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Solar Energy Powered Active Greenhouse for the Cultivation of Fresh Food during Winter in Trans-Himalayan Cold Arid Region, India

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ABSTRACT

The Trans-Himalayan Cold arid high altitude region of Ladakh have hostile climatic conditions particularly low temperature (-20°C to -45°C). The region shares international borders with two countries viz. China and Pakistan and hence large numbers of Army personnel are deployed in the region due to their strategic importance. Production of fresh food locally is difficult due to low atmospheric temperatures. The region remains cut off from the external world during the winter period for almost 6-8 months due to the closure of roads, which causes an acute shortage of fresh food. Some supply from other regions through the air is carried out but available only to a limited population and costly also, hence beyond the pocket of the common's man. The inhabitants hence mostly have to survive on packaged food containing food preservatives and harmful chemicals, which are the causes of many diseases. In addition, the unavailability of fresh food causes nutritional deficiency in the inhabitants of the region. Production of fresh food locally seems possible and realistic in closed structures, only if the temperature is maintained. The objective of this study is to prove fresh food production by maintaining suitable temperatures in structures during peak winter using solar energy. Solar energy is available in plenty in the region and stood at 4th position in India in terms of irradiation. A variety of fresh foods were produced by maintaining temperature in the coldest and largest existing structure using commercially available heating units successively from 2016-2019 during the winter period. The heating units were supplied energy from a Solar PV-based system. An average of 1500kgs-1800kgs of a variety of fresh vegetables were produced and supplied for the first time in the region during the peak winter period of 2016 to 2019. The survival percentage of 92.5% to 100% is found in a structure with an area of 3600^2 feet.Fresh foods were produced and supplied to the user by maintaining minimum survival temperature using solar energy as a source with commercially available heating technology in the largest and coldest existing structure.

Keywords: Active; Greenhouse; High altitude; Passive; Protected cultivation

1. INTRODUCTION

The Greenhouse structure is based on the utilization of solar energy. It is possible to grow food crops and horticultural products with the help of greenhouses. A Greenhouse is mainly intended for the maintenance of suitable temperatures and protection from pests**.** The production of fresh food becomes extremely essential, particularly in landlocked extremely cold desert areas like Ladakh, India to meet the nutrient requirements of the inhabitants. People of the region are mostly dependent on packaged food, particularly during the long winter periods.

Owing to harsh climatic conditions the production of fresh food in the winter period is not possible in open field conditions as well as even difficult in passive greenhouse structures.

Fresh food requirements of the region are met by transportation from plain areas during the summer period which involves the cost of fossil fuel. Defence Institute of High Altitude Research (DIHAR), India has estimated that transportation of 1 kg of fresh food by road to this region consumes approximately 21.4ml of diesel and if transported from plain areas by air during winter it costs approx 120 Rs/kg to 150 Rs/kg.

The total area under greenhouses worldwide, as of 2018 is approx. around 5.6million ha[1], with almost half of the world's area under greenhouses, found in Asia and China alone accounted for 83% [1,2]. The area under greenhouse in India increases from 10000-12000 ha[3] to 70000 ha by 2018. Greenhouses (passive type) are also found in Leh and adjoining areas for nearly 5 decades, and the Defence Institute of High Altitude Research (DIHAR) is the pioneer organization in introducing greenhouses for vegetable production. There are different types of passive greenhouses in the Defence Institute of High Altitude Research (DIHAR) (Leh & Partapur, Siachen sector India) (Fig. 1 to Fig. 4) and as of 2020, nearly 82885.5^2 ft/0.768 ha of land are under greenhouses mainly at Leh and Partapur (Siachen Sector) of Ladakh.

Based on collected data from existing passive greenhouses one of the main issues encountered is the maintenance of suitable temperature which is the major

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factor for success or failure in crop production during peak winter. In colder climates, heating needs to be supplemented to protect plants against extreme cold and thus make the production of greenhouse possible. One of the possible solutions is active solar greenhouses which use supplementary energy for the maintenance of essential temperatures necessary for proper growth and can be a solution to the product during the winter period. Vegetable production in greenhouses is nearly negligible, particularly during the winter period, and hence unavailable which causes nutritional deficiency to the inhabitants of the area[4]. Production of vegetables during the winter period becomes one of prime importance. The main purpose of the warming of the greenhouse is to create a suitable environment for plant growth during the winter period. Most of the crops require a minimum temperature of 4°C-5°C for survival. One of the effective solutions is the utilization of non-conventional energy for heating the structure and minimising dependency on fast-depleting fossil fuels.

This paper elaborates on the possibility of fresh food production by supplementary heating the passive greenhouse during the winter period using solar energy technology as a source of energy. It also throws light on fresh vegetable production during the winter period by temperature maintenance in comparison to passive greenhouses production.

2. EXISTING PASSIVE GREENHOUSES IN THE REGION

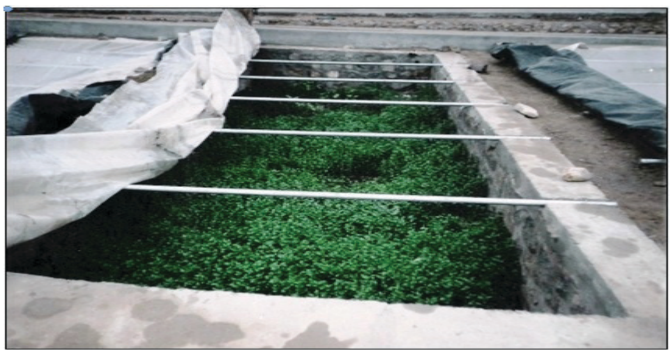
2.1 Trench

A Trench is a rectangular underground structure with dimensions of .00m×4.00m×0.90m (length×width×depth) covered with 120 GSM (grams per square meter) translucent polythene during winter for temperature maintenance5. It is also the most economical and simple structure as compared to other structures (Fig. 1).

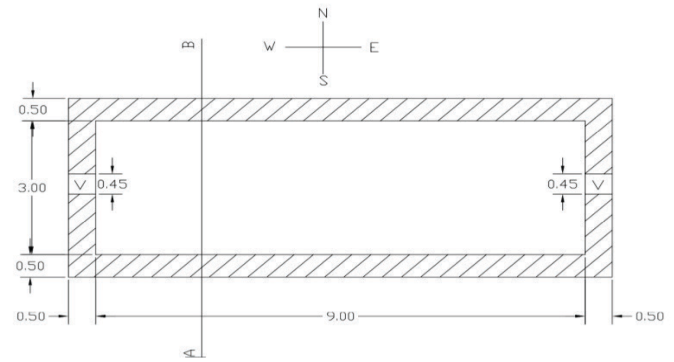
2.2 DIHAR Appropriate Greenhouse

DIHAR appropriate Greenhouse is a semi-underground structure (0.9m below ground level). It is similar to the Chinese type of greenhouse with a small buffer room of size 1.0 m×1.2 m to avoid abrupt fluctuation of temperature. The overall dimension of the greenhouse is 29.26 m×7 m×2.28 m (length×width×Height) with a center height of 3.14 m. Construction material comprises of mud brick northern wall of an overall thickness of 1m with an insulation gap of 0.33m which is filled with locally available materials like straw and sea buckthorn yakzee (stems) for insulation. Eastern and western walls were made up of mud bricks with similar insulation thickness in between the mud bricklayers. The Southern side consists of a network of iron frames with 200 GSM (grams per square meter) translucent polythene cover (cladding material).

The Roof of 29.26 m×1.52 m of the greenhouse is made of locally available tree trunks, straw, and sticks with mud on the top. It is sloped at 33° to block the sun during summer. Along with Trench, this structure proves efficient in the production of green leafy vegetables only during the peak winter periods (Fig. 2).



(a)



(b)

Figure 1. Trench (All dimensions in meters)

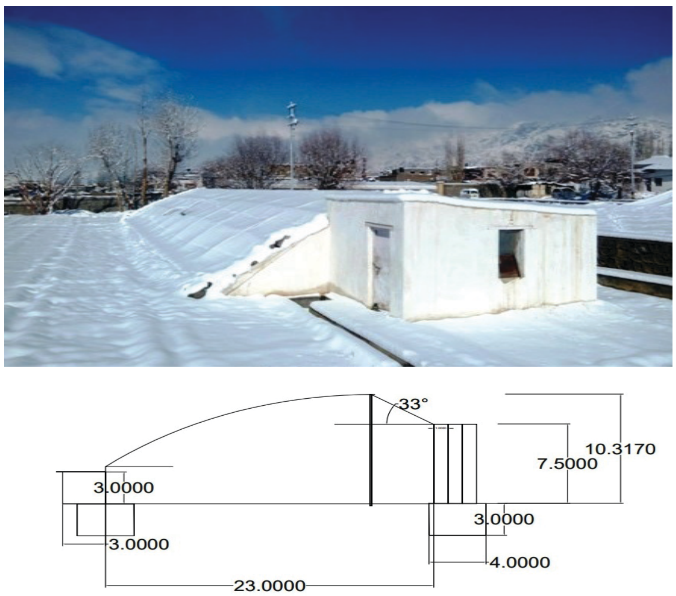
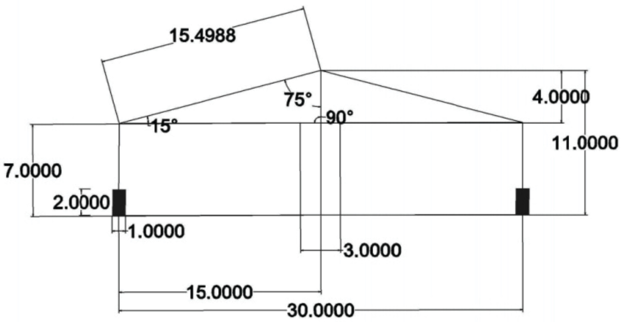


Figure 2. DIHAR appropriate greenhouse (All dimensions in feet).

2.3 Fiber-reinforced Plastic (FRP) Greenhouse

FRP (fiber-reinforced plastic) greenhouse (gable shaped) consists of FRP sheets on all four sides which are fixed on a galvanized iron frame on a 0.6m concrete wall above ground. It is gable shape with dimensions of 30.48 m×9.14 m×3.35 m (length×width×Height) the roof is also made up of FRP (fiber-reinforced plastic) sheets with a slope to avoid an accumulation of snow during the winter period (Fig. 3).

(a)



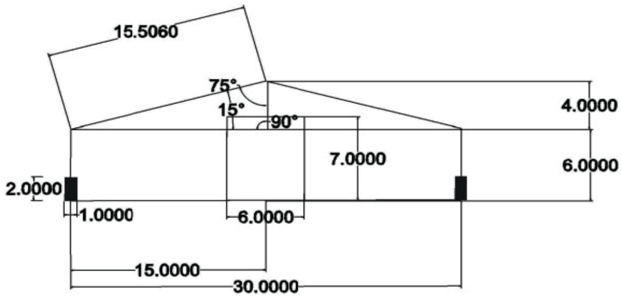
(b)

Figure 3 (a)-(b). FRP Greenhouse (Dimensions in feet).

2.4 Polycarbonate Greenhouse

Polycarbonate greenhouse 36.57 m×9.14 m×3.048 m is a gable-shaped passive greenhouse with 8mm triple layer polycarbonate sheets on all four sides along with the roof. The sheets were fixed on a galvanised iron frame on a 0.6096m concrete wall of 0.3048m width above ground on all four sides. This greenhouse is better than a trench and DIHAR-appropriate greenhouse for warm-season crops during summer only. No production is noticed in this greenhouse during winter due to high energy losses from the large exposed area. (Fig. 4)

(a)



(b)

Figure 4 (a)-(b). Polycarbonate Greenhouse (All dimensions in feet).

3. NEED FOR ACTIVE GREENHOUSE IN THE COLD-ARID REGION OF LADAKH, INDIA

Ladakh, India situated in the high hills of the trans-Himalayan region has the harsh geo-climatic conditions and remains isolated from the rest of the world in the winter. The availability of fresh vegetables is quite seasonal and can be grown in open fields only during the short summer season of 4 to 5 months (May to October) which can be extended in passive greenhouses (April and November). The temperature drops much below subzero from December to March and no production is possible even in a passive protected cultivation structure during this period. The fresh food requirements are mostly met by transportation from plain areas but the closure of roads results in the non-availability of fresh foods from plain areas also during this period. An acute shortage of fresh vegetables is often encountered during winter months which has an effect on the health of inhabitants in the long term.

The potential solution for maintenance of temperature will be either heat losses from the shelter were minimized by designing an energy-efficient shelter with suitable

Table 1. Monthly measured temperature at Leh from 2013 to 2018

Month	Year	Minimum Temperature °C						Maximum Temperature °C						Average Ambient Minimum Temperature °C					
		Temperature Limits																	
↓	→	'13	'14	'15	'16	'17	'18	'13	'14	'15	'16	'17	'18	'13	'14	'15	'16	'17	'18
Jan		-18.6	-17.9	-18.4	-18.8	-17.8	-18.5	3.5	5.6	3.8	3.6	5.9	3.7	-12.5	-11.9	-12.4	-11.4	-13.6	-11.9
Feb		-15.7	-14.8	-15.5	-18.7	-12.9	-16.5	9.0	9.3	7.8	7.1	8.9	6.9	-9.2	-8.5	-10.2	-11.1	-8.9	-8.8
Mar		-11.1	-9.2	-8.3	-11.5	-7.9	-15.8	11.3	14.1	13.2	12.5	14.4	14.3	-5.2	-4.9	-5.1	-6.1	-4.6	-6.7
Apr		-4.1	-2.4	-2.1	-3.5	-1.8	-3.7	17.9	17.2	16.5	17.2	17.7	17.6	-0.5	-0.2	0.8	2.0	-1.7	1.8
May		0.0	0.5	-1.9	0.0	0.5	0.1	21.1	19.7	22.8	19.8	19.9	21.7	3.4	4.1	4.9	4.8	3.5	5.1
Jun		3.5	6.3	5.8	3.9	7.8	3.8	26.5	21.7	27.7	26.5	26.9	22.8	9.3	7.6	11.5	7.5	10.9	6.9
July		8.5	7.5	8.5	8.9	8.9	6.9	32.1	28.5	29.8	29.4	29.7	29.7	13.4	11.5	14.0	13.6	13.2	11.4
Aug		6.0	8.5	7.8	9.8	9.9	3.7	30.0	28.8	29.5	29.4	30.8	29.5	12.0	12.3	13.4	12.6	12.8	12.5
Sept		2.0	1.1	3.9	3.9	0.1	1.9	24.8	22.5	25.9	23.9	26.9	26.5	6.7	6.1	7.7	6.8	7.6	7.5
Oct		-5.2	0.2	-5.5	-4.9	-5.9	-4.8	19.7	18.9	23.5	17.8	18.9	17.7	0.0	1.7	-0.3	-3.9	-1.6	-1.2
Nov		-12.6	-9.5	-9.9	-12.9	-9.9	-9.9	14.5	14.7	13.4	12.9	13.9	11.7	-8.1	-4.2	-5.3	-9.7	-6.5	-4.9
Dec		-16.5	-15.7	-14.2	-13.5	-17.5	-18.9	10.3	9.9	9.8	6.9	8.8	5.9	-11.7	-9.1	-9.6	-10.8	-12.2	-13.9

insulating material or by the inclusion of an external supplementary heating system which helps in making the region self–reliant in fresh vegetable production.

4. SELECTION OF RENEWABLE ENERGY FOR SUPPLEMENTING THE HEAT ENERGY

Ladakh, India situated at a latitude of 34.152 ºN, and 77.5676 ºE longitude is one of the main regions of India which has high solar energy potential. It has a solar irradiance of nearly 1900-2000kwh/m2/year (National Renewable Energy Limited, India, data) with an annual average recorded/collected sunshine duration of 7.9 h along with 300 plus cloud-free days. The average recorded Lux levels during winter in an open field and inside the greenhouse (polycarbonate greenhouse) were approx. 55330 and 36560 respectively with a maximum of 121400 and 51500 Lux levels around midday respectively in open and in the greenhouse. Solar energy looks to be one of the best sources to be used for meeting the power and thermal energy requirements of the region. This will not only reduce the dependence on exhausting fossil fuel reserve but also contributes to lowering greenhouse gases which contributes to global warming besides issues related to the transportation and storage of fossil fuels.

The annual average recorded temperature of Leh, India varies from 10.5°C to 12 °C with minimum recorded temperature going as low as -21°C. The monthly variation of temperature in open field conditions recorded at Leh (DIHAR, experimental field) from 2013 to 2018 is shown in Table 1.

The minimum and maximum temperatures (averages) for winter months from 2013 to 2018 are shown in Table 2.

Table 2. Minimum (average) and Maximum (average) outside Temperature during winter (2013 to 2018)

Months	Minimum Temperature (Average)	Maximum Temperature (Average)
October	-4.35	19.41
November	-10.78	13.5
December	-16.05	8.6
January	-18.33	4.35
February	-15.68	8.16
March	-10.63	13.3
April	-2.93	17.3

The ambient outside temperature has a role to play as far as the inside temperature of any structure is concerned. It was usually noticed that temperatures are favorable even during winter in the daytime, but it approaches the ambient outside temperature during the night which ultimately affects the survivability of the green vegetables. Hence no growth and production in the greenhouses are reported. The detailed recorded inside minimum temperature (monthly average) of various existing greenhouses at DIHAR Leh and the corresponding ambient temperature (average) are shown in Table.4b. The monthly average temperature inside different greenhouses year-wise (2013 to 2015) during the winter period (Oct to April) shown in Table 3.

The collected data (Table 4b) indicates that the productions of vegetables are not possible in any passive

Table 3. Minimum recorded temperature in different greenhouses during winter months from 2013 to 2015

Months	Year	Minimum Recorded Temperature in ⁰C in different Greenhouses											
		Polycarbonate			Trench			DAGH			FRP		
↓	→	'13	'14	'15	'13	'14	'15	'13	'14	'15	'13	'14	'15
Oct		-2.9	-0.1	-3.1	1.7	0.0	1.6	1.04	0.04	1.1	-3.79	-0.2	-4.12
Nov		-7.9	-5.9	-6.1	-2.9	-2.2	-2.3	-1.5	-1.1	-1.2	-7.6	-5.7	-6.0
Dec		-10.5	-9.9	-9.1	-4.4	-4.2	-3.8	-1.81	-1.7	-1.6	-9.4	-8.9	-8.1
Jan		-11.1	-10.6	-10.9	-6.5	-6.3	-6.4	-4.0	-3.8	-3.9	-11.0	-10.6	-10.9
Feb		-8.2	-7.7	-8.1	-4.6	-3.8	-4.5	-0.8	-0.6	-0.7	-7.8	-7.3	-7.7
Mar		-4.5	-3.7	-3.3	-1.7	1.4	1.1	4.5	3.8	3.4	-4.4	-3.5	-3.5
Apr		1.0	0.6	0.5	2.7	1.6	1.4	9.9	5.8	5.1	2.5	1.4	1.3

existing greenhouse without the maintenance of a suitable environment during winter. The average productions in different passive greenhouses throughout the year from 2013 to 2018 in summers and winters showed in (Table 4 (a)).

Table 4(a). Average production of fresh food in different passive greenhouses (2013 to 2018)

Period	Crops	Type of Structure & Quantity Produced			
		Trench	DAGH	FRP	PC GH
Mar-May	Onion Seedling	120,000 No.	490000 No.	605000 No.	655000 No.
May-Oct.	Tomato	450Kgs	1320Kgs	3920Kgs	4950Kgs
Oct.-Mar	Spinach	205Kgs	480Kgs	NIL	NIL

The production of fresh food during winter is possible only if the temperature is maintained inside the structure. This can be done either by designing an energy-efficient structure with suitable insulation material or by providing supplementary thermal energy. The former is a time taking study while the latter can be done instantly. There are several types of heating systems available for use in greenhouses. Selecting the proper system is important; some systems cost less or use less expensive fuels. Others may have a higher initial cost, but they are more efficient, compact, easy to install, portable, cheaper, and safer to operate. Selecting the appropriate heating system depends partially on the types of fuel/source that are available and the user. But in land-locked high-altitude areas like Leh, fuel needs to be transported and stored before the onset of winter hence only systems based on renewable energy seem to be the most promising and low costing and one-time solution. Solar energy

Table 4(b). Minimum (av) recorded temperatures in different greenhouses with ambient temperature (2013 to 2015)

Minimum Recorded Temperature(⁰C) (Average 2013-2015)					
MON	Amb. Tem.	Poly-Carb.	Trench	DIHAR Appro. Green-house	FRP Greenhouse
Oct	-3.5	0.1	1.1	0.7	-2.7
Nov	-10.67	-6.67	-2.5	-1.3	-6.5
Dec	-15.46	-9.83	-4.1	-1.7	-8.8
Jan	-18.33	-10.83	-6.4	-3.9	-10.9
Feb	-15.33	-8	-4.3	-0.7	-7.6
Mar	-9.5	-3.83	-1.4	3.9	-3.8
Apr	-2.8	0.67	1.9	6.9	1.7
Vol	-------	37.576m×9.14m×3.048m = 1018.93m3	9.14m×3.048m×0.914m =25.46 m3	22.86m×7.62m×3.048m =530.94	30.048m×9.14m×3.35m =920.04 m3

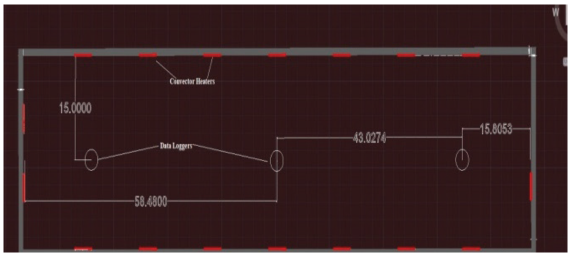
(Table 5) can be one of the best solutions for eradicating the problem mentioned above associated with fossil fuels. The annual average irradiance (GHI) on a horizontal plane in India is approximately around 4.3-4.9 kWh/m^2/day (National Renewable Energy Limited, India, data) in comparison to 5.1 KWh/m^2/day to 5.5KWh/m^2/day (GHI) at Leh[6], apart from the comparatively long annual average sunshine durations. The average monthly solar radiation and average sunshine duration collected at Leh Ladakh, India (DIHAR, experimental field) is tabulated in Table 5.

Table 5. Recorded sunshine duration and GHI

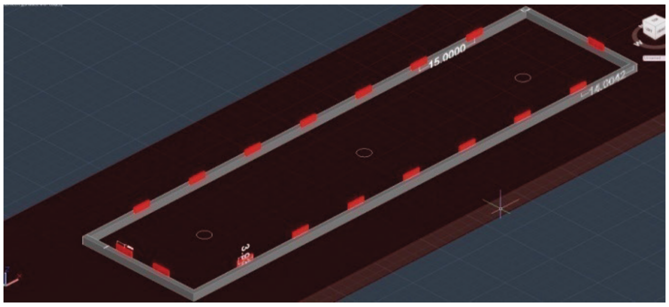
Month	Sunshine duration (hrs/day)	GHI at tilt latitude (Leh) (KWH/m^2/d)	GHI at horizontal surface (KWH/m^2/d)
Jan	5.85	5.40	3.27
Feb	6.45	4.79	3.65
Mar	6.7	5.40	4.51
Apr	8.0	5.21	5.17
May	8.55	6.51	7.17
June	8.7	6.33	7.45
July	10.2	6.30	7.23
Aug	9.1	6.17	6.39
Sept	8.6	7.19	6.33
Oct	7.9	6.33	4.64
Nov	7.7	5.03	3.44
Dec	6.7	4.51	2.74
Av	**7.9**	**5.76**	**5.16**

The basic purpose of this study is the maintenance of temperature for fresh food production during the winter period, especially in the condition of the Trans-Himalayan region.

Simply operated and commercially commonly available technology viz. convection heater with automatic user-defined parameter(temperature) setup system i.e. convection heater is chosen from among the other available systems which require initial civil works like solar heated underground hot water/HTF circulation system, phase change material applications, underground cabling systems, ground heat source system, etc.



(a) Top View (Position of heaters & data loggers)



(b) SW View. (Inter convectors distance)

Figure 5 (a)-(b). Convector heater layout.

Once proven that production is possible during peak winter in greenhouses by temperature maintenance, attention can be focused on low-cost, efficient, and low-energy-consuming systems in the future.

5. SELECTION OF GREENHOUSE FOR STUDY WITH THE SELECTED TECHNOLOGY

The largest and coldest greenhouse with the maximum volume and the exposed area is selected for the study. Collected data suggests that either FRP or polycarbonate greenhouses look appropriate for our study. But based on observations and past knowledge FRP sheets lose transparency with time and hence affect crop production (blocks 75 % PAR in approximately 4-5 years of installation[7] further R-value (a measure of resistance to flow of heat) of single layer FRP sheets (R value=0.83 approx.) is much lower as compared to 8mm triple layer polycarbonate sheet (R value=2.0 approx.), and hence high heat losses from FRP compared to polycarbonate sheets. The minimum and average minimum temperature collected in a passive polycarbonate greenhouse is shown in Table 6.

Table 6. Recorded minimum and average minimum temperature in polycarbonate greenhouse during the winter months of 2013 to 2015

Month	October		November		December		January		February		March		April	
Year	Min. (ºC)	Av. Min (ºC)	Min. (ºC)	Av. Min (ºC)	Min. (ºC)	Av.Min (ºC)	Min (ºC)	Av. Min (ºC)	Min. (ºC)	Av. Min (ºC)	Min. (ºC)	Av. Min (ºC)	Min. (ºC)	Av. Min (ºC)
2013	-2.9	2.4	-7.9	-4.3	-10.5	-6.3	-11.1	-7.7	-8.2	-5.3	-4.5	-2.3	1	4.8
2014	0.1	4.3	-5.9	-3.7	-9.9	-5.6	-10.6	-6.8	-7.7	-4.9	-3.7	-1.4	0.6	4.2
2015	3.1	5.6	-6.1	-4.1	-9.1	-5.9	-10.9	-6.1	-8.1	-5.8	-3.3	-1.6	0.5	3.8
Av.	0.1	4.1	-6.63	-4.03	-9.83	-5.93	-10.8	-6.86	-8.0	-5.3	-3.83	-1.76	0.7	4.26

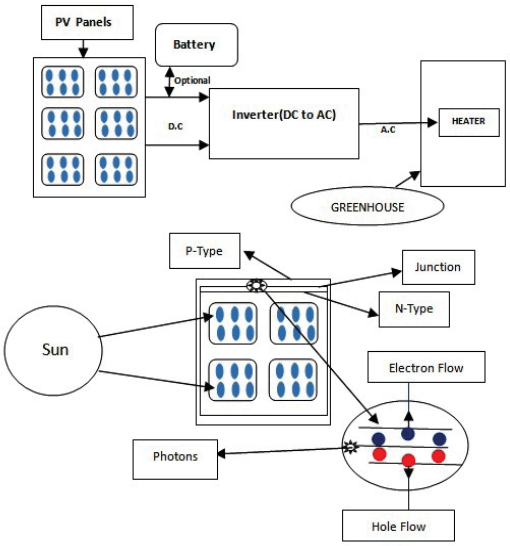


Figure 6. Schematic Diagram of Energy harvesting, conversion & Supply.

6. METHODOLOGY

6.1 Crops Cultivation Procedure

The seeds of the crops were sown manually through the line sowing method under 2 cm of the soil in the active polycarbonate greenhouse 35 days before the date of transplanting. Thorough water was given to the seeds immediately after sowing. As all the crops required for the study belong to the days Brassicaceae family the germination starts in a week. Irrigation for the seedlings was done at 7 days intervals and by the 35th day of sowing, the seedlings are suitable for transplanting. Plowing of the greenhouse was carried out manually by adding 300 kgs of properly decomposed farmyard manure and plots of equal size were made in the polycarbonate greenhouse and they were leveled well with the help of a leveler to avoid water clogging situation once the seedlings are transplanted. By the 35th day, healthy seedlings were selected and they were transplanted at a distance of 1ft×1ft between two plants and 1ft×1ft between two rows in the plots. Thorough flood irrigation was made just after the seedlings were transplanted in the plots. The seedlings start establishing in the soil by the 5th day of transplanting and urea was added to the soil after 20 days of transplanting. Weeding with the help of a garden hoe was carried out after 30 days of transplanting and irrigation was done at an interval of one week apart till harvesting.

6.2 Technology Details

A simply operated and commercially readily available convector heater was chosen for the study. It works on a single phase and operates on 230V and 50Hz, consumes a total of 2400W having 2 coils of 1200W each. It is based on an automatic user-defined parameter (temperature) setup and accordingly starts and stops as the set limit is reached. (Range: 4°C-5°C).

7. WORKING PRINCIPLE

The working principle of a convector heater is based on drawing room/shelter cold air into the unit and passing it through the space where the heating element is located. The air passes over the heating element and comes out back into the room as warm air (Air temperature comparatively higher than the previous air temperature). This process keeps on repeating till the set temperature is attained inside the greenhouse.

Based on the average ambient minimum temperature condition of six winter months (-7.1°C) of 2013, 2014 & 2015, (Table 1) the corresponding recorded average minimum temperature for the same period in a passive polycarbonate greenhouse is -3.2°C (Table 6).

The supplementary heat energy requirement and the total number of convector heaters required for temperature maintenance are discussed below:

1. Average recorded ambient Temp (Oct-Mar) = -7.1°C
2. Average Passive G/H Temp. for the same period (T1) = -3.2°C
3. Temperature to be maintained (T2) = 5°C (R-value of polycarbonate sheet=2 (97%-98% polycarbonate sheet), hence R-value of the wall not considered.
4. Temperature required to elevate from existing T1 to T2 i.e ΔT = 5°C-(-3.2°C=8.2°C=46.76°F
5. Supplementary heat required = A×1/R×ΔT = 132400.94 BTU/Hr = 38 KW
   Where A = Area of G/H = 5663 ft 2 & R = resistance to thermal transfer.
6. Rating of each convector heater = 2.4 KW
7. Net thermal output from a single heater = 2.4 KW
8. Number of heaters required = 38/2.4 = 15.83 ≈ 16
9. Hence 16 numbers of heaters are required to be installed.
10. In case of the failure of heaters one extra heater is used as a spare. Thus the total number of used heaters = 17

The total energy requirement for maintaining temperature is approximately 608 KWH (38 KW/H) for an average of 16 h during the night from 1700 h to 0900 h. The total power plant size required is approximately 130 KW and the cost of the plant as per MNRE (Ministry of New and Renewable energy, India) guidelines is approximately 55-60 lakhs.

8. THE LAYOUT OF CONVECTOR HEATERS

The detailed layout of the convector heaters and data loggers inside the greenhouse is shown in Fig 3 (a) & 3(b) (Centre-to-centre heater distance & heater center-to-wall distance on the shorter walls are 10' & 9' approx. respectively). It was generally observed during the trial that for every foot away from the heater there is a variation of 1.5 °C to 1.8 °C, at an average minimum ambient temperature of -15 °C to -18 °C in the greenhouse and accordingly the automatic temperature limits of the heaters were set up for maintenance of minimum temperature in the range of 4 °C to 5 °C inside the greenhouse. Parameters were measured with the help of 3 numbers HTC brand automatic data loggers, which were placed in the center of the greenhouse at a height of 3.0-3.5 feet (Fig. 5(a)).

9. PRINCIPLE OF ENERGY HARVESTING AND CONVERSION

One of the most readily available simple technologies for solar energy generation/harvesting from the last few decades is PV system-based technology. Solar radiation intensity affects the output current and efficiency of the system as well. This means high solar radiation intensity leads to an increase in output current from the PV panel. But an increase in solar radiation at the same time causes an increase in the PV cell temperature which affects the performance of solar cells8.PV system-based energy harvesting is most suitable for Ladakh, India condition considering the low outside atmospheric temperature, high average sunshine duration, and high solar radiation intensity. Solar PV system energy generation is based on the principle of the photovoltaic effect. It converts sunlight into direct current (DC) electricity. This can be stored in batteries or supplied directly to meet electricity requirements. Hence PV technology-based system was chosen for the supply of essential energy to the convector heaters.

10. BRIEF DETAILS OF THE PV PLANT

1. Peak Power (Pmax): 216 KWP
2. Peak Voltage (Vmax): 296V
3. Peak Current (Imax): 729.6 A
4. No. of Solar Panels: 960
5. Type of solar panels: Mono & polycrystalline
6. Type of battery used: Li-ion
7. Total Number of Batteries: 480
8. Number of inverters: 03
9. Capacity of each battery: 2V- 1125 Ah
10. No. of Charge Controller: 05 Nos.
11. The efficiency of the plant: 63.27%

The harvested electrical energy is supplied either directly to the selected convector heaters placed inside the greenhouse or stored in the battery and Fig. 6 Schematic Diagram of Energy harvesting, conversion & Supply supplied as per requirements for maintenance of set temperature.

11. RESULTS

The studies/trial results show that temperature in the range of 4°C-5°C was maintained in the largest and coldest existing greenhouse viz. polycarbonate greenhouse with 2.4KW convector heaters (16 in numbers) drawing energy from Solar PV plant during successive winter periods. This proves that maintenance of temperature is possible in any greenhouse and hence the production of fresh vegetables also.

Trial results with the installed renewable energy system collected successively over three years (2015-2018) are shown in Table 9. Further as a result of temperature maintenance the output in terms of yield for different crops like cauliflower, knol-khol, cabbage, and broccoli was noticed and reported for the first time in any existing greenhouse of the region during winter periods (Table 10). The actual total energy consumption of the heaters as recorded during the trials were found out approximately around 459 KWH depending on active operating time as per the set temperature limits inside the greenhouse and detailed collected parameters are shown in Table-7.

Table 7. Actual E cons. during trial 2016-2017

Month	Av. Min. Amb Out side Temp (^{0}C)	Av. Min Temp at Sunset. (^{0}C)		't' to reach 5°C from sunset Temp (Min)	Av. ON 't' (Min)	Av. (OFF) 't' (Min)	Tot active 't' (min) / 16 hrs	Tot 'E' con
		Out	GH					
J	-13.6	-4.8	1.2	35	11	2	816	517
F	-8.9	-2.8	2.12	22	9:20	3:30	690	437
N	-9.7	-2.1	3.01	20	7:50	4:50	601	381
D	-10.8	-3.0	1.94	32	10	2:13	792	502
Av	**-10.7**	**-3.0**	**2.06**	**27.2**	**9.4**	**2.98**	**724.9**	**459** KWH

The details of the cropping patterns observed at DIHAR in the greenhouse during summer and winter as also the approximate income generated are shown in Table 8.

The energy consumption looks higher, but the main objective of the study viz. production of fresh vegetables by maintaining temperature using solar energy during winter is proven.

The total approximate expenditure incurred on the whole system (Power plant, Greenhouse & convector heaters) is approximately 65lakhs. The energy from the power plant was possibly used only from November to February for warming the greenhouses for vegetable production and the rest of the year harvested energy can be utilized for other purposes like lighting and running other systems, which also contributes to income generation indirectly. Taking Rs.4/unit for generated power (existing rate for domestic use per unit in J&K, India), the total cost for approx. 460 units per day are approx. around Rs.1840 and yearly (mid-April to mid-Nov) it contributes Rs.3,86,400 and 330000 is expected to contribute from produced fresh foods. Hence we can conclude that the whole system payback time will be around 8 years to 9 years. Further, these calculations were carried out as per the prevailing vegetable government rates, which were lower than the prevailing market rate/kg fixed by the local administration of Ladakh[7].

The government is also providing subsidies and incentives on solar energy-related systems and greenhouses which further reduces the payback time and hence justifies the economics in the long run to the users besides meeting the nutritional needs of the inhabitants.

The required energy for the greenhouse in present trials is supplied from an already existing solar PV plant of capacity 216 KWH.

Table 8. Actual income generated and cropping pattern in Poly greenhouse over a year

Period	Crops	Total produce	Approx. income generated
Mar-May	Sapling (onion)	210000 n.	Rs.63,000 (Rs.30/100 n)
May-Oct	Tomato	1800kgs	Rs.72,000 (Rs.40/kg)
Nov-Feb	C. flower	2000kgs	Rs.200000 (Rs.100/kg)

*n=number.

12. ANALYSIS AND DISCUSSION

The production of fresh food (except leafy vegetables) (Table 4b) is not reported in the region in ambient conditions as well as in any existing passive greenhouses due to very low average atmospheric temperature during the long winter period (Table 1 & Table 4(a)) and corresponding low average temperature inside the existing greenhouse. The limited supply of fresh food to the inhabitants of the region is made through air routes from plain areas. The inhabitants of the region hence have to survive on frozen packaged food. People in the region have a high consumption of red meat and packaged foods during the winter period. High consumption of red meat and frozen packaged food accompanied by low/no vegetable intake causes many diseases like stomach cancer which is prevalent among people of the region 9, 10. Temperature proves to be the biggest atmospheric factor that decides the production of green fresh vegetables in any greenhouse during the winter period. This was proved by growing fresh vegetables during the winter period by maintaining temperature in one of the existing coldest greenhouses for three successive winters where the minimum temperature drops to as low as -8°C to -11 °C during peak winter months.

Table 9. Recorded temperature in greenhouses (Passive, active and ambient outside.

Month	Ambient Min. Temp.(°C) (Av.)	Polycarbonate T(°C) Passive	Polycarbonate T(°C) Active
Oct	-3.5	-2	4.01
Nov	-10.67	-6.67	4.1
Dec	-15	-9.83	3.9
Jan	-18.33	-10.83	4.2
Feb	-15.33	-8	4.3
Mar	-9.5	-3.83	4.2
Apr	-2.83	0.67	3.8

Feasibility studies were carried out successfully with simple & commercially easily available technologies viz solar PV plant and convector heaters for supplementing heat energy. This proves that if even temperature above 4 °C is maintained the production of crops is possible in any greenhouse which otherwise is not possible /reported

Table 10. Details of crop production during trials in Active polycarbonate Greenhouse from 2016 to 2019

Crops (Variety)	Transplanting details: Date			No. of plots	Plot Size	Plants in a plot/ Survival plants (%)			Date of Harvesting			Total Yield (Kg)			Av. Yield (kg/GH)		
	2016-17	2017-18	2018-19			2016-17	2017-18	2018-19	2016-17	2017-18	2018-19	2016-17	2017-18	2018-19	2016-17	2017-18	2018-19
Cauliflower (Shentha)	07-Dec-16	23 Nov 17	20 Nov18	12	10 ft x 6 ft	40/37 (92.5)	40/37 (92.5)	40/38 (95.0)	Apr-2017	Mar-2018	Mar-2018	334	512	224	1670	2160	2120
Knol-khol (P Virat)	07-Dec-16	23 Nov 17	20 Nov18	12		40/40 (100)	40/39 (97.5)	40/40 (100)	Apr-2017	Mar-2018	Mar-2018	336	288	324	1680	1440	1620
Cabbage (Gonzales)	07-Dec-16	23 Nov 17	20 Nov18	12		40/37 (92.5)	40/38 (95.0)	40/40 (100)	Apr-2017	Mar-2018	Mar-2018	420	164	348	2100	1320	1740
Broccoli (Fiesta)	07-Dec-16	23 Nov 17	20 Nov18	12		40/33 (82.5)	40/36 (90.0)	40/37 (92.5)	Apr-2017	Mar-2018	Mar-2018	120	144	170	600	720	850
Red Cabbage (Primero)	07-Dec-16	23 Nov 17	20 Nov18	12		40/38 (95.0)	40/38 (95.0)	40/37 (92.5)	Apr-2017	Mar-2018	Mar-2018	360	240	312	1800	1200	1560

in any existing passive greenhouses of the region.

It was also noticed that the total energy consumption for maintenance of temperature varies as per the ambient outside temperature and exposed surface area of the shelter. The present system used for successful maintenance of the temperature met our objective with slightly high energy consumption but it proves the possibility of fresh food production during the winter period using solar energy and paved the way for fresh food production throughout the year irrespective of the season. This helps in overcoming the nutrient deficiency of the inhabitants apart from protection from deadly diseases.

13. CONCLUSION AND RECOMMENDATION

Temperature maintenance with simple, easily available technologies was found effective in the production of fresh vegetables during the winter period in the cold arid high altitude conditions of Ladakh, which otherwise is not possible and hence making the availability of fresh foods to the inhabitants and fulfillment of the essential nutrient requirement.

A variety of warm-season crops were successfully grown in the active polycarbonate greenhouse during the winter period, but the time taken is slightly longer than what it takes during the summer season. Hence study can be carried out to identify the reason behind such time differences.

1. A comparative Study of yield during the winter period with different active greenhouses also needed to be carried out for identifying the best structure in terms of production for energy consumption and hence the continuous supply of fresh food to meet the user's demand at a cost-par with summer cost and to reduce dependency on transportation from plain areas.
2. Further study can be carried out on the material of the greenhouses which prevents the escape of trapped solar energy during the night time or application of suitable latent heat storage material which can store heat during day time from solar radiation
3. and supply stored thermal energy when the temperature dips particularly during the night, as excess heat are generated during day time even in winter months. Hence less supplementary heat energy supply is required which will have a bearing on the cost of the produce in the long run. The insulation of windows and open spaces can also be carried out to reduce energy losses, consumption, and hence final cost.

The scope of the study of alternative low energy-consuming renewable technology for supplementing thermal energy can also possibly reduce the energy consumption and final cost and make it affordable to every local inhabitant of the region.

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REFERENCES

1. Qasim,Waqas; Xia,Longlong; Lin,Shan;Wan,Li.;Zhao,Yiming.;Claus, Bahl & Butterbach, Klaus. Global greenhouse vegetable production systems are hotspots of soil N2O emissions and nitrogen leaching: A meta analysis. *Environ. Pollution.*, 2021 **272**, 116372. doi: 10.1016/j.envpol.2020.116372.
2. C Fei, S; Zang, B; Liang, J.; Li, L.; Jiang, Y.; Xu & X,Ding.Characteristic and correlation analysis of soil microbial biomass phosphorous in greenhouse vegetable soil with different planting years, ACTA Aric.Boreali-sinica **33**(1), 2018, 195-202.
3. Nair, Reena.;Barche,Swati. Protected cultivation of vegetables-present status and future prospects in India, *Indian J. Applied Res.* Vol.4 2014. doi:10.36106/ijar.
4. Dame, Juliane. & Marcus,Nüsse. Food security in high mountain regions: Agricultural products and the impact of food subsidies in Ladakh, Northern India, *J. Food Security* 2011, **3**, 179-194. doi: 10.1007/s12571-0110127-2.
5. Angmo,Stanzin.; Angmo,Phunchok.; Dolker,Disket.;Norbu,Tsewang.;Paljor,Eli.;Kumar,Bhuvnesh.&Stobdan,Tsering. All Year Round Vegetable Cultivation in Trenches in Cold Arid Trans Himalayan Ladakh. *Def. Life Sc. J.*, 2017 **2**(1), 54-58 doi:10.14429/dlsj.2.11001.
6. Rather, Rashid, ul, Nasir.; Singh, Anju.& Samoon, Asghar. Solar Resource Assessment in Jammu and Kashmir State. *Int. J. of Adv. Eng. Res. Sci.* 2018, 5(1), 58-63. doi:10.22161/ijaers.5.1.10.
7. Angmo,Phunchok; Dolma Tsering; Namgail,Desyong; Tamchos,Tsewang.;Norbu,Tsewang.;Chaurasia,o.p. & Stobdan,Tsering. Passive Solar Green house for round the year vegetable Cultivation in Trans-Himalayan Ladakh Region, India, *Def. Life Sci. J.*, 2019, **4**(2), 103-116. doi:10.14429/dlsj.4.14208.
8. Basher,Jenan,Maan.; Kadhem A.N. Al-Asadi. & Ali,A.K. Al-Waeli. Effect of solar radiation on photovoltaic cell, *Int. Res. Jr. of Adv. Eng. Sc.,* 2018, **3**(3), 47-51.
9. Hussain,Sajjad. High Incidence of Gastric Cancer in Kargil Ladakh, *Int. J. Sci. Res.,* 2019, **8**(8), 561-566. doi: 10.21275/ART2020278.
10. Singh, Narendra.; Aditika.; Rani,Seema. & Chaurasia, O.P. Vegetable micro-green farming in High Altitude regions of Trans-Himalayas to maintain nutritional diet of Indian troops. *Proceedings of the National Academy of Sciences, India - Section B: Biological Sciences,* 4, 743-752,. doi:10.1007/s40011-019-01147.

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