Solar powered movable cold storage structure for perishables

India has a vast potential of solar energy availability for about 300 sunny days in a year. It has an estimated potential of solar energy of approximately 5×10^{15} kWh/yr, which is far more than the total energy consumption of the country[1]. Even a part of this, if appropriately harnessed, will be able to meet a sizable portion of the demand. The daily average incident solar energy varies from 4 to 7 kWh/m^2 depending on the location[2].

Reduction in cooling loads through careful building design and insulation is desirable and will be less expensive than provision of additional cooling. Good building design and construction can reduce the load on any air conditioning or heating system[3]. Need is perceived to introduce energy supply, especially, to rural population for increased productivity and income generation[4]. The utilization of solar energy for refrigeration purposes in the agro-industry has a potential in developing countries[5].

India is known as the fruit and vegetable basket of the world. It is the second largest producer in the world after China and is one of the centres of origin of fruits and vegetables.

Fruits and vegetables are highly perishable and if not properly handled at their optimum conditions after harvesting or during packaging or transportation, they can easily deteriorate and become unsuitable for consumption[6]. The world over postharvest losses in fruits and vegetables are estimated at an average of 30–40% before they reach the final consumer. Globally average postharvest losses in general for fresh produce are estimated at 30% (ref. 7). The postharvest losses of fruits and vegetables in India have increased from 30% to 35% (ref. 8).

Besides, the quality of a sizable amount of produce also deteriorates by the time they reach the consumer, due to lack of cold chain to extend the shelf-life. Thus our farmers continue to suffer even though they take risk of cultivating high-value fruits and vegetable crops every year. A cold storage facility accessible to them will go a long way in removing the risk of distress sale and ensure better returns.

The cold storage facilities now available are mostly for a single commodity like potato, orange, apple, grapes, pomegranate, flowers, etc., which results in poor capacity utilization.

In view of this, a solar-powered movable cold storage structure has been designed and developed for storage of fresh fruits and vegetables, to enhance the storage life of the produce with minimum cost.

Materials such as galvanized iron sheet, polycarbonate sheet and plywood sheets were used to fabricate the structure with glass wool filled between them to provide insulation and reduce heat loss (Table 1). Plywood sheet was used as the outer surface, polycarbonate sheet was used as the inner surface and GI sheet was placed between them. Wheels were provided in the structure to enable it to be used at any place. The size of the storage structure was $1.83 \times 1.34 \times 1.98$ m having total volume of 4.85 m^3. An air-conditioner of 0.8 tonnes (800 W) was connected to the structure for cooling (Figure 1). Crates of size $56.5 \times 36.5 \times 27$ cm were used, with each crate having the capacity to keep 25 kg of fruits and vegetables. A total of 40 crates can be used to keep 1000 kg fruits and vegetables in the storage.

A solar photovoltaic (SPV) system consisting of eight solar panels of 210 Wp each, one solar inverter (3000 VA) and a battery bank of four batteries (12 V/150 Ah each) was used to power the AC to cool the storage (Figure 2). The electric current produced by SPV panels during daylight hours charges the batteries, which in turn supply power to the system. For maximum utilization of solar energy, the solar modules are carefully oriented so that they face true south (not magnetic south). The use of batteries with inverter gives electricity for a longer period by providing a consistent operating voltage and current to the system.

The solar intensity was measured with the help of a portable solarimeter. Average solar intensity was calculated at surface of the SPV panel during experimentation from April to August 2017. The maximum solar intensity was found to be 900 W/m^2. The solar intensity at the panel surface was always greater than that in the horizontal surface due to inclination.

The voltage (V_{oc}) and current (I_{sc}) of the battery and solar panel were measured at

Table 1. Properties of the material of the storage structure

Property	Galvanized iron sheet	Polycarbonate sheet	Plywood sheet	Glass wool
Thickness (mm)	3	3	5	50
Thermal conductivity (W/m K)	18	0.7	0.13	0.036

Figure 1. Solar-powered movable cold storage structure connected with 0.8 tonne AC to store tomato.

different time intervals to test the performance of the SPV system. The maximum voltage and current of battery were found to be 59.8 V and 26.8 A respectively, while the same for the solar panel were 51 V and 27 A respectively in the afternoon (Figure 3).

The load data indicated the average production of solar energy per hour per day as 1.32 kWh, which was about 65% more than the power consumption (rating of AC being 800 W) (Figure 3). These results show that the SPV system is suitable to supply electricity to cover the load demand without utilizing energy from the electrical grid during sunny days.

Figure 4 shows the hourly variation of outside ambient temperature, inside storage temperature, relative humidity (outside and inside) and power consumption for May 2017. With the increase in solar intensity as the day progressed, the ambient temperature also increased along with the storage structure temperature. The ambient temperature for two days in May varied from 27.4°C to 43.4°C, the temperature inside the storage structure varied from 9.5°C to 11°C, and the relative humidity outside and inside the structure was in the range 21.2–50.3% and 72.6–95% respectively. Lower temperature and higher relative humidity maintained inside the storage structure helped increase the shelf life of tomatoes by up to 20 days (Figure 5). It can be seen from Figure 5 that the tomatoes remained almost fresh at the end of storage. This helped in safe storage of the product and for the farmer to get better returns from sale in the market. Table 2 provides an economic analysis of the cold storage system. The tomatoes were purchased @ Rs 24/kg and after 20 days, the price of tomatoes in the market increased to Rs 100/kg, giving a cash profit of Rs 76/kg. So, for 1000 kg of tomatoes, the profit was Rs 76,000. After deducting the cost of operation @ Rs 6/day, the net profit was Rs 75,880 and such profit will encourage people to opt cold storage. The payback period of the system by considering the power saving cost would be approximately 9 years.

In addition, other fresh fruits and vegetables such as spinach, capsicum, cucumber, bottle gourd, and green beans, pointed gourd and papaya (fruit) can be stored in this structure to increase the shelf-life by 1–20 days. While in the evaporatively cooled storage structure the temperature can be maintained between 21°C and 23°C only[9], in the reported cold storage the temperature can be maintained up to 5°C. It enables to store fresh fruits and vegetables for comparatively longer duration.

This study showed that the solar powered system consisting of eight solar modules of 210 Wp power each, performs well to operate the movable refrigerated storage structure. An average solar power of 1.6 kWh was produced by the system. The temperature in the storage was found to be reduced by up to 26°C compared to the outside ambient temperature. There was significant difference in

Figure 2. Solar photovoltaic system with power control unit for cold storage.

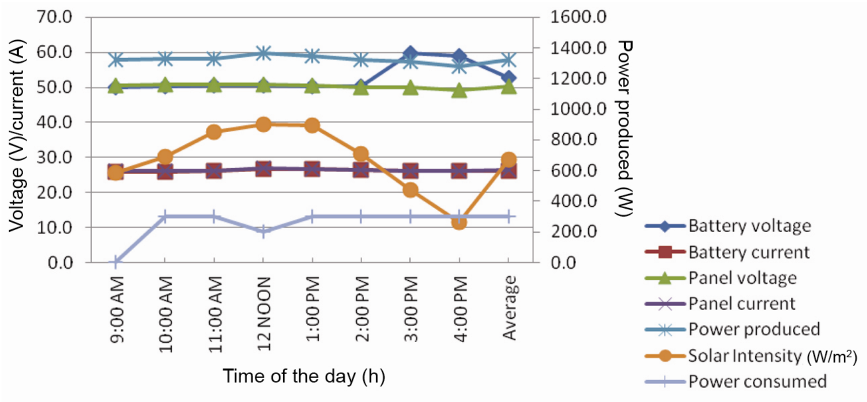

Figure 3. Voltage/current, solar intensity and power produced during May from the solar photovoltaic system.

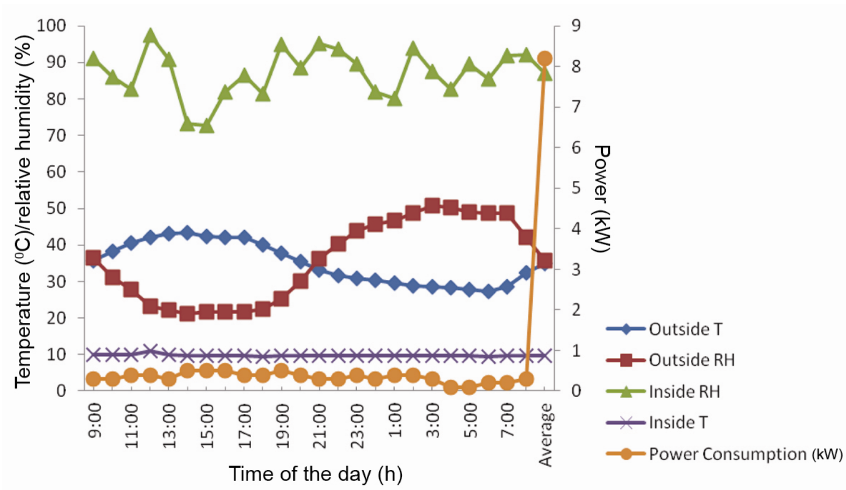

Figure 4. Hourly variation of temperature, relative humidity and power consumption in the cold storage system on a typical day in May 2017.

Figure 5. Photographs of (***a***) fresh tomatoes, (***b***) after 12 days of cold storage and (***c***) after 20 days of cold storage.

Table 2. Economic analysis of solar-powered cold storage system

Item	Cost (Rs)	Useful life (yrs)	Cost (Rs)/yr
AC	20,000	10	2,000
Solar panels (210 W × 8 = 1680 W)	72,000	20	3,600
Battery (4 × 12V)	65,000	5	13,000
Inverter 3 kVa	15,000	10	1,500
Total cost			20,100
Power cost saving (7 units @Rs 7)	49/day		17,885
Net cost/yr			2,215
Net cost/day			6.07
Cost/day/kg produce			0.006

temperature inside the storage structure compared to the outside ambient temperature. Temperature and relative humidity inside the system ranged from 9.5°C to 11°C and 73% to 92% respectively. This environment helps in keeping the perishables fresh for significantly more time ranging from 1 to 20 days. As the storage structure is movable, it can be used at different places in the rural farmlands. Also, this is useful in rural areas where there is shortage of electricity or its supply is erratic for storage of fresh fruits and vegetables. Thus it provides an opportunity to preserve or to extend the shelf-life of fresh produce.

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MangoDB: a database of mango varieties and landraces of the Indian subcontinent

Mango (*Mangifera indica* L.) is the most important commercially grown fruit crop in India, available throughout the length and breadth of the country and aptly acknowledged as the 'national fruit of India'. It enjoys a prominent place in the Indian fruit market, contributing more than 20% of total fruit production from 36% of the total fruit area. In Kerala, this crop covers an area of 77,158 ha with a production of 457,067 tonnes[1]. Commercially grown cultivars in this state are Alphonso, Bangalora, Banganappalli, Kalapady, Neelum, Bennet Alphonso, Mulgoa and Prior, whereas the local types mainly include Muvandan, Chandrakaran, Olour, Varikka and Vellaikolamban, apart from a large number of landraces[2].

Different regions of India, including the Western Ghats, bear huge genetic variability for this crop[3,4]. According to Chadha[5], India holds more than 1000 mango types. Most of the commercially popular ones, around 30 in number, have originated as chance seedlings, subsequently selected for fruit traits. Though evaluation of this genetic variability has been carried out in different parts of the country by surveys and data collection, systematic documentation of the varietal variation, including morphological, flowering and fruiting characterization is