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REVIEW ARTICLE

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A comprehensive review of greenhouse shapes and its applications

Abstract Greenhouse technology is a practical option for the production and drying of agricultural products in controlled environment. For the successful design of a greenhouse, the selection of a suitable shape and orientation is of great importance. Of various shapes of greenhouses, the even-span roof and the Quonset shape greenhouses are the most commonly used for crop cultivation and drying. The orientation of greenhouses is kept east–west for maximum utilization of solar radiations. Hybrid and modified greenhouse dryers have been proposed for drying of products. The agricultural products dried in greenhouses are found to be better in quality as compared to open sun drying because they are protected from dust, rain, insects, birds and animals. Moreover, various greenhouses shapes along with their applications have been reviewed.

Keywords greenhouse shapes, drying, solar energy, agriculture products, orientation

1 Introduction

It is well known that after air and water, food is the basic need for the survival of human beings. About half of the world population (about 3 billion) live in rural areas, and more than half of these people derive their livelihoods from agriculture [1]. Therefore, agriculture becomes an important engine for economic growth. But, nowadays, agricultural land is also being converted into commercial buildings, resulting in a shortage of agriculture land. Food losses which occur during harvesting and post harvesting processes are also considerable. Post harvesting losses of agricultural products are estimated to be 10%–40% [2]. The technique of preservation of the food in the suitable environment can lead to minimizing the food losses [3,4]

Greenhouses are manufactured for crop cultivation. Drying, as one of the applications of greenhouses, is in common use worldwide. Drying, i.e., the process of moisture removal from the products is the most important post harvest operation to save agricultural products [5]. Most of the agricultural products are traditionally solar dried for their preservation in which the product is spread on ground exposing directly to solar radiations [6]. Drying of any product is essentially the phenomenon of heat and mass transfer. The heat from the surrounding air and sun ray is transferred to the product surface by different modes of heat transfer. A part of this heat travels into its surface by heat transfer and takes the latent heat of vaporization. The remaining part of this heat is utilized to raise the product surface temperature. This causes the evaporation of moisture to the surrounding air in the form of sensible heat. However, considerable losses may occur due to dirt, dust, insects and microorganism, animals, and birds. Products may also get discolored due to ultraviolet radiations. So, the advance technique such as greenhouse drying may be adopted to diminish the post-harvest losses and increase the worth of agricultural products significantly [3,7–9]. The greenhouse is an enclosed structure having transparent walls and roofs made of glass, polyethylene film, etc. [9]. The commodity to be dried is placed in suitable trays and receive the sun radiations through transparent plastic cover and the moisture present in the product is removed by natural or forced convection [3].

In recent years, the demand for unseasonal vegetables has been increased. Nowadays, more than 55 countries in the world are using greenhouse technologies for crop cultivation. The total world greenhouse covered area is estimated to be 414127 hectares [10]. China is the leading

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country with about 28 million hectares of greenhouse area, followed by Republic of Korea, Spain, and Japan [11]. In this paper, design aspects related to different shapes of greenhouses have been discussed and the work performed by many workers on drying of various products in different shapes of greenhouse has also been reviewed.

2 Classifications of greenhouses

Greenhouse is an enclosed framed structure covered with transparent walls and roofs [9]. Greenhouses can be classified into different groups as shown in Fig. 1 [12]. Different shapes of greenhouses are given in Fig. 2 [12–16].

3 Studies on even-span greenhouse

Sutar and Tiwari [17] conducted studies on greenhouses for the summer and winter climate conditions in Delhi, India. The design parameters were provided for the optimal growth of plants. The effect of water flowing over the roof of CEA and its effect on plants and inside temperature was also studied. Tiwari et al. [18] presented an energy balance equation for an active winter greenhouse with a north brick-wall. Tiwari et al. [19] derived equations for thermal efficiency and greenhouse efficiency factor for a greenhouse regarding design and climatic parameters. Condori and Saravia [8] presented the evaporation of greenhouse driers (for the climatic conditions of Argentina) under forced mode — the single and double chamber was used to dry pepper. Double chamber greenhouse dryer was found to be 87% more efficient than others. The instantaneous thermal efficiency of the greenhouse was experimentally studied [20]. Lafont and Balmat [21] conducted a simulation study of a greenhouse using the fuzzy controller technique to control the greenhouse climate.

Jain and Tiwari [22] investigated the drying of cabbage and peas in a greenhouse dryer and evaluated the convective heat transfer coefficient (CHTC) and reported that the CHTC in a forced convection greenhouse drying (FCGHD) mode was double that of natural convection. Jain and Tiwari [23] proposed a mathematical expression to forecast the various crop temperatures and moisture evaporation under the open sun drying (OSD) and natural convection greenhouse drying (NCGHD) and FCGHD modes. The thermal modeling for NCGHD and FCGHD modes is given by Eqs. (1) to (4) [18,23].

The energy balance equation at the crop/product surface inside NCGHD and FCGHD is given as

$$(1-F_{\mathrm{n}})\,F_{\mathrm{c}}\alpha_{\mathrm{c}}\sum IA\tau = M_{\mathrm{c}}C_{\mathrm{c}}\frac{\mathrm{d}T_{\mathrm{c}}}{\mathrm{d}t}+h_{\mathrm{c}}(T_{\mathrm{c}}-T_{\mathrm{ghr}})\,A_{\mathrm{c}} +0.016h_{\mathrm{c}}[P(T_{\mathrm{c}})-\gamma_{\mathrm{ghr}}\,P(T_{\mathrm{ghr}})]\,A_{\mathrm{c}}. \quad (1)$$

The energy balance equation at the ground surface for NCGHD and FCGHD is given by

$$(1-F_{\mathrm{n}})(1-F_{\mathrm{c}})\alpha_{\mathrm{g}}\sum IA\tau = h_{\mathrm{g}\infty}(T|_{x=0}-T_{\infty})A_{\mathrm{g}} +h_{\mathrm{gr}}(T|_{x=0}-T_{\mathrm{r}})(A_{\mathrm{ghf}}-A_{\mathrm{c}}). \quad (2)$$

The energy balance equation at the natural convection greenhouse chamber is given by

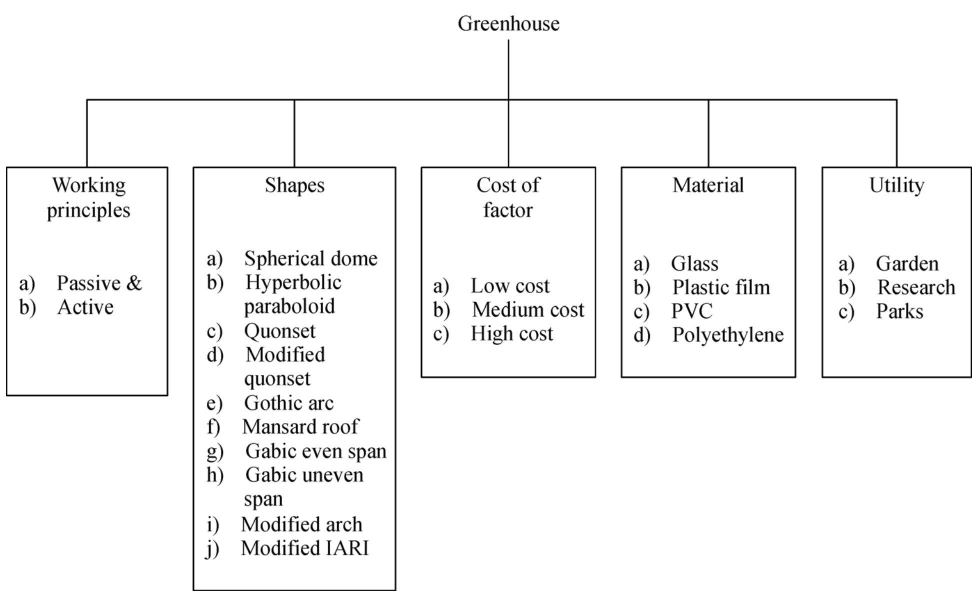

Fig. 1 Classification of greenhouses based on different parameters [12]

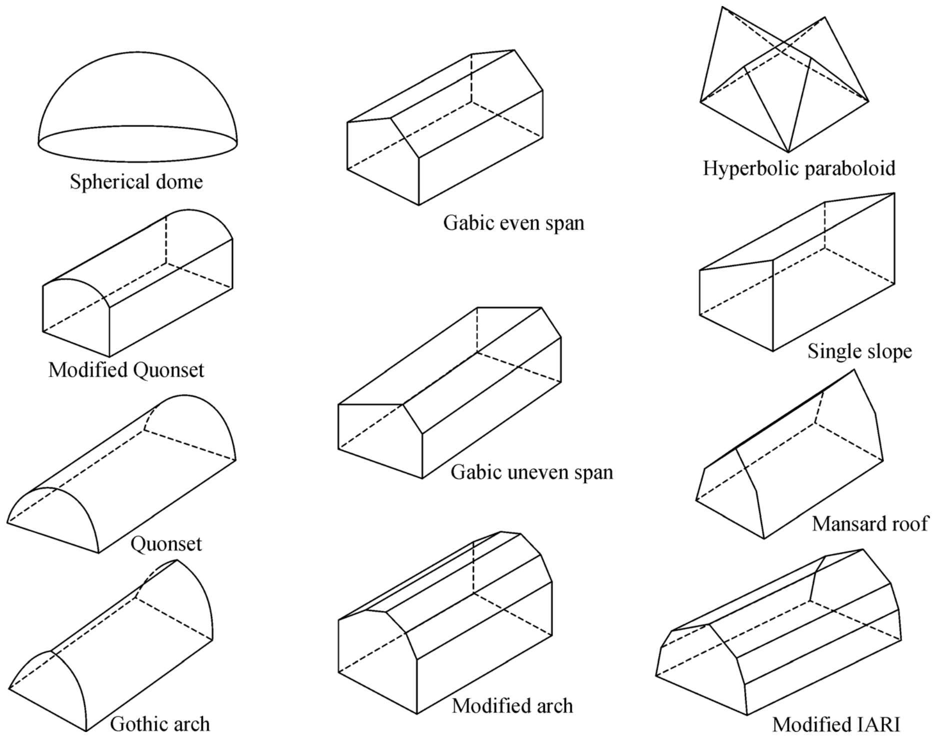

Fig. 2 Greenhouses based on different shapes [12–16]

$$(1-F_n)(1-F_c)(1-\alpha_g)\sum IA\tau + h_c(T_c - T_{ghr})A_c$$
$$+0.016h_c[P(T_c)-\gamma_{ghr}P(T_{ghr})]A_c$$
$$+h_{ghfr}(T|_{x=0} - T_r)(A_{ghf} - A_c)$$
$$= C_d A_v \sqrt{2g\Delta H}\Delta P + \sum U_i A_i(T_{ghr} - T_{amb}), \quad (3)$$

where $\Delta H = \dfrac{\Delta P}{\rho_r g}, \Delta P = P(T_r) - \gamma_a P(T_a)$.

The energy balance at forced convection greenhouse chamber is given by

$$(1-F_n)(1-F_c)(1-\alpha_g)\sum IA\tau + h_c(T_c - T_{ghr})A_c$$
$$+0.016h_c[P(T_c)-\gamma_{ghr}P(T_{ghr})]A_c$$
$$+h_{ghfr}(T|_{x=0} - T_r)(A_{ghf} - A_c)$$
$$= 0.33NV(T_{ghr} - T_{amb}) + \sum U_i A_i(T_r - T_{amb}). \quad (4)$$

Ghosal and Tiwari [24] proposed a mathematical model for greenhouse heating. An analytical model was developed to study the effectiveness of greenhouse coupled with recirculation type earth air heat exchanger (EAHE) and was reported to be more efficient in winter than summer [25]. Tiwari et al. [26] presented the effect of various parameters on the thermal performance of EAHE, which was validated with the model [27]. The convective mass transfer coefficients (CMTC) for different sizes and shapes of jaggery pieces in the greenhouse were determined [28] and the CHTC in FCGHD was reported to be higher. Kumar and Tiwari [29] studied the effects of various sizes and shapes for jaggery drying of constant mass on the CMTC for natural and forced convection greenhouse drying.

Kumar et al. [12] carried out a review of various applications of greenhouse technology in agriculture engineering in which greenhouses were classified as natural and forced convection greenhouse modes. Kumar and Tiwari [30] studied the complete drying of given mass of jaggery inside the even-span roof greenhouse. Kumar and Tiwari [31] conducted studies on drying of various masses of onion OSD and greenhouse drying (GHD) modes in even-span roof greenhouses. Nayak and Tiwari [32] presented an energy analysis and an exergy analysis of a photo voltaic thermal (PV/T) integrated even-span greenhouse. Das and Tiwari [33] studied the drying of prawn under FCGHD mode. The value of convective heat transfer coefficient was reported to lie in the range of 9.2–1.23 W/(m$^2\cdot$°C) and 21–1.5 W/(m$^2\cdot$°C) under NCGHD and FCGHD modes respectively. Barnwal and Tiwari [34] proposed a hybrid even-span roof greenhouse dryer which can operate as an active and passive mode. Sarkar and Tiwari [35] studied the heating of aquaculture pond in even-span shaped greenhouses and developed a thermal model. Sethi and Arora [36] improved the greenhouse dryer by implementing the reflective mirror on inside the north wall in both NCGHD and FCGHD modes. By using inclined north wall reflection (INWR), the greenhouse air temperature and the crop temperature were reported to be increased by 1–6.7°C and 1–4°C in NCGHD and FCGHD modes respectively. Ganguly and Ghosh [37] carried out studies on a natural convection floriculture greenhouse whose performance was reported to be influenced by solar radiation intensity, the space between side vent and roof vent, and air velocity speed.

Panwar et al. [38] presented a comprehensive review on universal thermal modeling for heating, cooling, and greenhouse ventilation. Berroug et al. [39] performed studies on the thermal performance of a greenhouse (for Mediterranean climate) having a north wall which was made with phase change material (PCM) as a heat storage material. Ganguly and Ghosh [40] investigated the performance analysis of a solar PVT-electrolyser-fuel cell system integrated greenhouse (floriculture). Gupta et al. [41] studied the distribution of sun rays coming inside an even-span greenhouse, on floor and on all walls, for the different orientations at a latitude of 28.5°. The overall solar fraction was reported to be higher in winter. Almuhanna [42] attempted a new approach of utilizing an even-span roof greenhouse as a solar air heater (SAH) for the drying of dates. The study on active and passive greenhouse dryer under no-load conditions was presented [43]. Kumar [44] studied the drying of papad in NCGHD condition and reported that the value of CHTC was within the range of 1.08–1.37 W/(m^2·°C). Kumar [45] evaluated the CHTC and evaporative heat transfer coefficients (EHTC) for the drying of papad in FCGHD mode whose average values were reported to be 0.76 W/(m^2·°C) and 23.5 W/(m^2·°C) respectively. Vadiee and Martin [46] studied the closed Ulriksdal greenhouse (located in Stockholm, Sweden) concept, and implemented thermal heat storage to utilize the excess heat produced inside a greenhouse.

An even-span roof greenhouse was heated by biogas, ground and solar energy, which were renewable energy sources. A greenhouse heat pump which was integrated with biogas, solar collector and ground source was studied in the climatic condition of eastern Turkey [47]. Prakash and Kumar [48] developed and tested a greenhouse modified with an opaque north wall under no load conditions. The dryer was tested by covering the inside concrete floor with and without covering the floor with black PVC sheet. A significant rise in room temperature and reduction in relative humidity (RH) inside the floor of the dryer was reported in the former case. Prakash and Kumar [49–51] studied the performances of active and passive even-span shaped modified greenhouse dryers under no-load conditions in the climatic conditions in Bhopal, India. Prakash and Kumar [52] studied tomato flakes drying in a forced convection modified even-span greenhouse dryer and analyzed the mathematical modeling, the performance, and the environment. Tomato flakes were dried from an initial moisture level of 96.0% (w.b.) to a safe moisture level of 9.09% (w.b.) in 15 h.

Prakash and Kumar [53] developed a model based on adaptive-network-based fuzzy to predict various temperatures such as jaggery, greenhouse room temperatures and moisture evaporated of jaggery drying inside NCGHD mode using the Matlab software. Prakash and Kumar [54] presented a comprehensive review on greenhouse systems.

Kumar [55] determined the CHTC for different sizes of khoa samples under the FCGHD condition. The CHTC and convective mass transfer coefficient (CMTC) were found to vary from 2.15 to 3.13 W/(m^2·°C) and 63.23 to 94.95 W/(m^2·°C) for different khoa sizes of 0.075 × 0.06 × 0.015 m^3 and 0.025 × 0.02 × 0.015 m^3, respectively. Kumar [56] also studied the drying of different khoa sizes in a natural convection greenhouse dryer. The values of CHTC and CMTC were reported to increase with the decrease in khoa sizes. A hybrid forced convection greenhouse (in the climatic condition of Tunisia) dryer integrated with a flat plate solar collector was proposed for drying of red pepper and grapes [57]. The drying time for grapes and red pepper were shortened by 17 and 7 h respectively by using the newly designed greenhouse.

From the literature, it is seen that extensive work on even-span greenhouse has been carried out by many researchers. Modified greenhouses with a north brick wall, an inclined north wall reflector, a plastic sheet on the ground, an earth air heat exchanger, and biogas have also been proposed for increasing the greenhouse room temperature during the winter season (cold climate) or at night. The fuzzy control technique and the ANFIS model have also been applied to predict different temperatures and moisture evaporation etc. Various commodities (agricultural products, jaggery, papad, khoa, fruits, vegetables, medicinal plants, fish, rubber sheets, etc.) have been dried in greenhouses to evaluate parameters. Mathematical models have also been suggested to study the drying behavior of products inside the greenhouse in different climates. The hybrid photovoltaic thermal greenhouse has been proposed for drying of various commodities. However, very few studies on uneven and sandwich greenhouse have also been conducted.

4 Studies on Quonset shape greenhouse

Condori et al. [58] carried out studies on a low cost forced convection greenhouse drier (covered with a ultraviolet protected polyethylene sheet) for drying garlic and sweet pepper in the climate condition of Argentina. Fadhel et al. [59] made an investigation into the drying of Sultanine grapes in a solar tunnel greenhouse dryer (STGHD) in the climate condition of Tunisia. Öztürk [60] evaluated the energy and exergy efficiencies of a greenhouse dryer (for Turkey climates) which used paraffin wax as phase change material (PCM). A mathematical model was developed for the drying of peeled logan and banana in a solar greenhouse dryer (PV-ventilated) located at Thailand [61]. The shape of the roof was parabolic and the floor was covered with polycarbonate sheets. Djevic and Dimtrijevic [62] analyzed the energy input and output for various greenhouse constructions (in Serbia region) in winter lettuce production. Ayyappan and Mayilsamy [63] studied the drying behavior of copra (coconut) in open sun and in a natural solar tunnel greenhouse. The copra dried in the dryer was reported to be of superior quality.

Kaewkiew et al. [64] presented the drying performance of chilli in a parabolic shape greenhouse solar dryer (with a floor area of 8×20 m^2) in the climatic conditions of Ubon Ratchathani, Thailand. Bala and Debnath [65] presented a critical review of potentials and developments of various solar drying technologies for drying of different commodities. Sangamithra et al. [66] presented a comprehensive review of polyhouse dryers. Arun et al. [67] presented the drying behavior of coconuts in a natural convection tunnel greenhouse dryer in the climatic conditions of the Pollachi region in Tamilnadu in India. The coconuts dried in the greenhouse were reported to be superior as compared to open sun-dried coconuts. Arun et al. [68] used a biomass backup heater (after 5 PM) coupled with a STGHD dryer to study the drying behavior of coconuts in Pollachi, Tamilnadu in India. The coconuts were dried to a moisture level of 7.003 % (wet basis). The dryer took 104 h less time to dry coconuts of the same level as compared to OSD condition. Arun et al. [69] investigated the drying characteristics of coconuts under OSD, STGHD modes.

Fadhel et al. [70] compared the drying of red pepper (Baklouti) in a greenhouse, a natural convection solar drier and in OSD modes in the climatic condition of Tunisia. The drying time in the greenhouse, in the natural convection solar drier and in the OSD mode was observed to be 5, 4 and 11 days respectively. The maximum product temperature in the greenhouse and in the open sun drying condition was found to be 60°C and 45°C respectively. Phusampao et al. [71] presented the drying performance of in-shell macadamia nuts in a polycarbonate covered greenhouse solar dryer in the climatic conditions of Loei, Thailand. The products dried in the greenhouse were found to be of superior quality. Panwar et al. [72] presented the thermal modeling for the drying of fenugreek leaves inside STGHD and was experimentally validated. Ayyappan et al. [73] compared the use of various heat storage materials (HSM) such as sand, concrete, and rock bed inside a NCGHD dryer for the drying of coconuts. The rock bed was found to be the most efficient sensible heat storage material with a maximum greenhouse dryer efficiency of 11.65 %.

From the literature, it is observed that different fruits, vegetables, spices, medicinal plants, fish, coconuts, nuts, pork, etc. are dried under Quonset shape greenhouses. A hybrid PV-ventilated greenhouse has also been implemented for drying purposes. Modified greenhouse dryers with a biomass backup heater and solar air heaters have been used to study the drying characteristics of various commodities.

5 Studies on other shapes of greenhouse

Other greenhouse shapes include dome-like, single slope, uneven-span roof, modified arch, gothic arch, mansard roof, semi cylindrical roof, and sandwich greenhouses which are rarely used for drying agricultural products and other products. A brief analysis of the work carried out on different greenhouse shapes other than the even-span and Quonset shape is summarized in Table 1. The effect of various shapes and different orientations of a greenhouse was presented [74], and the east–west orientation for greenhouse applications was also suggested.

6 Studies on miscellaneous applications of greenhouse

The greenhouse technology is also extended for crop cultivation, biogas, solar still and fish pond systems. Many authors have attempted these greenhouse applications which are briefly discussed in this section. Tiwari and Sharma [93] studied the production of cucumber outside and inside a greenhouse. The average weight of cucumber grown inside the greenhouse was reported to be more than five times that grown outside the greenhouse and the cost/benefit ratio was found to be 0.69 for the production of cucumber in the greenhouse.

Banaeian et al. [94] evaluated the energy use efficiency/hectare for strawberry production inside a greenhouse and compared the input energy use and cost. The benefit/cost ratio was reported to be 1.74. Ganguly and Ghosh [40] presented a performance analysis of a floriculture greenhouse (integrated with a PV-electrolyser and a fuel cell system). Recently, the effect of different plastic covers on internal parameters and yield of cucumber was also investigated [95]. The performance of a biogas plant integrated with a greenhouse was presented [96]. Kumar and Kasturi Bai [97] studied the performance of a greenhouse which was integrated with a biogas plant in the hilly area of Nilgiris, India. The yearly average slurry temperature was reported to be 24%–35.3% higher than ambient temperature. The yield of biogas was also found to be 11.5% higher than that of the conventional biogas plant. Zhang et al. [98] integrated a greenhouse with a dairy farm for the promotion of waste to energy. The integrated farm greenhouse was reported to reduce non-renewable energy consumption and the impact of climate change etc. by 40% as compared to the conventional method.

Sea/Impure water is made suitable for drinking purpose

Table 1 Analysis of work on various greenhouse shapes

S. No	Shape of the greenhouse	Remarks	References
1	Geodesic dome	The geodesic dome solar greenhouse dryer was designed and tested for drying grapes under natural and forced modes. Fresh air was heated between the outer shell and the black absorber inner shell and passed through the grapes for the drying purpose	[75]
2	Even-span, uneven-span, modified arch, vinery and modified IARI	Various shapes of greenhouses were studied. The effect of north wall was also evaluated. Modified arch and vinery shape greenhouses were found to be most suitable in terms of room temperature and thermal load levelling	[76]
3	Even-span, uneven-span and modified IARI	The uneven-span greenhouse was proposed from the heating point of view	[77]
4	Even-span, uneven- span, vinery, modified arch and Quonset	Various shapes and orientation of greenhouses were studied. The uneven-span shape greenhouse was reported to receive the maximum and Quonset shapes the minimum solar radiations during each month of the year at all latitudes	[14]
5	Uneven shape greenhouse	A model was developed to analyze the optimum orientation of an uneven shape greenhouse. The east–west orientation was reported to be most suitable orientation for greenhouses	[78]
6	Mansard roof	A low cost solar active water heating system was proposed to increase night temperature and to avoid freezing inside greenhouses	[79]
7	Mansard roof greenhouse	The Mansard roof greenhouse for the climatic conditions of Nepal was presented	[80]
8	Mansord roof/chapel shape greenhouse	The thermal analysis of a solar air heater with a latent storage collector (SAHLSC) in the east–west oriented mansard roof greenhouse was carried out	[81–84]
9	Chapel shaped greenhouse	The effect of nocturnal shutter and the heat provided by a solar air heater with a latent heat storage collector inside a chapel shaped insulated greenhouse in the climatic condition of Tunisia was studied	[85]
10	Solar tunnel greenhouse	A mathematical study was carried out to describe the drying performance of drying red sweet pepper in a solar tunnel greenhouse. The dryer was considered as a collector and the output temperature was observed to be directly proportional to incident global radiations	[86]
11	Solar tunnel greenhouse	A comprehensive review of research and development on solar tunnel greenhouse dryers were presented	[87]
12	Semi cylindrical roof greenhouse	New approach for drying pork in semi cylindrical roof solar greenhouse was proposed in the climatic conditions of Thailand	[88]
13	Modified gothic arch greenhouse	A modified gothic arch greenhouse dryer was presented. A model for greenhouse climate enabling the optimization of the cover and ventilation rate was also developed	[89]
14	Modified arched greenhouse	A mathematical model was developed to predict the thermal efficiency of a novel hybrid solar energy saving system inside a heated polyethylene modified arched greenhouse	[90]
15	Single slope greenhouse	A solar air heater to heat the greenhouse air temperature was presented	[15]
16	Single slope PVT thermal greenhouse	A semi-transparent PVT greenhouse was investigated and the numbers of fans were optimized	[91]
17	Single slope hybrid photovoltaic (PVT) greenhouse solar dryer	A mixed mode hybrid PVT greenhouse solar dryer was proposed for drying of grape.	[16]
18	Sandwich greenhouse	A novel forced convection sandwich greenhouse for drying of rubber sheets was proposed	[92]

by solar still with the help of solar energy [99]. Speitel et al. [100] presented a solar still greenhouse which utilized seawater and sunlight for providing fresh water for plant use. Yadav and Tiwari [101] carried out a simple brief analysis of a greenhouse integrated with a solar still (SSIGH) during the winter season. Expressions for various temperatures were also developed. Lawrence and Tiwari [102] discussed the thermal modeling of a solar still integrated greenhouse (SSIGH). Fath [103] presented a brief analysis of a SSIGH. Papanicolaou et al. [104] presented a heat transfer analysis of the air inside a solar still integrated greenhouse. The performance of SSIGH was analyzed in the climatic condition of Jeddah, Saudi Arabia [105] and south-eastern Spain [106]. Mutasher et al. [107] developed a mix mode SSIGH (coupled with a flat-plate solar collector and PVT system) and reported that the thermal efficiency of the mix mode SSIGH was 15.85% more than that of the passive solar still. Also, the solar still efficiency with a sun tracking system was found to be 3.98% more than the solar still without a sun tracking system. Recently, Al-Ismaili and Jayasuriya [108] presented a comprehensive review on seawater greenhouse (SWGH).

Pond water temperature is one of the important factors for fish growth. In cold climatic conditions, fish growth is reduced. So, the need was felt to raise the water temperature to an optimum level which was required for fish growth. The greenhouse technology was considered to be a good alternative to keep the water temperature at the optimum value. Sarkar and Tiwari [109] studied the greenhouse fish pond system and proposed a thermal model to heat the pond using an even-span roof greenhouse. An increased temperature of about 5°C was reported in the greenhouse pond as compared to the outside pond. Das et al. [110] presented a greenhouse (Quonset shape) fish pond system with and without a flat plate collector. The greenhouse with collectors was reported to be better. Studies on even-span greenhouse fish pond systems were also conducted in the central Himalayan area [111] and a thermal model to predict the greenhouse pond water temperature was also developed. Tiwari and Sarkar [112] investigated the energy output-input relation and their specific growth yield relationship for production of rohu fish. The yield in the greenhouse pond was found to be more than double as compared to that in the open pond. Jain [113] studied the performance of an even-span roof greenhouse for heating the fish pond in the winter season in northern India. The greenhouse thermal efficiency of the fish pond system was found to be 19.1%. Ghosh and Tiwari [114] presented the performance of dissolved oxygen in a greenhouse fish pond.

From the literature, it is found that the greenhouses are being used for crop cultivation in which desired greenhouse room temperature can be maintained as per the crop planted; for biogas plants in which the slurry temperature can be increased earliest (as solar radiations get trapped inside the greenhouse and increases the greenhouse room temperature) and reduce the time to reach the optimum temperature for biogas production is reduced; for solar still in which still efficiency was reported to increase; and for fishpond system where the pond water temperature can be raised as per the requirement of the growth of fish.

7 Fabrication, orientation of greenhouse and factors affecting its working

It is essential to develop greenhouses with a maximum intensity of natural light inside and a better air circulation to maintain a uniform temperature inside the greenhouse. These are fabricated for natural and forced mode of operations. Small greenhouses are made from PVC pipe framework clad in a transparent ultraviolet (UV) stabilized polyethylene film of suitable thickness, whereas large sized greenhouses are made up of aluminum structures which can withstand the adverse climatic conditions. In the case of natural mode, an effective opening for air ventilation is provided, whereas in forced mode, a fan is provided on the side wall of the greenhouse for the removal of moisture content. Suitable covering materials having a maximum transmittance such as glass, acrylic, polycarbonate, fiberglass reinforced plastic panels and polyethylene are used whose transmittance property is shown in Fig. 3 [9,115,116]. It can be observed from Fig. 3 that polyethylene has the maximum solar radiation transmittance. Nowadays, ultraviolet stabilized polyethylene sheets are most commonly used as covering material for greenhouses as these sheets are most economical and easy to

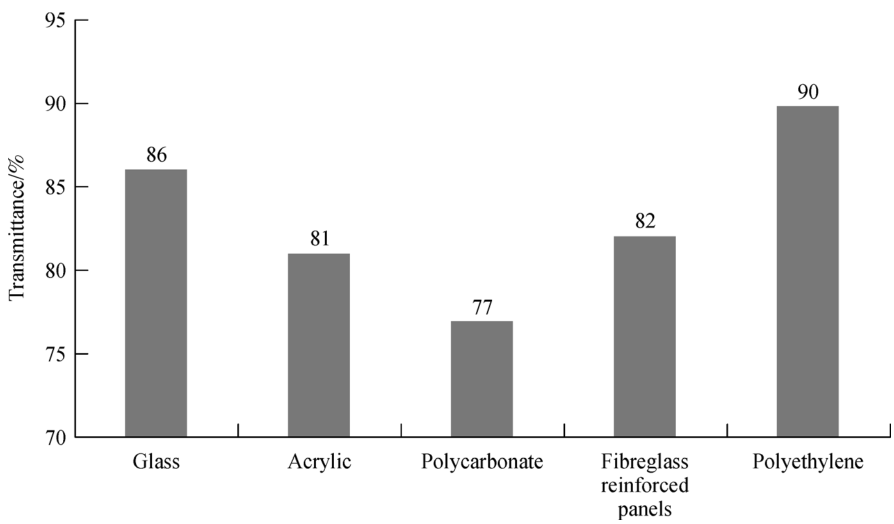

Fig. 3 Transmittance of greenhouse covering materials [9,115,116]

install. Double layers of polyethylene (D-Poly) as covering material for greenhouses for higher productivity is proposed by Cemek et al. [116].

The orientation of greenhouse has a great influence on the transmission of solar radiation inside the greenhouse during the winter months, when radiation is lower. The orientation is dependent on the geometry and slope of the greenhouse roof, the latitude and the season of the year. The east–west orientation is reported to be the most suitable for the year round as this (east–west) orientation receives more radiations in winter (maintaining a higher inside air temperature) and less radiations in summer, which is suitable for the composite environments [74,78].

Various factors which affect the working of a greenhouse are solar radiations, temperature inside the greenhouse, location, covering material, shape, and slope of the greenhouse. The intensity of solar rays is one of the important parameters influencing the greenhouse working. The greenhouse structures and covering materials are responsible for the losses of solar radiation. Solar radiation intensity is decreased by reflection and absorption at the greenhouse cover material and dust on the greenhouse covering material etc. The transmittance of the solar radiation is also influenced by the greenhouse orientation and the sun elevation. The slope of the greenhouse roof is kept at the same angle as that of the latitude of the place. An east–west orientation of greenhouse is also reported to be better than a north–south orientation [117] as it provides more radiations in winter and less radiation in summer, which is the requirement for composite environments [36]. The transitivity of the covering material (Fig. 3) also plays an important role in selecting the suitable greenhouse covering material. Therefore, suitable greenhouse structures are to be constructed after keeping all the factors in mind.

8 Summary

As world population continuously increasing, agricultural land is being converted into commercial buildings and hence lost to urban development. Therefore, urgent need is felt to develop a cost effective technology which is most appropriate to local environments to improve the greenhouse industry. Greenhouse, a unique method for drying food and agricultural produce, may be successfully implemented to minimize post-harvest damages and to increase the quality of various products. Different shapes such as even-span, uneven-span, single slope, dome, Quonset, modified Quonset, mansard roof, gothic arch, modified arch, modified IARI of greenhouses are being used to give controlled environment to agricultural products. Of the various shapes of greenhouse, even-span and Quonset shapes are the most commonly used throughout the world. Since it is not practicable to use 2 different shaped greenhouse shapes throughout the year, it is reported that a greenhouse which receives optimum solar radiations during winter and summer, i.e., an even-span roof greenhouse should be preferred. The east–west orientation for greenhouse drying is being used for maximum utilization of solar radiations. From the literature review, it is observed that greenhouses are being used for crop cultivation, solar still, biogas and fishpond systems. Greenhouse advantages are increased yield of crops (15%–17%), high reliability, possibility of off-season cultivation of vegetables and fruit crops, better quality dried products, reduced drying losses, and controlled environment for crop cultivation, solar still, biogas production and fishpond systems.

Notations

A	Area/m^2
C	Specific heat/($J\cdot kg^{-1}\cdot °C^{-1}$)
F	Fraction of solar radiation
g	Acceleration due to gravity/($m\cdot s^{-2}$)
ΔH	Difference in pressure head/m
h_c	Convective heat transfer coefficient of crop/($W\cdot m^{-2}\cdot °C^{-1}$)
I	Solar radiation on greenhouse wall/($W\cdot m^{-2}$)
M	Mass/kg
N	Number of air passes per hour
$P(T)$	Partial vapor pressure at temperature T/($N\cdot m^{-2}$)
ΔP	Difference in partial pressure/($N\cdot m^{-2}$)
U	Overall heat loss/($W\cdot m^{-2}\cdot °C^{-1}$)
Greek letters	
α	Absorptivity of the crop surface
γ	Relative humidity of air/%
ρ	Density of air/($kg\cdot m^{-3}$)
τ	Transmissivity of greenhouse cover
Subscripts	
amb	Ambient
c	Crop
ghf	Greenhouse floor
ghr	Greenhouse room air
ghfr	Greenhouse floor to room
g∞	Greenhouse floor to underground
$\|_{x=0}$	Greenhouse floor surface

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