New technologies in tomato greenhouse production


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Abstract

In the last years new technologies for greenhouse production have been development to improve efficiency in water and energy as well as fruit quality. One of these technologies is the closed and semiclosed greenhouses, it is an innovative concept in sustainable energy management. In principle, it is designed to maximize the utilization of solar energy through seasonal storage. The available stored excess heat can be utilized later in order to satisfy the heating demand in the greenhouse. The additional benefits of this technology is the improvement in CO$_2$ enrichment efficiency, the storage of water from condensation to be used in crop irrigation, as well as pest and insects invasion prevention.

This study focuses on a Venlo-type semiclosed greenhouse (307 m$^2$) located at Humboldt University of Berlin, equipped with cooling, heating, fog systems and CO$_2$ enrichment. Also, there are additional components such as a 40 kW heat pump, water tank with capacity of 300 m$^3$, a cooling tower and a phytomonitoring system. In this greenhouse latent and sensible heat are collected from solar radiation and plant transpiration.

Our particular interest is on the amount of heating energy saved by harvesting and recycling the energy exhausted from cooling and dehumidification of the greenhouse. In this process temperature and humidity play an important role.

The work we present here is motivated by the strong dependence of the solar-collector greenhouse upon the weather. Since it is not possible to build similar research greenhouses in different locations, a computational model can help to estimate the performance of such a facility subject to different climatic conditions.

The continuously long-term measurements of parameters generated by the phytomonitoring system which describe the functional condition of plants and their surrounding conditions (environment), were used in an ANN model for estimation of the energy flux to the tank, based on external environmental conditions and the tomato plant growth stage.

The results show that the ANN model provide a good approximation for the energy flux to the tank in the cooling process; however, in the heating process the ANN model does not provide a good estimation. A sensitivity analysis was performed on the input variables showing that solar radiation, temperature and wind velocity have more impact on the energy flux to the storage tank.

The main advantages of this model is the estimation of the amount of energy storage in a tank, under different environmental conditions existing in other places, which can provide suggestions about the feasibility of having such kind of facility for energy savings.

Keywords: Closed greenhouses, energy savings, water savings
1. Introduction

Greenhouse vegetable production is the most energy-intensive agricultural sector. Energy cost in greenhouses is between 20-40% of the total cost. For instance, Djevic and Dimitrijevic (2009) reported an energy use of 9.76 MJ/m² for multi-span greenhouse, and 13.93 MJ/m², for the tunnel type. Moreover, the average energy productivity of tomato is about 0.01 ton/GJ, this means that 0.01 units output was obtained per unit energy (Pahlavan, et al. 2011). This huge amount of energy use in greenhouses is also due to the high losses in the system, therefore based on the limited supply of fossil fuels and the uncertainty about the oil supply in further years, alternative technologies, such as solar collector technique (closed greenhouses) and heat pump application for heating and cooling purposes, have a lot of potential to be used in many countries.

A closed greenhouse is a greenhouse that has no venting operation or air exchange with the outside air. It can be used to save energy very effective and can reduce the costs for energy requirements in year-round operations. This technology has been successfully used in countries like Netherlands, Spain, USA and Germany. Some results for closed greenhouses in Netherlands using heat pump and aquifer were 30% in energy savings, 22% more production, 40% sustainable energy production, 80% reduction in chemical products and 50% improvement in water (Netherhoff, 2006). In California Greenhouses Hardin et al. (2008) found that almost all the transpired water in the closed heat pump system was collected by dehumidification. The water is conserved in the confined system that might make the water consumption zero (theoretically speaking).

The mentioned benefits can be classified in the following aspects: a). the accumulation of heat from solar radiation can be stored and recycled; b). conservation of heat and prevent heat losses to the outside environment; c). improvement in CO₂ enrichment efficiency; d). water can be stored and recycled for irrigation and cooling system; e). prevent pest and insects invasion; f). increase crop yields and improvement crop quality.

During the winter and spring months, the greenhouse system would be operated as closed system, in order to conserve the resulting amounts of water and to consume much less energy to keep the thermal environment at desirable levels. During the summer months the greenhouse would be operated as a semiclosed system, which will enable the ventilation of the greenhouse to reduce high temperatures and remove excess humidity, accompanied by a reduction of the cooling load over the heat pump.

2. Case of study

In 2009 a prototype facility for closed greenhouse experimentation was established at the Humboldt-Universität zu Berlin. Figure 1 shows the closed and reference greenhouses, the water storage tank and heat pump. These greenhouses are equipped with finned pipe roof cooling system, alternative heating systems, CO₂ enrichment, fog system, multi-layer thermal screens, heat pump, heat storage tank and fully automated irrigation, and fertilization control. Since April 2011 two prototypes of Phytomonitoring systems generate uninterrupted information about plant net photosynthesis, leaf transpiration, stomatal conductance, and tissue temperature. With this innovative technology, a short time evaluation of the different influence of the microclimate conditions on plants is possible.

The conventional closed greenhouses located in Spain and Netherlands use heat pump and aquifer. However the aquifer storage systems with water in a depth of about 100 to 300 m costs a lot of primary energy for pumps. Therefore, the new technology in the experimental greenhouses in Berlin store the thermal energy in above-ground solar lagoons instead of an aquifer.
The CO₂ decrease inside the greenhouse due to the CO₂ consumption of plants. Therefore, CO₂ enrichment is mandatory, having the advantage of increasing yields. Because there is no ventilation which eliminates the water excess from the greenhouse, a dehumidification like condensation of water vapor is necessary. In a closed greenhouse there is heat and vapor accumulation which gives an opportunity to recover and store thermal energy with increased performance of the heat exchanges. Thus, the collector efficiency is higher than the efficiency of technical thermal collectors caused by the coupled latent and sensible heat exchange.

The energy stored in the water tank is used for heating purposes. If the energy contained in the storage tank is not enough for heating the greenhouse, there is a need to buy district heating. On the other hand, if there is too much energy, the storage should be discharged using the cooling tower. Therefore, it is necessary to have a better control of the system in such a way that a minimum amount of energy is lost through the cooling tower.

### 3. Experimental Results

Some of the results reported by the Division of Biosystems Engineering are significant increase of the lycopene and β-carotene contents increasing the internal fruit quality (Dannehl, et al., 2014).

Besides, Schmidt et al.(2012). report an energy input of -1.41 MJ in the collector GH, in order to produce one kilogram tomatoes, the energy use efficiency in the collector GH was improved by means of the additional yield in closed greenhouses. The energy use efficiency (EUE) is defined as the amount of energy required to produce one kg of marketable fruit and was expressed as MJ kg⁻¹. The EUE for both greenhouses( collector and reference) was approximately 40 MJ kg⁻¹ produced tomatoes, when the excess energy stored in the rain water tank was not considered to calculate the EUE for the collector GH (data not shown). In contrast, the results elucidated that the EUE in the collector GH can be improved by 103% compared to the reference GH as consequence of the reuse of the stored energy. Especially in summer, there was an energy excess, which can be used primarily to cover the basic load for heating in other greenhouses or to provide subareas in greenhouses.

The semiclosed greenhouse is equipped with 16 finned tube heat exchangers (4 per roof bar) installed under the roof, hot humid air rises by natural buoyancy to the top in where it is condensed on fin-tubes installed under the roof. A high evapotranspiration rate of the plants results in a stronger cooling effect. Sensible heat caused by transmitted solar energy and latent heat produced by plant transpiration are collected simultaneously. Figure 2 displayed the system and a graph of the condense water in a day bases, the maximum amount of water collected by condensation in the finn tubes was 1.45 Lt m⁻² d⁻¹ which mean a maximum of 445 Lt of water per day can be collected in the Greenhouse. This water is collected in a tank and it is used in the irrigation system.

### 4. Modelling Results

The information generated by the phytomonitoring systems have been used to optimize the control of the greenhouse. Since 2012 a bilateral project “Modeling and Control of Horticultural Closed Systems with Artificial Intelligence (ai) methods” between Humboldt-Universität zu Berlin and the Autonomous University of Chapingo in Mexico is going on.

Artificial Neural Networks(ANN) have been successfully used to control greenhouse environment (Salazar, et al., 2010) because it often offers a superior alternative to traditional physical-based models, particularly in cases where the governing system dynamics are ei-
ther poorly understood or oversimplified, and/or where data uncertainty (e.g. model parameters) is high. ANNs excel at uncovering patterns or relationships in data, and are also powerful non-linear estimators.

Our first interest is related with the amount of energy generated by the solar collector. Since it is not possible to build similar research greenhouses in different locations, a computational model based on the strong dependence of the solar-collector greenhouse upon the weather, can help to estimate the performance of such a facility subject to different climatic conditions.

Figure 3. shows the inputs of the ANN: meteorological data as well as the plant condition (LAI, Sowing date). There were few measures of the Leaf Area Index (LAI) of two tomato varieties Komeett and Encore, for years 2010-2012, an average of LAI for these two tomato varieties is presented on Table 1. To generate five minute data, the LAI measurements available were fit into Gaussian distribution (Figure 4). To avoid noise in the sensors and eliminate outliers, the filter proposed by Savitzky & Golay (1964) was implemented for all data set.

Five minute data from years 2010 – 2011 were used for training validating and testing the ANN. Figure 5 shows a comparison between actual and predicted energy harvesting for the years 2010 - 2011, with an overall correlation coefficient of 0.8958. Using the ANN model developed for the years 2010-2011, a simulation of the energy harvesting for year 2012 was done, feeding the model only with outside meteorological variables and the stage of the tomato plant. Even though the correlation coefficient between actual and simulated energy flux is 0.67, using the model we can have a rough idea about the energy available for the next day (Figure 6).

5. Conclusions

A semi-closed solar collector greenhouse can be recommended as agronomic approach to produce a high quantity of marketable tomatoes and additional energy and water savings. This kind of technology is growing in Europe as well as USA, countries with very low temperatures during Winter, because energy savings is one of the main benefits in the semi-closed greenhouse.

The main findings from experimental research in the semiclosed greenhouse located at the Humboldt-Universität zu Berlin, is the increase in internal fruit quality, as well as the increase of the energy use efficiency by 103% with respect to the reference greenhouse.

Regarding the modelling results we found that ANN model provide a good approximation for the energy flux to the tank. This model will be a first step for controlling the charging and discharging process of the heat storage by an intelligent control using Artificial Neural Networks, with integration of meteorological forecast data, the ANN models could estimate the energy flux to the tank in a days-scale.

6. References


Table 1. Average leaf area index from 2010-2012.

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Data provided by Dennis Dannelh, the Humboldt-Universität zu Berlin
Figure 2. Collected water from condensation

Temperature $[^\circ C]$
Relative Humidity [%]
Solar Radiation [W/m²]
Wind Velocity [m/s]
Leaf Area Index [m²/m²]
Days from sowing [No]

Energy Flux to Tank [kW]

E(t)

Figure 3. Inputs for the Artificial Neural Network Model.

Figure 4. Gaussian distribution adjustment to LAI measurements.
Figure 5. Neural Network Performance 2010-2011

Figure 6. Energy flux to tank in a day basis from January 20th to May 27th 2012. Left: Time-series. The strong deviation (model underestimation) on days 20 to 70 can be interpreted as a need of heat from the tank, due to the cold weather on January and February. The measured values stay close to zero because there was not enough energy in the tank to cover this need (heating was performed with conventional district heat). Right: Scatterplot of the same data. The underestimation can be noticed on the lower-center part of the graph.