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Design and Performance Analysis of Solar Greenhouse Heating

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ABSTRACT

Climate change and 'Greenhouse effect' have been subjects of interest for many years due to their importance in achieving a 'greener' planet with energy efficiency and less GHG emissions. New technologies are enthused to be developed to succeed in this mission and as a result, different renewable power generation technologies have evolved over time. Wind energy, hydro power, solar thermal systems, solar photovoltaic systems, biomass and fossil fuels, geothermal energy are some of the popular ones among those new technologies which are in action. The temperate countries around the world always faced challenges in producing crops and vegetables during the winter season. The concept of 'Greenhouse effect' helped to overcome this obstacle. In many temperate countries the 'Solar Greenhouse Heating' is now being practiced for the production of different crops and vegetables during the winter season. Studies showed that the 'Greenhouse' needs more energy than any other commercial spaces in winter. To supply this huge amount of energy and also to achieve a system with low GHG emissions, 'Solar energy' is used. This particular renewable energy source is chosen because of its feasibility in application, availability and low cost. 'Solar Greenhouse Heating' is the concept where thermal energy is stored in a medium which is later, in the absence of solar power, gives away heat and helps to maintain a favourable temperature and also assist in the cultivation process. The medium can be water, soil or thermal mass. Regardless of whatever the medium is, the 'Solar Greenhouse Heating' process is proving to be very efficient concept and is being adopted all over the world gradually.

Keywords: Green house, GHG, Heat storage, solar energy, Passive Solar Greenhouse

INTRODUCTION

The sun is a source of uninterrupted energy. This solar energy is utilized by the plants to successfully accomplish the photosynthesis process. The process takes place under specific atmospheric conditions. The 'Greenhouse' concept can assist in attaining these conditions artificially. The heat required by the plants to grow during winter can be provided by the greenhouse which stores solar energy in a medium such as water, salt or any other thermal mass. 'The Greenhouse Effect' is known as the process in which heat rays from a terrestrial part is consumed by environmental greenhouse gases, and is then again emitted along all courses. Since part of this comes back towards its source, that is, the surface, it increases the temperature of the surface which would not have happened if the gases were not present.

This increase in temperature has been a major concern because of its impact on the climate change. But the concept of 'The Greenhouse Effect' turned out to be useful in some scientific fields where increase of temperature is the goal. The 'Solar Greenhouse Heating' is one of the successful implementations of the 'Greenhouse' concept. 'Greenhouse' is defined as the establishment where agricultural procedures take place in order to grow plants. 'Greenhouse heating' is the process of increasing the temperature of the greenhouse, to facilitate the cultivation process. The term 'Solar Greenhouse Heating' means the greenhouse heating process operates using the 'Solar energy'. According to different studies, maintaining the temperature of agricultural greenhouses consume a lot of energy compared to other agricultural activities. Keeping in mind the cost of energy and many researches, 'Solar' energy was found to be a very good source for the 'Greenhouse Heating' and have been used for many years since

1980.The ‘Solar Greenhouse Heating’ is mostly used in agriculture industry. It also has been applied in the drying industry. The concept of ‘Greenhouse Heating’ is also used in the design of ‘Solar houses’.

SOLAR GREENHOUSE

Solar Greenhouses are fundamentally of two types, which are: 1) Active solar greenhouses and 2) Passive solar greenhouses [1]. Active solar greenhouses are those which have an independent heat storage system and the collecting system which is detached from the greenhouse cell is used by the solar system. On the other hand, passive solar greenhouses are designed to make the most out of the solar energy. The collector system is incorporated in the greenhouse cell.

Design

Over the past three decades, there have been many researches to come up with a design for a low-cost, efficient solar greenhouse. The greenhouse built at the Southwest Research Centre of the University of Missouri can be presented as a successful illustration. This solar greenhouse was established at a place which was considered to be very difficult site. Despite that fact, this greenhouse delivered great results for more than a decade. The design of this greenhouse can be considered as a very simple one. This greenhouse was constructed with recycled materials [1].

The measurement of the building was as follows: Length= 24 feet, Width= 12 feet, Height= 11 feet at its top. There was a slope of 450 on the south side, which stood on a 34-inch-high vertical wall. The surfaces which face the south were glazed with a dual coating of 6-mil greenhouse plastic. Outside air was pumped between the layers of the plastic for insulation. To make the surfaces greatly reflective, the inner surfaces were painted white. 20 plastic barrels each with 55-gallon capacity were stacked along the north wall. The barrels, filled with water act as the collector system. The containers were tinted dark to make them good absorbers of solar heat. The total growing area of about 123 square feet is divided in two parts with one bed measuring 22x3 square feet with a height of 10 inches and the other one 19x3 square feet. A non-freezing hydrant was installed in the structure and there were hoses which ran along each bed’s length. These provided the irrigation for the plants together as a system.

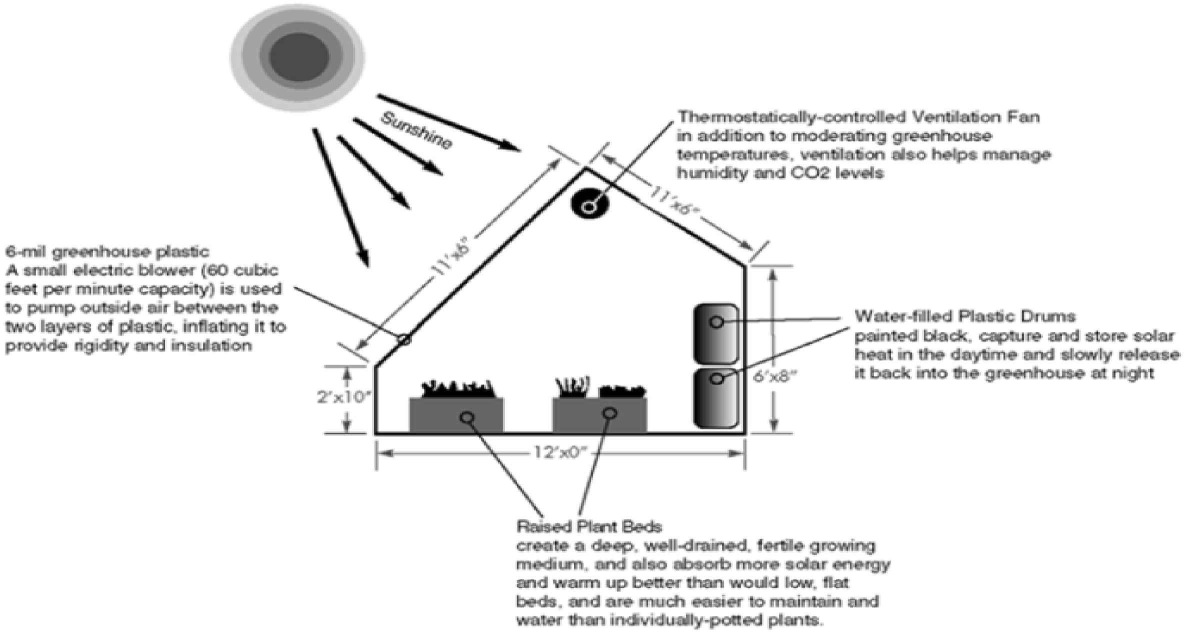

Fig. 1 Schematic of the construction of a solar-heated greenhouse [1]

REVIEW

Many experiments have been carried out to design a cost-effective, energy-efficient solar greenhouse system over the years. Some of those were done in different locations and some were done by changing the collector system. Overviews of some of those experiments are discussed below:

Passive Solar Greenhouse with Water Storage

In the experiment involving water storage as the heat storage medium for the greenhouse, it was suggested to use a heat-transfer fluid if the heat storage medium was placed outside the greenhouse. But the option of placing the heat storage medium inside the greenhouse was still available. The basic principle was to transfer the excess heat existing in the greenhouse to the water storage through a heat transferring liquid. The heat storage can either be in the form of water in plastic bags placed among the plants or water kept in containers. The water storage takes up the excess heat from the solar energy during the daytime and at night the heat is transferred to the plants by the convection and radiation processes.

Passive Solar Greenhouse with Latent Heat Storage Material

Among many other alternatives, latent heat materials have also been considered as heat storage medium for solar greenhouses. 'Chliarolithe' ($CaCl_2.6H_2O$) possess very good characteristics to be used as a latent heat material [1]. It has a melting temperature of 25^0C and latent heat of 154900 kJ/m^3. The latent heat storage can either be placed underground or can be put on the north side of the house provided that it is well-insulated [2]. During the day, the air inside the greenhouse gets hot by taking up heat from solar energy and this hot air is passed through the storage where the latent heat storage material absorbs the heat. During this process, there might be a change of phase of the material. At night, the cold air inside the greenhouse is circulated through the storage system and gets heated. While giving up heat, the latent heat storage material encounters phase change once again and returns to its initial state. Air-to-air heat pumps are coupled to the storage system to prevent the effects of humidity. An important fact about the system is, for the effective operation of this system, the greenhouse temperature needs to be much higher than the melting temperature of the latent heat storage material.

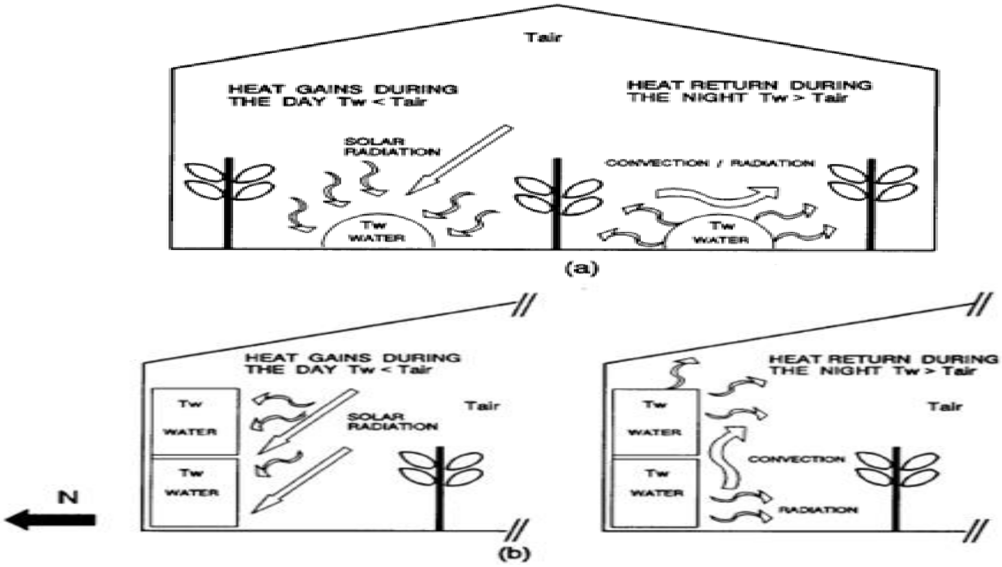

Fig. 2 Schematic of a passive solar greenhouse with water storage in (a) plastic bags and (b) water containers [1]

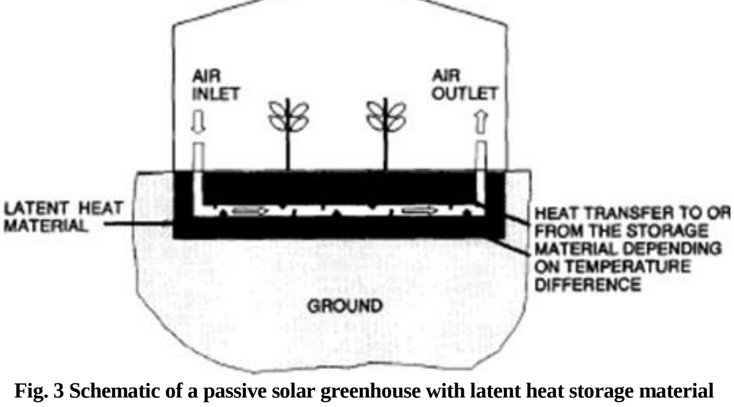

Fig. 3 Schematic of a passive solar greenhouse with latent heat storage material

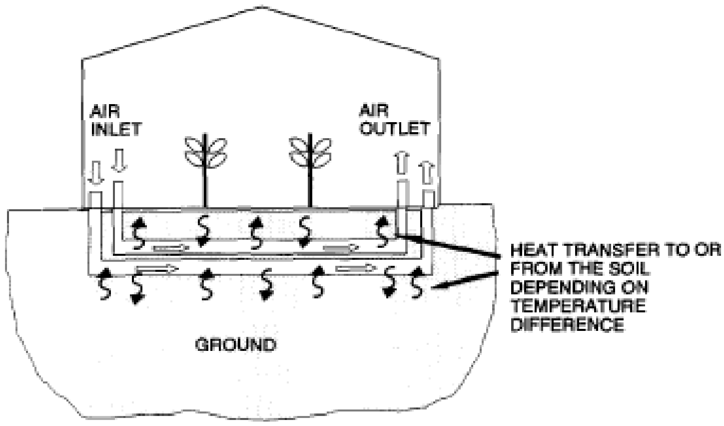

Fig. 4 Schematic of a passive solar greenhouse system with buried pipes

Passive Solar Greenhouse with Buried Pipe

In this method, some aluminium or plastic pipes are buried in the soil so that they can absorb the excess heat from the air in the greenhouse and deliver the heat at night. The soil usually attains higher temperature than the ambient air in a few meters depth. This characteristic of the soil is considered to use it as a storage medium. The buried pipes receive the heat from the warm greenhouse air and store them as latent heat [3]. Due to the condensation process through which the air gives up heat, the soil temperature close to the pipes also increases. At night, the cold greenhouse air is blown through the pipes. By forced ventilation process, the heat is transferred to the air from the soil. Passive conduction of heat also takes place through the soil and then in the greenhouse by convection and radiation. This system can also be used in the summer when the soil temperature is lower than the ambient temperature. Circulation of air through the buried pipes then plays the role of cooling.

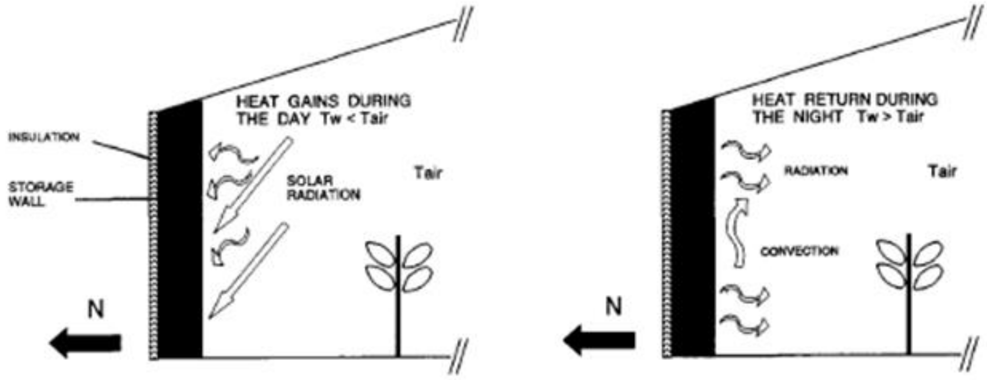

Fig. 5 Schematic of a passive solar greenhouse system with rock bed as thermal storage

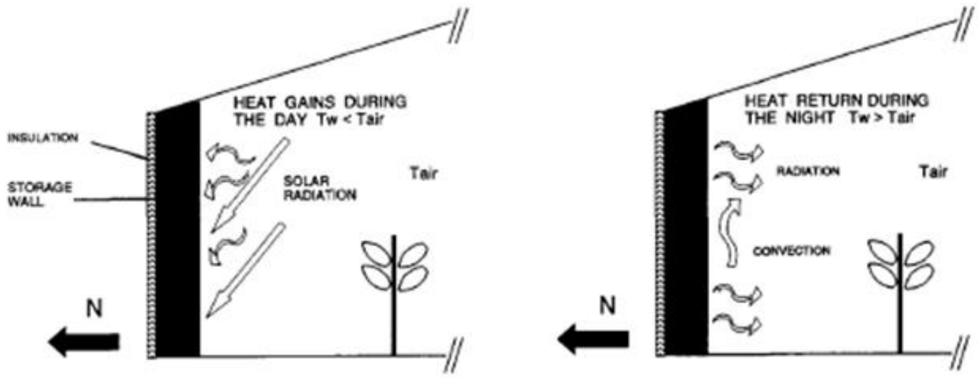

Fig. 6 Schematic of a passive solar greenhouse system with the north wall as the heat storage

Passive Solar Greenhouse with Rock Bed Storage

Rock beds are also considered to be very good thermal storage for solar greenhouses. They are also very cost-effective. A rock bed with a gravel of 20-100 mm diameter can be used as heat storage. The system is placed underground in 40 to 50 cm depth. An insulated concrete storage can be used to enclose the gravel. During the daytime, the heat from the greenhouse air is transferred to the thermal storage with the help of a ventilator. The reverse process takes place at night when the cool air enters the thermal storage and takes up the heat to increase the greenhouse temperature.

Passive Solar Greenhouse with North Wall Storage

The Using the north wall of the greenhouse is a great choice if saving money is given the first priority. In order to use the north wall as a thermal storage, the exterior of the wall should be well-insulated and the interior should be painted dark. The use of north wall as a thermal storage is favorable in cases where the required temperature raise is not that high and also where plants with low-temperature prerequisites are grown.

ADVANCED SOLAR HOUSES

Solar houses are becoming popular day by day as they are environment friendly and saving the environment is now a major challenge for the world. The 'Solar Greenhouse' concept is followed while designing a 'Solar house' that will generate the energy it requires by itself using renewable technologies, mostly solar energy. There have been researches carried out to design a house which not only will generate the energy it needs but also will contribute the excess energy to other fields. The collaboration of solar thermal collectors and BIPV/T (Building integrated photovoltaic systems with additional function of thermal energy recovery) systems is found to be helpful for the design [4]. The concept of 'Passive solar greenhouse' is chosen in some researches for the best results.

DISCUSSION

Solar greenhouses can really play an important role in agricultural industry due to their cost-effectiveness and energy efficiency. Various researches have been carried out over the last three decades to find out a successful design of a solar greenhouse. Many designs have come out and with different results with respect to different locations and different methods. Some tables representing the results of the design methods using different materials as thermal storage mediums are given below which can be considered to be helpful in choosing a suitable thermal storage medium while designing a solar greenhouse [4].

Table-1The Results of Passive Solar Greenhouse Design with Water Storage System

Ground Area (m^2)	Cover Material	Cultivation	Storage Medium	Installed	Results
120	Glass	Tomatoes	Grounds tubes	1986	1-1.5˚C higher
	P.E.	Vegetables	Grounds tubes	1985	2-4˚C higher
	P.E.	Vegetables	Grounds tubes	1985	2-4˚C higher
72	P.E.	Strawberries	Grounds tubes(1.5 m^3)	1988	2-4˚C higher
22	Filon	Plants	Water tanks(2.25 m^3)	1976	16-22˚C >Tair
40	Glass	Plants	Water tanks(18.2 lt)	1977	4-5˚C higher
350	Glass	Vegetables	Grounds tubes	1986	4˚C higher
350	Glass	Vegetables	Grounds tubes	1987	10˚C higher
150	P.E.	Tomatoes	Grounds tubes(5 m^3)	1987	2-4˚C higher
231	P.E.	Plants	Grounds tubes(5.4 m^3)	1978	2-4˚C higher
1000	P.E.	Roses	Water tanks(400 m^3)	1979	11˚C higher
12	Glass	Tomatoes	Water barrels(3.2 m^3)	1986	4˚C higher
	P.E.	Vegetables	Grounds tubes	1985	2-4˚C higher
190	Glass	Plants	Water barrels(4 m^3)	1979	10˚C higher
287	P.E.	Melons	Grounds tubes(25.6 m^3)	1985	2˚C higher

Table-2TheResults of Passive Solar Greenhouse Design with Latent Heat Storage System

Ground Area (m^2)	Cover material	Cultivation	Storage Medium	Storage Mass (kg)	Installed	Results
445	Glass	Plants	$NaOH+Cr_2N$		1978	Gain 5000 lt oil
176	Polycarbon.	Tomatoes	$CaCl_26H_2O$	3000	1985	30% cover
20	Glass	Plants	$CaCl_26H_2O$	100	1983	1˚C>Tair
200	Glass	Roses	$CaCl_26H_2O$	3000	1979	
66	Glass	Vegetables	$CaCl_26H_2O$+ $CaBr_26H_2O$		1983	21% cover
5000	Glass	Roses	$CaCl_26H_2O$	135000	1979	75% cover
500	Glass	Roses	$CaCl_26H_2O$		1986	51% cover
100	Fiberglass	Plants	$CaCl_26H_2O$		1982	2˚C Higher
4	P.E	Plants	$CaCl_26H_2O$+ Acetic Acid	32	1983	2-3˚C Higher

Table-3The Results of Passive Solar Greenhouse Design with Buried Pipe Storage System

Ground Area (m^2)	Cover material	Cultivation	Storage Medium	Installed	Results
835	P.E.		Plastic(50cm deep)	1984	5˚C Higher
1000	Fiberglass	Roses	Plastic(1.5cm deep)	1986	48% cover
1000	Glass	Flowers	Plastic(1.5cm deep)	1988	30% cover
150	P.E.		Aluminium(2m deep)	1981	3˚C Higher
176	Polycarbon	Vegetables	(.4 & .8 cm deep)	1985	50% cover
		Plants	Plastic(40cm deep)	1986	
200	P.E.		Concrete(40cm deep)	1989	3-4˚C Higher
72	Fiberglass	Plants	Plastic(30cm & 60cm deep)	1985	10˚CHigher
1000	Glass		Concrete	1985	

Table-4The Results of Passive Solar Greenhouse Design with Rock Bed Storage System

Ground Area (m^2)	Cover material	Cultivation	Storage Medium	Installed	Results
500		Flowers	Pebble Bed	1989	
240	P.E.		Rock Bed(50mm gravel)	1988	4-6˚C Higher
161	Double Glass	Flowers	Rock Bed	1979	20% cover
100	P.E.		Bricks	1984	
1000			Pebble Bed	1989	
1700	Polycarbonate	Pot Plants	Rock Bed	1981	30% cover
2850	P.E.	Tomatoes	Rock Bed(40mm gravel)	1982	40% cover
50	P.E.	Melons	Rock Bed	1984	
300	P.E.		Rock Bed	1982	76% cover
500	Fiberglass	Plants	Solar Geometry	1986	3-4˚C Higher
19	Filon		Rock Bed	1980	10-20 ˚C mean T

Table-5 The Results of Passive Solar Greenhouse Design with Other Types of Storage System

Ground Area (m^2)	Cover material	Cultivation	Storage Medium	Installed	Results
350	Glass	Vegetables	North wall storage	1986	1-2˚C Higher
100	Plastic	Plants	North wall storage	1988	
2000	P.E.	Plants	North wall storage	1989	
121	Glass	Pot Plants	Reflective Blinds	1984	
1000	Glass	Strawberry	North wall storage	1988	
30	Glass	Tomatoes	Insulated N.E. W side	1980	82% cover
340	P.E.	Plants	North wall storage	1988	7-8˚C Higher
104	Polycarbon	Plants	North wall storage	1988	9˚C Higher
20	P.E.	Vegetables	North wall storage	1988	15-20˚C>Tair
38	P.E.	Plants	Reflective Insul. N.E.W	1973	35% cover
150	P.E.	Plants	Deep Ground Water	1983	8˚C Higher
50		Plants	Reflective North Wall	1980	14% cover

From the tables [1-5], it can be seen that, insulating the north, east and west walls in the cultivation of tomatoes produced a significant result of 82% cover of the total heating needs, whereas in Nicosia, CY, using rock bed as thermal storage covered 76%. Buried plastic pipes when used as the heat storage medium, increased the temperature up to 10^0C, but the water tanks as thermal storage gave a significant increase in temperature which was 16-22^0C higher than the ambient temperature.

RECOMMENDATIONS

In the experiments to find out an optimum design for a solar greenhouse, some problems were found and few recommendations were made to overcome those. Some of these are noted below:

- Future designs can be done is such a manner that more sunlight will be allowed.
- Important factors like CO2, humidity, temperature should be measured regularly and controlled mechanically.
- Soil enhancing techniques should also be studied and considered.

CONCLUSION

In the temperate countries, greenhouses make it possible to cultivate fresh vegetables and fruits in the winter, when the weather is not very favourable. The temperature preservation of a greenhouse is very costly. After many researches, solar energy was found to be a suitable energy source for greenhouses as it satisfies both the prerequisites of cost-effectiveness and energy-efficiency. The concept of ‘Solar greenhouse heating’ was not only limited to the agricultural sector but also was implemented in the drying industries and building technologies. There have been studies about passive solar greenhouses and different types of thermal storage systems in them. The use of water storage as heat storage medium resulted in 2-15^0C increase in temperature when water tanks are used and the use of water barrels fulfill about 70-75% of the total heating needs. Solar greenhouses with latent heat materials and buried pipes as heat storage medium respectively can cover up to 20-75% and 30-60% of the heating needs per year [6]. Rock beds can perform very well as thermal storage mediums in solar greenhouses as they can achieve temperature increase of 4-20^0C and also can provide 20-70% of the total annual heating needs. Again, the ‘Solar greenhouse concept’ is also being utilized in the design of ‘Solar houses’. So, it can be said that the ‘Solar Greenhouse Heating’ concept is rapidly becoming popular as it serves all the factors of cost, energy efficiency, energy security and availability. It also gives scope for researches to improvise and modify systems for an ultimate design.

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