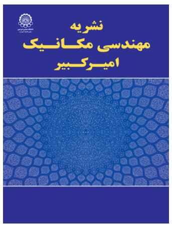

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Energy, Exergy and Economic Analysis of a Semi-Solar Greenhouse with Experimental Validation

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ABSTRACT: In this study, modeling of a semi-solar greenhouse has been done using Matlab software from the viewpoint of energy, exergy and economic, for the first time to the best of the author's knowledge. This simulation predicts the four different point's temperatures of the semi-solar greenhouse, considering mass and heat transfer between greenhouse components and the crop evapotranspiration. The results of the proposed modeling have evaluated by data recording from the constructed typical semi-solar greenhouse experimentally. Noticeable value of 19.5 °C has obtained for the temperature difference of the inside air and the outside air during tests. For statistical error functions of for coefficient of determination, model efficiency, mean absolute percentage error, total sum of squared error and root mean squared error average values of 97.5%, 87%, 6.08 %, 213.4°C^2 and 2.1°C have been calculated which shows the acceptable accuracy of the thermodynamic analysis. Moreover, exergy destruction of heat and mass transfer processes in the greenhouse system has been inspected. Considering the aim of this study as providing suitable thermal conditions for the inside air, the greenhouse air unit cost for each time step of one minute was analyzed. The unit cost of the air inside the greenhouse increases considerably by raising the interest rate from 10% to 20%. Using the technique of double layer glass separated with air filled space as the greenhouse cover, total exergy destruction of the semi-solar greenhouse decreases about 45.36%.

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1. Introduction

The geothermal energies are stable, reliable, and unlimited souWhen greenhouse cultivation is the popular intensive kind of crop production with a yield per cultivated unit area more than 10 times higher than a field crops. Heating and cooling of greenhouse is one of the most energy consuming operations among the various activities performed for protected cultivation. Raising fossil fuels application as energy source has many side effects on the environment. In this respect, the solar energy as an abundant, clean and sound source can be regarded as a favorable energy source instead of the conventional ones. In addition, using fossil fuels for greenhouse heating can cause the agricultural crops cost dependent on oil cost and so unstable [1]. Specifically, fossil fuels decline and so their price increase will encourage farmers to apply new energy sources for cultivation [2]. Furthermore, the solar energy with more suitable energy saving properties can play a valuable role in greenhouse heating. Recently, many studies have been performed by researchers on the application of the solar energy for the greenhouse heating.

Most of the greenhouses in the developing countries, especially Iran, use fossil fuels due to the high level of oil and gas sources. Therefore, to our knowledge, energetic, exergetic and economic evaluation of a semi-solar greenhouse has not been conducted in the published articles in the Iran's conditions until now. In this research, simulating the heat and mass transfer in a semi-solar greenhouse by an innovative dynamic model and then inspecting the exergy destructions through processes were taken into account to satisfy the lack of information in this field. Particularly, there are not noticeable inquiries on the experimental inspection of solar greenhouses. The final part of this study concentrated on the exergoeconomic assessments and offering some economic suggestions. The modeling results were validated with measured values from the constructed greenhouse of 15 m2. The results of this project can be used in commercialization of the semi-solar greenhouses in the future and help farmers and customers by decreasing the crop cost.

2. Methodology

For experimental evaluation of the thermodynamic simulation in this study, an innovative structure was designed and installed at the Tabriz city, Azerbaijan Province, Iran. Researchers showed that greenhouse heating consumed over than 30% of its total operational energy [3]. Furthermore, to use the highest amount of solar energy in greenhouse structures, shape and orientation of a greenhouse are highly emphasized [4] . Then, at the present study, attempting to select the most suitable shape and orientation for the

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constructed structure, many shapes were inspected from view point of solar energy capture in two main orientation of east–west and north–south. In this way, the greenhouse structure and orientation was chosen after radiation calculation and using and Tabriz Meteorological center information.

3. Discussion and Results

The performance of the dynamic model and innovative semi-solar greenhouse structure is dealt energetic and exergetic. Fig. 1 presents the variations of the experimental temperatures of the greenhouse parts (constructed in Tabriz city) and the outside air since 9:00 for 8 hours. The data was recorded every one minute.

In this experimental set, the inside cover was manufactured from single layer glass, then, its inside and outside surfaces had a few temperature difference. This caused the inside surface of the cover had a significant temperature difference with the inside air, leading a considerable amount of energy loss. Therefore, energy efficiency decreased because of normal heat transfers by radiation and convection from the cold surface of the greenhouse cover and other greenhouse parts.

Referring to Fig. 1, average temperature of the greenhouse air during the test was 33°C, almost 20°C more than outside air temperature, then, the installed structure could prepare an acceptable situation for crop cultivation in cold days, because its performance in absorbing and keeping the solar energy during the test was efficient and comparable with other research. Uncertainty assessment results listed at Table 1. As discussed before, the experiments were done over again on 29 and 30 November of 2017 with the same conditions of the main experiment on 28 November of 2017 and the obtained data from consecutive days were evaluated with uncertainty analysis. The results indicated that the experimental measurements during the tests were reliable to evaluate the accuracy of the thermodynamic modeling.

Table 1. The uncertainty analysis results

Measurement Devices	Uncertainty (U)
SHT11 (T_p)	±0.387 K
SHT11 (T_{coi})	±0.311 K
SHT11 (T_a)	±0.243 K
SHT11 (T_g)	±0.425 K
SHT11 (RH_a)	±0.263 Relative Humidity (RH)
SHT11 (RH_o)	±0.314 RH
ST8894 (v_o)	±0.098 m/s
TES1333 (I_{in})	±1.23 W/m^2

The air unit cost of the semi-solar greenhouse is presented in Fig. 2 based on Eq. (39) for three interest rates since first minute to minute 480. As it can be seen from this diagram, the trend is rising in predominant minutes. This is justified, because; the capital investment related to nth time step is added to the total outlet cost of (n-1)th time step, however; for some time steps the trend is flat or descending due to variations of the inside air temperature and so its exergy flow rate. For the time steps of 400 to the end the trend is highly rising due to two parallel factors of capital investment increase and the air temperature and so its exergy flow rate decrease.

4. Conclusions

The most important conclusions induced from this research are:

Raising the temperature of the greenhouse air during the test to 33°C in a cold day, showed that the greenhouse performance is efficient in absorbing and keeping the solar energy.

Uncertainty assessment results indicated that the experimental data recorded during the tests were reliable to evaluate the accuracy of the thermodynamic modeling.

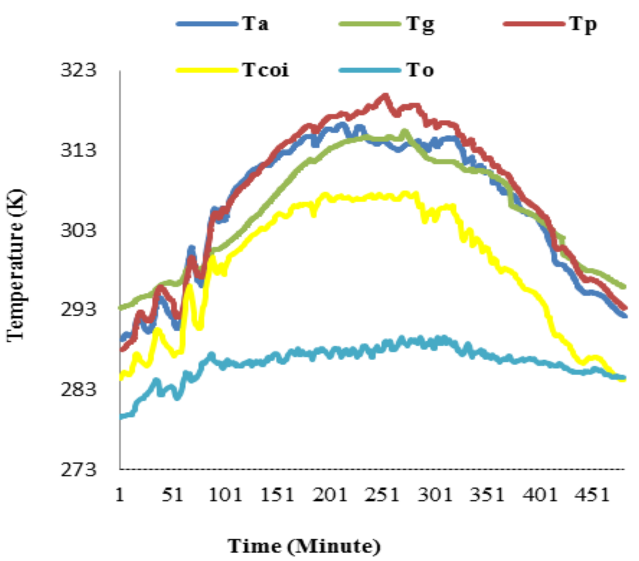

Fig. 1. Changes of the experimental temperatures of the greenhouse parts and the outside air

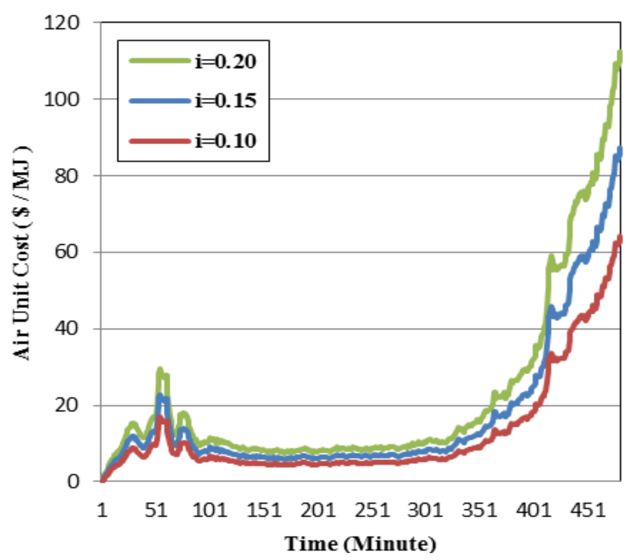

Fig. 2. Air unit cost at time steps of n=1 to n=480 for different interest rates

Considering the target of this research as providing suitable environmental conditions for the inside of the greenhouse, the air unit cost was inspected from first step time to the end.

Exergoeconomic evaluation sowed that the air unit cost trend was rising in most minutes.

The air unit cost was highly influenced by the interest rate value.

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