

# **Techno-Commercial and Feasibility Analysis of Energy Efficient Solar Powered Technologies for Indian Scenarios**

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## **Abstract**

In today's era, global warming is playing a major role in raising the average temperature of Earth's surface due to rising levels of greenhouse gases. It has led to severe climatic changes worldwide, including rise in sea level, depletion of ozone layer and has had many negative effects on the ecosystem. In an attempt to alleviate these negative effects, the scientific community is focusing its efforts towards harnessing renewable energy resources and development of environment-friendly energy efficient systems. However, constraints like the initial cost and specific operating conditions for adapting these innovative technologies are of major obstacle in their practical implementation.

In the scenario of a developing country like India, using solar power as a sustainable source of renewable energy is highly feasible due to its abundant availability. The present work describes three innovative products which would contribute to the Indian critical and ever-increasing energy demands keeping in mind adverse environmental effects. The products described are selectively diverse and not compulsively constrained to a specific application since they are most common for domestic use in India. The working principle, return on investment analysis and methodology of product design are discussed in depth.

## **Keywords**

Solar energy, global warming, return on investment (ROI) analysis, performance improvement, energy efficient systems.

## **1. Introduction**

India, being a developing country, holds energy as a majorly important asset and is the third largest global consumer of electricity in the world after China and the United State of America [1]. In spite of being one of the largest consumers, with a population of about 1.27 billion, India has one of the lowest per capita energy consumption in the world, which is one-third of the world's average per capita energy consumption [1]. Of the world's 1.3 billion people who live without access to power, a quarter — about 300 million — live in rural India [1]. In India, the demand of electricity per head is more than generation of electricity. As a result, it can be seen that many power cuts occur especially in rural areas, and a large disparity of power consumption exists between the urban and rural areas. Although India has a self-sufficient capacity of power generation, the main reasons for these power cuts are lack of resources like inadequate infrastructure for transmission, disruptions in domestic fuel transport, failures of transformers, transmission and distribution losses, theft of power and technical problems in moving electricity between various areas. With the rapid growth of industrialization in India, energy consumption is bound to increase further expeditiously. Industrialization has already increased the consumption by multiple times. The per capita consumption in India has almost doubled in the current millennium [1]. With

the increase in India's GDP, it can be predicted that there would be a considerable increase in demand for energy, meeting the supply of which would be a truly challenging task.

India's electricity sector is dominated by fossil fuels, particularly coal. In the fiscal year 2017-18, three-fourths of all the electricity was produced by fossil fuels [1]. However, the government is supporting for using alternate means of producing energy, i.e. renewable energy. India is densely populated and has high solar insolation, an ideal combination for using solar power in India. It was the first country in the world to set up a ministry of non-conventional energy resources, during the early 1980s. India's renewable energy sector is amongst the world's most active players in renewable energy use, especially solar and wind electricity generation. Despite the same, renewable energy accounted for only 18.2% of the total installed power capacity in India in 2017 [1]. For a developing country like India, with ever increasing demand, every attempt is encouraged to harness renewable energy resources towards partial reduction of dependence on conventional energy. As of 31 March 2018, India has grid-connected installed capacity of about 69.02 GW non-conventional renewable technologies-based electricity capacity [2].

The present work reports three products which make use of innovative technologies in harnessing solar power and use it for domestic applications. The main focus is taken on these products as India being a country with majority of its regions lying in the Torrid Zone, that is, south of the Tropic of Cancer, it receives abundant sunlight which is adequate to harness solar power as per India's requirement. These energy efficient systems are of great significance due to the large amount of energy savings as compared to system which use conventional sources of energy.

## **2. Innovative Technologies**

### **2.1 Solar Desalination**

#### **2.1.1. Working Principle**

Desalination can be defined as a process of removing minerals and salts from saline water to produce freshwater, that can be used for human use or irrigation. It is normally considered that salinity below 500 ppm is suitable as drinking water. Generally, a complete desalination process includes 3-4 steps with, first pumping water, pre-treatment of pumped water, desalination process and lastly, a post-treatment, if necessary. The most common technologies to produce freshwater with desalination technologies are Reverse Osmosis (RO), Multi-Stage Flash (MSF) Process and Multi-Effect Distillation (MED) [3].

RO technology is based on the properties of semi-permeable membranes which can separate water from a saline solution when excess of osmotic pressure is applied on the membrane systems. Pressure is applied with a high-pressure pump to 70-90 bars. Around 35-50 % of the flow goes through the membrane, with a salt concentration lesser than 500 ppm, while the rest of the flow called retentate (50-65 %), containing high concentration of salts, gets directly rejected [3].

Figure 1 depicts the schematic representation of RO technology.

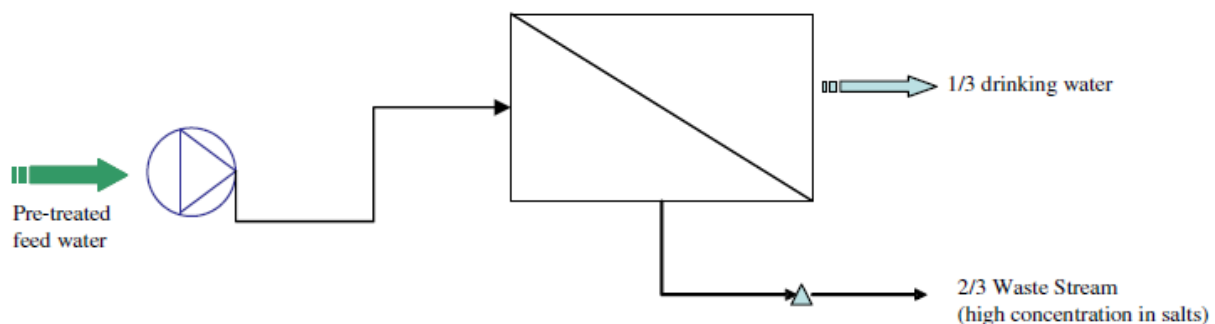


Figure 1. Schematic representation of Reverse Osmosis (RO) technology [3]

In the MSF process, seawater is heated in a vessel, called the brine heater, up to a temperature of 120 °C, and then flows into another vessel, called a stage, where the ambient pressure is reduced, causing the water to boil. Steam is then condensed on a range of tubes passing through the vessel. This well-known technology is used on large installations, typically more than 50,000 m<sup>3</sup>/day, by coupling with any heat generation source [3]. Schematic representation of MSF technology is as shown in Figure 2.

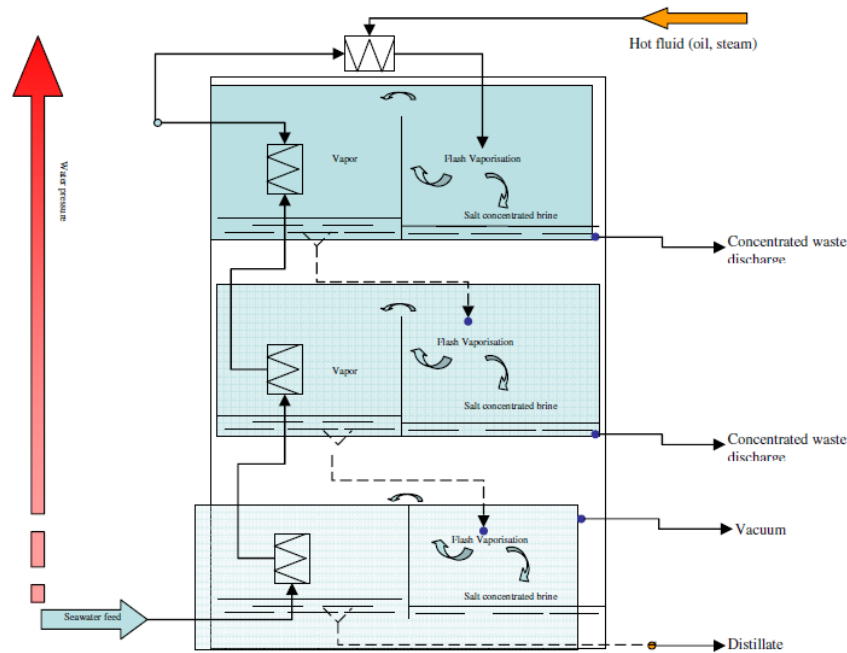


Figure 2. Schematic representation of Multi-Stage Flash (MSF) technology [3]

Multi-Effect Distillation (MED) process is based on using latent heat of condensation of the vapour from the first cell to provide heat to a second cell. The evaporation takes place in cells where equilibrium temperature of liquid-vapour is maintained between 40 °C and 68 °C. The steam produced in the first cell is injected into the second, in order to ensure the evaporation and condensation at a lower temperature. This process then gets subsequently repeated in all the following cells. MED is also suitable for small capacity installations and represents more than 10% of the total capacity of desalination plants worldwide, with still promising developments [3].

Figure 3 represents the schematic layout of MED technology.

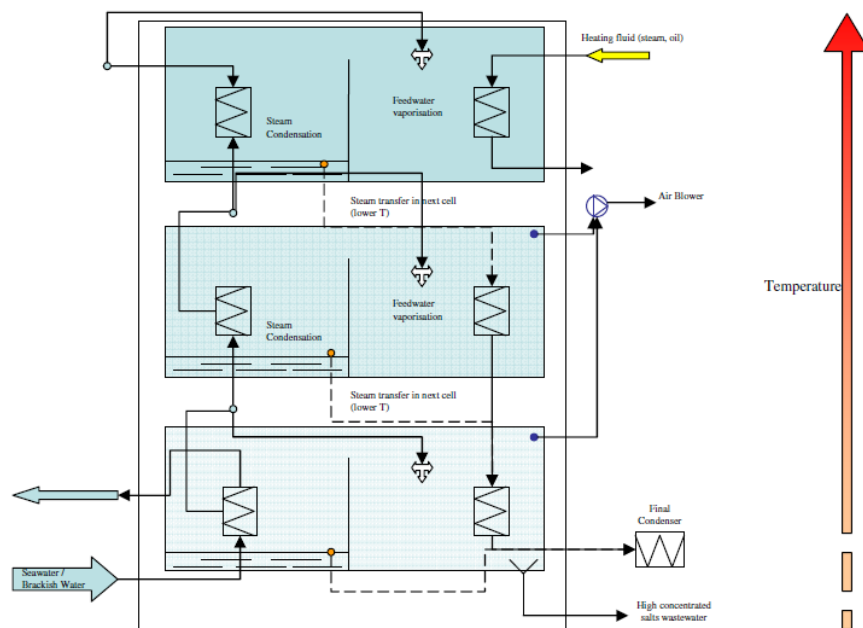


Figure 3. Schematic representation of Multi-Effect Distillation (MED) technology [3]

Desalination needs are mainly in dry countries, which receive huge intensity of solar radiation. Hence, it becomes eventually indispensable to use solar power for running the plants. Solar technologies can produce heat and thus electricity through a turbine (CSP, Concentrated Solar Power), or directly electricity (CPV, Concentrating Photovoltaic) [3]. Recent technical developments on these technologies have made them more popular and employable, characteristically for such countries.

Concentrating Solar Power Technologies mainly include Parabolic Trough, Linear Fresnel Reflector systems and Central Tower Receiver. These technologies concentrate solar radiation on an absorptive pipe (receiver) containing thermal fluid which receives heat. When water is used, heat from solar radiation is used to convert the water directly into steam. In case of oil or salt, the thermal fluid acts as an intermediate thermal energy carrier, which passes through different heat exchangers, ultimately converting water into steam. These CSP systems generate power using a steam-driven Turbine, typically employing Rankine cycle. Photovoltaic technology uses flat-plate PV module, which is the most commonly implemented technology, and CPV technology, which is a developing technology. The main difference between these two technologies is that CPV technologies use DNI (direct normal solar radiation) as a solar source instead of Global Irradiation [3].

### 2.1.2. Product Design

Coupling RO systems with solar PV electricity is most widely employed technology. Most common way is to convert DC power supply from PV panels through an inverter to produce AC supply which can be directly used in pumps. Another technique to harness and employ solar power is by connecting panels to a brushless DC motor to drive the pump, thus allowing direct use from PV panel to pump [3,4]. Battery banks can also be added to the system to store energy during night time to allow running of RO operation throughout. However, this increases the cost substantially in terms of initial investment. Figure 4 represents a schematic of a solar-powered desalination system using RO technology. The system is further coupled with a Vertical Axis Wind Turbine (VAWT) as well to cope up with the balanced power in case of emergency.

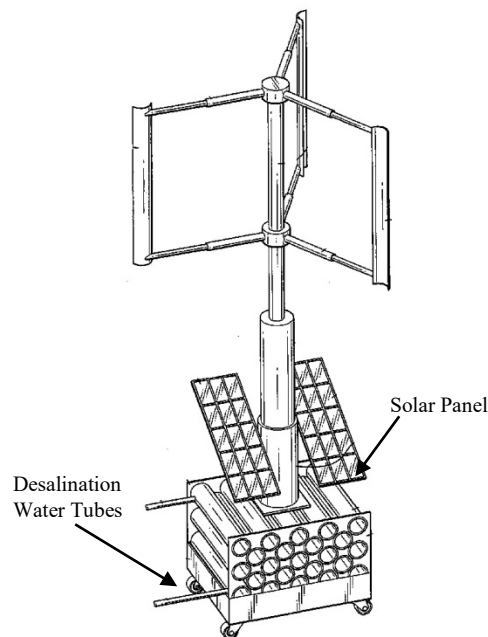


Figure 4. Schematic representation of a solar-powered RO desalination system [4]

The MSF process can also use solar power with parabolic troughs. Steam produced by parabolic troughs is used as a heat source at the MSF inlet. A thermal storage device can also be added to the system to support smooth flow of thermal energy supply and cope up with the demand of continuous production of fresh water during night-time or low radiation period as well. Similar to MSF process, MED technology can also employ solar power for the heat transfer involved in the phase change process. Most popular technique implemented till now is Central Tower Receiver due to its geometrical advantages, followed by Parabolic Trough. Linear Fresnel Reflector systems is adapted as the last preference due to its inherent limitations of complex structure [3,5]. Figure 5 depicts the solar-powered desalination unit that could be coupled with any of the three technologies discussed, viz. RO, MSF and MED.

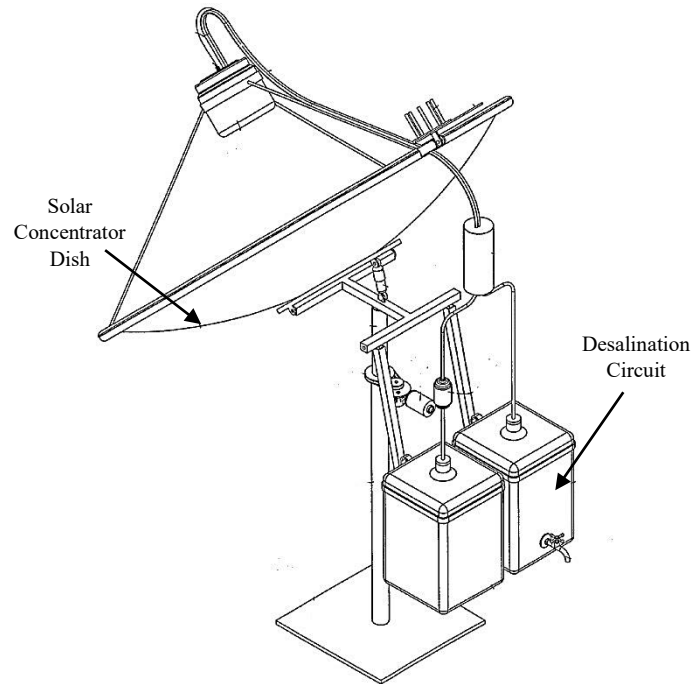


Figure 5. Solar powered universal desalination unit [5]

### 2.1.3. RoI Analysis

A conventional electricity-driven 1000 LPD seawater desalination RO system available in market consumes 1.9 kW of electricity and working for 20 hours per day [6]. On the other hand, the solar-powered desalination system can produce 200 gallons per day (i.e. 760 LPD) [7]. Accordingly, only 760 LPD are to be considered instead of 1000 LPD to compare the performance of the two units. Consequently, the total energy consumption of the conventional desalination system per day would be  $1.9 \times 20 \times (760/1000) = 28.9$  kW-hr. Such types of desalination plants are prominent at big residential complexes, Government quarters, hostels, guest houses, dormitories, etc. The weighted average cost of electricity consumption per month used at urban / semi-urban residential premises in India is ₹ 7.4 per kW-hr [8]. This yields the total electricity consumption as  $28.9 \times 7.4 = ₹ 213.86$  per day. Based on market survey, the cost of a solar desalination system is \$ 7,450 (i.e. ₹ 5,33,500) [7], while the cost of a conventional electric-driven desalination system is ₹ 4,30,000 for 1000 LPD [6], which further needs to be transformed for its equivalent of 760 LPD as  $4,30,000 \times 0.76 = ₹ 3,26,800$ . This, ultimately, offers the recovery of the investment in  $((5,33,500 - 3,26,800) / 213.86 = 996.5$  days, i.e. around 2 years and 7 months.

## 2.2 Solar Powered Trash Compactor Bin

Municipal Tash Disposal is a seriously growing issue worldwide. Rapid urbanization and population growth contribute towards enhanced municipal solid waste generation. People often forcefully dump their waste into a trash container on top of the already overloaded waste. Municipal corporations and local bodies try their best to employ more and more trash containers, vacate them quickly and restore them at their places to avoid this situation. This demands for substantial wastage of manpower, and time. Ultimately, cost of this disposal system also gets raised multifold. Lack of appropriate collection, transportation and disposal system, lack of technical expertise and insufficient financial resources further add to the overall mismanagement and chaos. Due to these poor practices, this waste is disposed off in low lying areas or open dumps in the outskirts of towns/cities without necessary precautions. This kind of unscientific practice of solid waste disposal leads to environmental unsustainability by air, soil and water pollution.

### 2.2.1. Product Design

The solar-powered compaction garbage bins are equipped with a solar photovoltaic panel and a small battery. The battery is charged during the day, allowing the unit to operate even during night time. The bins automatically compact the waste when the garbage inside reaches a certain level. As users deposit garbage, it

falls into an inner unit. When the level of garbage eventually rises above the top of the inner bin, the garbage interrupts an electric eye beam, triggering the motor to compact the garbage down into the bin, making room for additional garbage. The method chosen as a means of compaction was a hydraulic system actuated by pressing down on a foot pedal. The process repeats automatically as needed until the machine is ready for collection. At that point, a LED light indicator on the front panel goes from green to yellow, notifying staff that the unit is ready for collection. Internal structure of a typical solar-powered compactor is as shown in Figure 6 [9,10].

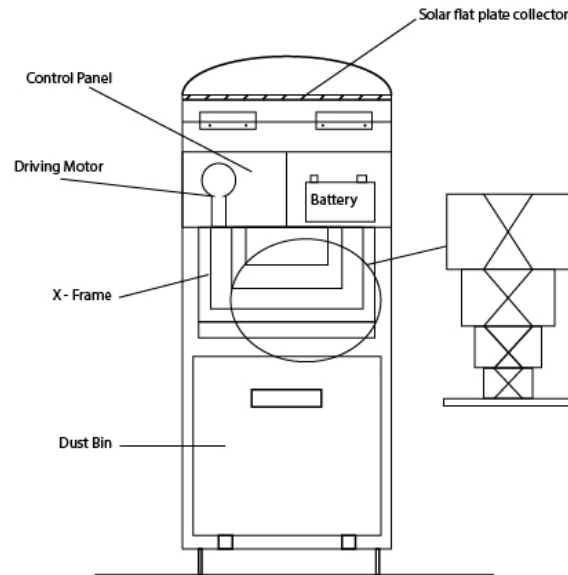


Figure 6. Schematic representation of solar-powered trash compactor bin [9]

These solar-powered bins hold typically around 4-6 times the volume that of the average mobile garbage bin, leading to considerable saving in collection trips. This not only reduces operating costs, unsightly litter overflows and public disturbance, but also minimizes emissions from waste-carrying vehicles, further benefiting the environment.

### 2.2.2. RoI Analysis

For an electric powered waste compacting bin commercially available [11] having a capacity of 1.4 cu.ft. (i.e. 40 liters) which consumes 1/3 HP (i.e. 0.25 kW) of electricity and having compaction ratio of 5:1, it is assumed that last 1 liter of the total capacity is left without compression as it is highly uneconomical to employ power for the same. Added to that, such control is easily possible using position sensors. Accordingly, it can be seen that 17 cycles occur before every garbage collection for a single bin. Each cycle lasts for 27 seconds which ultimately results in  $27 \times 17 = 459$  seconds for a single bin before each garbage collection. Assuming for 2 garbage collections per day, it would take  $459 \times 2 = 918$  seconds. The power consumption of the conventional electric powered bin unit is reported to be 250 W [11]. Accordingly, for 34 compactations it would yield total electric consumption of  $(918/3600) \times (0.25 \times 34) = 2.16$  kW-hr. Such types of waste bins are very prominent at public services like parks, hospitals, multiplexes and shopping malls. The average cost of Electricity used at Low/Medium Voltage in all non-residential, non-industrial premises and/or commercial premises for commercial consumption meant for operating various appliances used for purposes such as heating, cooling, washing/cleaning, etc. in India is ₹ 7.12 per kW-hr [8]. This yields the electric consumption to be  $2.16 \times 7.12 = ₹ 15.4$  per day. It is reported that the capacity of the solar waste compacting bin is 33 gallons (i.e. 125 liters) [12]. Accordingly, the recovery analysis needs to be done with respect to  $125 \text{ liters} / 40 \text{ liters} = 3.125$  bins. Hence, the electricity consumption cost would amount to  $3.125 \times 15.4 = ₹ 48.1$  per day. The cost of 1 solar powered waste compactor is \$ 4,000 (i.e. around ₹ 2,87,000) [13], while the cost of an equivalent of 3.125 electric powered waste compactors is \$ 2,497 (i.e. around ₹ 1,79,000) [11]. Thus, the usage of solar powered waste compactor would offer a recovery of investment in  $((2,87,000 - 1,79,000) / 48.1) = 2250$  days, i.e. about 6 years 2 months. Taking into account the life reported of the solar waste compacting bin to be of 10 years, this clearly reflects that the remaining period of nearly 4 years is sheer beneficial in terms of monetary investment from public funds.

## 2.3 Solar Dryer

Drying by exposure to the Sun is one of the oldest methods using solar energy, for food preservation, as vegetables, fruits, fish, meat, etc. Already from the prehistoric times, mankind used the solar radiation as the only available thermal energy source to dry and preserve all necessary foodstuffs for winter time, to dry soil bricks for their homes and animal skins for dressing.

Drying (or dewatering) is a simple process of excess water (moisture) removal from a natural or industrial product in order to reach the standard specification moisture content. It is an energy intensive operation. Especially essential is to reduce the foodstuff moisture content, as these have in general a water content much higher (around 25–80%, but generally for agricultural products around 70%) than the one suitable for long preservation. Reducing moisture content of foodstuff down to a certain level slows down the action of enzymes, bacteria, yeasts and molds [14]. Thus food can be stored and preserved for long time without spoilage. Another case of drying (or dewatering) is the total removal of moisture until food has no moisture at all. Dehydrated food, when ready to use, is re-watered and almost regains its initial conditions.

The widest among drying methods is convective drying (whereby heating takes place by convection between the hot air and the products surface), i.e. drying by flowing heated air circulating either over the upper side, bottom side or both, or across its mass [14]. Hot air heats up the product and conveys released moisture to atmosphere. Drying by solar radiation can be divided into two main categories:

- (a) Direct, or open-air sun drying, the direct exposure to the sun.
- (b) Indirect solar drying or convective solar drying.

In direct solar drying called “sun drying” the product is heated directly by the sun’s rays and moisture is removed by natural circulation of air due to density differences. Whereas, Special solar collectors used in drying and methods of coupling to the various solar dryers are described as an indirect solar thermal energy source. Direct solar drying has some disadvantages concerning both quality and quantity due to losses, attacks by insects, etc., thus in recent years, direct sun drying is replaced by mechanical dryers heated indirectly by solar energy.

### 2.3.1. Product Design

Drying by solar energy is a rather economical procedure for agricultural products, especially for medium to small amounts of products, to preserve excess of production. It is friendly to the environment. It is still used for domestic up to small commercial sizes for drying of crops, agricultural products and foodstuff, such as fruits, vegetables, aromatic herbs, wood, etc. [15], contributing thus significantly to the economy of small agricultural communities and farms. The solar dryers can be classified by various modes, as according to the type of dryer, to the operation temperature or the material to be dried, to type of operation, e.g., batch or continuous, etc. [14]. According to the drying process, e.g. direct or indirect, solar dryers may be classified as passive and active ones:

- (a) Passive dryers are heated directly from the sun’s radiation with or without natural air circulation, and
- (b) Active (or forced convection) solar dryers, where hot drying air circulates by means of a ventilator.

Figure 7 depicts the classification of the solar dryers, while Figure 8 reflects the constructional details of typical solar dryers.

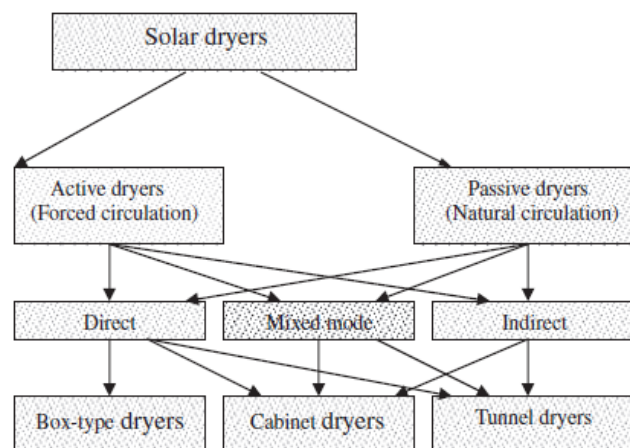


Figure 7. Classification of solar dryers [14]



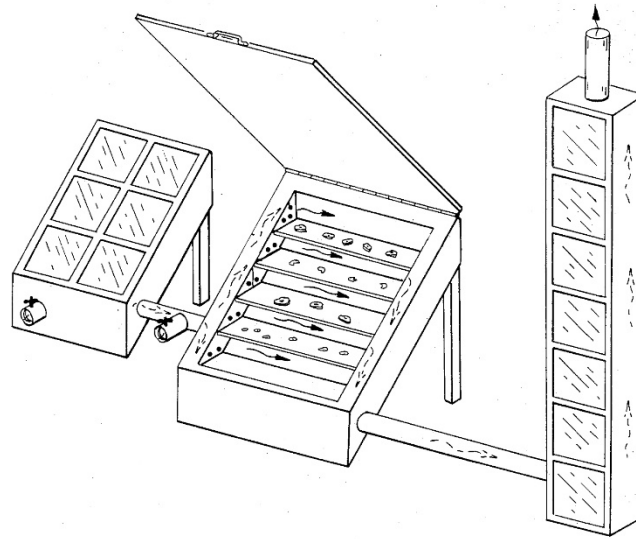


Figure 8. constructional details of typical solar dryers [15]

### 2.3.2. RoI Analysis

The typical conventional dryer which is driven by electricity has 4 trays, each having area of 12" X 12" [16]. On the other hand, the solar-powered drying unit has a single large tray of area 16" X 32". One needs to calculate equivalent area to compare the electricity consumption with solar energy. Executing the same, the drying area of electrically driven conventional dryer unit requires equivalent to about 3.5 trays as a substitute of a single solar dryer tray area. Consequently, the energy consumption of only 3.5 trays needs to be considered instead of 4. The power consumption of the conventional electric drying unit is reported to be 220 W [16]. The standard time for drying the watermelon which consumes least time to be dried is around 8 hrs, whereas grapes consume highest amount of time to be dried which is around 26 hrs. The average time for drying of commercial fruits comes out to be around 14 hrs as per the standard references [17]. Accordingly, the energy consumption of the conventional electric drying unit for the present analysis would be  $0.22 \times (3.5/4) \times 14 \times = 2.695$  kW-hr. The average cost of electricity in non-residential and commercial sector in India is ₹ 7.12 per kW-hr [8]. This yields the electric consumption to be  $2.695 \times 7.12 = ₹ 19.2$  per day. On the basis of market inquiries, the cost of a solar drying unit is around ₹ 18,800 [18] and that for a conventional electric dryer is around \$ 130 (i.e. ₹ 9,350) [19]. This offers a recovery of investment in  $((18,800 - 9,350) / 19.2 = 493$  days, i.e. around 1 year 4 months.

## 3. Concluding Remarks

Of the 1.4 billion people in the world who have no access to electricity, India accounts for over 160 million living in around 32 million homes [20]. The technologies and fuel sources that India has adopted are inadequate in providing the required energy and are continuously depleting. As a result of this, it could be seen that majority of the rural areas are completely lacking with supply of electrical energy. To overcome this, shifting to solar energy as a renewable energy source is proposed in the present work as India has abundant solar energy supply to completely fulfill its energy requirements. The present work discusses about three such innovative products which are environment-friendly alternatives to their nonconventional counterparts.

The above-mentioned products play a vital role in the domestic and semi-commercial scenario in India. As far as the domestic applications are concerned, the prime focus must be towards satisfying the requirement in the easiest possible manner and in the most economical way. Many rural areas in India do not receive adequate electrical energy to power conventional desalination systems. This problem could be overcome with the use of a solar-powered desalination unit. This unit completely relies on solar energy which would ultimately yield extensive amount of national saving in terms of energy. Another innovative product is the solar-powered trash compactor which is quite useful in an urban scenario. A very high amount of waste is generated in urban areas which doesn't have any proper disposal practices in India. The conventional waste compactor uses quite high amount of energy which is not economical. The solar waste compactor is a much more feasible solution as could be seen from the Return on Investment Analysis provided. The solar dryer, on the other hand, has a wide usage in the agricultural sector. Drying of fruits, vegetables, dry fruits, meat and flesh, etc. using conventional sources such as supplying thermal energy are proven to be quite slow and uneconomical as thermal energy is a low



grade one. With the use of solar dryer, this problem could be overcome and it can be proved to be a highly economical alternative. India is blessed with abundant solar energy and harnessing this energy increases the installed electricity generation capacity of the nation, which in turn, will make a significant impact to global resource usage and environmental issues.

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## Biographies

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