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Recent Passive Technologies of Greenhouse Systems-A Review

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Abstract: There are 130 countries produces greenhouse vegetables commercially with more than 1.1 million acres in 2016. Most of the greenhouses deal with high operating costs due to the great energy needs. The high heat loss because of the greenhouse envelope material is responsible for the high energy demand in greenhouses. Nevertheless, each area having a specific need which affects to the energy level and conventional greenhouse technologies tend to have poor U-values. It causes energy for heating is very dominant up to 85% of the total greenhouse energy demand in cold climates countries. While, for the hot climate countries the energy for cooling is more prevalent. Therefore, this paper presents the latest technological developments used in greenhouses in various countries used to control the microclimate in the greenhouse focusing on passive techniques. It is found that PCM recently used to provide heating and cooling for Mediterranean climate. Moreover, closed greenhouse concept based system for Northern climatic improves the reduction energy demands by 80% with a potential payback of 6 years. Additionally, for most countries double glazing envelopes to be the most frequently powerful to increase the greenhouse performance.

Keywords: *closed concept, energy demand, greenhouse, HVAC, retrofitting*

1. INTRODUCTION

Energy increasing in the greenhouse becomes an important issue for securing sustainable harvesting (Steenis, 2009). Meanwhile, the building, includes greenhouses, contributing to energy consumption by 40% of total world energy and greenhouse gas emissions in the world by 30% (Lemmet, 2013). It becomes a major cause of global warming and climate change (Cuce & Cuce, 2013). In contrast, renewable energy is just supply a small amount of world energy needs of about 14% (Cuce et al., 2013) and 20% of total world electricity (Lemmet, 2013) therefore the potential for the future is very promising.

Hee et al. state that the heat loss of windows and roof reach 20-40% (Hee et al., 2015). Though most greenhouses use glass (Joudi & Farhan, 2014), plastic/polyethylene (Mongkon et al., 2014), semi-rigid plastic (Esen & Yuksel, 2013), and the plastic film (Marucci et al., 2012) as the envelope. Whereas, these material easy to gain heat and release the heat (Ghoshal & Neogi, 2014). Thereby, the energy for heating in greenhouses is supreme (Santamouris et al., 1994) and reaches 65-85% of total energy demand (Runkle & Both, 2012). Meanwhile, the need energy for temperature, lighting and humidity vary in each region (Yang et al., 2014). The countries of the four seasons are usually more in need of a technology that can provide heating for most of the year. For example, the countries of the Mediterranean (Bouadila et al., 2014), China (Xu et al., 2014), British Columbia (Steenis, 2009), the Netherlands (Van Beveren et al., 2013) and parts of the Middle East (Joudi & Farhan, 2014). In the meantime, the tropical and subtropical countries are more in need of cooling technology to decrease the high temperature in midday in the greenhouses because of the abundant sunlight intensity (Sonneveld et al., 2010). For instance, Indonesia (Campen, 2005), Malaysia (Al-Shamiry et al., 2007), Thailand (Mongkon et al., 2014), Turkey (Ozgener et al., 2011), and India (Bansal et al., 2010).

There are two types of agricultural solar greenhouses which utilize solar energy for heating purposes. Firstly, the passive greenhouses, which are utilized as collectors and designed for maximizing the solar heat gains by using a special cover and structure materials (Bot et al., 2005). Secondly, the active greenhouses, which are equipped with solar systems that utilize a separated collecting system from the greenhouse with an independent heat storage system, such as adding thermal energy inside the greenhouse from an air heating system in addition to direct thermal heating (Sethi et al., 2013). In case of heating and cooling are needed in balance, thus technologies combination of passive and active techniques is a necessity. Besides, a closed greenhouse type could be a good system than the others (Vadiee & Martin, 2012). Since a large part of the available excess heat will be stored for high sun radiation area. Other benefit is integrated forced-ventilation systems that use fresh air as a rapid response for primarily humidity control.

This paper reveals partly the modest passive technology in existing greenhouses in brief. Additionally, this review may be used to retrofit existing greenhouses. Since there are 130 countries produce greenhouse vegetables commercially with more than 1.1 million acres in 2016 (Cuesta Roble Greenhouse Vegetable Consulting, 2016), thus the retrofitting will save milestone carbon, energy and cost. This review provides a clear delineation of the technology efficient to be applied in greenhouses in the future.

2. RECENT PASSIVE TECHNOLOGIES OF GREENHOUSES

The technologies used in greenhouse to experience rapid growth. The simplest Greenhouse uses the cover of plastic and wooden stands (Briassoulis et al., 1997). Additionally, traditional greenhouse in China is equipped with coal stoves, natural gas, and combustion of straw for heating. Afterwards, the modern greenhouse use glass and steel framework (Carlini et al., 2012) as the cover material. These are geared to meet the appropriate and optimal conditions for plant growth (Pérez-Alonso et al., 2012) and protection from pests (Yang et al., 2014).

2.1. Heat Storage

In general, passive heating technology that is used to provide heat energy is by taking heat from the greenhouse during the day to be stored in a thermal storage. This heat is then used at night in accordance with the required heat in the greenhouse (Panwar et al., 2011). The system use water storage (Zhang et al., 2015), rock storage (Sanaye & Niroomand, 2010), phase change material (Benli & Durmuş, 2009), thermal screen/curtains (Barral et al., 2000), soil water collector (Mongkon et al., 2014), and north wall storage and mulching (Sethi & Sharma, 2008).

Phase Change Material (PCM)

PCM is used as heat storage in greenhouse since 80's (Huang et al., 1986) and up to now. Likewise, experimentally shows that utilise PCM, the temperature could be kept around 10-30 □C (Boulard et al., 1990). PCMs have advantages compare to another sensible heat storage, such as high heat capacity, less volume, low storage temperature, thermal energy stored and released at an almost constant temperature (Bouadila et al., 2014) and it is available over a wide range of phase change temperature. Most of PCM is used for heat storage and release the heat in nocturnal. Further, PCM could be used to reduce the excess heat inside the greenhouse. Najjar and Hasan use a simulation to reveal the effect of PCM to greenhouse inside temperature use Palestinian data weather. PCM is placed inside the greenhouse to absorb the excess heat. The result shows that PCM could decrease the temperature about 3-5°C (Najjar & Hasan, 2008).

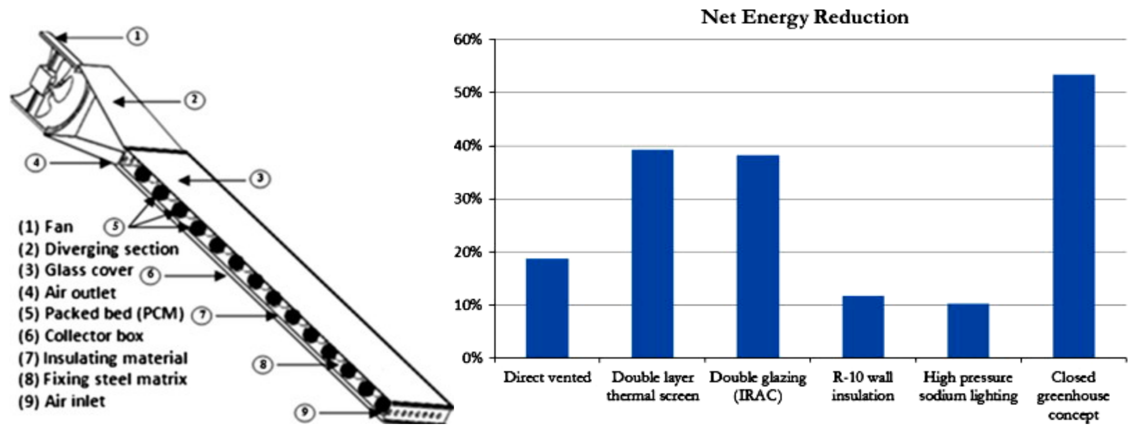

Figure 1. A. Schematic view of SAHLSC and its placement inside the greenhouse (Kooli et al., 2015)***, B. Net Energy reduction in a commercial greenhouse*** (Vadiee & Martin, 2014a)

In Mediterranean areas such as Turkey and Tunisia, the greenhouses face overheating problems during the day and excessive cold at night. These problems affect the product quality and the production. Therefore, for heating energy needed in the night can be fulfilled by PCM as the one of storage heat materials. Benli et al. study performance analysis of a latent heat storage system with PCM for new solar collectors design in greenhouse heating in Turkey. The system provides up to 23% of total daily thermal energy requirements of the greenhouse for 4 h, in comparison with the conventional heating device (Benli & Durmuş, 2009). Also, in Tunisia, Kooli et al also use PCM to provide heating for the greenhouse temperature stable at 15°C for 17h (Kooli et al., 2015). Similarly, PCM is utilised as shown in Figure 1a, to capture the heat inside the greenhouse then produce heating for greenhouse 5 °C higher than conventional greenhouse and provide by 31% of total heating. The SAHLSC assessed that the payback period was approximately 5 years if the system operates only 3 months per year. The environmental impact from reducing carbon emissions is about 1% of the total Tunisian greenhouses emissions (Bouadila et al., 2014).

Solar Water Storage (SWS) and Solar Air Storage (SAS)

Water can be used as a thermal energy storage material because easy to obtain, also water has fluid properties which do not undergo a chemical change when is heated. Subsequently, it is used as the conductor material from the solar collector into the U-pipe heat exchanger under the greenhouse through the heat storage tank temporary (Zhang et al., 2015). The water in the tank serves as buffer (STTES) for BTES accordingly STTES improves the overall performance of the system applied (Xu et al., 2014). Attar et al use water for heating using solar collector and cooling using soil for the heat storage in Mediterranean climate (Attar et al., 2014). In heating mode (December to February) the air temperature drops gradually from 5pm-8am without storing the heat water underground. After utilize heat water which is stored in underground the air temperature can be maintained at 20 °C. While in cooling mode (June to August), the inside air temperature reach 65 °C. Using cold water 18 °C which is circulated underground 1.6m of altitude the temperature could reduce by 12 °C. But when it is altered with water circulation of 10 cm of depth, the air temperature starts to rise by 4 °C. It means that water tank as buffer can increase the performance of heating system in greenhouse.

In Tunisia the use of solar air heater and PCM is to meet the needs of heating in the greenhouse of 31% at night. Kooli et al. use SAS module to dissipate heat that is captured by flat plate solar collector to the material of latent storage energy (PCM). The use of solar air heater module is proven can increase the effectiveness of the overall system to keep the greenhouse temperature remains at 15 °C, whereas the outside temperature is 8 °C (Kooli et al., 2015).

2.2. Solar Thermal Collector

Sunlight possesses thermal energy, produced by 47% of IR wavelength generated by the sunlight can be utilised directly or later on (Patil & Gawande, 2016). Therefore, various solar thermal collector modules are built and optimized in order to obtain heat energy as much as possible in order to be released for heating greenhouses at night or in winter. Firstly, Flat Plate Solar Collector (FPSC) as one of solar collector modules is rarely used in greenhouses. One of the causes is its low thermal efficiency. In heating experiment using 10 pieces of FPSC in Turkey, this system able to provide 18-23% of thermal energy every day for 3-4 hours (Benli & Durmuş, 2009).

Moreover, in the simulation using TRNSYS software, 10 m^2 of flat plate collectors are used to provide heat energy for greenhouse of 130 m^2 in Tehran and stable at 18 °C. It is noted that thermal supply which could be met by flat plate collector is only 30% in greenhouse simulations (Mehrpooya et al., 2015). Therefore, the use of flat plate solar collector on the greenhouse is subjected to innovation with a combination of the various types of absorber plate, the type of fluid used, and the heat storage material. Attar et al. use a type of FPSC as heat collector in combination with ground as a coolant in a greenhouse in Tunisia (Attar et al., 2014). A FPSC with area of 2.18 m^2, 200 L of hot water storage tank, and 200 L of cold water storage tank can be used to control the stabilized greenhouse temperature at 20 °C in 10 m^3. Although, in the winter this system still needs a control system and electricity from the network (electricity grid) but the system is promising enough to provide good condition for the pepper plants.

Secondly, Fresnel lens is used as the solar concentrating. The average efficiency of Fresnel lens and other concentrating collector modules is higher than the non-concentrating collectors like FPSC. This is because of its higher light concentration ratio and lower heat loss (Imtiaz Hussain & Lee, 2014). Besides, cost optimization and analysis shows that concentrated solar collectors is better than non-concentrated solar collectors in terms of design system, application, and turnover period (Sait et al., 2015). In addition, Sonneveld et al. uses LFL with a factor 25 to obtain thermal energy and electrical energy to meet the needs of a greenhouse measuring 36 m^2 in Netherland (Sonneveld et al., 2011). LFL is placed inside the double glass to protect the lens from dirt and damage due to the weather. The LFL covers the entire roof of the greenhouse. In this case heat energy is more needed than the electrical energy for that reason the use of solar collector depends on the needs of the system. The system able to generate electrical energy of 29 kWh/m^2y and the heat energy up to 518 MJ/m^2y. Latterly, Hussain et al. comparing the performance of Linear Fresnel Lens (LFL) and Spot Fresnel Lens (SFL) for heating in two identical greenhouse in South Korea. The experiment results show that the SFL had 7-12% higher performance compared to LFL collector (Imtiaz Hussain et al., 2015). Besides, the availability of energy per unit area and thermal efficiency of SFL are also higher than the LFL, and so there is availability of heat in the greenhouse every day.

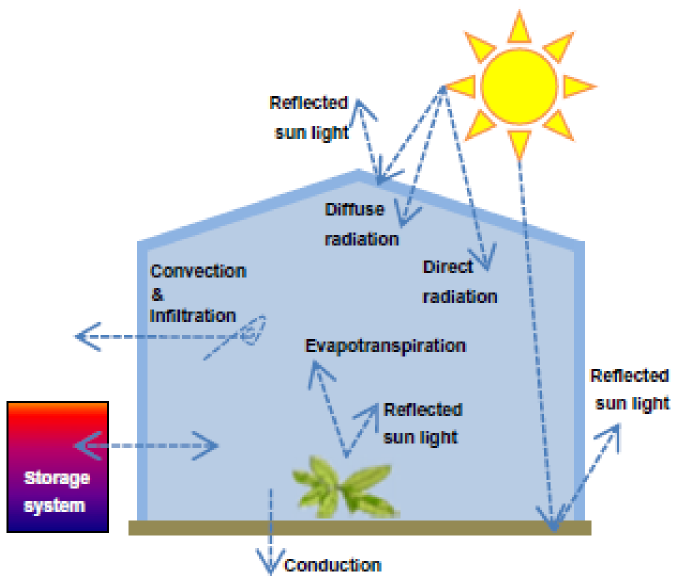

Figure 2. Closed Greenhouse thermal flow (Vadiee & Martin, 2013)

2.3. Envelope

The greatest heat loss occurred in a conventional building is on the window part therefore 40% of the total energy used is for heating (International Energy Agency, 2013). As well as in greenhouse, even worse, occurred in all parts of the walls and roof (Konroyd-Bolden & Liao, 2015) consequently the heat loss is high in greenhouses. Hence, insulation technique in walls and roof of the greenhouse becomes the most important factor that determines its feasibility in terms of cost and energy needed to control the microclimate conditions in it. Bibi-Triki et al. throughout experimentation and simulation propose a dynamic modelling of a greenhouse system in Mediterranean Basin, the characterization and analysis of the thermal behaviour of the wall for both experimental greenhouses. The first one is made of polyethylene/PE (tunnel greenhouse) and the second of glass (chapel-shaped greenhouse). The simulation shows that the heat loss vary from 0.45 to 1.77 °C for the glass greenhouse and from 0.57 to 2.31 °C for the PE greenhouse. It is also mentioned that convective losses, due to wind and greenhouse ventilation effects, are an important part in the overall losses of heat flows through the wall (Bibi-Triki et al., 2011).

Double glazing compare with single glazing could lowering the energy demand to 45% (Tantau et al., 2011) and even up to 60% (Vadiee & Martin, 2014a). Thus, greenhouse-glazed glass-based can be used to reduce the heat loss and saving the production cost of greenhouse (Blanchard & Runkle, 2009). Other type of solid plastics such as Polycarbonate sheets may be used as the cover and saving the heating energy demand by 30% without reducing the amount of light enter the greenhouse (Fabrizio, 2012). In addition, polycarbonate boasts the best fire rating among plastic products and has excellent insulation properties, all leading toward the design and construction of safe, energy-efficient agricultural buildings. Because of better thermal efficiencies and greater diffusion of natural sunlight, twin wall polycarbonate is likely the product of choice. Besides the use of the thermal screens are commonly drawn over the crop at sunset and removed at sunrise; can reduce the overnight heat loss by 35–60% (Bailey, 1981). A screen with a low emissivity upper surface and high emissivity lower surface gives high energy saving. Similarly, the radiation heat loss rate is estimated by 24% of the total losses heat of the IG with shutter and 61% of the IG without shutter at night (Kooli et al., 2015).

2.4. Wind-catcher

Wind-catcher is a wind control system or building ventilation. Wind is usually captured from the roof and then cascaded down to the whole room of the building (Esfeh et al., 2012; Su et al., 2008). The function of wind catcher is to make down the temperature inside a building by flowing fresh air from the roof of the building (passive cooling). It is fully mechanical hence does not need electricity for its operation (Afshin et al., 2016). Moreover, it is an environmental friendly system and widely used in Middle East countries to ensure the immediate air circulation in the building. The installation on the roof top over have a good effect rather than mounted on a flat roof where there is a larger region of flow separation exists (Su et al., 2008).

Because of the advantages of the wind-catcher, it is used in greenhouses to anticipate the excess heat in the growth chamber (cultivation). The heat from the plant during summer or during the day will flow out above the roof as a result of density differences of hot and cold air (Mongkon et al., 2014). Thus wind-catcher will reduce the energy consumption for cooling, heating and ventilating, especially in the extreme temperatures areas (summer and winter) (Attar et al., 2014) and during the peak hours (Dehghani-sanij et al., 2015). Although cooling technologies that is using wind-catcher is very beneficial for the greenhouse, but the change of seasons that cause high humidity and high temperatures can bring diseases and insect pests (Mongkon et al., 2014). The anticipation of the pest entry should be taken seriously because the wind-catcher with a cooling system is very open and direct contact with the greenhouse. Therefore it needs surrounding environment protection by using Insect-proof nets (Kumar et al., 2009).

Table 1: Summary of recent technologies of Greenhouse

Climate	Demand	Technologies	Reference
Mediterannean	Heating	PCM, Air, Water, FPSC, Fresnel Lens	(Attar et al., 2014; Benli & Durmuş, 2009; Bouadila et al., 2014; Imtiaz Hussain & Lee, 2014; Kooli et al., 2015)
	Cooling	Wind-catcher	(Attar et al., 2014)
Northern	Heating,	Water, Fresnel Lens, Double glazing, Closed concept	(Campen et al., 2006; Fabrizio, 2012; Imtiaz Hussain et al., 2015; Sonneveld et al., 2011; Vadiee & Martin, 2014a, 2014b; Xu et al., 2014; Zhang et al., 2015)
Sub-Tropical/Tropical	Cooling	Wind-catcher	(Dehghani-sanij et al., 2015; Kumar et al., 2009; Mongkon et al., 2013, 2014)

2.5. Closed Concept

A closed greenhouse is a concept with no ventilation window and the excess heat in both forms of sensible and latent heat is harvested and stored for covering the heating demand at a later time. Opdam et al. show that this concept can reduce energy use of 20 and 35% for closed and closed-combination greenhouse, respectively (Opdam et al., 2005), and the energy efficiency is improved by 50%. Moreover, in north Europe the concept can collect the incident solar radiation by 80% or 2.5 GJ/m^{2}y (Campen et al., 2006). Vadiee & Martin state that using TRNSYS, the design load has the main impact on the payback period. In the case of the base load being chosen as the design load, the payback period for the ideal closed greenhouse might be reduced by 50% (Vadiee & Martin, 2013). Figure 2 shows the thermal flow in closed greenhouse. Furthermore, Vadie and Martin use TRNSYS simulation to assess the potential of cutting external energy demand as well as maximizing solar energy utilization in a commercial greenhouse for Northern climate condition. The results reveal that solar blind system use glazing Polycarbonate with thermal screen and closed concept could reduce the heating and cooling energy demand by 80% and 60%, respectively as compared to conventional one (Vadiee & Martin, 2014b).

The most expensive opportunity of retrofitting is by applying the double layer thermal screen with 5 years PBP. The low cost opportunities are using the “Double polyethylene” (6 months PBP) and “Double ply IRAC” (10 months PBP). Whereas, the highest improvement (80%) by using the closed greenhouse concept, with a potential payback of 5–6 years under favourable conditions. Additionally, the net energy reduction due to energy performance improvement opportunities is presented in Figure 1b. It depicts that the closed greenhouse concept with double glazing has the highest impact (50%), and double thermal screen for almost 40% (Vadiee & Martin, 2014a). Table 1 shows the summary of greenhouses passive technologies recently used in different areas.

The closed or semi-closed greenhouse concept fit to be the trend since the flexible climate control, higher level of yields and less energy (De Gelder et al., 2012). Semi-closed greenhouses produced higher crop photosynthesis and yield increase of 20% or even higher (Dannehl et al., 2014). Additionally, semi-closed greenhouses have better control of greenhouse environment; reduced water needs, reduced entry of insects and fungal spores in the greenhouse through the ventilation openings, and reduced pesticide use. This is crucial in arid and semi-arid area because of limited water resources such as Mediterranean countries (Baeza et al., 2013).

3. CONCLUSION AND RECOMMENDATION

For Mediterranean and Northern climate, the heating and cooling are used PCM, water and air as the heat storage material. Moreover, Fresnel lens to be the most benefit compare with other solar collector. While sub-tropical and tropical areas are prefer to use wind-catcher to have direct cooling. Furthermore, to lower the energy demands double glazing envelope to be trending technologies. In Northern climatic, double glazing polycarbonate combine with thermal screen and closed greenhouse concept may decrease the heating demand to 80% and 60% for cooling. Since closed greenhouse sometime severe with excess heat in the day hence natural ventilation/wind-catcher on the roof top (semi-closed concept) may reduce temperature significantly. Therefore semi-closed concept is more applicable for Mediterranean and sub/Tropical climate.

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