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Using solar greenhouses in cold climates and evaluating optimum type according to sizing, position and location: A case study

Uğur Çakır [a,*], Erol Şahin [b]

[a] Department of Mechanical Engineering, Bayburt University, 69000 Bayburt, Turkey
[b] Department of Mach. and Metal Tech. Dep., Vocational School of Technical Sciences, Ordu, Turkey

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ABSTRACT

This study deals with a comparison among five common greenhouse types with regard to total solar radiation gaining rates in greenhouse using season under some assumptions. Additionally, possibility of using greenhouses in cold climate regions is investigated. We analyzed five greenhouse types and developed a script in MATLAB platform for the solar radiation availability. This model is applicable and suitable for other buildings and places on the world. Even-span, uneven-span, vinery, semicircular and elliptic types of greenhouses have been analyzed. A "k" value (ratio of length to width of greenhouse) and greenhouse azimuth angle (GAA) are described. Seven different floor area are assigned for each greenhouse type such as 50 m^2, 100 m^2, 150 m^2, 200 m^2, 250 m^2, 300 m^2 and 400 m^2, respectively. For each floor area, k value is assigned from 1 to 10. Each greenhouse is oriented in 90 different angles according to south facade. Seasonal total solar energy gaining rates is computed individually for all possible greenhouse types, area, k number and orientation. Then a comprehensive comparison is made to determine the optimal greenhouse. The results show that greenhouses are usable and suitable for using in cold climate regions to increase the productivity. In addition, the elliptic type is the optimum one in all analyzed types of greenhouses for Bayburt conditions for all floor areas. It is followed by uneven-span, even-span, semi-circular and vinery type of greenhouses respectively. Shape and type of the roof are main effective parameters on solar energy gaining rates of greenhouses. Elliptic greenhouse should be preferred on the band of the latitude of Bayburt, unless there is restrictive factor like sizing and terrain.

1. Introduction

Solar energy is widely acknowledged as the main source of the all energy types on the world. It is safe, abundant and clean source of energy and an attractive to substitute for the conventional fuels for heating, cooking and generating power. It is possible to use the energy of the sun directly or indirectly by the help of any auxiliary equipment by converting its energy to another type of energy. Solar energy is generally used for illumination and thermal heating of a greenhouse, which is a structure that provides the suitable microclimate ambiance for the optimum plant growth during off-season. One of the most dominant and significant parameters which affect the plant growth is interior temperature level of greenhouse. Transparent covering of the greenhouse allows the shortwave solar radiation to enter but it is partially opaque to the long wave radiation resulting in the greenhouse effect. In cold climates or seasons, higher inside air temperature is desirable during all hours for maximum plant growth and that can be achieved by keeping the greenhouse closed for maximum greenhouse using any suitable heating system.

Because of the reasons mentioned above designing, positioning, orientation and shapes of the greenhouses are very important to gain more energy from the sun to reach the best of it (Pieters and Deltour, 1999). There are many studies made on improving the greenhouse systems to get maximum energy from the sun or use minimum energy in the case where conventional heating systems are used. For instance, Sethi made a study on selecting the shapes and positions of a greenhouse by using experimental data and thermal modeling. In this study five greenhouse types which have single span shapes and are most used types were compared. The types of the analyzed greenhouses are even-span, uneven-span, vinery, modified arch and quonset. They say that, quonset type of greenhouse receives minimum solar radiation while uneven span type greenhouse receives maximum for all months in a year and for all latitudes (Sethi, 2009). Gupta and Chandra put forward a mathematical model and they used it to investigate

* Corresponding author.
E-mail addresses: ucakir@bayburt.edu.tr (U. Çakır), erolsahin@odu.edu.tr (E. Şahin).

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the effect of several measurement of energy conservation to obtain some designing features for an energy efficient greenhouse. They reported that, 30% heat energy can be saved by insulating the north wall of gothic arch greenhouse which is positioned in east–west direction. Additionally, using night curtain decreases 70.8% heating demand of system at night and 60.6 in all day (Gupta and Chandra, 2002). Auto-CAD was used to calculate the total solar fraction for different position of greenhouse using 3D-shadow analysis. The staggering of the incoming transmitted solar radiation on the floor and inner walls of a greenhouse were studied. Total solar fraction has a big effect for the small greenhouses and the technique they supposed may be used for building a greenhouse of any shape and dimension for any place (Gupta et al., 2012). Abdel-Ghany and Al-Helal made a study on determining the general relations to evaluate the gathered solar energy by the components of a greenhouse and amount of the energy that is given to the environment. The relations take into account the cross relation as well as their multiple reflections on solar radiation between these elements. In the study superposition theory and ray tracing technique were used (Abdel-Ghany and Al-Helal, 2011). Exergetic performance of a solar greenhouse building, which is supported with earth to air heat exchanger, is investigated according to three cooling seasons. In the study the exergetic performance (efficiency) of a closed loop earth to air heat exchanger is investigated experimentally in cooling mode. The data, which is used by authors, is consisted of hourly thermodynamics records in a cooling period of the years between 2009 and 2011. The studiers made a long term exergetic modeling of a closed loop earth-to-air heat exchanger for a solar greenhouse cooling system (Ozgener and Ozgener, 2012). A mathematical model was made to investigate the thermal treatment of a greenhouse while using a ground air collector heater. Improved tests were made between December 2000 and March 2001 for an even span greenhouse with 24 m^2 floor area and with a ground air collector and with a north wall with brick (Jain and Tiwari, 2003). Simplified designing method is presented on greenhouses and solar heating systems. Effects of parameters in designing a greenhouse construction and storage characteristics on thermal performance are investigated by using computer modeling and simulations. The main performance effects were identified according to the total solar contribution and solar heating (Lau and Staley, 2009). Maximum change of inside air temperature of a greenhouse was tried to decrease by the help of energy storage in a phase change material PCM. A mathematical model was improved for the storage material and greenhouse. Both of the models were solved using some numerical ways and Java script program. The effect of various factors on the inside temperature of greenhouse was researched (Najjar and Hasan, 2008). A computer model was made based on transient analysis of a greenhouse. The model calculated inner temperature of the room, temperature of the water which is used for storage and the thermal energy storage effect of a water mass in a passive and low cost greenhouse (Gupta and Tiwari, 2002). Using multi-rack tray system is investigated to produce maximum number of nursery plants for an east–west directed greenhouse. The number of stacks in a greenhouse of fixed height is a direct function of the maximum altitude angle of the sun at noon at particular latitude (Sethi and Dubey, 2008). The effect of replacing the transparent north wall of a greenhouse with a reflecting surface on energy absorbing performance was researched. Distribution rates of the reflected solar radiation by the north wall on the floor are studied in terms of two locations in India (Gupta and Tiwari, 2005). One of the studies made on solar greenhouses presents a new and integrated methodology on designing a geothermal supported greenhouses which decreases the fossil fuel using rates. The model is run and the basic design factors are determined for reducing the whole installation heat losses and the electricity consumption. A case study is presented where the suggested methodology has been applied with interesting results considering the financial efficiency (Kaldellis and Kondili, 2006). A mathematical model was developed by taking into account the four main components of a greenhouse viz. cover, inside air, canopy surface and bare soil surface in a study (Singh et al., 2006). Modeling and control of greenhouses inside climate can be defined by two variables: the temperature and hygrometry. The control objective serves ensuring an optimum inside microclimate for the development of culture and to decrease the cost. To overcome this objective is difficult, since the complexity of the phenomena including the plant growth process. Two parameters are correlated and very sensitive to the weather at the outside and also to many other practical constraints. High performing regulation for the greenhouse internal state based on H2 robust control design is investigated (Bennis et al., 2008). Description of various technologies for passive and active utilization of solar radiation is performed, as well as some results of short-term and long-term tests, including calculating of 1 year operation of the greenhouse from the energy and temperature viewpoints. A comparison of the evaluated energy flows in the greenhouse to real measured data, for realizing the model is also involved (Korecko et al., 2010). A model was developed to estimate the overall heat transmission coefficient based on radiation, conduction and convection heat transfer coefficients and to predict the heat flux of soil (Abdel-Ghany and Kozai, 2006).

Energy and exergy efficiency of using latent heat storage in greenhouses is evaluated experimentally in a study. A seasonal thermal energy storage using paraffin wax as a PCM with the latent heat storage method was used to heat the greenhouse (Öztürk, 2005). Configuration of Building Façade Surface or Seasonal Selectiveness of Solar Irradiation was studied by taking into account the Absorption and Reflection in a paper. A new building façade surface composition is proposed and it consists of grooved cavities which are configured in a manner that reflects summer (cooling season) insolation and absorbs winter (heating season) insolation (Naraghi and Harant, 2012). A solar air heater system was studied experimentally to heat a greenhouse which has innovative aspects in Baghdad, Iraq (33.3°N, 44.4°E). The innovative greenhouse combined a conventional greenhouse and a solar air heater bank on the roof as one structure. When compared with a normal greenhouse, the construction of this system did not affect the needed solar radiation inside the greenhouse in winter for heating. Heating load is evaluated by using an energy balance method. This situation is different with the standard method which does not contain soil heat storage. The soil surface heat gain was took into account in this work (Joudi and Farhan, 2014). Determining the vegetable diseases in greenhouses by using monitoring video was researched. A method that combines the visual saliency and online clustering to bring out the key frame from greenhouse vegetables monitoring video. This way can get information of whole leaf area of vegetables and extract the key frame effectively (Ma et al., 2015). An understanding to obstacle detection in a greenhouse environment using the Kinect 3D sensor was improved. The depth data are evaluated by using slope computation. The obstacle detection decision is made via information on the pixel slope, its intensity and surrounding neighbor pixels. The system produces rewarding results (all obstacles were detected with only few false positive detections) and is suitable to run on a common used computer (Nissimov et al., 2015). Another article describes the solar radiation distribution and the change of humidity and temperature by considering the climate conditions in the greenhouse in which 50% of the roof area was constructed with photovoltaic modules. The shading effect of PV bank on vegetable in the greenhouse integrating the natural radiation with auxiliary lighting worked by PV energy (Cossu et al., 2014).

Some researchers made an investigation on the effect of accumulation of dust and dirt on solar radiation transmissivity of