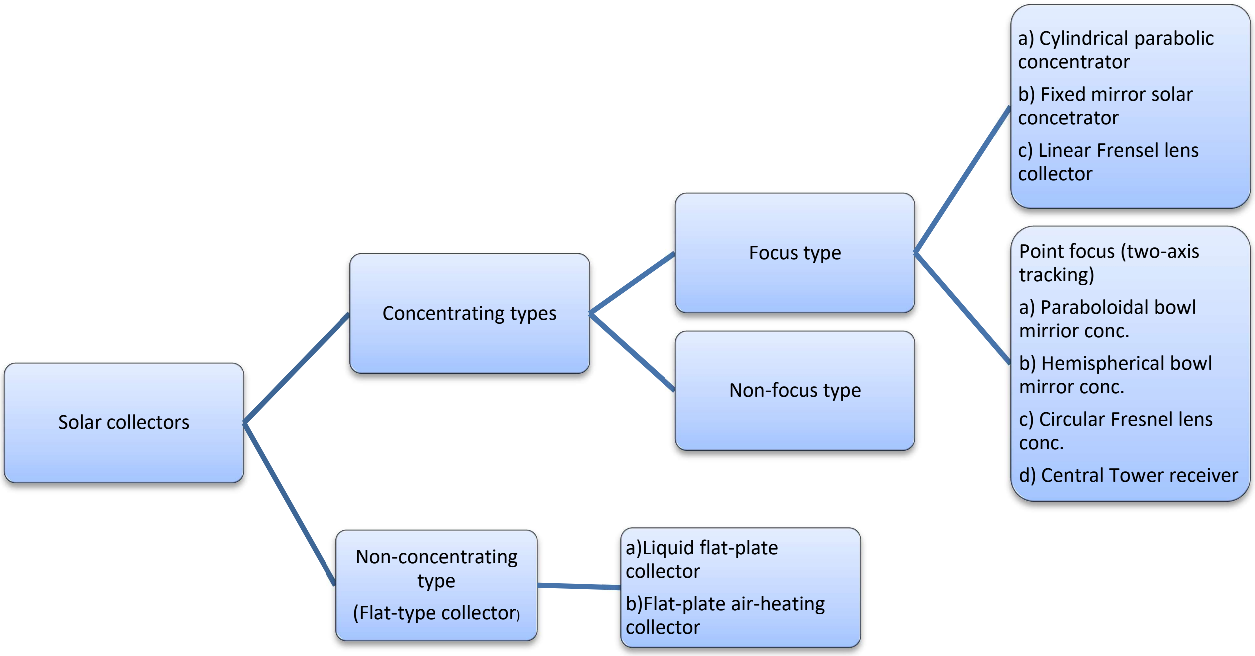


Fig 4.1: Classification of collectors

Solar radiation is converged from a large area into a smaller area using optical means in concentrating-type solar collectors. Reflection or refraction techniques can converge beam radiation, which has a single path and travels in a straight line. Diffused radiation, on the other hand, has no distinct direction and hence disobeys optical principles. As a result, it is impossible to concentrate the diffuse component. As a result, concentrating-type solar collectors primarily use the beam radiation component (with only a small amount of diffuse radiation passing directly over the absorber), whereas non-concentrating (Rat plate) collectors absorb both beam and diffused radiation, which is a distinct advantage of a flat-plate collector. Because a flat-plate collector is simple to build and does not require sun tracking, it may be securely mounted on a rigid platform, making it mechanically stronger than those that require flexibility for tracking.

The flat-plate design is more likely to: survive extreme outdoor circumstances, as the collector is put outdoors and exposed to atmospheric disturbances (rain, storm, etc.).A flat-plate collector also requires little maintenance due to its basic stationary design.The principal disadvantage of a flat-plate collector is that because of the absence of optical concentration, the area from which heat is lost is large. Also, due to the same reason high temperatures cannot be attained.

The basic benefit of concentrating-type collectors is that they may achieve high temperatures due to the concentration of radiation. This generates high-temperature thermal energy as well. To maximise collection, a flat-plate collector is oriented so that its length lines with the line of longitude and is appropriately tilted towards the south.The positioning of the collector is shown in Fig 4.2.

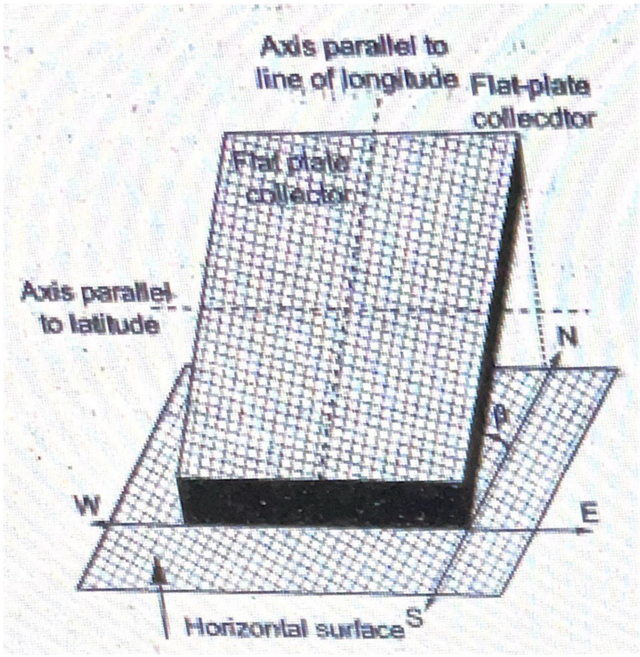


Fig 4.2 Positioning of the collector

The majority of these collectors have the following basic components: (1) a transparent cover (one or two sheets) of glass or plastic (3) tubes, channels, or tunnels in thermal contact with the absorber plate—in certain designs, the tubes constitute an integrated part of the absorber plate (iv) weather proof, insulated container to enclose the above components.The heat-transport medium from the collector to the next step of the system is a liquid, most commonly water. If the ambient temperature is projected to drop below O°C throughout the night, a mixture of water and ethylene glycol (antifreeze mixture) is occasionally utilised. Solar radiation is absorbed by a specially treated metallic absorber plate, which raises the temperature of the plate. Metal sheets with thicknesses ranging from 0.2 to 1 mm are commonly used for the absorber plate. The heat is transferred to the heat-transfer liquid circulating in the tube (or channels) beneath and in close proximity to the absorber plate.A metal sheet with a thickness of 0.3 to 1.2 mm is used to make the absorber plate. The heat is transferred to the heat-transfer liquid circulating in the tube (or channels) beneath and in close proximity to the absorber plate. The diameter of the metallic tubes ranges from 1 to 1.5 cm. With a pitch ranging from 5 to 12 cm, these are soldered, brazed, welded, or pressure bonded to the absorber plate.A metal sheet with a thickness of 0.3 to 1.2 mm is used to make the absorber plate. The heat is transferred to the heat-transfer liquid circulating in the tube (or channels) beneath and in close proximity to the absorber plate. The diameter of the metallic tubes ranges from 1 to 1.5 cm. With a pitch ranging from 5 to 12 cm, these are soldered, brazed, welded, or pressure bonded to the absorber plate.The tubes are either glued to the top or are in line with and integral to the absorber plate in some configurations. Header pipes, which are slightly larger in diameter and typically have a diameter of 2 to 2.5 cm, lead water into and out of the collector and distribute it to tubes. Copper is the most typical metal used for the absorber plate, tubes, and header pipes, but other metals and polymers have been attempted as well. Thermal insulation provided by a 2.5 to 8-cm thick layer of glass wool in the bottom and along the side walls inhibits heat loss from the collector's back surface and sides.Because it is permeable to incoming short wavelengths, the glass cover allows solar radiation to pass through, but it is substantially opaque to longer infrared radiation reflected off the absorber. As a result, much like a green house, the heat is trapped in the gap between the absorber plate and the glass cover. In addition, by keeping the air stagnant, the glass cover inhibits heat loss due to convection. The glass cover can reflect up to 15% of incoming solar radiation, which can be lowered by covering the outer surface of the glass with an anti-reflective coating. One or two coverings are usually used, with a 1.5 to 3 cm space between them.The most popular material is 4 to 5 mm thick plain or toughened glass. Transparent polymers can be used in place of glass, however their performance is generally inferior to that of glass. Glass is more impermeable to infrared radiation than most polymers. In addition, as they age, their transparency to incoming solar radiation reduces. When exposed to sunlight, a plastic material's life is cut short as it degrades and cracks form over time.

The absorber and tube configuration of a solar air-heating collector differs from that of a liquid flat-plate collector (riser).Between the absorber plate and the air, the heat-transfer coefficient is quite low. As a result, the surfaces of the air-flow route are occasionally roughened or equipped with longitudinal fins. Other types of absorber plate shapes include corrugated, V-shaped, matrix, and so on. Drying for agricultural and commercial purposes, as well as space heating, are the most common uses for these collectors.Compared to a liquid fat-plate collector, it has the following advantages:

1) It's small, easy to put together, and requires little upkeep.

2) Because air is used directly as the working fluid, there is no need to transfer thermal energy from the working fluid to another fluid.

3) Corrosion is no longer an issue.

4) There is less air leakage from the duct.

5) The possibility of the working fluid freezing is also eliminated.

6) There isn't a lot of pressure inside the collector.

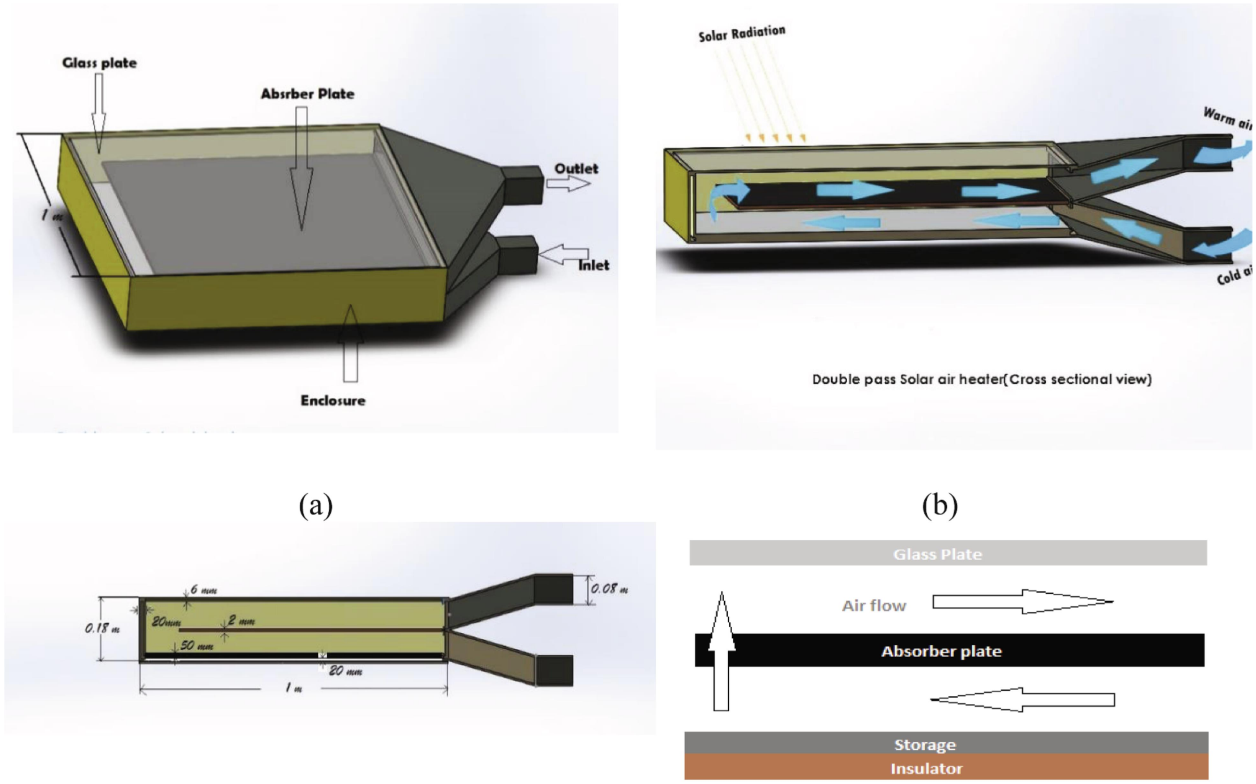
The following are the principal drawbacks of air collectors:

1) Due to the low density, a big amount of fluid must be handled. As a result, if the pressure drop is not kept within defined limits, the electrical power required to move the air through the system can be significant.

2) There is insufficient heat transfer between the absorber plate and the air.

3) Due to poor heat capacity, there is less thermal energy storage.

(Prakash et al., 2022) discussed the exergy and energy analysis of a solar air heater as shown in a sectional view in fig 4.3 .It was an innovative design with double pass and sensible heat storage as shown in fig. This system was used for crop drying and space heating and the best operating conditions were selected. The operating conditions selected were namely natural convection mode, induced force convection mode and induced forced convection mode with a reflector. For storing the sensible heat metco material and aluminium scrap were used. The embodied energy found in the fabrication of this system was around 3030.588 MJ. For natural convection mode the average energy and exergy efficiency was found to be 11.47% and 2% while for the system operating under induced force convection mode it was 56% and 10.43%. Of all the three operating conditions, system operating under induced forced convection mode had superior heat performance as its energy and exergy efficiency was found to be 86.19% and 17.617%.



(a) (b)

(c) (d)

Fig 4.3: Sectional view of double pass solar air heater with sensible thermal storage concept(Prakash et al., 2022)

(Lamnatou et al., 2014) analysed the embodied energy and energy payback time for a building integrated solar thermal collector. The analysis was done by comparing with recycling and without recycling. A significant reduction in embodied energy was found if materials were recycled. The embodied energy without recycling was found to be 6000 MJ while with recycling it was around 400-500 MJ. The energy payback time with recycling was around 1.5years.

(Battisti & Corrado, 2005) used Sima Pro 5.0 software to do the life cycle assessment of solar thermal collector with integrated water storage as shown in fig 4.4. The embodied energy and energy payback time were found by considering two cases: 1) without glass cover and 2) with glass cover. The embodied energy without glass cover was found to be 3100 MJ while for with glass cover it was around 3170 MJ. The energy payback time without glass cover was ranging from 0.5-1.5 years while with glass cover it was around 0.45- 1.2 years.

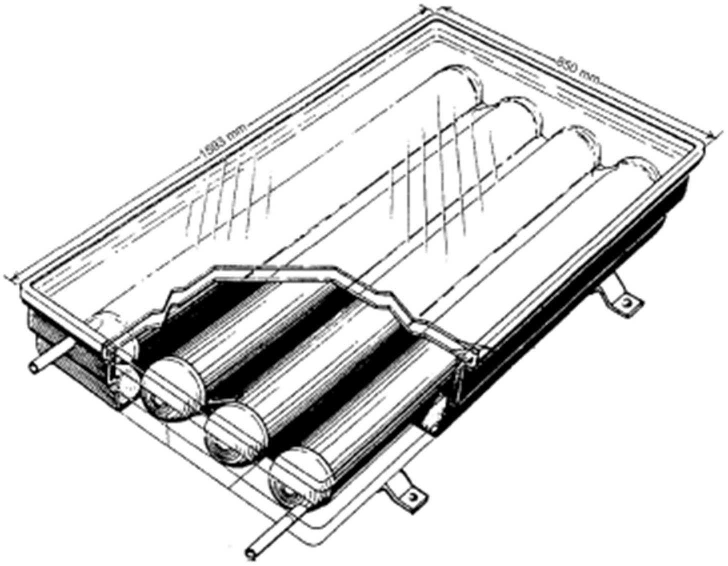


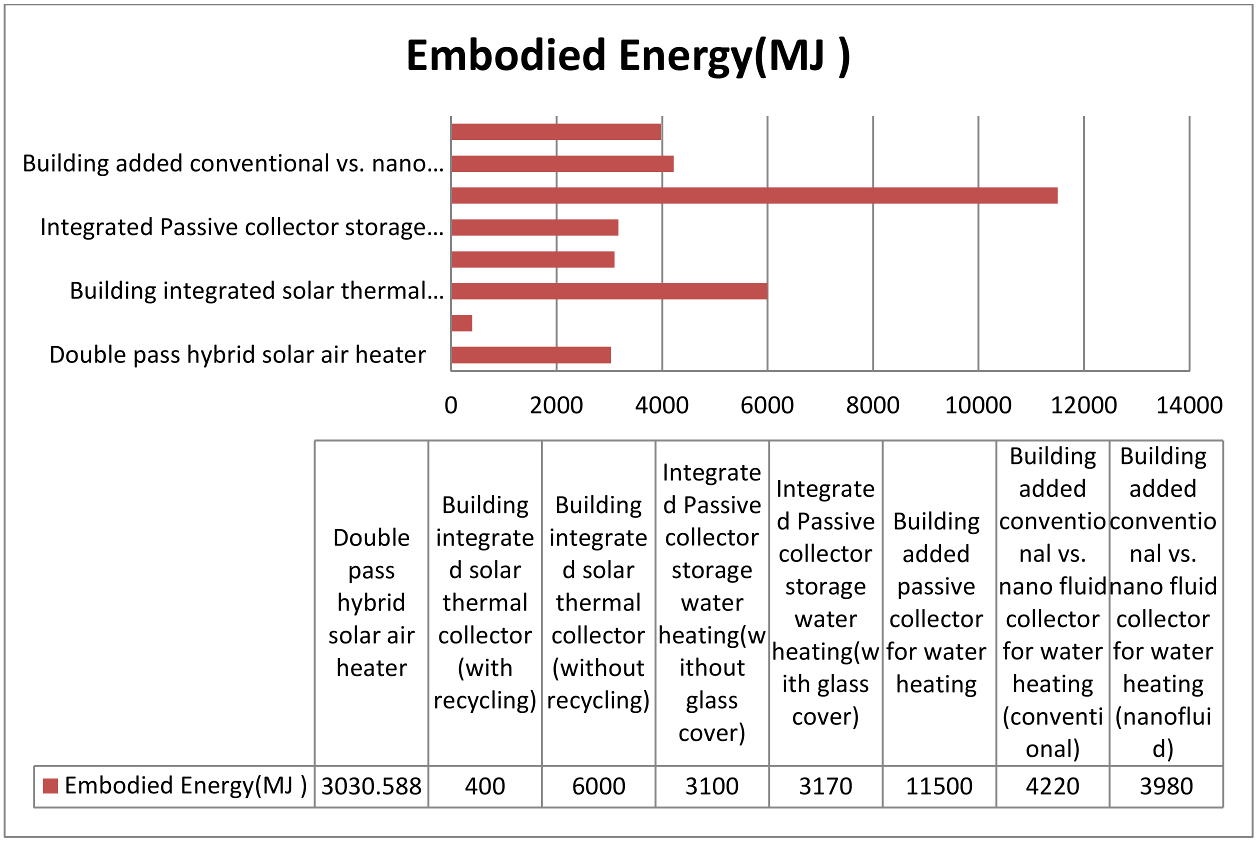
Fig 4.4: Integrated collector storage(Battisti & Corrado, 2005)

A similar study was done by (Ardente et al., 2005)for a solar thermal collector used for sanitary warm water. The embodied energy for this system was found to be 11500 MJ while the energy payback time found was less than 2 years. The CO_2 emission was ranging from 500 to900kg.

A comparitive Environmental and economic analysis of conventional and nanofluid solar hot water technologies was done by (Otanicar & Golden, 2009) it was said that the nanofluid based solar collector had slightly longer payback period but economic savings were found to be same for both of them considering useful life of them. Also the embodied energy was slightly less for the nanofluid based system. For the conventional system it was around 4220 MJ while the one with nanofluid it was around 3980 MJ.

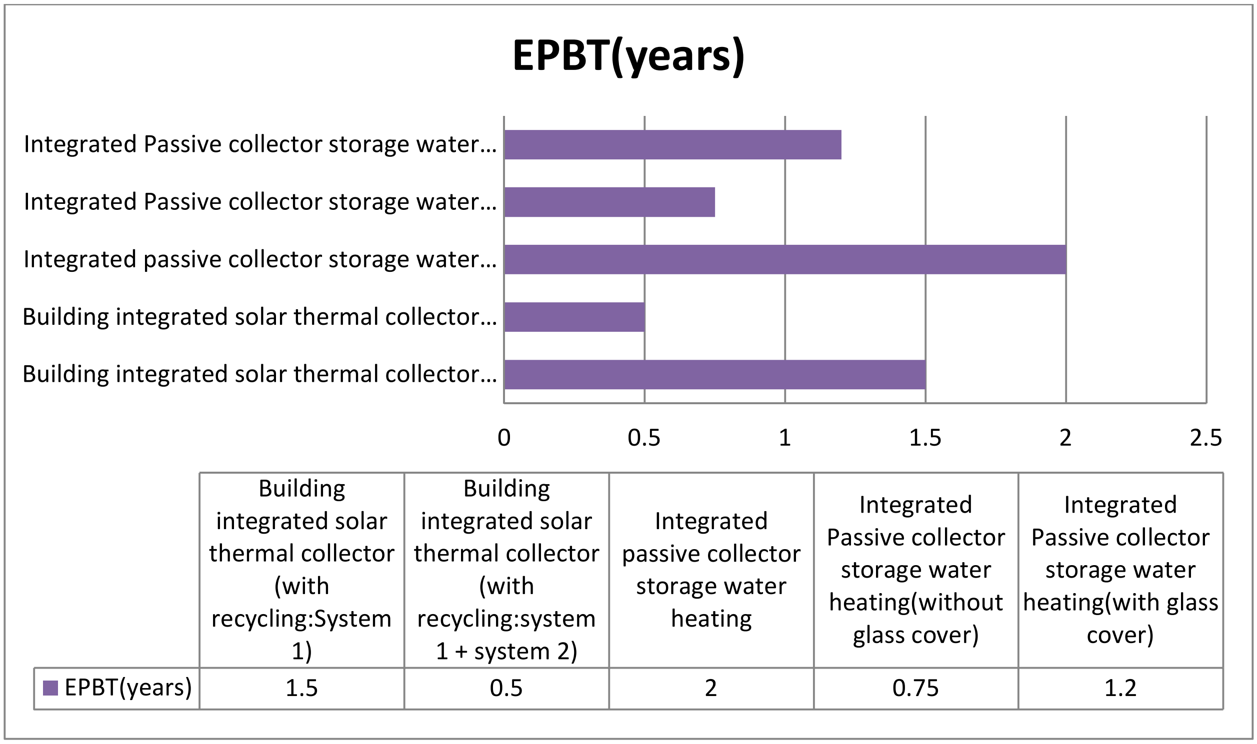
Table 4: Embodied energy and energy payback time of different collectors

Ref.	System	Embodied Energy(MJ)	Energy Payback Time(EPBT)(years)	Carbon Credit(USD)
(Lamnatou et al., 2014)	Building integrated solar thermal collector	Recycling(with) – 400-500 Recycling(without) – 6000	Recycling(with) : System 1 : 1.5 System 1 + System 2 : 0.5	–
(Battisti & Corrado, 2005)	Integrated Passive collector storage water heating	Without glass cover : 3100 With glass cover : 3170	Without glass cover: 0.5 – 1.5 With glass cover: 0.45 – 1.2	–
(Prakash et al., 2022)	Double pass hybrid solar air heater	3030.588	–	–
(Ardente et al., 2005)	Building added passive collector for water heating	11500	< 2	–
(Otanicar & Golden, 2009)	Building added conventional vs. nano fluid collector for water heating	Conventional : 4220 Nanofluid: 3980	–	–



	Double pass hybrid solar air heater	Building integrated solar thermal collector (with recycling)	Building integrated solar thermal collector (without recycling)	Integrated Passive collector storage water heating(without glass cover)	Integrated Passive collector storage water heating(with glass cover)	Building added passive collector for water heating	Building added conventional vs. nano fluid collector for water heating (conventional)	Building added conventional vs. nano fluid collector for water heating (nanofluid)
🟥 Embodied Energy(MJ)	3030.588	400	6000	3100	3170	11500	4220	3980

Fig 4.5: Comparision of Embodied Energy of different collectors



	Building integrated solar thermal collector (with recycling:System 1)	Building integrated solar thermal collector (with recycling:system 1 + system 2)	Integrated passive collector storage water heating	Integrated Passive collector storage water heating(without glass cover)	Integrated Passive collector storage water heating(with glass cover)
■ EPBT(years)	1.5	0.5	2	0.75	1.2

Fig 4.6: Comparision of Energy Payback Time of different collectors

CHAPTER 5

SOLAR WATER AND SPACE HEATING

The most prevalent type of solar water heater is depicted in detail in Fig. 5.1. Water is utilised as a heat-transfer fluid in a tilted flat-plate solar collector. Above the collector is a thermally insulated hot-water holding tank. The collector's heated water rises to the hot water tank, where it replaces an equal amount of cold water that enters the collector. The cycle repeats again, heating up all of the water in the hot water tank. When hot water is removed from the hot water outlet, it is replaced with cold water from a make-up tank installed above the hot water tank. The technique is referred to as a passive beating scheme because water circulates naturally in the loop due to thermo-siphon action. A pump is necessary to induce circulation of water in the loop when the collector is set above the level of the hot-water tank, and the scheme is known as an active (or forced) solar thermal system. During cloudy weather, an auxiliary electrical emersion heater can be utilised as a backup. A solar water heater may be utilised for roughly 300 days per year in ordinary Indian climatic conditions. A rooftop solar water heater that produces 100 litres per day (LPD) of water at 60-80 degrees Celsius is normal. It has a 10-12 year life lifetime and a 2-6 year payback period.

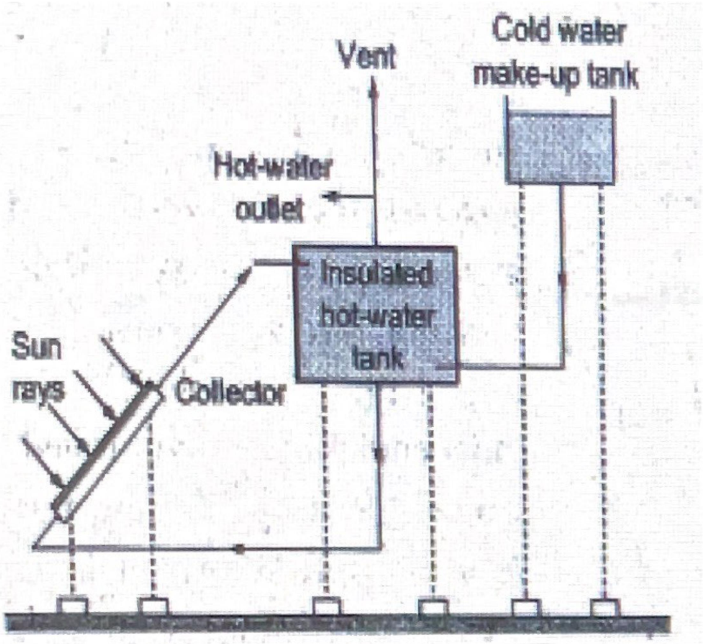


Fig 5.1: Domestic solar water heating system

Solar energy can also be utilised to heat or cool a structure to keep it at a comfortable temperature. Passive systems do not require any mechanical devices and rely on natural heat transfer processes such as convection, radiation, and conduction. The use of passive heating/cooling systems places limits on building design in order to allow for natural heat movement. A solar house is such a specially constructed structure. Passive cooling technology is far less developed than passive room heating technology. Natural passive cooling may not always be sufficient to meet the demand, and supplementary cooling may be required at peak loads, but it significantly reduces the load on the air-conditioning unit. Active heating/cooling systems use mechanical equipment such as pumps, blowers, and other similar devices to circulate the working fluid for heat transportation, hence a unique building design is not required as in the case of passive heating. Nonetheless, good building design and insulation are important and will cost less than an additional heating/cooling load caused by poor design.

Figure 5.2 depicts a solar passive space heating system. Trombe is the thick south-facing wall. Walls consisting of concrete, adobe, stone, or brick-and-sand composites are used for thermal storage. The exterior surface has been painted black to improve absorption. One or more sheets of glass or plastic cover the whole south wall, with a small air gap (typically 10-15 cm) between the wall and the inner glazing.

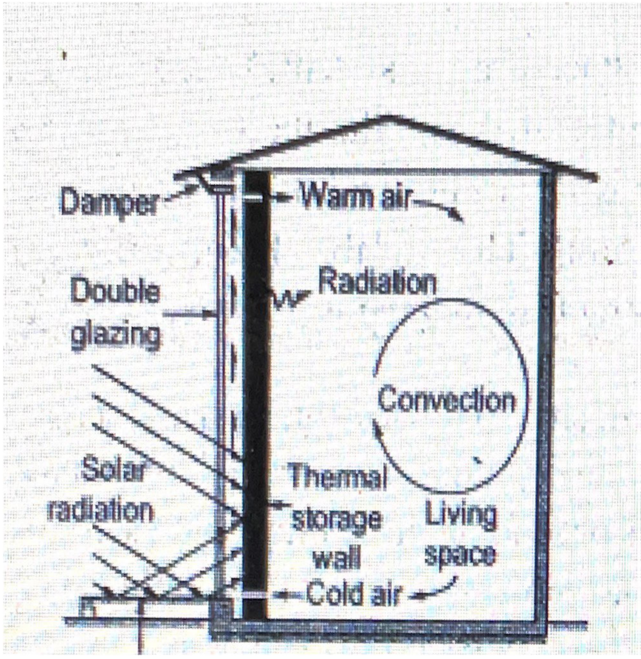


Fig 5.2: Solar space heating

The thermal storage wall absorbs solar radiation after it passes through the glazing. As a result, the air in the air gap between the glazing and the wall heats up, rises, and enters the room through the higher vent, while cold room air replaces it through the bottom vent: The air circulation continues until the wall continues to heat the air. The thermal wall gathers, stores, and transports heat to the room in this manner: The air flow via the entrance and output vents can be controlled by shutters to adjust the heating. When no heat is required, the damper at the top of the glazing is opened, allowing the extra heat to flow outdoors.

(Streicher et al., 2004) outlined the methodology for determining energy payback time of thermal Solar systems and how factors like pump operating hours or fractional energy savings influence it. Two Domestic hot water systems has been used for the study with difference in only the material used for the collector and the supporting frame. Also the embodied energy has been outlined by the author. The embodied energy for system 1 was 6408 MJ whereas for system 2 it was 8632.8 MJ.The energy payback time was 1.4 years and 2.14 years for system 1 and system 2 respectively.The savings compared to a conventional system with electricity or diesel backup was about 80% for system 1 that is domestic water heating system while if both electricity and diesel are used as backup then it drops to 75%.For the case of system 2 that is Solar space heating and water heating ,the saving is about 40%.However for system 2 greater quantities of pollutant gases were saved in comparison to system 1.

(Kalogirou, 2004) studied the environmental protection offered by two of the most widely used renewable energy systems which is solar water heating and solar space heating as shown in fig. The embodied energy for solar water heating system was 8700 MJ while for solar water heating along with space heating it was 82500 MJ. The energy payback time for both of them was around 1.2 years. Another study by kalogirou.2008 was done on thermosiphon solar water heaters for the environmental protection offered along with economics and thermal performance. The embodied energy and energy payback time was found to be 6950 MJ and1.1 years respectively.Also with electricity or diesel back up the saving as compared to conventional system was 70%.

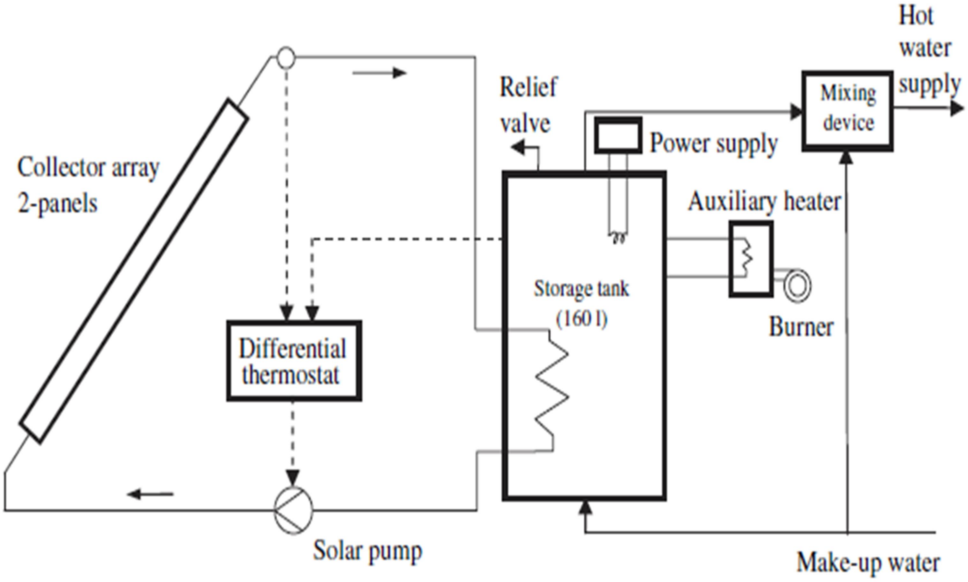


Fig 5.3 : Schematic diagram of the solar water heating (SWH) system (Kalogirou, 2004)

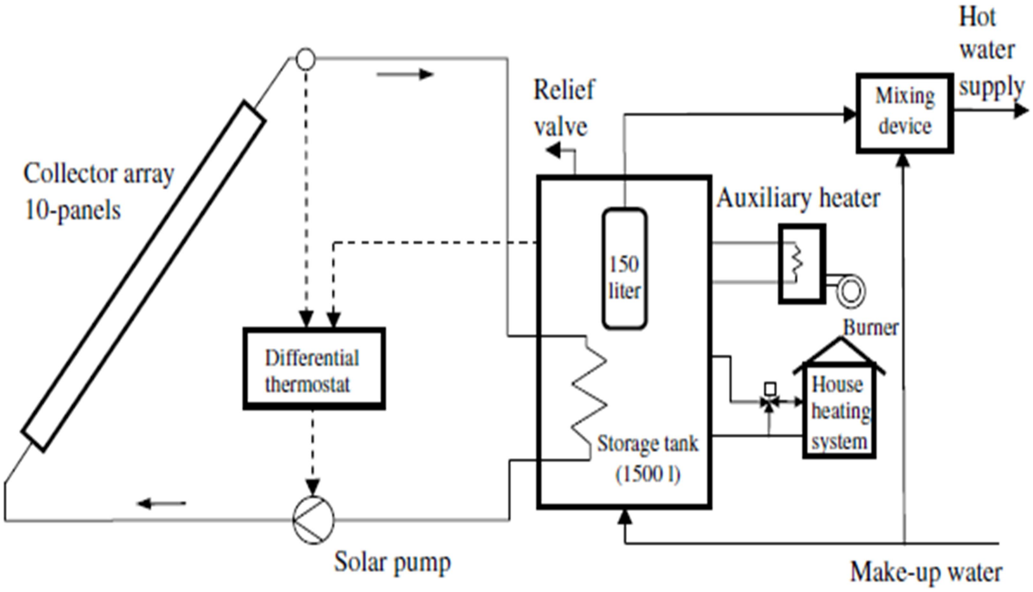
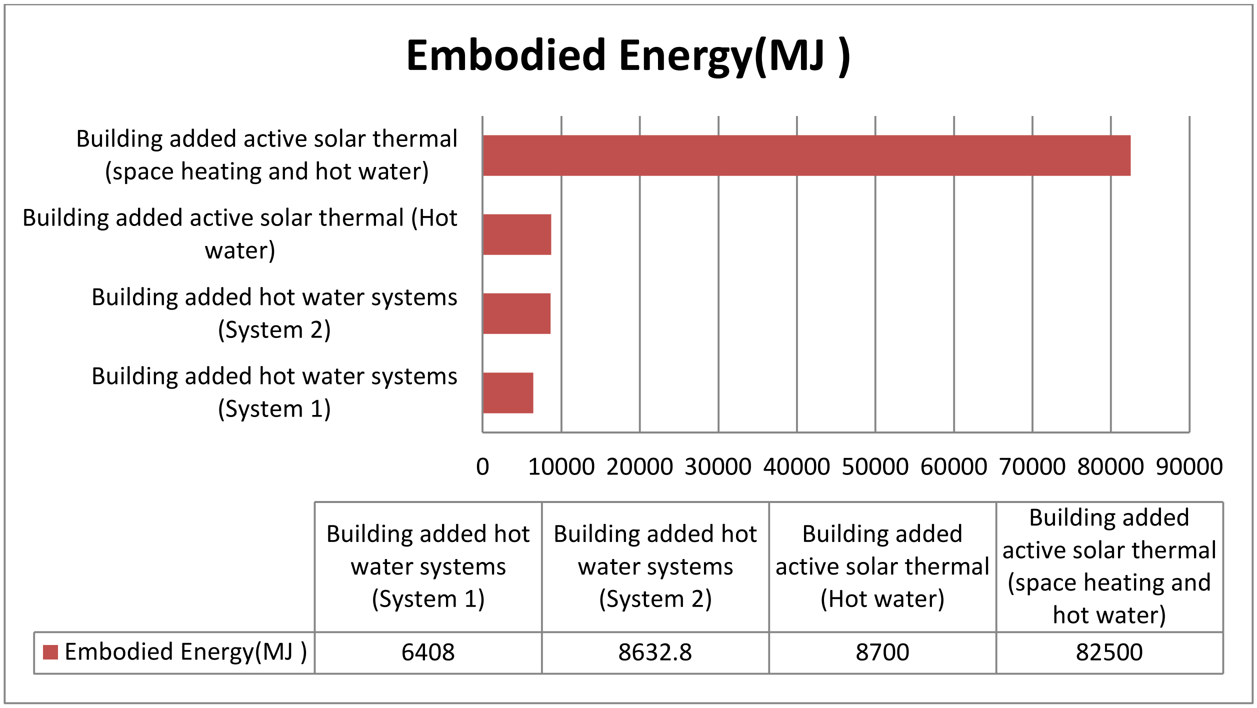


Fig 5.4:Schematic diagram of the solar heating and water heating (SSWH) system (Kalogirou, 2004)

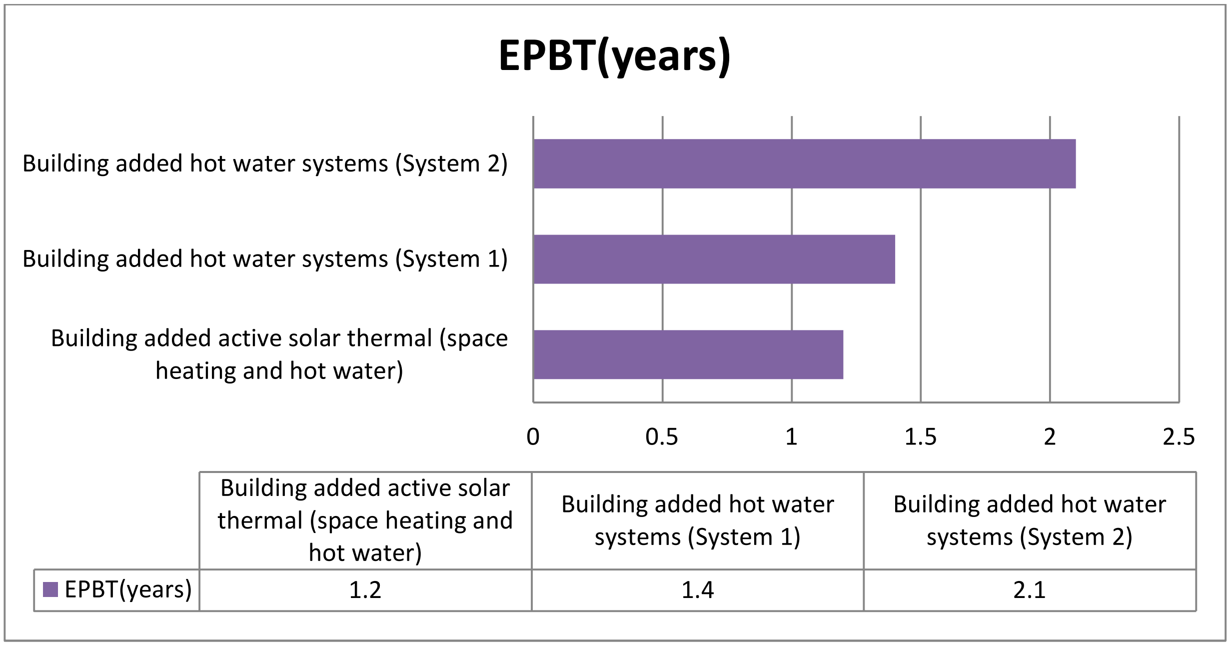
Table 5 : Embodied energy and energy payback time of solar space and water heating

Ref.	System	Embodied Energy(MJ)	Energy Payback Time(EPBT)(years)	Carbon Credit(USD)
(Streicher et al., 2004)	Building added hot water systems	System 1 : 6408 System 2 : 8632.8	System 1 :1.4 System 2 : 2.14	_
(Kalogirou, 2004)	Building added active solar thermal System1 : Hot water System 2 : Space heating and hot water	System 1: 8700 System 2: 82500	Around 1.2	_



	Building added hot water systems (System 1)	Building added hot water systems (System 2)	Building added active solar thermal (Hot water)	Building added active solar thermal (space heating and hot water)
🟥 Embodied Energy(MJ)	6408	8632.8	8700	82500

Fig 5.5: Comparison of embodied energy of solar water and space heating systems



	Building added active solar thermal (space heating and hot water)	Building added hot water systems (System 1)	Building added hot water systems (System 2)
🟪 EPBT(years)	1.2	1.4	2.1

Fig 5.6: Comparison of energy payback time of solar water and space heating systems

CHAPTER 6

SOLAR DESALINATION

Potable or fresh water (water with a salt level of less than 500 ppm) is one of humanity's most basic needs. Fresh water is also required by industries and agriculture, without which they cannot grow. Humankind has relied on rivers, lakes, and underground water reservoirs to meet its fresh water needs, an act that is closely linked to the development of civilization. The demand for fresh water has risen dramatically as a result of rapid industrialisation and population growth. The average per capita water usage has increased in tandem with the development in the standard of living. Fresh water, which was formerly abundant in rivers, lakes, and ponds, is becoming limited as a result of climate change and less rainfall in many parts of the world. Furthermore, the available resources are becoming degraded as a result of large-scale discharges of industrial effluents and sewage. As a result of climate change, pollution, and overconsumption, over 2000 million people do not have regular access to enough, safe water. People in some places trek up to 30 kilometres to collect fresh water. According to one estimate, 79 percent of the water accessible on the planet is salty, 20% is brackish (less salty water from wells), and 1% is fresh. As a result, if there is lots of saline water and sun, converting brackish or saline water to fresh water through the distillation process utilising solar energy is an excellent concept.

Solar energy has been used to desalt sea water and brackish well water at a number of medium-sized pilot facilities in the United States, Greece, Australia, and other countries. The concept was originally used in 1872 in Las Salinas, Chile, in a factory that provided drinking water for animals working in nitrate mines as well as transportation. Solar still is the name of the converting equipment. Modern advances in solar distillation have focused on the use of materials and designs that are both cost-effective and robust, while also increasing output, in order to lower product costs. Solar stills have grown into a variety of shapes and sizes. However, only the basin-type has been tested on a wide scale in a commercial setting. A simple basin-type solar still is made up of a shallow blackened basin that is filled with distilled saline or brackish water. The water depth is regulated between 5 and 10 cm. A slanted translucent roof protects it. After passing through the roof, solar energy is absorbed by the blackened surface of the basin, raising the temperature of the water. The moisture content of the evaporated water rises, which condenses on the cooler beneath the glass. Condensed water runs down the slope and collects in the condensate channel built into the glass. The construction is schematically shown in fig 6.1.

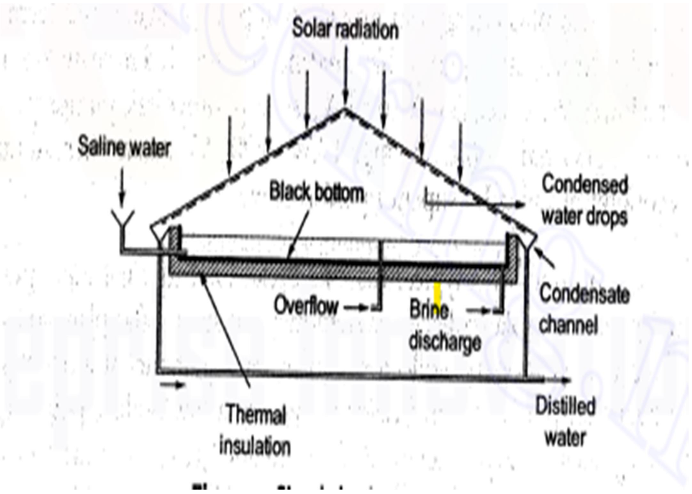


Fig 6.1: Simple basin type solar still

The still is set up in an open space, with its long axis pointing east-west. The still can be fed either constantly or sporadically with saline water. The supply is usually maintained at twice the pace at which fresh water is produced, however this can vary depending on the salinity of the input water at the start. In India, the production of a typical solar still varies between 5.3 1/m2 day (in summer) to 0.91/m2 day (in winter) (in winter).

(Cherif et al., 2016) did life cycle assessment of a water pumping and desalination process whose architecture is shown in fig 6.2 for a period of 20 years, this system was powered by a hybrid PV-Wind system. Mono-crystalline, poly-crystalline, and amorphous silicon PV modules were all investigated. Mono-crystalline, poly-crystalline, and amorphous silicon have embodied energies of 4779 MJ, 3815 MJ, and 2462 MJ, respectively. For 20 years lifetime the embodied energy of $1m^3$ of permeate water water was around 2.2 MJ.

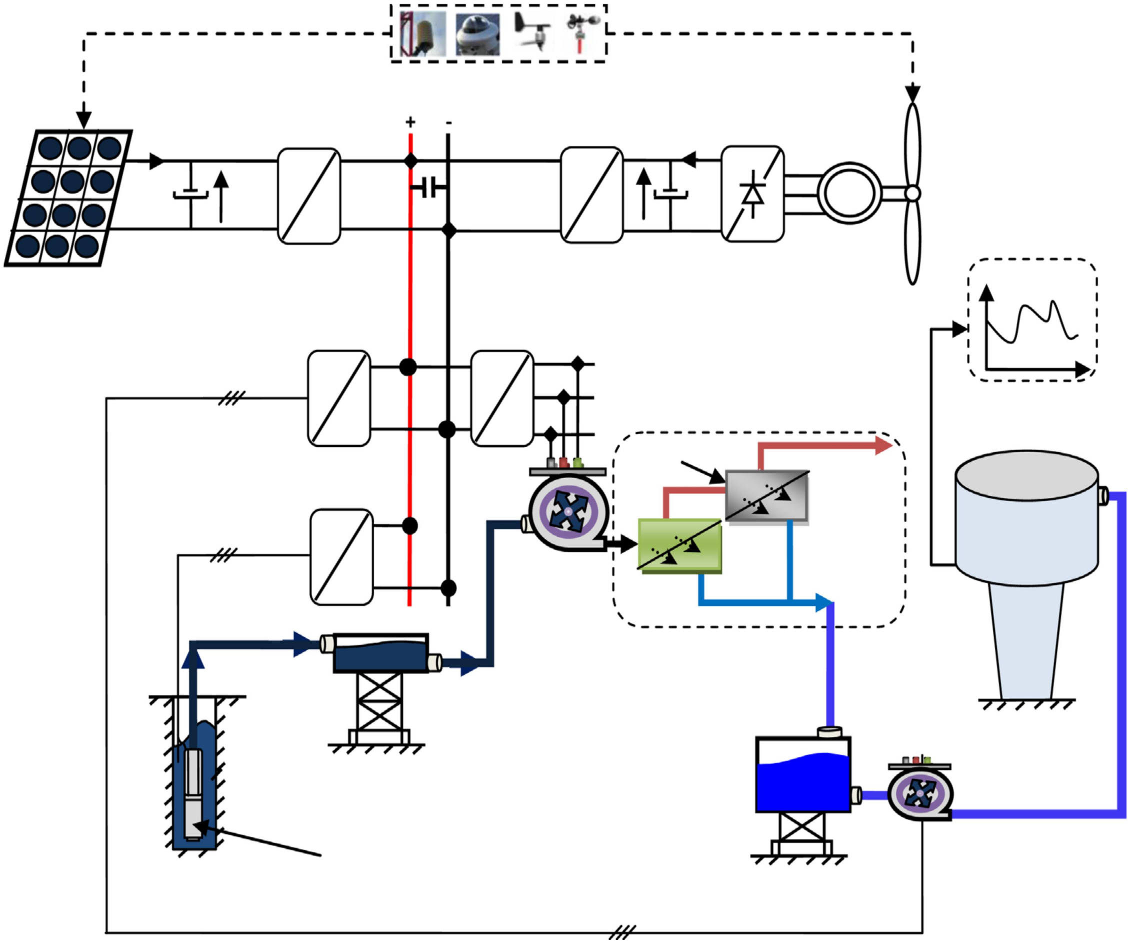


Fig 6.2: Architecture of hydraulic process powered by photovoltaic/wind hybrid source without battery storage(Cherif et al., 2016)

Table 6: Embodied energy of water pumping and desalination process

Ref.	System	Embodied Energy(MJ)	Energy Payback Time(EPBT)(years)	Carbon Credit(USD)
(Cherif et al., 2016)	Water pumping and desalination process	Mono : 4779 Poly : 3815 Amorphous Silicon : 2462	–	–

CHAPTER 7

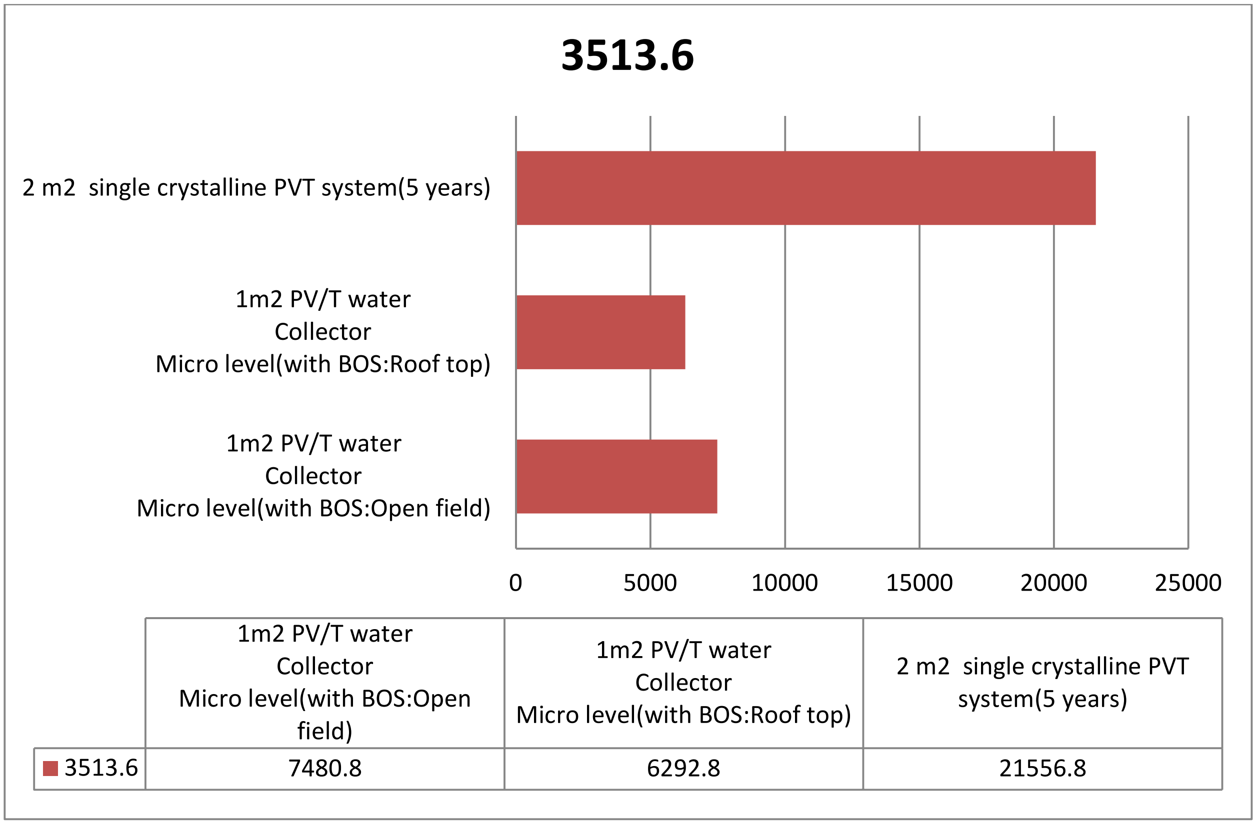
SOLAR IRRIGATION SYSTEM

Pumping water for drinking or modest irrigation during daylight hours is a particularly successful application of a stand-alone PV system with no storage. Water pumping looks to be most suited for solar PV applications because water consumption rises during dry days when there is plenty of sunlight. During the rainy season, when solar energy is also scarce, there would be less need for water. Solar photovoltaic (SPV)water-pumping systems in the range of a few hundred Wp to 5 kWp have been effectively deployed in many places of the world. On a clear sunny day, an SPV water-pumping system should supply at least 15,000 litres per day for a 200-Wp panel and 1,70,000 litres per day for a 2,250 Wp panel from a suction of 7 metres and/or a total head of 10 metres. Permanent magnet dc motors (used in low-capacity pumping systems), brushless de motors, and variable voltage and variable frequency ac motors with electronic control and conversion systems have all been employed.

(Todde et al., 2018) did life cycle assessment of three large - power stand alone photovoltaic irrigation system. The peak power output was ranging from 40 kWp to 360 kWp. The analysis showed that the embodied energy for 40 kWp system was 1306000 MJ and the energy payback time was 5.25 years.For 160 kWp system the embodied energy and energy payback time was 5186000 MJ and 2.79 years respectively.Embodied energy and energy payback time for the 360 kWP system was 10788000 MJ and 1.54 years respectively. The carbon dioxide emission ranged from 72.6 to 79.8 kg/kWp. The outcomes of the energy and carbon payback times showed an inverse trend with respect to the power size of photovoltaic as the energy payback time increased from 1.94 to 5.25 years and carbon payback time ranging from 4.62 to 9.38 years.

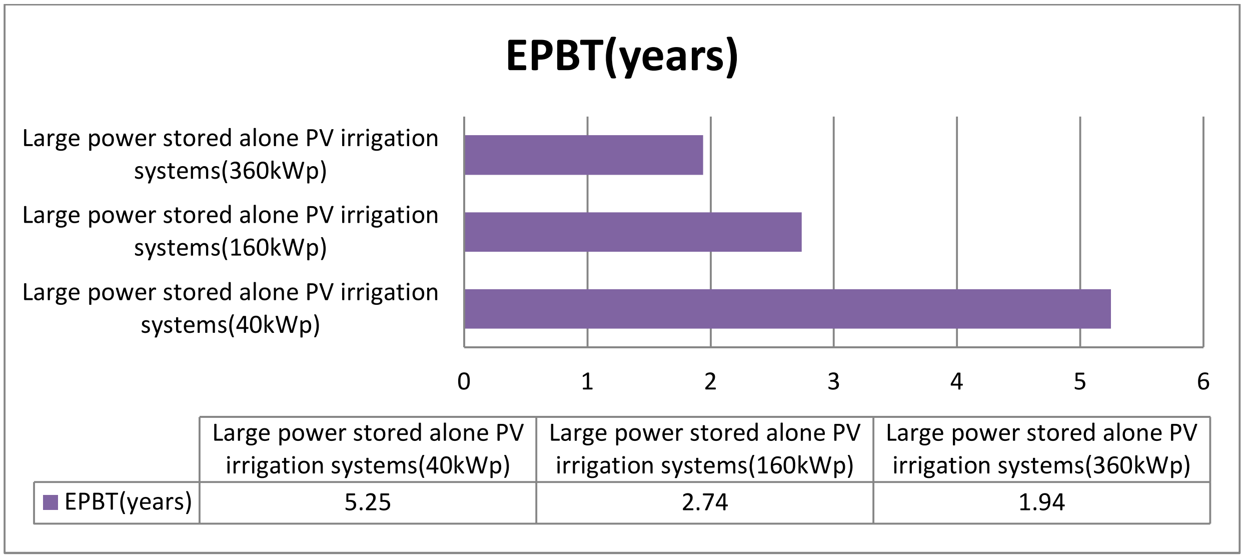
Table 7: Embodied energy and energy payback time of different systems of PV irrigation system

Ref.	System	Embodied Energy(MJ)	Energy Payback Time(EPBT)(years)	Carbon Credit(USD)
(Todde et al., 2018)	Large power stand alone PV irrigation systems	40 kWP : 1306 * 10^3 160 kWP : 5186 * 10^3 360 kWP : 10788 * 10^3	40 kWP : 5.25 160 kWP : 2.79 360 kWP : 1.54	–



	1m2 PV/T water Collector Micro level(with BOS:Open field)	1m2 PV/T water Collector Micro level(with BOS:Roof top)	2 m2 single crystalline PVT system(5 years)
🟥 3513.6	7480.8	6292.8	21556.8

Fig 7.1 : Comparison of embodied energy for different peak power stand alone large power PV systems



	Large power stored alone PV irrigation systems(40kWp)	Large power stored alone PV irrigation systems(160kWp)	Large power stored alone PV irrigation systems(360kWp)
🟪 EPBT(years)	5.25	2.74	1.94

Fig 7.2: Comparison of energy payback time for different peak power stand alone large power PV systems

CHAPTER 8

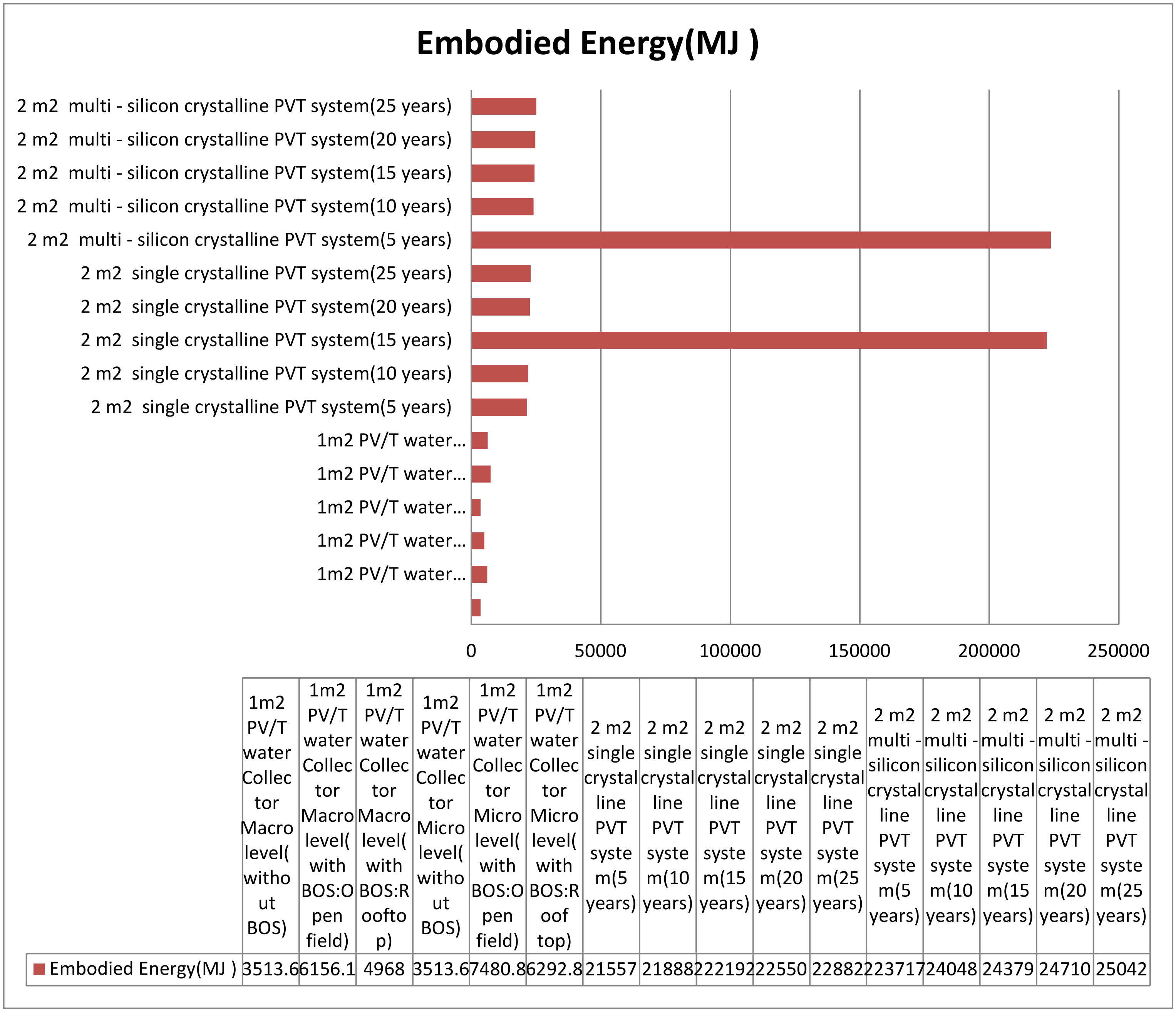
HYBRID SOLAR COLLECTOR

Two technologies can directly utilise solar energy: (1) Solar Thermal and (2) Solar Photovoltaic. Solar thermal systems generate heat for a variety of processes.Heating air for comfort and hot water for washing, cleaning, and other home and industrial uses necessitates a substantial amount of low-grade thermal energy in frigid climes. According to various industry surveys, heating fluids to a reasonable temperature consumes up to 24% of all industrial heat. As a result, solar energy is best suited for low-temperature applications. Even in high-temperature heating applications, solar energy for preheating (up to 180°C) can save a significant amount of fuel. As a result, solar-water heater manufacturing has become a successful sector in a number of nations, including Australia, Israel, the United States, and Japan. In the drying and processing sectors, solar thermal energy is also used. It can also be transformed into mechanical and electrical energy and used in the same way as any other thermal system.

Solar photovoltaic (PV) systems convert sunlight into electricity directly. A solar photovoltaic cell, often known as a solar cell, is the basic conversion device employed. Although photovoltaic electricity can be generated by various light sources, only sunlight-based PV cells are discussed in this chapter. A solar cell is essentially an electrical current generator that is powered by a radiation flux. Solar cells were created for the first time in 1954. Based on semiconductor electronics technology, it was quickly developed to provide power for space missions. Its terrestrial applications were only seriously investigated following the 1973 oil crisis, when a genuine worldwide need for alternate energy sources became apparent for the first time. Power utilisation efficiency is dependent not only on efficient cell generation, but also on dynamic load matching in the external circuit. Solar cells are the most expensive component in a solar PV system (approximately 60% of the total system cost), while their prices are steadily decreasing. In regular sunlight, commercial photocells can produce electrical energy of 1-2 kWh per sq. m per day and have efficiencies of 10-20%. In full solar radiation of 1 kW per sq. m, it typically produces a potential difference of around 0.5 V and a current density of roughly 200 A per sq. m of cell area. A typical commercial cell with a surface area of 100 square centimetres produces a current of 2 amps. It has a lifespan of more than 20 years. PV systems have no moving parts, therefore they provide almost maintenance-free service for long periods of time and can be operated in inaccessible locations unattended. Space satellites, remote radio-communication booster stations, and marine warning lights are among the most common applications for photovoltaics. In isolated places, particularly in underdeveloped countries, these are increasingly being used for illumination, water pumping, and medical refrigeration. Vehicles that run on solar electricity and some of the more modern and fascinating applications of solar PV power include battery charging.

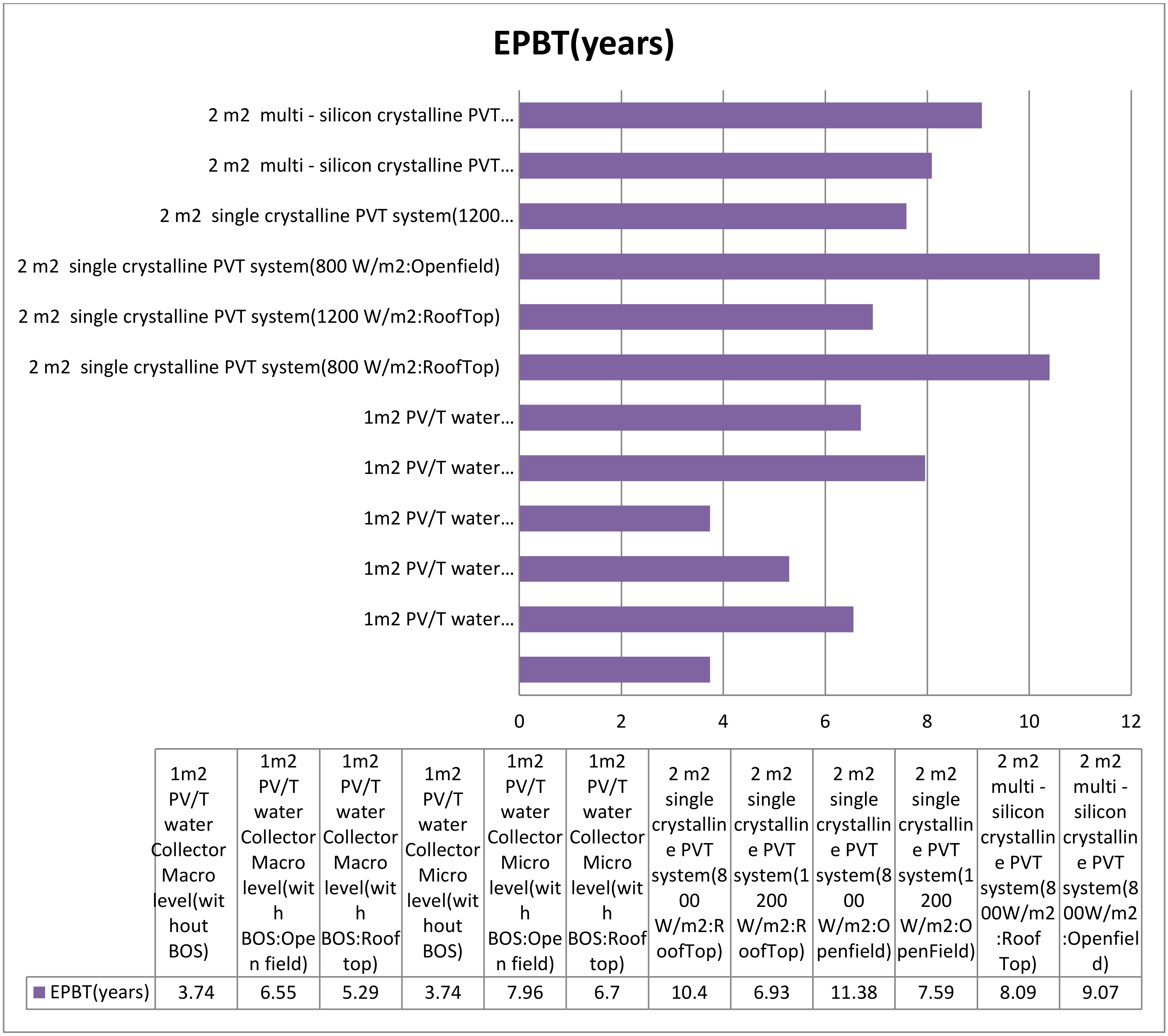
Table 8: Embodied energy, energy payback time and carbon credit of different hybrid collectors

Ref.	System	Embodied Energy(MJ)	Energy Payback Time(EPBT)(years)	Carbon Credit(USD)
(Tiwari et al., 2007)	$1m^2$ PV/T water Collector Macro level	Without BOS: 3513.6 With BOS (open field) : 6156.14 With BOS (roof-top) : 4968	Without BOS: 3.74 – 4.67 With BOS (open fluid) : 6.55 – 8.48 With BOS (roof-top) : 5.29 – 6.6	–
(Tiwari et al., 2007)	$1m^2$ PV/T water Collector Micro level	Without BOS: 3513.6 With BOS (open field) : 7480.8 With BOS (roof-top) : 6292.8	Without BOS: : 3.74 – 4.67 With BOS (open fluid) : 7.96 – 9.94 With BOS (roof-top) : 6.7 – 8.36	–
(Tirupati Rao & Raja Sekhar, 2022)	2 m^2 single crystalline PVT system	battery replacement :- 5 year : 21556.8 10 year : 21888 15 year :222192.2 20 year : 22550.4 25 year : 22881.6	Rooftop (800 W/m^2): 10.4 Open field(800W/m^2):11.38 Rooftop (1200 W/m^2): 6.93 Open field(1200W/m^2):7.59	Rooftop (800 W/m^2): 140.88 Open field(800W/m^2):131.40 Rooftop (1200 W/m^2): 261.54 Open field(1200W/m^2):252.06
(Tirupati Rao & Raja Sekhar, 2022)	2 m^2 multi - silicon crystalline PVT system	battery replacement :- 5 year : 223716.8 10 year : 24048 15 year : 24379 20 year : 24710.4 25 year : 25041.6	Rooftop (800 W/m^2): 8.09 Open field(800W/m^2):9.07	Rooftop (800 W/m^2): 152.01 Open field(800W/m^2):142.53



	1m2 PV/T water Collector Macro level(without BOS)	1m2 PV/T water Collector Macro level(with BOS:Open field)	1m2 PV/T water Collector Macro level(with BOS:Rooftop)	1m2 PV/T water Collector Micro level(without BOS)	1m2 PV/T water Collector Micro level(with BOS:Open field)	1m2 PV/T water Collector Micro level(with BOS:Roof top)	2 m2 single crystalline PVT system(5 years)	2 m2 single crystalline PVT system(10 years)	2 m2 single crystalline PVT system(15 years)	2 m2 single crystalline PVT system(20 years)	2 m2 single crystalline PVT system(25 years)	2 m2 multi - silicon crystalline PVT system(5 years)	2 m2 multi - silicon crystalline PVT system(10 years)	2 m2 multi - silicon crystalline PVT system(15 years)	2 m2 multi - silicon crystalline PVT system(20 years)	2 m2 multi - silicon crystalline PVT system(25 years)
🟥 Embodied Energy(MJ)	3513.6	6156.1	4968	3513.6	7480.8	6292.8	21557	21888	22219	22550	22882	223717	24048	24379	24710	25042

Fig 8.1: Comparison of embodied energy of different hybrid collectors



	1m2 PV/T water Collector Macro level(without BOS)	1m2 PV/T water Collector Macro level(with BOS:Open field)	1m2 PV/T water Collector Macro level(with BOS:Rooftop)	1m2 PV/T water Collector Micro level(without BOS)	1m2 PV/T water Collector Micro level(with BOS:Open field)	1m2 PV/T water Collector Micro level(with BOS:Rooftop)	2 m2 single crystalline PVT system(800 W/m2:RoofTop)	2 m2 single crystalline PVT system(1200 W/m2:RoofTop)	2 m2 single crystalline PVT system(800 W/m2:Openfield)	2 m2 single crystalline PVT system(1200 W/m2:OpenField)	2 m2 multi - silicon crystalline PVT system(800W/m2:Roof Top)	2 m2 multi - silicon crystalline PVT system(800W/m2:Openfield)
🟪 EPBT(years)	3.74	6.55	5.29	3.74	7.96	6.7	10.4	6.93	11.38	7.59	8.09	9.07

Fig 8.2: Comparison of energy payback time of different hybrid collectors

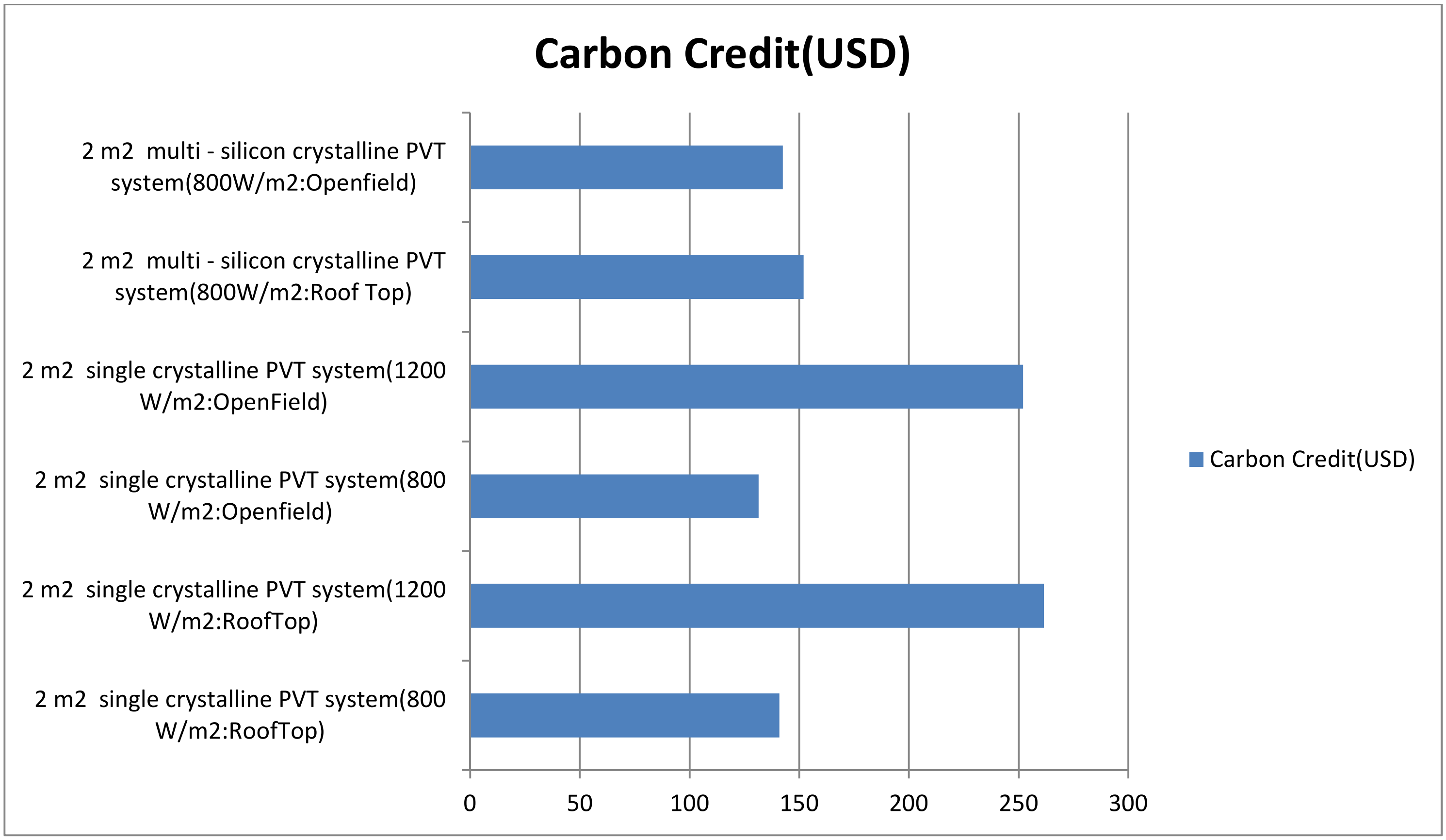


Fig 8.3: Comparison of carbon credit of different hybrid collectors

Conclusion

Energetic feasibility analysis of low temperature solar thermal applications has been done and based on that the following conclusions are arrived:

1. The embodied energy of solar cooker varied from 966.58 MJ to 2376.316 MJ and the energy payback time varied from 1.78 years to 4.13 years. The carbon credit calculation was not found in the literature.
2. The embodied energy of solar dryer varied from 2263.428 MJ to 3894.48 MJ depending upon its classification. The energy payback time was as low as 1.04 years while it was as high as 4.36 years.Net carbon credit varied from 176-2061 USD.
3. The embodied energy and energy payback time of a solar collector varied from 400-11500 MJ and 0.5-2 years.
4. The embodied energy of solar space and water heating was ranging from 6408-82500 MJ while the energy payback time was around 1.2-2.14 years.
5. The embodied energy for solar desalination was between 2462-4779 MJ depending upon the material used.
6. The highest value of embodied energy was found for solar irrigation system which was powered by stand-alone PV system. The embodied energy was ranging from 1306000 MJ - 10788000 MJ. The corresponding energy payback time was between 5.25-1.54 years.
7. The hybrid solar collector is a combination of solar thermal system and solar PV system. The embodied energy for the system was ranging from 3513.6-25041.6 MJ depending upon various factors. The energy payback time was found to be ranging from 3.74-11.38 years. The carbon credit was ranging from 131.40-261.54 USD

Therefore as the size of a system is increasing, its fabrication, manufacturing, transportation and installation is also requiring more consumption of energy which in turn is increasing the embodied energy of the system. But it is not necessary that the energy payback time will be more if the embodied energy is more as it also depends upon the total energy output of the system while it is in operational phase. Carbon credit is also an important parameter to be considered for the energetic feasibility of a system.

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