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SCIENCE DIRECT
Renewable Energy 29 (2004) 1991–1996
RENEWABLE ENERGY
www.elsevier.com/locate/renene

Technical note

Aquifer thermal storage (ATES) for air-conditioning of a supermarket in Turkey

H.O. Paksoy [a,*], Z. Gürbüz [b], B. Turgut [a], D. Dikici [a], H. Evliya [a]

[a] *Faculty of Arts and Sciences, Chemistry Department, Çukurova University, 01330 Adana, Turkey*
[b] *Gürbüz Engineering Co., Yüregir, Adana, Turkey*

Received 24 February 2004; accepted 17 March 2004

Abstract

A heating, ventilation and air-conditioning (HVAC) system with integrated aquifer thermal energy storage (ATES) was designed for a supermarket building in Mersin, a city near the Mediterranean coast in Turkey (36° 49′ N and 34° 36′ E). This is the first ATES application carried out in Turkey. The peak cooling and heating loads of the building are 195 and 74 kW, respectively. The general objective of the system is to use the groundwater from the aquifer to cool down the condenser of the HVAC system and at the same time storing this waste heat in the aquifer. Cooling with groundwater at around 18 °C instead of utilizing outside summer air at 30–35 °C decreases consumption of electrical energy significantly. In addition, stored heat can be recovered when it is needed in winter. The HVAC system with ATES started operation in August 2001 in cooling mode with an average coefficient of performance (COP) of 4.18, which is almost 60% higher than a conventional system.

Keywords: Aquifer thermal energy storage; Air-conditioning; Energy conservation

1. Introduction

Research on high efficiency systems in heating, ventilation and air-conditioning (HVAC) applications has been progressing steadily. As the demand for energy increases, any work done to enhance energy conservation is crucial. In order to sustain present levels of thermal comfort HVAC system, designers must find feasible solutions to the energy problem. Thermal energy storage (TES) applications around the world are known to provide economical and environmental solutions to

* Corresponding author. Tel.: +90-322-338-64-18; fax: +90-322-338-60-70.
E-mail address: hopaksoy@cu.edu.tr (H.O. Paksoy).

0960-1481/$ - see front matter
doi:10.1016/j.renene.2004.03.007

the energy problem [1–5]. TES systems, which help match energy supply and demand, contribute significantly to improving energy efficiency. Such systems increase the potential of utilizing renewable energy sources such as ambient cold air or waste heat. The use of fossil fuels and their release of carbon dioxide (CO_2) emissions into the atmosphere can be significantly reduced with TES systems. Additionally, the use of conventional mechanical cooling, which utilize ozone depleting substances (ODS), such as CFC and HCFC refrigerants, can also be greatly reduced or eliminated through direct cooling with TES. The challenge for the HVAC system designer is the integration of TES into HVAC system for improving the performance.

Aquifer thermal energy storage (ATES) systems have worldwide applications in buildings for heating and cooling purposes [3–6]. The feasibility study for an ATES system for heating and cooling of a hospital in Adana, Turkey, shows that the savings in energy will decrease CO_2 emission by 2100 tons/year, SO_x by 7 tons/year and NO_x by 8 tons/year [7].

The following work attempts to describe the HVAC system with integrated ATES for a supermarket in Mersin, Turkey. The performance of the ATES system is also compared with a conventional system.

2. System description

2.1. Heating and cooling requirements

The supermarket building is in Mersin, a city near the Mediterranean coast of Turkey (36° 49′ North and 34° 36′ East). The typical elevation is 6 m above the sea level. The climate conditions to be used in heat load calculation are 35 °C dry bulb and 29 °C wet bulb temperatures in the summer. The mean daily fluctuation in temperature is 7.4 °C and the winter design condition is 3 °C dry bulb temperature. The gross area for the building is 1800 m^2 of which 1400 m^2 is to be air-conditioned. E20-II Hourly Analysis Program (HAP) V3.23 by Carrier Corporation was run to estimate the heat load of the building throughout the year. The resulting peak cooling load occurred in August at 13:00 h as 195 kW and peak heating load as 74 kW at 3 °C outside air. The magnitude of the load arising from ventilation is a large portion of total load; 53% of total cooling and 64% of total heating load. The components of the heating and cooling load of the supermarket are given in Table 1.

2.2. ATES system components design

The ATES system contains two groups of wells connected to HVAC system, as shown in Fig. 1. Each group contains one well with a depth of 100 m and casing diameter of 150 mm. The distance between the wells is 75 m. Groundwater is extracted from the wells by submersible pumps placed in the wells. The ATES system is designed to use 4 kg/s of groundwater. Total head required for the pump

Table 1
Heating and cooling load requirement in the supermarket

Load name	Cooling load (W)	Heating load (W)
From building components	36,800	34,800
Lighting	18,500	–
People	13,800	–
Ventilation	102,700	47,700
Other	23,200	−8500

is 40 m and with an average 50% electric-to-water pump efficiency, the pump will consume 3 kW of electrical energy.

HVAC system employs four Copeland ZR19M3 scroll compressors. They are connected in parallel to form one refrigerant circuit. Compressors are equipped with several protection devices, such as high and low pressure switches, electric motor over-heating and over-loading switches. For heat-pump operation, each compressor is attached to a reversing valve, but later modified to only one larger ball valve group to decrease the pressure drop across the valve. Capacity of the system is controlled by the return air thermostat and high and low pressure sensors.

The air handling unit has a double inlet forward curved air fan that is connected to a 7.5 kW electric motor. The air volume is 5500 l/s at 600 Pa external static pressure. The direct expansion heat exchanger is made of aluminum fins and

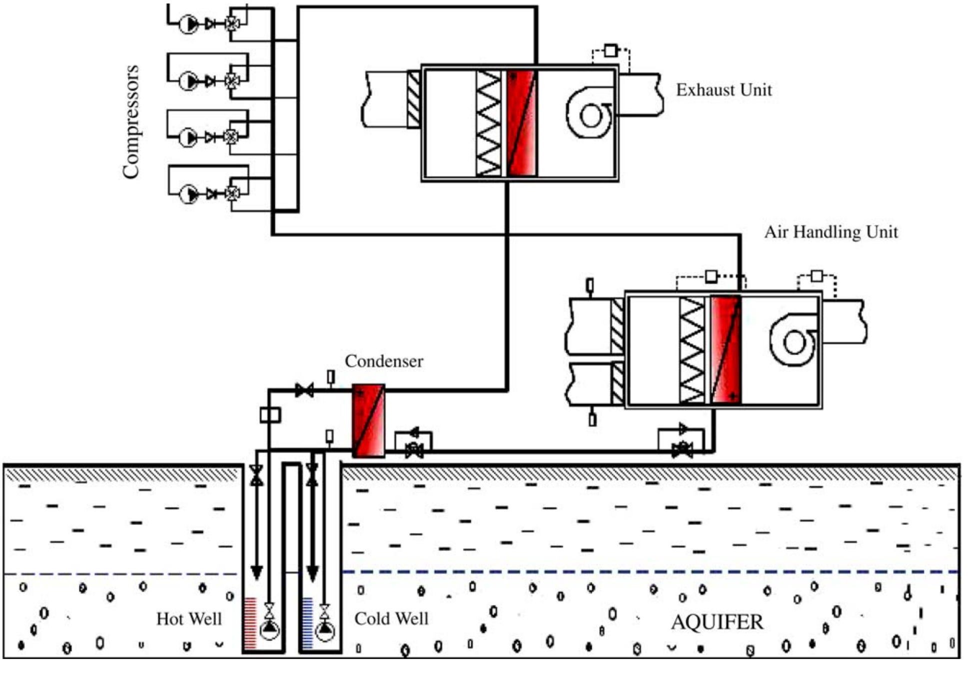

Fig. 1. Schematic lay-out of the HVAC system with integrated ATES.

copper tubes. Total heat transfer area is 200 m^2 and face velocity is 1.6 m/s. The unit can handle 2000 l/s fresh air. The exhaust unit has the same fan type connected to 1.5 kW electric motor. The air volume is 2000 l/s at 350 Pa external static pressure. The condenser is plate heat exchanger with 50 ASTM 316 stainless steel plates. Total condensing capacity is 200 kW at 35 °C condensing temperature and 4 kg/s of water at 20 °C.

2.3. Operation mode

There are two operation modes: the cooling mode uses groundwater from the cold well to cool down the condenser of the HVAC system at the same time storing this waste heat in the aquifer through the warm well. Cooling with groundwater at around 18 °C instead of utilizing outside summer air at 30–35 °C decreases consumption of electrical energy significantly. In the heating mode, the stored heat can be recovered from the warm well, when it is needed in winter. The total energy that can be stored in this operation is 0.4 MW h.

3. Results

Conventional HVAC systems composed of refrigeration compression cycle use outside air to reject the heat energy for cooling or heating process. In cooling, the energy is discharged from low level of temperature to high level of temperature (inside to outside of the building) or vice versa in heating. This operation requires addition of external power. The amount of power consumed is directly effected by the temperature of outside air in both cooling and heating. As the outside air temperature increases, more power has to be used in cooling of the building. The opposite of this situation is also true for heat-pump operation in heating. More than twice as much as electrical energy has to be consumed when the outside temperature rises from 25 to 50 °C. A typical conventional system, Mitsubishi DR101HEA packed type air-conditioner, is chosen as the reference system to compare the energy consumption of the ATES system with conventional system [8]. The conventional unit has an air cooled condenser with a cooling capacity of 31.8 kW at 35 °C outside air temperature. The conventional system with air cooled condenser consumes 898 kW h/day to meet the peak cooling demand of 2400 kW h/day in August. The average coefficient of performance (COP) is 2.67 for this system.

The HVAC system designed for the integrated ATES employs similar components as for conventional system with the main difference being that the heat is to be rejected to low level temperature heat sink (groundwater). The average temperature of groundwater is around 18 °C which decreases electrical energy consumption to transfer heat energy, compared to 30–35 °C outside air. The ATES system started operation with cooling mode in August 2001. Using groundwater at 18 °C yields an average COP of 4.18, which is almost 60% higher than that of the conventional system. The COP of cooling for the ATES system is expected to increase in cooling season 2002, following the heating mode where aquifer will be used for

Table 2
Comparison of ATES system with conventional system

Hour	T (°C)	Cooling load (kW)	Energy consumption (kW)		COP	
			Conventional	ATES	Conventional	ATES
09:00	29.7	164.5	59.41	40.15	2.77	4.10
10:00	30.8	184.7	66.57	44.16	2.77	4.18
11:00	32.1	187.0	68.78	44.62	2.72	4.19
12:00	33.3	193.4	72.26	45.91	2.68	4.21
13:00	34.2	194.7	73.85	46.17	2.64	4.22
14:00	34.8	188.9	72.75	45.00	2.60	4.20
15:00	35.0	192.4	74.16	45.71	2.59	4.21
16:00	34.8	190.7	73.34	45.36	2.60	4.20
17:00	34.3	188.8	72.07	44.98	2.62	4.20
18:00	33.4	186.1	70.07	44.44	2.66	4.19
19:00	32.5	181.7	67.61	43.56	2.69	4.17
20:00	31.5	176.1	64.75	42.44	2.72	4.15
21:00	30.7	172.5	62.80	41.73	2.75	4.13
		2401.5 kW h	898.4 kW h	574.2 kW h	2.67	4.18

heating in winter 2002. The heating mode will extract heat from groundwater which will decrease the groundwater temperature below 18 °C. Table 2 shows hourly cooling load, energy consumption and COP values for the ATES system in comparison with the conventional system.

4. Conclusions

The first application of HVAC system with integrated ATES in a Mediterranean type climate is carried out in Turkey. The results from the cooling mode in summer 2001 show that the ATES system uses 60% less electrical energy compared to a conventional system. The COP of the system is expected to improve even more after completion of the heating mode in winter 2002. The total energy that can be stored with the ATES system is 0.4 MW h in the cooling demand months.

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