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A Review of Greenhouse Energy Management by Using Building Energy Simulation

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Abstract. This paper attempts to present a review about simulation of different greenhouse parameters and energy supplying techniques by using building energy simulation, to find out the optimal solution for keeping greenhouse microclimate favorable for the crop production. The objectives of conducting this study were, to describe the various energy systems and techniques used for the greenhouse energy management and efficiency analysis of these technologies by using building energy simulation. We describe different models to understand the behavior of the energy saving technologies with respect to the resources available and different outside climatic conditions. We identified main features of the building energy simulation software, that enable users, to simulate hybrid agricultural building projects by using user defined parameters. At the end of the paper we draw some important concluding remarks on the basis of reviewing all the investigators contributions for the developments of simulation model of agricultural greenhouse energy management, using a building energy simulation software specifically TRNSYS. In conclusion, this paper provides information that TRNSYS have great potential for agricultural buildings energy simulation along with the renewable energy resources and energy saving techniques. This review paper provides aid to greenhouse researcher and energy planner for the future studies of greenhouses energy planning.

Additional Key words : energy saving, heating, microclimate, TRNSYS

Introduction

During recent years as demand of energy is increased, researchers attracts towards energy production, consumptions, storage, management and saving (Carlini et al., 2010). Likewise, agriculture energy management of greenhouse is one of the most important aspects of the greenhouse farming is to be considered. Due to higher energy demand for greenhouse heating, and continuously increasing price of the fossil fuel, there is much interest to develop efficient technologies to save energy. In all over the world many technologies have been developed for cooling and heating of greenhouses to maintain the optimum inside greenhouse temperature (Xamán et al., 2014). In the modern greenhouse heating cost of the greenhouse reached 49.5% of the total production cost (Yang et al., 2012).

Various energy saving measures are being used to reduce heating cost of the greenhouse (Arinze et al., 1986) like use of thermal insulation, solar energy, earth to air heat exchanger, geothermal energy and different heat storage systems. These energy management techniques are under consideration of researchers and they are working on analysis of these technologies for greenhouse energy management (Sethi et al., 2013). Analysis of energy management techniques in real greenhouses by experiments will no doubt provide the most reliable data; the results obtained from such tests are site-specific and so are only valid for that particular greenhouse and its local climatic conditions. Investigators are doing research by making experiments, numerical simulations and using different computer programs for greenhouse energy management analysis (Kolokotsa et al., 2010). The Presence of building energy simulation tools for energy analysis of different buildings, allows greater opportunity towards energy management and saving (Fitz-Rodriguez et al., 2010). The effort is to inform the reader about feasibility of building energy simulation of agricultural buildings by using TRNSYS software that allows greater opportunity to simulate all greenhouse parameters efficiently.

In this paper we present a review of TRNSYS software used by researchers to find out the optimal solution for the energy saving and better productivity. The papers provide information who and how many people were using this software for the specific focus on agricultural greenhouse.

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TRNSYS

TRNSYS stands for TRaNsient SYstem Simulation program. A versatile, component based and extensible energy simulation tool for simple and complex systems as well as complete energy analysis of single/multi-zone buildings. This program was designed by University of Wisconsin's Solar Energy Lab and has been commercially available since 1975, since then this program has been under continuous development (Patil, 2010). Initially TRNSYS was developed for the thermal system simulations only but now after passing 35 years of continuous up gradation it becomes a hybrid simulator by including, photovoltaic, thermal solar and other systems. (Sinha and Chandel, 2014). TRNSYS consists of series of programs and add-ons to enable it for the simulations of complex designed projects. Main features of the program are, TRNSYS simulation studio, simulation engine (TRNDLL) executer (TRNExe), building input interference (TRNBuild), Editor (TRNSEdit), with add-ons Google sketch up for 3D modelling. Moreover in agriculture, software demonstrates extreme flexibility to improve various case studies to continue work for structure and energy analysis and allows simulation of best situation by adding different components (Carlini et al., 2010).

Categories of TRNSYS usage

Referring to introduction section, TRNSYS software is available commercially since 1975, and after continuous development, it becomes hybrid simulator. The software provides greater opportunity to agriculture researchers for the agriculture building energy analysis. Since recent years, agriculture researchers are taking interest in use of TRNSYS for the, greenhouse structure design and environment analysis and energy resources analysis.

Fig. 1 shows the overall view of TRNSYS usage in agriculture, designing of structure, environment, and use of different energy technologies. Based upon the literature review researcher's work in the field of agricultural greenhouses is shown in the Fig. 1, with all the parameters they studied until now.

Data summary

Table 1 is a summary of, recent increasing trend of build-

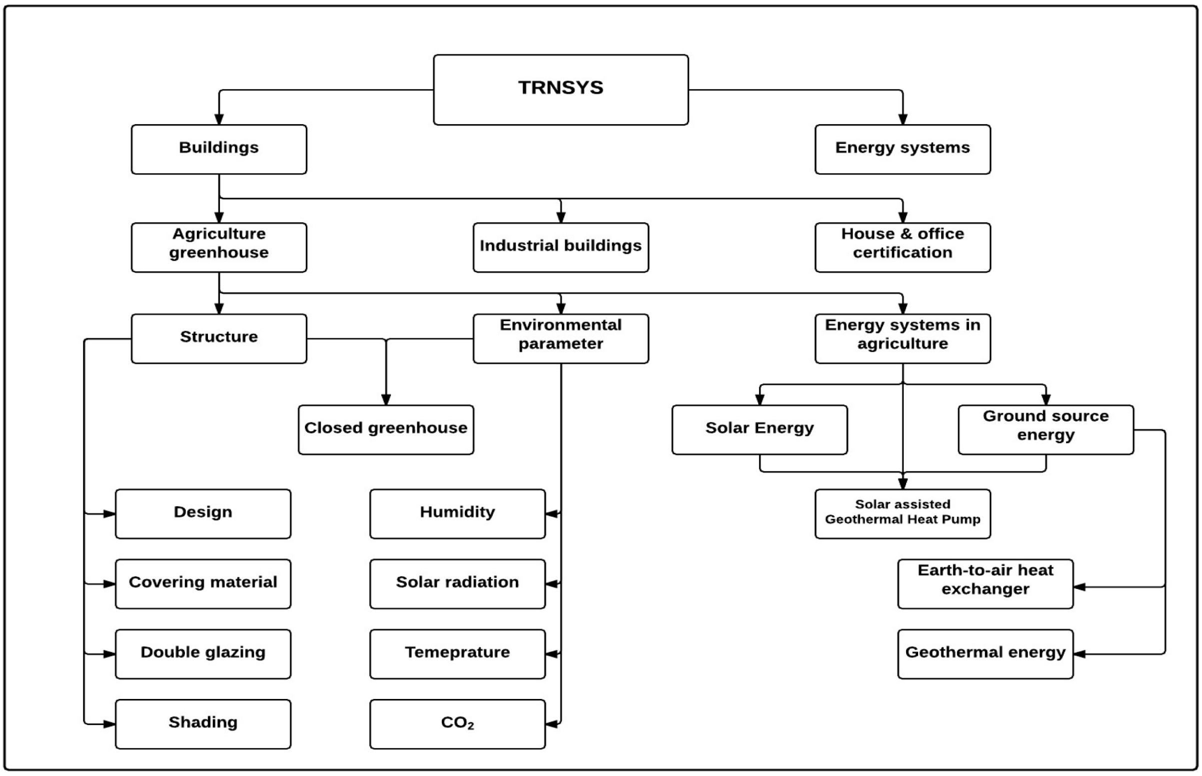

Fig. 1. Application of TRNSYS in agricultural greenhouses.

Table 1. Summary of researches using TRNSYS for agricultural greenhouses analysis.

Category	Author	Main Concern	Parameter studied
Solar Heating	(Patil et al., 2013)	Solar heating with seasonal storage	1- Comparison between results of TRNSYS and eQUEST. 2- Control environment of the facility. 3- Thermal storage and solar thermal heat.
	(Asdrubali et al., 2012)	Solar system	1- Greenhouse energy balance. 2- Simulation results compared with real energy consumption.
	(Attar et al., 2013)	Greenhouse heating	1- Solar water heating system. 2- Parameters influences on storage system.
	(Vadiee and Martin, 2014)	Solar energy	1- Feasibility evaluation of solar energy to fulfill energy demand of the greenhouse. 2- To minimize the energy demand and maximizing the solar energy utilization for the commercial greenhouses.
	(Voulgaraki and Papadakis, 2008)	Solar heating system with seasonal storage	1- The potential of the solar heating system with seasonal storage for greenhouse. 2- Analysis of thermal and economic performance of the system.
	(Carlini et al., 2012)	Photovoltaic greenhouses	1- Check the feasibility of the cultivation under PV modules. 2- Analyze the influence of outside climate, plant cultivated, structural material, wind conditions, soil, altitude, slope, exposure on energy balance
	(Chung et al., 1998)	Thermal and economic aspects of solar heating system	1- Analysis of solar central heating plant combines with seasonal storage system. 2- Simulation of agricultural greenhouse connected with office building.
Energy management	(Carlini and Castellucci, 2010)	Greenhouse affecting parameters	1- Structural and thermal behavior of greenhouse. 2- Optical and thermal exchanges between external environment and the greenhouse.
	(Aye et al., 2010)	Greenhouse heating	1- Air to water heat pump system. 2- Assessment of economic and environmental viability.
	(Ishigami et al., 2014)	Environmental control of greenhouse	1- Calculation of heat balance. 2- Fogging system of greenhouse.
	(Kolokotsa et al., 2010)	Development of intelligent indoor environment	1- Fuzzy logic controllers were developed and prototyped using Matlab environment and simulated with greenhouse model. 2- Implementation of Matlab greenhouse model as module in the TRNSYS software for the energy efficiency analysis, considering all the factors affecting greenhouse environment.
	(Marucci et al., 2013)	Energy efficient	1- Energy efficient greenhouse for the plant material propagation, to conserve forest biodiversity. 2- Parameters such as, structure, covering material, cooling and heating system were analyzed for energy saving of the greenhouse.
	(Serir et al., 2012)	Greenhouse under semi-arid climate	1- Estimation of the heat transfer coefficient for covering material of the greenhouse. 2- Thermal behavior of unheated greenhouse.
	(Kyriakarakos et al., 2011)	Greenhouses and animal buildings	1- Identification of agricultural building's energy needs. 2- Designing of fully customized energy management system.
	(Dalamagkidis et al., 2005)	Ambient greenhouse air condition	1- Optimization of, control scheme, cooling, heating, humidification and dehumidification.
	(Zhang et al., 2015)	Seasonal soil heat storage system for greenhouse	1- Development and investigation of soil heat storage for the greenhouse. 2- Comparison between experimental and simulation results.
	(Mashonjowa et al., 2013)	Naturally ventilated greenhouse	1- Simulation of greenhouse microclimate. 2- Evaluation and optimization of thermal performance.
	(Park et al., 2015)	Cooling and heating load of greenhouse	1- Estimation of cooling and heating load of greenhouse using plant hot wastewater.
	(Lee et al., 2012)	Energy load of greenhouse	1- Optimal selection of cooling and heating facilities.

Table 1. Continued.

Category	Author	Main Concern	Parameter studied
Geothermal energy	(Carlini et al., 2010)	Geo- thermal plant for energy management in greenhouse	1- Efficiency of geothermal heating and cooling. 2- Energy requirement of greenhouse.
	(Chargui et al., 2012)	Geothermal heat pumps	1- Performance evaluation of geothermal heat pumps on heating mode of greenhouse. 2- Comparison between numerical and simulation results.
Closed greenhouse	(Hoes et al., 2008)	Closed greenhouse	1- Greenhouse Crop behavior towards environment. 2- Climate and energy interaction.
	(Vadiee and Martin, 2012)	Energy analysis of closed greenhouse	1- Energy analysis of closed greenhouse. 2- Simulated with climate data, building components, user defined components and control system.
	(Hellmuller and Lachal, 1998)	Closed greenhouse	1- Energy analysis of closed greenhouse 2- Short-term heat storage system.

ing energy simulation in agricultural greenhouses by using TRNSYS software. Moreover, provides existing studies completed for agricultural greenhouse energy management by using building energy simulation. The parameters studied for the energy management of the greenhouses were, utilization of renewable energy resources and different energy management techniques. The focus of the previously done work shown in the table 1 was towards following four categories

1) Solar heating system, 2) Energy saving /management, 3) Closed greenhouse, 4) Geothermal energy

1. Solar heating system

Increasing demand of energy in, industrial production, urban facilities as well as in agriculture required new energy sources (Carlini et al., 2010). In all over the world direct solar radiations and high annual sunshine are considered the most promising source of energy (Attar et al., 2013). There are many studies for maximizing the use of solar energy for greenhouse heating, to get the desired greenhouse microclimate for crop production with reduction in energy cost (Imtiaz Hussain et al., 2015). The Simulation of hybrid photovoltaic-thermal (PV/T) solar energy system was done by using TRNSYS. System consists of PV panels embedded with heat exchanger with fins; this type of system can operate on lower temperature. Performance of hybrid PV/T system was investigated on daily and monthly basis. The hybrid system increases the mean annual efficiency of the PV solar system from 2.8% to 7.7% (Kalogirou, 2001).

Usually solar irradiations are high in summer and low in winter (Calise, 2012). Voulgaraki and Papadakis (2008) used idea of seasonal storage to compensate the seasonal demand of energy supply for greenhouse heating. In his research he evaluated solar heating with seasonal storage by using medium size solar heating plants with seasonal storage (SHPSS) and simulated the system with TRNSYS-16 to check the system's thermal and economic performance. The simulation results shows, by storage tank we can get high temperature for long time, 90°C for about 4000 hours (Voulgaraki and Papadakis, 2008).

Investigation of solar heating system combined with the seasonal storage facility was done with TRNSYS, for a under construction agricultural greenhouse connected with the office building in Korea. The prediction was that 39% of the total energy demand can be fulfilled by the system. Low cost solar heating and storage system can be constructed anywhere in Korea with the suitable greenhouse size (Chung et al., 1998).

The design of photovoltaic technology with integrated system was evaluated for the estimation of cooling and heating load of common commercially used plastic greenhouse. Plant hot wastewater was used as a power source, process was simulated with TRNSYS. Experimental and TRNSYS results shows good match (Park et al., 2015). TRNSYS modelling and simulations were done to evaluate the optical and thermal behavior of the PV solar greenhouse. Three different greenhouse cultivation locations in Italy having different climate conditions were selected for the simulation. Results show the 30% of summer cooling and 11% of winter heating saving (Carlini et al., 2012). Another research was done to investigate the solar energy during heating period of greenhouse, alone and attached with the building in both cases energy balance, energy losses and behavior of the entire greenhouse environment was evaluated by using TRNSYS simulation tools, 20% of reduction in energy demand was reported (Asdrubali et al., 2012).

2. Energy saving/ Management

There is always demand of high crop yield and low energy use, many of the researchers started working to achieve this goal (Bronchart et al., 2013). A low cost seasonal soil storage system was developed and investigated experimentally, and by using TRNSYS. The purpose was to use stored solar energy during high demand period of greenhouse heating (Zhang et al., 2015). University of Tuscia research group by uses TRNSYS software for analyzing detailed greenhouse structure designs, resources used to get optimal greenhouse environment (Carlini and Castellucci, 2010). A project was done to develop a greenhouse model and different simulation were run for the greenhouse structural and temperature, relative humidity, solar radiation, Co_2 concentration, cooling, heating, humidification, dehumidification. All parameters were calculated to achieve the desired greenhouse microclimate. And then model was tested with real greenhouse situation and compare results (Dalamagkidis et al., 2005). A fully customized energy management system was design by using computer simulation programs 1) TRNSYS, 2) MATLAB for the greenhouse and animal buildings energy simulations. Both electrical and thermal consumption of the building were investigated to fulfill their energy needs by the feasible cost effective energy technology (Kyriakarakos et al., 2011). Factors affecting on energy balance of the greenhouse are; conduction heat loss or gain, solar input, thermal radiation to sky, heat of ventilation, heat loss or gain to ground, infiltration heat, equipment heat, heat of respiration, heat of photosynthesis. For evaluation of these factors, a dynamic climate model of greenhouse was simulated by using TRNSYS and experimental results were obtained for the comparison and validation of computer model. The model was optimized for the ventilation rate, crop evapotranspiration, humidity, covering material properties and control system of climate management. Experimental and simulation results shows good accuracy of the model (Mashonjowa et al., 2013).

The energy department of National institute of rural engineering Japan developed a simulation model for large and combined agriculture project (100 acres of land covered with greenhouses and adjacent buildings) to evaluate environmental control by using TRNSYS. Local conditions were selected and model was modified for various parameters i.e. ventilation, fog cooling module, evapotranspiration module. They analyzed heat balance, necessary to predict the inside air temperature and humidity, to control greenhouse microclimate. Comparison of TRNSYS and experimental results, were found good and accurate enough (Ishigami et al., 2014). Grow green power research group developed individual energy systems and attached with greenhouse for energy supply and then simulated together with greenhouse design model to get the results for the best energy efficiency and energy need of the greenhouse and concluded that TRNSYS shows extreme flexibility for the development of greenhouse project (Patil et al., 2013).

3. Closed greenhouse

In agriculture sector, greenhouse has highest demand of energy. The Closed greenhouse integrated with thermal storage is an innovation for sustainable energy management to maximize the utilization of solar energy through seasonal storage. In a fully closed greenhouse, there is no ventilation, which means that removal of excess sensible and latent heat. Then, this heat can be stored using thermal energy storage and used later in order to satisfy the greenhouse heating demand (Vadiee and Martin, 2012). The concept of closed greenhouse is, a controlled environment, circulation of air, air conditioning, dehumidifying, heating of air, and air distribution inside greenhouse after treatment (Opdam et al., 2005). A vegetable production research group in Belgium made an analysis between closed greenhouses and traditionally widely used open greenhouse with TRNSYS. Climate control and energy balance simulations of greenhouses were performed by three ways; 1) air side simulation, 2) water side simulation by providing hot and cold water, 3) innovative energy supply systems simulation (Hoes et al., 2008).

Energy department in Sweden assessed energy use in open and closed greenhouse by using TRNSYS. The results of theoretical and TRNSYS models were compared for validation purpose. And concluded that an ideally closed greenhouse heating requirement is much lower than the congenitally constructed greenhouse (Vadiee and Martin, 2013). University of Genève conducts a research on closed greenhouse combine with energy storage system. Simulations were run for feasibility evaluation, among these three systems; 1) Energy storage in water tank, 2) energy storage in buried pipes for short-term energy saving, 3) fuel heating system combined with closed greenhouse. And concluded, energy storage in buried pipes is most efficient system among these three (Hollmuller and Lachal, 1998).

4. Geothermal energy

Geothermal energy is one of the fastest growing renewable energy source, in the last one decade geothermal energy widely spread over 30 countries with annual increase of 10% (Curtis et al., 2005). Worldwide use of geothermal energy for greenhouse heating is also increasing, 34 countries are reported using geothermal energy in greenhouse sector (Lund et al., 2011). Geothermal energy is defined as heat inside the earth, not only energy extracted from the earth also energy stored in the earth (Hyun et al., 2014). An experimental research conducted on geothermal source for greenhouse heating, research concluded following advantages that, making perforation for geothermal source is not necessary because farm already contains a well for irrigation, although efficiency is low but water comes freely without any pumping requirement, complete system is easy to assemble maintenance and operation is very simple (Adaro et al., 1999). Many growers reports 80% of saving in fuel cost and 5 to 8% saving in total operating cost by using geothermal energy in their agribusiness (Lund et al., 2005). Energy analysis is very important tool to understand the thermodynamic of the any energy system (Ozgener et al., 2005). Researchers from all over the world are doing experimental analysis as well as computer modelling of geothermal energy for best utilization of the energy. As use of geothermal energy in agricultural greenhouses is increasing, energy analysis can give the best estimate about its feasibility in agricultural greenhouse according to available conditions and crop needs. University of Tunsia, Italy did work on simulation of geothermal energy use in greenhouse sector. Approach of the modelling was carried out by using TYRNSYS. Automatic construction of the model was achieved by putting user data for measuring the effect of the outside climate on greenhouse. Main objective to run this simulation was the exploitation of the geothermal heat pumps systems in greenhouse sector (Carlini et al., 2010). Geothermal energy is used for the both heating and cooling of the greenhouse. A research was done for the evaluation of geothermal energy on heating mode using geothermal heat pumps. Simulation was completed with TRNSYS by presenting a mathematical description of the heat pump on TRNSYS model. And study the numerical and thermodynamic phenomena of heat pumps including power consumption (Chargui et al., 2012).

Conclusion

Proper management of all parameters influencing greenhouse environment is very necessary. Energy management plays a decisive role in the greenhouse cultivation. Researchers have been evaluating different energy alternates and greenhouse energy balance for the efficient and cost effective greenhouse farming. Firstly, we need to manage available heat energy saving for greenhouse by analyzing all parameters that can reduce energy losses. Main factor affecting on greenhouse energy balance is solar radiation which is affected by greenhouse orientation, structural design, thermal insulation and covering materials. Form energy saving point of view evaluation of these factors is very important. Moreover, as whole world is looking for the renewable energy sources, which are long-term source of energy, after payback period, it can be used free of cost but a little maintenance cost. Agricultural researchers are also paying attention towards these resources to use it for minimizing energy cost for greenhouse farming. However, in recent situation, building energy simulation for agricultural greenhouse is limited, but literature review shows the increasing trend of TRNSYS use for agricultural buildings energy simulation. TRNSYS use is increasing in all over the world for the building energy simulation, many researchers compare experimental and TRNSYS results for its validation. Use of TRNSYS can be a wise choice for the agricultural building analysis. Greenhouse models can be used to enhance our understanding of the physical greenhouse climate and can provide help for making designing and climate management strategies for greenhouse, and thus to control greenhouse microclimate optimally. As a general conclusion, most of the researchers successfully simulated solar energy for its feasibility evaluation to minimize the energy demand especially during heating season by joining solar energy with seasonal storage system.

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BES 프로그램을 이용한 온실의 에너지 관리

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적 요. 본 논문에서는 온실작물 생육에 적절한 미기상환경을 제공하기 위한 최적의 조건을 찾아내기 위하여 TRNSYS 프로그램을 이용하여 온실의 구조 및 환경인자와 에너지공급기술들에 대하여 시뮬레이션을 실시한 연구논문들을 분석하였다. 본 연구의 목적은 온실에너지 관리를 위해 사용되고 있는 여러 가지 에너지시스템과 기술들에 관하여 검토하고 이들에 대해 TRNSYS 시뮬레이션을 통해 실시한 효율분석에 관하여 검토하는 것이다. 사용가능한 에너지자원과 다양한 외부기상조건에 따른 에너지절감기술들의 성능을 분석하기 위한 여러 가지 시뮬레이션 모델들에 대해서도 검토하였다. 사용자가 정의하는 인자들을 사용하여 하이브리드 농업시설을 시뮬레이션 할 수 있는 TRNSYS 프로그램의 주요 구조들을 찾아내었다. 문헌검토에서 얻어진 결과를 토대로 TRNSYS 프로그램을 이용하여 온실의 에너지관리를 위한 시뮬레이션 모델을 개발하는데 필요한 몇 가지 중요한 결론들을 도출하였다. TRNSYS 프로그램은 앞으로 온실의 에너지 시뮬레이션을 수행하는데 크게 활용될 것으로 기대된다.

추가주제어 : 난방, 미기상, 에너지절감, 트랜시스