Greener Greenhouses

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ABSTRACT

Agricultural greenhouses are solution to the increased demand for higher production yields, facilitating off season cultivation and allowing the growth of certain varieties in areas where it was not possible earlier. Heating and/or cooling system, required to maintain the inside micro-climate in greenhouses mostly rely on fossil fuels and/or electricity. This paper aims to discuss the "greener" solutions for heating and cooling systems of greenhouses based on different thermal energy storage concepts. Results from a greenhouse Aquifer Thermal Energy Storage (ATES) application in Turkey producing tomatoes with zero fossil fuels and up to 40% higher yield are presented.

Keywords: Agricultural greenhouse, heating, cooling, thermal energy storage

INTRODUCTION

Fossil fuel prices have been rising at an ever faster rate. Climate change and energy security seem to be the most urgent issues that concern our societies who try to meet their increasing energy demands by merely consuming more fossil fuels. The best solutions appear to be a better exploitation of renewable energy sources and higher energy efficiency. Intermittent characteristics of renewable energies can be avoided by using Thermal Energy Storage (TES) systems to match supply and demand. Since the 1970's these systems have proven to be a significant tools to increase energy efficiency in contrast to conventional energy systems (Dincer and Rosen, 2002). TES systems provide alternative heating and cooling solutions to decrease consumption of electricity and fossil fuels and also replace mechanical cooling devices that use ozone depleting gases (ODS).

Greenhouse production has reached 44000 ha in Turkey. For higher yields and better quality of greenhouse products, temperatures should be maintained within critical ranges that vary with the species grown in a greenhouse. For tomatoes this critical inside temperature range is 12-30ºC. The heating load of a greenhouse in the Mediterranean Region is about 150 W/m2. Heating is needed for about 90 days at 8 hours/day during the year (Abak et al., 1995). Conventional greenhouses use 6 L/m2 of oil or 9 kg/m2 of coal to meet these demands. The energy cost is the major burden for any grower and fossil fuels come with adverse environmental effects.

The aim of this study is to determine the heating and cooling potential of greenhouses in the Mediterranean climatic zone - using aquifer thermal energy storage (ATES) systems. The cooling needs for greenhouses in early autumn and spring months and the advantages provided by this cooling were also evaluated.

THERMAL ENERGY STORAGE FOR GREENHOUSES

The main thermal energy storage technologies may be listed as (Paksoy, 2007).:

- Underground Thermal Energy Storage (UTES)
  - Aquifer Thermal Energy Storage (ATES)
  - Borehole Thermal Energy Storage (BTES)
  - Cavern Thermal Energy Storage (CTES),
- Ice Storage, Phase Change Materials (PCM), and
- Chemical Reactions

UTES systems using groundwater reservoirs have gained acceptance in many countries with great success (Snijders, 2000, Kabus et al., 2000, Dirven and Gysen, 2000, Andersson et al., 2003, Paksoy et al., 2004). The main reasons that make aquifer storage attractive are large energy savings where smaller amounts of driving energy have proven to produce very large returns. In ATES installations cold and heat are taken down into, and extracted from, the subsoil, with the help of groundwater. Most of the energy is stored in the body of soil and rock, but exchange of heat occurs via the pore and fissure system in the soil and rock layers.

ATES GREENHOUSE IN TURKEY

The system was located in Adana, Turkey where typical Mediterranean climate prevails. Two separate greenhouses with PE covers, each having an area of 360 m^2 at Cukurova University have been used. The first has been heated and cooled by ATES technique. In the second control greenhouse a conventional heating system has been used without any cooling. Figure 1 shows the basic concept of our ATES system. Two groups of wells- each having a cold and a warm well combination- operated for each greenhouse -as seen in Figure 1. Each group had a well with a depth of 80 m and casing diameter of 0.40 m. During first drilling - site investigations were done to determine the following hydrogeological properties of the aquifer:

- Aquifer(s) and their thickness
- Stratigraphy
- Static draw down
- Groundwater table gradient
- Hydraulic conductivity (permeability)
- Transmisivity
- Storage coefficient
- Boundary conditions

The cuttings were collected at every 3 m depths- followed by sieve analysis of cuttings. SP, Resistivity, and Natural Gamma logs were also taken to confirm the information from cuttings and sieve analysis results. Pump tests were done to determine the hydrogeological parameters and capacity of the wells. Chemical analysis of the water samples and thermal logging were also included in these site investigations (Turgut, 2008). The results obtained from these investigations were used as input data for CONFLOW simulation program used for design of ATES systems (Claesson, 1996). The distance between the wells were designed at 108 m. Groundwater was extracted from the wells by submersible pumps placed in the wells. The ATES system was designed 1.2 L/sec of groundwater flow.

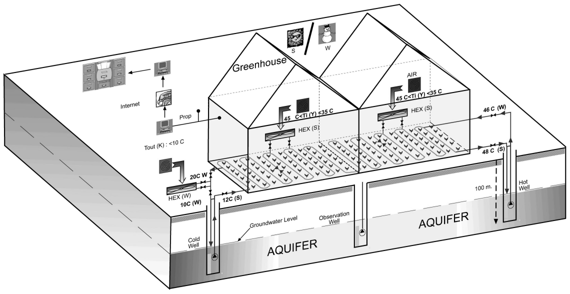

Figure 1. Basic concept of the system

The basic concept of the ATES system utilized the heat stored from summer to heat the greenhouse - as well as the cold stored in winter for cooling in summer. Greenhouse is the “solar collector” to store heat in sunny days. Temperatures in the greenhouse varied between 40-60ºC about 6 hours/day for 5 months in this climate. Winter air colder than 10ºC is the source for cooling. Four fan coil exchangers inside each greenhouse with flow capacities of 8300 m^3/h used 350 W motors. In summer, the fan coils transferred heat from air in the greenhouse to groundwater extracted from the aquifer for heat storage. In winter, these units distribute the heat stored in the aquifer to the greenhouse. Perforated polyethylene air ducts assembled at the exhaust of the fan coils distributed and extracted the air in the greenhouse. One additional fan coil-located outside the greenhouse- served to extract cold from the winter air and transfer it to the aquifer via water.

This ATES system was automated and monitored using a data acquisition and control system (Campbell CR23X). Temperatures in greenhouses, outside, wells, fan coils were monitored at several points, humidity in the greenhouses and water level in the wells were measured and recorded every 5 minutes.

Our tomato varieties (Terminator-F1, hybrid) and eggplants (Phaselis-F1, hybrid) were plants grown in both the ATES and conventional greenhouses. Organic farming techniques to achieve in-greenhouse pollination by Bombus bees were also used. Planting was made October 2005 see Figure 2.

Figure 2. Planting in the greenhouse (October 2005)

Growing parameters were monitored by taking samples from plants at 90 days, 135 days, and 180 days after planting. Figure 3 shows the ATES greenhouse when tomatoes (on the right) and eggplants (on the left) were fully grown. The perforated polyethylene ducts used with fan coils are also seen in Figure 3.

Figure 3. ATES greenhouse in February 2006, tomatoes on the right and eggplants on the left

RESULTS FROM ATES GREENHOUSE IN TURKEY

The ATES system operated during 2005-2006 for 70 days in storing heat and for 138 days in heat recovery and cold storage. Energy stored with respect to days of operation in summer 2005 is shown in Figure 4. Total energy stored in the warm well in this period was 103.9 GJ. In this heat storage process, groundwater temperature increased from 18-20ºC to 30-35ºC.

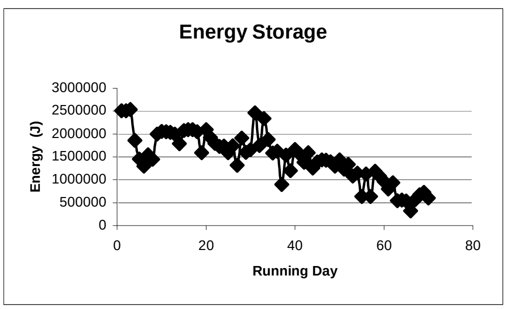

Figure 4. Heat storage during summer 2005

Heat stored was recovered in winter to heat the greenhouse, when inside temperatures were below 11ºC. During the heat recovery process, inlet temperature of groundwater to the fan coils from the warm well was 24-25ºC. Groundwater after transferring its heat to the greenhouse air was injected back to the aquifer through the cold well. Figure 5 shows temperature distributions on November 22, 2005 where T1 is the temperature in the greenhouse with ATES system in operation and T2 is the temperature for the other greenhouse where no heating was used and Ta is the outside air temperature. Although Ta and T2 went down to less than 5ºC, the temperature in the ATES greenhouse, T1 was always kept above 11ºC. This was the minimum temperature allowable for optimum growth of tomatoes.

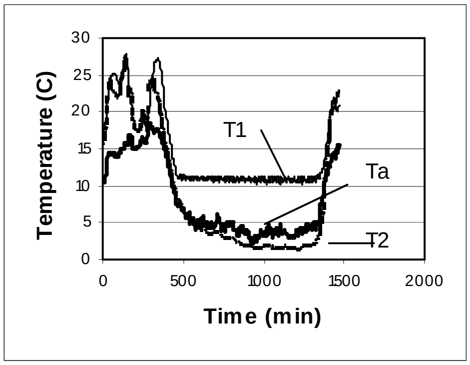

Figure 5. Temperature distributions during heat recovery on November 22, 2005, T1: ATES greenhouse temperature, T2: Conventional greenhouse temperature, Ta: Ambient temperature

During heat recovery in winter, groundwater was further cooled down by the outside fan coil unit after leaving the greenhouse. Total energy stored in the cold well during this period was 76.0 GJ. Cold stored was recovered for cooling of the greenhouse for 32 days in spring 2006. When temperature inside the greenhouse exceeded 30ºC, the ATES system was used for cooling. During the cold recovery process, inlet temperatures of groundwater to the fan coils from the cold well were 16-18ºC. Figure 6 shows temperature distributions in the ATES greenhouse (T1), conventional greenhouse (T2) and ambient. ATES greenhouse was maintained below the critical temperature of 30ºC, whereas the temperature in the conventional greenhouse reached 33-35ºC.

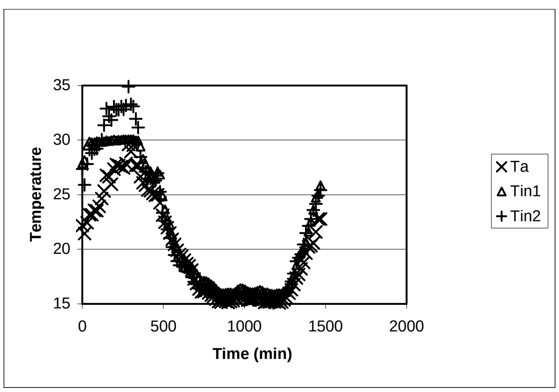

Figure 6. Temperature distributions during cold recovery on April 18, 2006, T1: ATES greenhouse temperature, T2: Conventional greenhouse temperature, Ta: Ambient temperature

The growth parameters in Table 1 demonstrate that the product yield of tomatoes in the ATES greenhouse-in terms of fruit weight- was 40% higher than those for the conventional greenhouse. Product yield increase resulting from extension of harvest time due to cooling is not included in Table 1.

Table 1. Comparison of growth parameters for tomatoes in the ATES (G1) and conventional (G2) greenhouses and % differences (D) in March 2006.

	G1	G2	% D
Plant height	155	138	12

(cm)			
Number of leaves per plant	22.1	22.1	0
Plant fresh weight (g/plant)	1405	1258	12
Fruit fresh weight (g/plant)	659	463	40

During the total operation of our ATES system in 2005-2006, no fossil fuel for heating was consumed. Additionally, it was possible to cool the greenhouse in a period when normally, under Mediterranean climate conditions- production would have been halted. Thus, the yield from the harvest was increased further. The conventional greenhouse was heated using fuel oil No.6. For the ATES system electricity was used to run the fan coils and pumps for groundwater circulation. COP for the ATES system for heating and cooling for this period were 7.6 and 3.2, respectively.

Table 2 compares the economical parameters for the greenhouses. Total cost for both greenhouses were almost the same, making ATES the more viable choice for greenhouse heating and cooling. Economic benefit resulting in higher yield is not included in the calculations. Market price for tomatoes varies during the year. Another benefit was that tomatoes could be harvested earlier with the ATES system. Early harvested tomatoes have higher market value providing us with an even better economics.

Table 2. Comparison of economical parameters for greenhouses

	Conventional Greenhouse	ATES Greenhouse
Energy cost (YTL*/year)	1600	550
Investment cost (YTL/m^2)	20	25
Operational cost (YTL/m^2)	11.5	4.9

*1 YTL=1.8 Euros

Energy cost for ATES system was about one third of the conventional greenhouse (Table 2). The environmental benefits introduced due to the avoidance of fossil fuel consumption are shown in Table 3.

Table 3. Emissions reductions introduced by the ATES greenhouse compared to a greenhouse using coal for heating

Emissions	Reduction (ton/year)
CO_2	5.6
SOx	0.6
NOx	0.7

Ash	2

CONCLUSIONS AND RECOMMENDATIONS

ATES system has been utilized for the first time in the heating and cooling of a greenhouse in Mediterranean climate. With "zero" fossil fuel consumption- leading to 68% energy conservation, 20-40% increase in product yield depending on season and short payback time of less than 1 year, the ATES system shows a very high potential for greenhouse climatisation. Longer harvest periods provided by the cooling process, increases product yield and competitiveness in the market. Further research on different plant varieties besides tomatoes or eggplants is highly recommended.

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