DYNAMIC MODELING OF A HEATING SYSTEM USING GEOTHERMAL ENERGY AND STORAGE TANK

by

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This paper analyzes a greenhouse heating system using geothermal energy and storage tank and the possibility of utilization of insufficient amount of heat from geothermal sources during the periods with low outside air temperatures. Crucial for these analyses is modelling of the necessary yearly energy requirements for greenhouse heating. The results of these analyses enable calculation of an appropriate storage tank capacity so that the energy efficiency of greenhouse heating system with geothermal energy could be significantly improved.

Key words: *greenhouse, geothermal energy, numerical simulation, heating, storage tank*

Introduction

Dynamic modelling of a heating system is an efficient tool for energy efficiency improvement and implementation of renewable energy sources [1-3]. Currently, this type of testing is common for residential and commercial building sector, but not so widespread for agricultural facilities. Greenhouses are large energy consumers. Thus, it is necessary to optimize heating, ventilation, and irrigation systems in order to approach design performance to the real working characteristics. Static thermal load design can not give real energy consumption data, especially when it is known that the thermal behaviour of the facility depends on a large number of parameters, such as outside temperature and humidity, solar radiation, wind velocity and direction, *etc*. [4, 5]. For this reason, in this study energy consumption of the greenhouse is analysed using a dynamic model and the data obtained from the typical meteorological year for a given location, in order to evaluate annual energy requirements. Results of these analyses enable calculation of storage tank capacity, so that the energy efficiency of the greenhouse heating system with geothermal energy could be significantly improved.

The analysed greenhouse is located in Debrc, Serbia, at about 50 km from Belgrade, close to the main road between Obrenovac and Sabac. In the immediate vicinity of the green-

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Figure 1. Inside of the Debrc greenhouse with geothermal heating system

house there are geothermal wells with the capacity of 22 l/s and temperatures around 53 °C which are used for heating the greenhouse. Total area of the greenhouse is 4.2 hectares positioned along the east-west direction, so that the two longer walls are oriented to the north and south, respectively.

Figure 1 shows inside of the greenhouse in Debrc. From the geological and hydrological point of view, the area where the greenhouse is located is the area at the south of the Pannonian basin, which includes Vojvodina, Macva, Danube and north-east Serbia. This area is characterized by small thickness of the earth's crust, of about 25 km, and high values of underground heat flux, ranging from 80 to 110 mW/m^2 which clearly indicates a significant geothermal potential [6]. Use of geothermal energy as renewable energy source in agriculture has many advantages, especially in greenhouses. Also, energy consumption of the facility can be significantly decreased by dynamic modelling of the heating system.

Modelling energy requirements of the facility

Modelling energy requirements of the facility is sensitive depending on variable outside atmosphere parameters. Thus it is very important to get as accurate data as possible, *i. e*. to provide as accurate input weather data as possible, in order to achieve the most accurate modelling [7, 8]. In this case, typical meteorological year data – TMY files can be considered as values which will give relevant input parameters from numerical simulation. TMY files contain average values of meteorological parameters in the last 10 years for all 8760 hours during the year. Weather data were obtained from TMY for the given location and compared with measured data obtained at the location. Figure 2 shows data for air temperature obtained by performing TMY file for Sabac location.

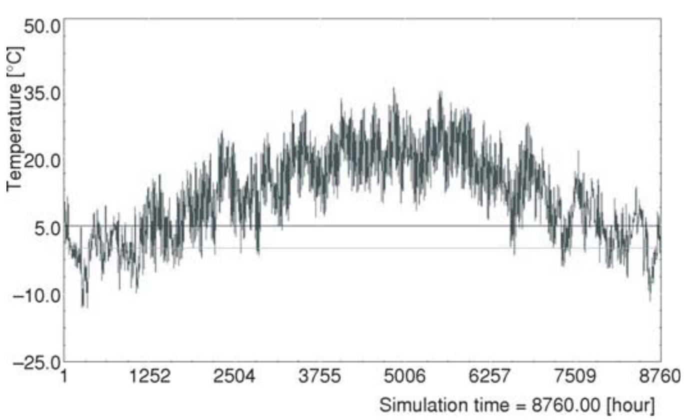

Figure 2. Outside air temperature changes during the year

Chosen software package TRNSYS can give output results depending on different input parameters as hourly values of the outside temperature, available solar radiation, wind velocity and direction and other relevant parameters. [4, 8]. For example, it is possible also to calculate influence of the transmitted solar radiation on the energy requirements of the greenhouse depending on different envelope materials. Modelling of this parameter presents a problem because the permeability of the envelope materials can change in time. Figure 3 shows values of the measured and calculated transmitted solar radiation for the presented greenhouse. As can be seen, matching percentage is relatively high.

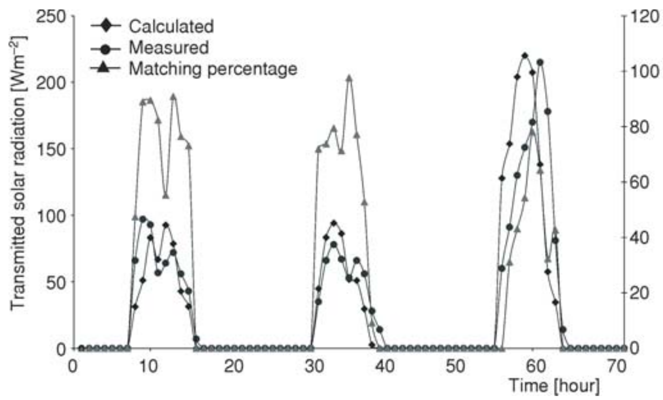

Figure 3. Calculated and measured transmitted solar radiation in the zone of vegetable growing

Dynamical simulation of the greenhouse energy requirements

In order to make dynamical simulation of the Debrc greenhouse energy requirements the facility was conditionally divided into three zones according to their thermal comfort demands. The first zone includes office spaces, the second is a part of seedlings preparation and the third zone is a part of vegetables growing, which is the largest area covering 4 ha.

Result of the analysis shows that, without the heating system, the minimum temperature during the winter period in the area of vegetable growing is about –7 °C. Higher temperature values were obtained in the seedlings preparation zone, due to the impact of artificial light.

Energy requirements of the greenhouse were dynamically analysed, depending on the inside greenhouse air temperature and humidity according to the hourly values of the outside temperature, available solar radiation, wind velocity and direction and other relevant parameters.

It was assumed that the inside temperatures and humidity varied in some zones of the greenhouse depending on the technical and physiological characteristics of the vegetable growing. In the second and third zones of seedlings preparation and vegetables growing temperatures varied from 16 °C up to 25 °C respectively, and for office spaces air temperature was set up at 20 °C.

The diagram in fig. 4 shows hourly heating load of the second greenhouse zones if the inside air temperature is 25 °C and humidity 50%.

Tables 1 and 2 shows monthly and yearly heat requirements of the second and third greenhouse zones depending on the inside air temperature varying from 16 °C to 25 °C.

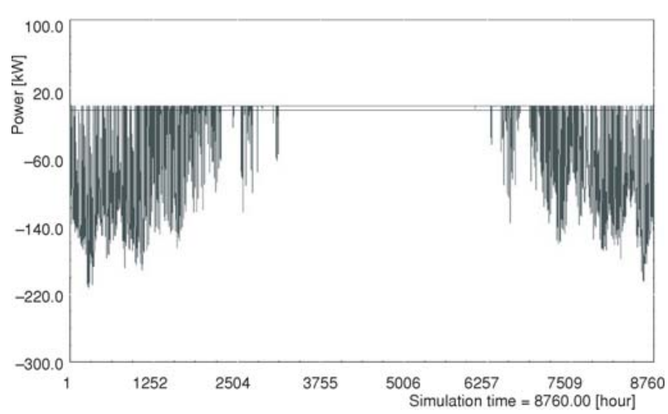

Figure 4. Hourly heating load for the second greenhouse zone if the inside temperature is 25 °C

Table 1. Monthly and yearly heat requirements [kWh] of the second greenhouse zone for different inside temperatures

Inside temperature [°C]	16	17	18	19	20	21	22	23	24	25
January	32300	37300	40700	44600	48400	56300	62900	69293	74071	78901
February	10300	13400	16400	21300	26400	31200	35400	44272	47975	51751
March	1000	2320	4080	5320	7265	8346	11100	16400	20532	23686
April	0	0	17	105	317	721	1380	2337	3309	4553
October	824	1513	2384	3455	4784	6640	8256	10375	12684	15283
November	13948	16970	20206	21890	26220	29060	35281	39368	43506	47722
December	33241	37477	41864	43740	46890	53690	59631	64269	68862	73487
Total	91613	108980	125651	140410	160276	185957	213948	246314	270939	295383

Table 2. Monthly and yearly heat requirements [kWh] of the third greenhouse zone for different inside temperatures

Inside temperature [°C]	16	17	18	19	20	21	22	23	24	25
January	876125	951609	1028649	1106752	1187374	1267774	1347699	1428731	1512127	1596328
February	549780	607120	666719	726603	787507	850401	913462	1000000	1043615	1110204
March	184066	223684	267272	314127	364524	417583	473049	520000	588055	648390
April	10765	20371	33404	49734	68889	90851	115404	133000	175424	211841
October	81325	108464	139029	173233	212181	255933	303834	355252	409527	467931
November	422454	485067	549189	615519	683841	753213	825307	897900	971502	1046104
December	793446	868959	946582	1022475	1101927	1180282	1259802	1341260	1422174	1503592
Total	2917961	3265274	3630844	4008443	4406243	4816037	5238557	5676143	6122424	6584390

Based on the results of this analysis it is possible to calculate heat requirements of the greenhouse for different air temperature and humidity values. Table 3 shows monthly and yearly energy requirements of the greenhouse heated with the existing geothermal source. This is the case when the inside temperatures in the second and third zones of the greenhouse amount to 25 °C and 22 °C, respectively, according to plants physiological needs, the air temperature of office spaces is 20 °C, and the humidity is 50% for all zones, where:

– Necessary – means thermal energy required for greenhouse heating.

– Excess – means excess amount of heat energy from the geothermal source, this is the case when the outside temperature is high, so that the geothermal source has an excess amount of energy.
– Deficit – means deficit of heat energy from the geothermal source, this is the case when the outside temperature is low, so that the geothermal source is not able to cover the whole energy requirements.

According to previous analyses, the existing heating system had an energy deficit amounting to 219.4 MWh during the heating period, when the outside temperatures are low, so that the desired air temperature in the greenhouse cannot be achieved. Also during the heating period there is 7677.6 MWh of excess energy when the outside temperatures are higher.

Table 3. Monthly balance of heat required for greenhouse heating

Month	Thermal energy		
	Necessary [MWh]	Excess [MWh]	Deficit [MWh]
January	1638.6	693.3	99.8
February	1053.4	1005.8	42.7
March	458.5	1776.4	2.9
October	233.5	1998.5	0.0
November	861.1	1373.9	6.0
December	1472.4	829.7	67.9
Total	5717.4	7677.6	219.4

Heat storage tank modelling

In order to use excess energy from the geothermal source and increase the energy efficiency of the heating system the heat storage tank with geothermal water was set up. For an efficient heat storage modelling, and selection of the appropriate tank volume, dynamic simulations are a very effective tool, which gives to the designer the possibility to optimize the system.

Figure 5 presents seasonal hourly values of the necessary water flow rate from the existing geothermal source.

From fig. 5 it can be clearly concluded that the available water flow rate of 22 l/s can mostly provide the necessary heat during the heating season (from October till April). Also the period with extremely high values of water flow rate, which goes up to 70 l/s can be identified.

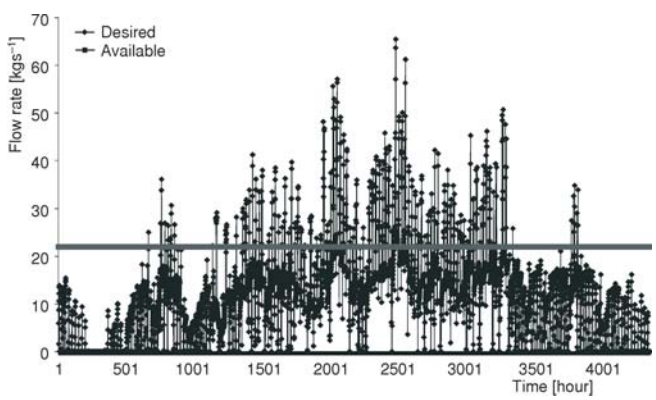

Figure 5. Seasonal hourly values of desired water flow rate and available flow rate from the geothermal heat source

The case when the heat requirements of the greenhouse are greater than the geothermal energy potential is of particular interest in this analysis This case is usual occurring during the night time when the outside air temperature is low. In these periods, measured air temperature inside the greenhouse was lower than 20 ºC, especially when the outside air temperature was lower than –10 ºC. Numerical simulation of the greenhouse heat requirements shows that the en-

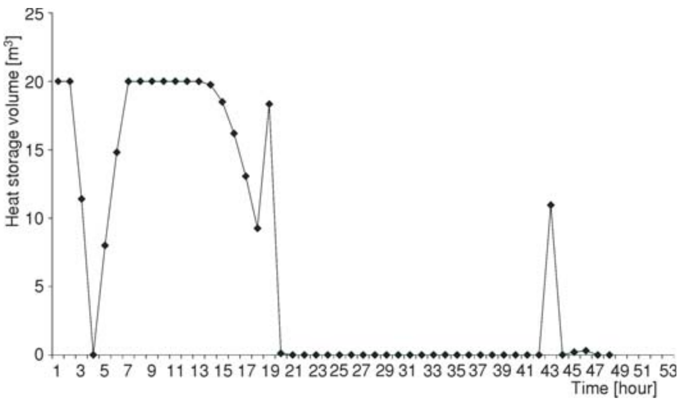

Figure 6. Hourly profile of the heat storage tank charging and discharging for two typical days in heating season

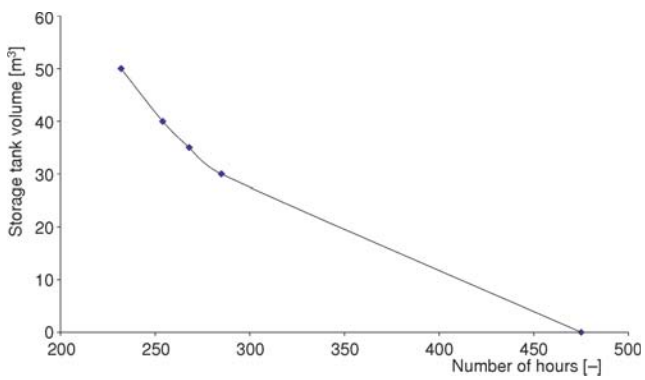

Figure 7. Number of hours that could be covered with heat energy compared with storage tank volume

ergy from the geothermal source is insufficient in 475 hours during the heating season. In these periods additional heating of the greenhouse is necessary because the inside air temperature is lower then the desired temperature of 20 ºC.

Figure 6 presents a diagram of charging and discharging the 20 m^3 storage tank with geothermal water during two typical days within heating period.

Figure 7 shows the relation between the storage tank volume and time in hours when the tank can not cover the heat requirements

Without the storage tank, value of 475 hours presents the time while geothermal heating system is not able to cover all heat requirements. With the storage tank of 50 m^3 the geothermal heating system can not cover 225 hours of full heat requirements. For the full heat energy coverage the storage tank would have to have a volume of over 70 m^3.

Conclusions

Application of geothermal energy in agriculture, especially in greenhouses has many advantages: improvement of energy efficiency of the facility, decrease of CO_2 emission by substitution of fossil fuels with renewable energy and establishment of a sustainable food chain. Setting up the right working parameters in the greenhouse is subject to complex requirements. Therefore, in these analyses heat requirements of the greenhouse during the heating period are dynamically described based on data obtained from typical meteorological year for given location (Debrc, Serbia) in order to find an optimum between the desired temperature inside the facility and the geothermal energy source potential. Numerical simulation results were validated with data obtained from experimental measurements in the facility. The results of these analyses enable calculation of storage tank capacity so that the energy efficiency of the greenhouse heating system with geothermal energy could be significantly improved.

Modeling of heat storage tank shows that the system would be able to cover almost the whole heat energy needed during the season. Also it can be concluded that the tank volume up to

30 m^3 is a rational solution. Tank volume greater than the suggested one would cause unnecessary costs. The analysis of the greenhouse heating system with the storage tank of 30 m^3 shows that it enables saving of about 10 000 EUR per heating season so that the return period of the investment is less then one year. From environmental point of view, the CO_2 emission is reduced about 60 t.

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