CO_2 mitigation with thermal energy storage

Halime Paksoy* and Hunay Evliya

Chemistry Department
Çukurova University
01330, Adana, Turkey
E-mail: hopaksoy@cu.edu.tr
E-mail: hevliya@cu.edu.tr
*Corresponding author

Şaziye Bozdağ

Geological Engineering Department
Çukurova University
01330, Adana, Turkey
E-mail: abaci@cu.edu.tr

Muhsin Mazman

TÜBİTAK MAM
Energy Institute
Gebze/Kocaeli-Turkey
E-mail: Muhsin.Mazman@mam.gov.tr

Yeliz Konuklu

Chemistry Department
Çukurova University
01330, Adana, Turkey
E-mail: yeliz@eksoy.com

Bekir Turgut

Geological Engineering Department
Çukurova University
01330, Adana, Turkey
E-mail: bturgut@cu.edu.tr

Özgül Gök, Metin Yılmaz, Selma Yılmaz and Beyza Beyhan

Chemistry Department
Çukurova University
01330, Adana, Turkey
E-mail: ozgulgok@gmail.com
E-mail: metinyi@poas.com.tr
E-mail: selmayilmaz01@gmail.com
E-mail: beyzabeyhan@gmail.com

Abstract: Thermal Energy Storage (TES) provides us with a flexible heating and/or cooling tool to combat global warming through conserving energy while utilising natural renewable energy resources. This paper aims to show how CO_2 emissions can be decreased by utilising different TES concepts in Turkey. The first project is for the heating and cooling of a supermarket using Aquifer Thermal Energy Storage (ATES) in Mersin. With a 60% higher Coefficient of Performance (COP), the yearly CO_2 emissions reduction contribution of this project is 113 tonnes. The second project concerns ATES for the heating and cooling of a greenhouse in Adana. The greenhouse was used as a 'solar collector' and source of energy for the ATES system. No fossil fuels were consumed for heating the greenhouse and cooling was made possible with the ATES system. Energy conservation amounted to 68% and CO_2 emissions were reduced by 26 tonnes/year. The third one is a pilot project using TES in micro-encapsulated phase change materials in a test cabin in Adana with a floor area of 4 m^2. By using a 3.5 kg Phase Change Material (PCM) together with insulation panels in the test cabin, 7% cooling energy and 28% heating energy can be conserved. The corresponding CO_2 emissions reduction would be 0.5 tonnes/year.

Keywords: global warming; renewable energy; thermal energy storage; TES; CO_2 mitigation.

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Biographical notes: Dr. Halime Ö. Paksoy is a Full Professor at the Chemistry Department of Çukurova University, Adana, Turkey. She received her BS in Chemical Engineering in 1983 from Bosphorous University, Istanbul, Turkey. She obtained her MSc in 1986 and PhD in 1992 in Physical Chemistry from Çukurova University. Her Associate Professorship is in Energy Technologies, which she received in 1995. She has been the Turkish delegate for the International Energy Agency Energy Conservation through Energy Storage Implementing Agreement (IEA-ECES IA) since 1995. She has been representing Turkey at the Energy Programme Committee of the European Council since 2007. She is the Associate Editor of the *International Journal of Solar Energy Society.*

Dr. Z. Hunay Evliya is a Full Professor at the Chemistry Department of Çukurova University, Adana,Turkey. She is the founder of the Centre for Environmental Research of Çurakova University and its present Director. She took an active part in a UNDP project supporting the newly established Faculty of Basic Sciences in 1975. She has been the alternate Turkish delegate for the IEA-ECES IA since 1995. She was also the Secretary of the Executive Committee of IEA-ECES IA between 1999–2002.

Dr. Şaziye Bozdağ is an Associate Professor at the Geology Department of Çukurova University, Turkey. After taking her Master's at the same university, she realised her PhD at Nottingham University (UK) and also obtained a PhD in Environmental Geology in 1993. She worked as an Assistant Professor at Çukurova University until 1994 and became an Associate Professor in 2001. She worked as the Vice Head of the Geology Department between 1994 and 2000. Her research work is mainly on environmental geology, especially pollution and energy. She has about 40 articles published in international and national journals and symposium proceedings.

Dr. Muhsin Mazman is a Senior Researcher at the Tubitak Marmara Research Center Energy Institute, Kocaeli, Turkey. He received his BS in Chemistry in 1997 from Çukurova University, Adana, Turkey. He obtained his MSc in 2000 and his PhD in 2006 in Organic Chemistry from Çukurova University. While completing his MSc and PhD studies, he was a Research Assistant at the Chemistry Department of Çukurova University (1998-2006). He worked on thermal energy storage systems (especially Phase Change Materials or PCMs) and is still working on electrical energy storage systems.

Dr. Yeliz Konuklu received her BS in 2001 from the Chemistry Department of Çukurova University, Adana, Turkey. She obtained her MSc on the Microencapsulation of Phase Change Materials (PCMs) in 2004 and her PhD on Microcapsulated PCMs for Energy Conservation Applications in Buildings in Physical Chemistry in 2008 from Çukurova University. She worked at EKSOY Chemistry Company as an R&D Engineer and Outsourcing Engineer from 2006-2008.

Dr. Bekir Turgut has been a Research Assistant at the Çukurova University Centre for Environmental Research, Turkey, since 1999. He received his BS in 1998 from the Department of Geology Engineering of Engineering and Architectural Faculty. He obtained his MSc in 2002 and his PhD in 2008 from Çukurova University Institute of Basic and Applied Sciences in Geology Engineering. His research mainly focuses on underground thermal energy storage systems.

Özgül Gök is a PhD student at the Chemistry Department of Çukurova University, Adana, Turkey. She received her BSc in 2001 from the Chemistry Department of Çukurova University and obtained her MSc in Physical Chemistry in 2005 from the same university. She studies the development of PCMs for waste heat recovery by thermal energy storage systems.

Metin Yilmaz is the Laboratory Quality and Technical Director of Petrol Ofisi, a fuel distribution company in Antalya, Turkey. He graduated from the Chemistry Department of Çukurova University in 2001. He obtained his MSc in 2005 and has been doing his PhD at Çukurova University since 2005. He studied the use of different heat exchanger types to enhance the heat transfer of PCMs in latent heat thermal energy storage in Spain between 2006-2007. He has studied thermal energy storage systems, especially boreholes and the heat transfer of PCM.

Selma Yilmaz is a PhD student of Chemistry at Çukurova University, Turkey. She graduated from the Department of Chemistry of Gazi University in 2004. She received her MSc in 2008 from Çukurova University. Her research is mainly focused on PCMs for low-temperature applications.

Beyza Beyhan is a Masteral student at the Chemistry Department of Çukurova University, Adana, Turkey. She received her BSc in 2004 from the Chemistry Department of Osmangazi University, Eskişehir. She is currently working on developing PCMs for greenhouse applications at the Chemistry Department of Çukurova University.

1 Introduction

We all share a small planet. Our growing thirst for energy is already threatening the future of our world. Fossil fuels – the energy resources of today – are not evenly distributed on the earth. Ten percent of the world's population exploits 90% of its resources. Today's energy systems rely heavily on fossil fuel resources which are diminishing ever faster. The world must prepare for a future without fossil fuels. Sustainable energy consumption – thereby maintaining continuity and security of energy resources – has become an urgent matter to all countries. Concerns over an imminent climate change have increased as a consequence of global warming and many recent storms, 'heat waves' and 'black-outs' experienced around the world.

Thermal Energy Storage (TES) provides us with a flexible heating and/or cooling tool to combat climate change through conserving energy and increasing energy efficiency. The utilisation of local and renewable sources can be greatly improved and made more productive when coupled with TES systems (Dinçer and Rosen, 2002). TES can also be used to level out both diurnal and seasonal peaks occurring in energy demand curves, especially those which result from cooling demand. Another interesting application of thermal energy storage is using Phase Change Materials (PCMs) in building materials or structures to increase the thermal mass and hence reduce heating and cooling demands. This can be achieved through the impregnation of porous construction materials such as plasterboard with PCMs, or adding PCMs into concrete mix or plaster. PCMs need to be capsulated with a hard shell when they are used with such building materials. The challenge in PCM utilisation with building materials is to find the optimum combination of appropriate phase transition temperature, thermal property and encapsulation technique. Recently, microencapsulating paraffin as PCM has been practised by researchers and producers to meet these challenges (Jahns, 1999; Hawlader *et al.*, 2002; 2003; Özonur *et al.*, 2006).

Energy conservation introduced by TES systems leads to significant reductions in greenhouse gas emissions. Many countries around the world utilise TES to benefit from the CO_2 mitigation opportunities of these systems. Within the framework of the International Energy Agency Implementing Agreement on Energy Conservation Through Energy Storage (IEA ECES), 13 countries have been collaborating for the research-development and deployment of energy storage since 1970s.[1]

Germany achieved a 25% reduction in energy-related CO_2 emissions into the atmosphere before 2005, partly with a successful renewable energy implementation programme that supports TES activities. New long-term goals have been set by Germany to further reduce the consumption of fossil fuels by 50% until 2050. Eight large-scale systems have been built using different storage technologies and are designed to cover 30%–62% of the annual heat demand of newly developed housing areas by solar energy (Wille and Lottner, 2006). The Reichstag parliament building in Berlin (Kabus *et al.*, 2000) is heated and cooled with an Aquifer Thermal Energy Storage (ATES) system storing waste heat from a cogeneration plant. The microencapsulated PCMs for building purposes were first developed and are now being used in Germany (Jahns, 1999).

The Netherlands is the leading country in the world in the number of ATES applications, reaching 600 by the year 2006 (Snijders, 2006). Seventy-eight percent of these projects are for buildings, 12% for industry and 10% for agriculture. ATES has become a standard design option for large buildings in the Netherlands. The amount of 15 PJ of energy, which is equivalent to 200 million m^3 of natural gas, is expected to be replaced by TES systems in the country by the year 2020 (Snijders and Van Aarssen, 2003).

In Sweden, contribution of 50 large-scale ATES and 300 Boreholes Thermal Energy Storage (BTES) systems to CO_2 emissions reduction is 2.3 million tonnes/year. This value is equivalent to 3.5% of the total CO_2 emissions in Sweden (Andersson, 2006).

The largest BTES project, with 370 boreholes each at a depth of 200 m, is at the University of Ontario Institute of Technology in Canada (Beatty *et al.*, 2006). The Drake Landing Solar Community in the town of Okitoks, Alberta, Canada is the first district solar heating plant in North America (Wong *et al.*, 2006). The system is designed to store solar energy underground by BTES technology during summer months and to distribute the energy to each home for space heating in winter. This is the first project in the world where 90% of the heating load will be met by solar energy. A reduction of approximately 5 tonnes of greenhouse gas emissions per house per year is expected.

In the USA, ice storage is used for peak shaving and load-levelling purposes. It has been estimated that with the addition of storage to all buildings needing air-conditioning, 40% fewer power plants and smaller transmission and distribution lines would be required (MacCracken, 2006). One of the largest BTES applications with 400 boreholes is for heating and cooling of Richard Stockton College in NJ, USA. This project alone reduces CO_2 emissions by 2300 tonnes each year (Sanner and Stiles, 1997).

Japan also uses ice storage systems to benefit from the variable electricity tariffs. The number of ice storage installations in Japan was 16 000 in 2001 (Paksoy, 2003). These systems with their 15% energy conservation feature reduce CO_2 emissions by more than 20% (Sakai, 2000).

This paper aims to show CO_2 reduction introduced through the application of TES based on the results of three recent projects in Turkey. The projects are for heating and cooling of a supermarket, a greenhouse and a test cabin. Users from different sectors and different TES techniques are involved in these projects. Prospects for the widespread application of the TES systems in Turkey will also be given.

2 Thermal energy storage

TES can be realised as a result of the change in internal energy of a material. One or a combination of the following heats is utilised in TES systems:

- sensible heat
- latent heat
- chemical reaction heat.

The sensible heat resulting from a change in the temperature of a material is utilised in this method. The effectiveness of sensible heat storage systems depends on the heat capacity and density of the storage medium, where volume is an important factor. Sensible heat storage may be classified, on the basis of the storage materials used, as liquid, solid and hybrid systems.

Latent heat accompanying a phase change of the material is used for energy storage. The phase change can be solid-solid, solid-liquid and liquid-vapour. The latent heat of a solid-solid phase change is small. Solid-vapour and liquid-vapour transitions typically have a large latent heat transformation, but the large changes in volume make the systems complex and impractical. Solid-liquid transformations involve relatively smaller changes in volume. The energy storage density of a latent heat system is typically higher than that of a sensible heat system.

Thermal energy may also be stored as the energy of a chemical compound, and energy can be repeatedly stored and released in the same materials by reversible chemical reactions. Reactions absorb energy when proceeding in one direction and release it when proceeding in the reverse direction. Every reaction has a characteristic 'turning temperature' which marks the point at which it will change from naturally tending to favour reaction in one direction to favouring reaction in the reverse direction. The energy storage density of reversible chemical reactions is generally higher than in the latent heat transitions. But the technology is at an early stage of development, and economic and efficient systems have not been actually demonstrated. It is not known whether the reactions will continue to cycle over the long term.

TES technologies can be classified as follows (Paksoy, 2007):

- Underground Thermal Energy Storage (UTES)
- PCMs
- thermochemical reactions
- water storage
- building structure storage.

Underground soil and/or rock provide a large, invisible and isolated storage volume. UTES technologies use the heat capacity of this volume to store thermal energy from any natural or artificial source for seasonal or diurnal applications. Ground Source Heat Pumps (GSHPs) also use the underground area, but their purpose is different. GSHPs use the ground as either a heat source or a heat sink. The application of a GSHP system is based on the natural ground temperature. The GSHP extracts heat from the ground in winter and injects heat into the ground in summer. UTES is based on the storage of heat and cold underground for later use. In most cases UTES is applied as a seasonal storage. The stored energy can be used for direct heating or cooling, but it can also be used in combination with a heat pump.

The UTES technologies are:

- ATES
- BTES
- Cavity Thermal Energy Storage (CTES).

PCMs have been used for various heat storage applications since the 1800s, but they have only recently been used as a cold storage media. Cold storage systems utilise the latent heat of PCMs during the phase change from liquid to solid to store thermal energy. The PCMs that can be used for TES are:

- ice
- snow
- others (organic and inorganic).

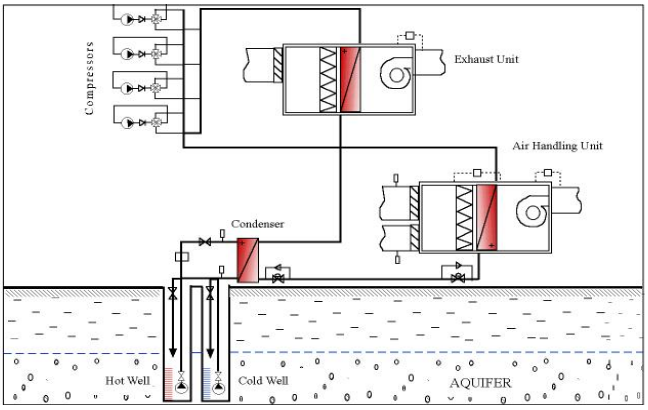
Thermochemical storage generally involves a reversible chemical reaction, absorption, adsorption or a hydration process.

3 TES projects for the evaluation of CO_2 mitigation in Turkey

3.1 Aquifer thermal energy storage for a supermarket

The supermarket building in this study is in Mersin, a city near the Mediterranean coast of Turkey. The gross area for the building is 1800 m^2 and 1400 m^2 of this area is to be air-conditioned. The peak cooling load is 195 kW and the peak heating load is 74 kW. The ATES system (Paksoy *et al.*, 2004) contains two groups of wells connected to an Heating Ventilation and Air Conditioning (HVAC) system (Figure 1). Each group contains one well with a depth of 100 m and a casing diameter of 150 mm. The distance between the wells is 75 m. The ATES system is designed to use 4 kg/s of groundwater.

Figure 1 ATES system for the supermarket (see online version for colours)



The HVAC system shown in Figure 1 employs four Copeland ZR19M3 scroll compressors. They are connected in parallel to form one refrigerant circuit. The compressors are equipped with several protection devices, such as high- and low-pressure switches and electric motor overheating and overloading 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. The 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 aluminium fins and copper tubes. The total heat transfer area is 200 m^2 and the 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 a 1.5 kW electric motor.

The air volume is 2000 L/s at 350 Pa external static pressure. The condenser is a brazed plate heat exchanger with 50 ASTM 316 stainless steel plates. The total condensing capacity is 200 kW at 35°C condensing temperature and 4 kg/s of water at 20°C.

There are two operation modes. The cooling mode is basically to use 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 outside summer air at 30°C~35°C – decreases consumption of electrical energy significantly. The stored heat can be recovered from the warm well in the heating mode, when it is needed in winter. The total energy that can be stored in this operation is 0.4 MWh.

A conventional system with an air-cooled condenser consumes 898 kWh/day to meet the peak cooling demand of 2400 kWh/day. The average Coefficient of Performance (COP) is 2.67 for this system. The ATES system started operation with the 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 a conventional system. Table 1 shows the hourly cooling load, energy consumption and COP values for the ATES system in comparison with the conventional system.

Table 1 Comparision of the performance of the ATES system with the conventional system

Hour	*T (°C)*	*Cooling load (kW)*	*Energy consumption (kW)*		*COP*	
			Conv.	*ATES*	*Conv.*	*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 kWh	898.4 kWh	574.2 kWh	2.67	4.18

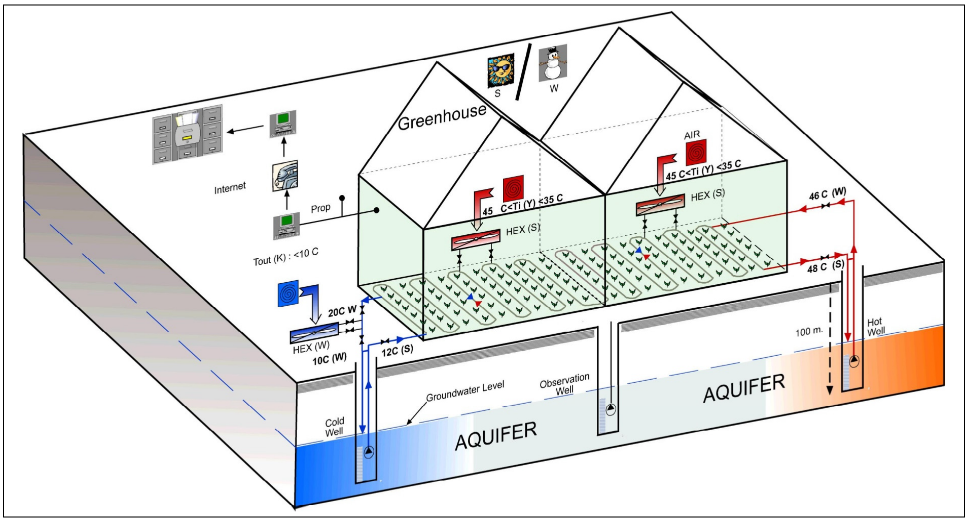
Because of the 60% higher COP, the heat pump of the ATES system was downsized, making the system more economically viable. The extra investment that was required for drilling the wells was cancelled out with the decrease in investment on the heat pump. With this performance the ATES system consumes 574.2 kWh/day. The total annual electrical energy conservation introduced by the ATES system becomes 118 MWh.

3.2 Aquifer thermal energy storage for a greenhouse

The ATES system for greenhouses was located in Adana, Turkey. Two separate greenhouses with polyethylene covers, each having an area of 360 m^2 at the Çukurova University research farm, have been used. The annual heating demand of such a greenhouse is 150 W/m^2. Heating is needed for about 90 days at 8 h/day during the year (Abak *et al.*, 1995).

The first greenhouse was heated and cooled by the ATES technique. In the second control greenhouse a conventional heating system was used without any cooling. Two wells – a cold and a warm well – were operated for the ATES greenhouse. The wells had a depth of 80 m and a casing diameter of 0.40 m. The schematic diagram of the system is shown in Figure 2.

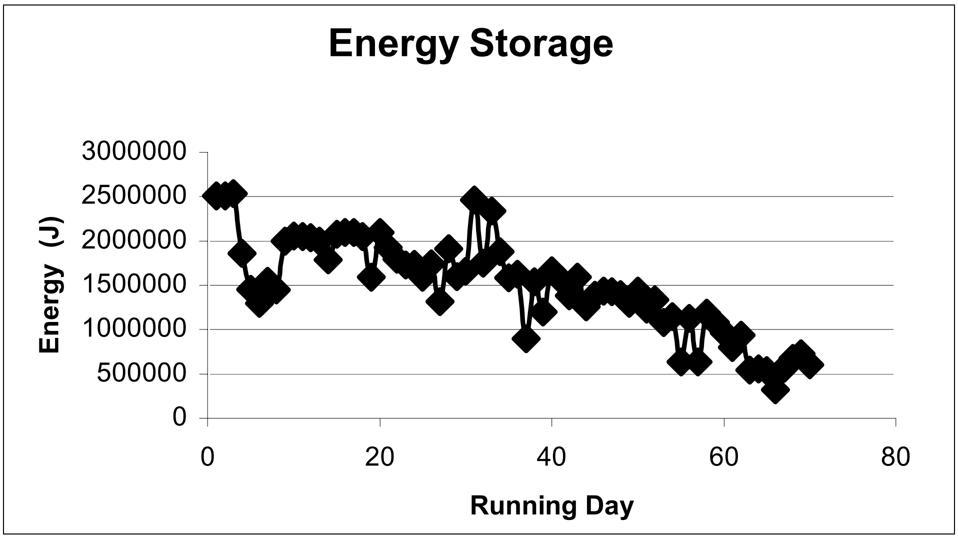
Figure 2 Schematic diagram of the ATES system for a greenhouse (see online version for colours)



The basic concept of the ATES system was to utilise the heat stored from summer to heat the greenhouse, and the cold stored in winter for cooling in summer. The greenhouse is the 'solar collector' to store heat on sunny days. Temperatures in the greenhouse varied between 40°C–60°C about 6 h/day for five months in this climate. Winter air colder than 10°C was 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 distributed 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.

The ATES system operated during 2005–2006 for 70 days in storing heat and for 138 days in heat recovery and cold storage. The energy stored with respect to days of operation in summer 2005 is shown in Figure 3. The total energy stored in the warm well in this period was 103.9 GJ. In this heat storage process, groundwater temperature increased from 18°C–20°C to 30°C–35°C.

Figure 3 Heat stored in the ATES system for a greenhouse in the summer of 2005

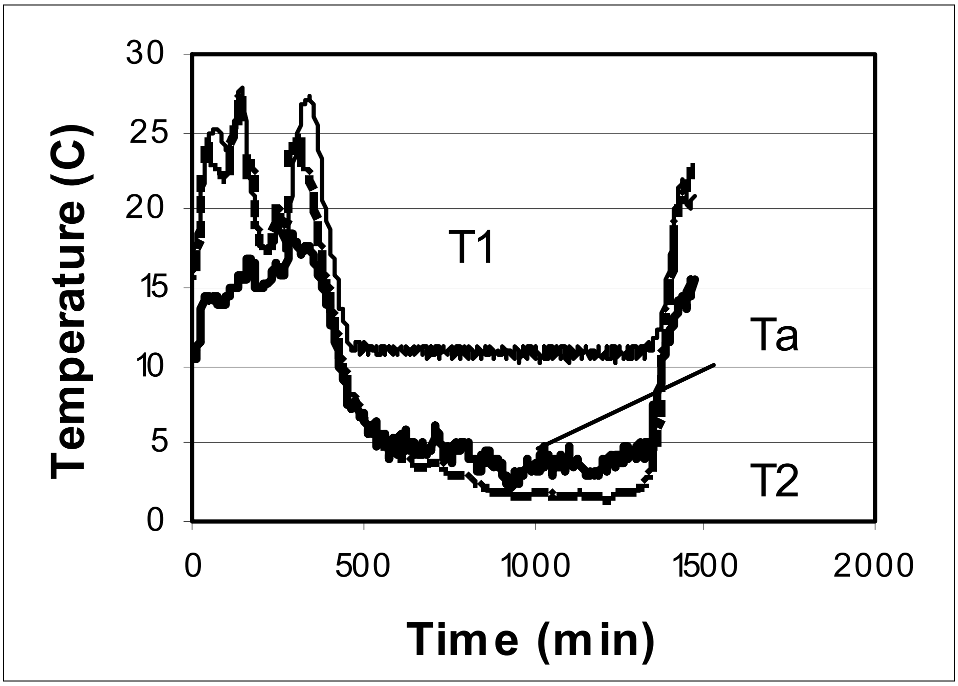


The heat stored was recovered in winter to heat the greenhouse, when inside temperatures were below 11°C (minimum temperature allowable for the growth of tomatoes). During the heat recovery, the inlet temperature of groundwater to the fan coils from the warm well was 24°C–25°C. After transferring its heat to the greenhouse, groundwater was injected back to the aquifer through the cold well. Figure 4 shows temperature distributions on 22 November 2005, where T1 is the temperature in the greenhouse with the ATES system in operation, 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 5°C, the temperature in the ATES greenhouse, T1, was always kept above 11°C.

During heat recovery in winter, groundwater was further cooled down by the outside fan coil unit after leaving the greenhouse. The total energy stored in the cold well during this period was 76.0 GJ. The cold stored was recovered for cooling of the greenhouse for 32 days in spring 2006. When the temperature inside the greenhouse exceeded 30°C, 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°C–18°C.

The product yield of tomatoes in the ATES greenhouse (in terms of fruit weight) was 40% higher than those for the conventional greenhouse. The product yield increase resulting from an extension of harvest time due to cooling is not calculated.

Figure 4 Temperature distributions during heat recovery on 22 November 2005



Notes: T1: ATES greenhouse temperature, T2: conventional greenhouse temperature, Ta: ambient temperature.

During the total operation of the 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, 3 MWh of electricity was used to run the fan coils and pumps for groundwater circulation. The COP for the ATES system can be calculated according to Equation (1):

$$\mathrm{COP} = E_r/E_c \tag{1}$$

where E_r (J) is the energy recovered from the ATES system for heating and/or cooling and E_c (J) is the energy consumed in storage and recovery for heating or cooling. For the 2005–2006 operation of the system, the COPs for heating and cooling were 7.6 and 3.2, respectively. Total energy conserved was 36 MWh/year.

Table 2 compares the economical parameters for the greenhouses. The total costs for the two greenhouses were almost the same, making ATES the more viable choice for greenhouse heating and cooling. Another benefit was that tomatoes could be harvested earlier with the ATES system. The extra investment for the ATES system was about 1440 USD (1 USD = 1.25 YTL). When the operational and energy costs of the conventional greenhouse are taken into account, the total cost of the ATES system becomes 1300 USD less than the conventional one. Moreover, the product yield in the ATES greenhouse was 40% better than in the conventional greenhouse. The economic benefit resulting in higher yield is not included in the calculations here.

Table 2 Comparison of economical parameters for the 360 m^2 greenhouses

Cost	*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

Note: * 1.25 YTL = 1 USD.

3.3 Thermal energy storage in microencapsulated phase change materials for buildings

The TES in microencapsulated PCMs together with insulation materials was utilised in a pilot project to decrease the heating and cooling loads of a test cabin with a 4 m^2 floor area in Adana, Turkey. The cooling and heating requirements of the cabin calculated according to ASHRAE were 2391 W and 665 W, respectively. Two different PCMs – Micronal 5001 (melting point 26°C and latent heat 110 kJ/kg) and Micronal 5008 (melting point 23°C and latent heat 110 kJ/kg) – were used. Macropackages of the PCMs in rectangular shape with size 0.35 × 0.30 m^2 and thickness 0.05 m were prepared using aluminium foil. The total amount of PCM used was 3.5 kg. As insulation material, Izopan (from IZOCAM Co.), which is a sandwich panel of glass wool in between aluminium layers, was used.

The temperature distribution in the cabin was measured in summer (July 2007) and winter (December 2007) for the following cases:

- without PCMs and insulation
- with PCM macropackage-lined walls only
- with insulation panel-lined walls
- with insulation panel and PCM macropackage sandwich-lined walls.

In summer, the average reduction in temperature of the cabin during the day was 2.49°C with PCMs only and 0.59°C with insulation only. With this reduction in temperature, the cooling load calculated with the ASHRAE method is 2261 W. This shows that the cooling energy was reduced by 7% as a result of using PCM macropackage lining on the walls.

In winter, the average temperature reductions were 1.61°C, 1.26°C and 2.24°C, for only PCMs, only insulation and insulation together with PCMs, respectively. The heating loads calculated with the ASHRAE method for these temperature levels are 601 W, 545 W and 510 W, respectively. The heating load was decreased by 10% when PCMs were used. Energy conservation increased to 23% when PCMs were used together with insulation. The annual energy saved E_s (kWh/year) for the cooling with PCMs only case in 1440 h (16 h/day in June, July and August) is 186.3 kWh/year, and for the heating with insulation together with PCM case in 1890 h (21 h/day in December, January and February) is 292.2 kWh/year. The extra investment for insulation, mounting material and PCM of the test cabin is 110 USD.

4 Results

CO_2 mitigation for the three projects is evaluated based on the energy reductions introduced when TES was used. Depending on the type of fuel that is replaced by TES, the reduction in CO_2 varies. Heating demand is usually met by burning fossil fuels. Table 1 shows the emission factors for CO_2 for commonly used fossil fuels. Electricity is the main energy source for cooling systems. Electricity is also consumed when heat pumps or electrical resistance heaters are used for heating; Table 2 shows the reduction in CO_2 when electricity produced from the different primary energy sources is conserved.

CO_2 emission reductions for the three projects described here are calculated using Tables 3–4. Emissions reductions are calculated based on the measured energy conservation values and corresponding alternatives of fossil fuel replacements. Life-time emissions analysis of the systems is not attempted here. Table 5 compares the annual energy savings and additional investments for the three projects described here.

Table 3 Emission factors for CO_2 (tonnes of CO_2/tonnes of oil equivalent)

Coal	*Fuel oil*	*Natural gas*
4.23	3.24	2.35

Source: World Energy Outlook 2000 (2001)

Table 4 CO_2 reduction for electricity from various primary sources

Primary source	*CO_2 emissions (tonnes/GWh)*
Coal (different technologies)	751–960
Oil	726
Natural gas	428

Source: Cağla and Altuntaşoğlu (2003)

Table 5 Comparison of the energy savings and additional investment in TES

Project	*Capacity (kW)*		*Floor area (m^2)*	*Additional investment cost of TES (USD)*	*Annual energy savings kWh/m^2*
	Heating	*Cooling*			
ATES for supermarket	195	74	1400	–	84
ATES for greenhouse	54	–	360	1440	100
Microencapsulated PCMs for test cabin	2.4	0.7	4	110	119

Using Table 5, annual CO_2 emissions reductions in tonnes/year for different fuel alternatives are calculated and shown in Table 6.

The impact of widespread TES utilisation in heating and cooling applications in greenhouses, supermarkets and buildings can be estimated using Tables 5–6. the total greenhouse area in Turkey is more than 7×10^7 m^2 (Abak *et al*., 1995). The applicability of the ATES system in greenhouses depends on the following parameters:

- geological conditions
- climate conditions
- availability of aquifers
- growth parameters for the plants.

On the condition that the above parameters are suitable and ATES could be used for heating for all of these greenhouses, CO_2 emissions will be reduced by 5 million tonnes/year with an extra investment of 280 million USD. One hundred sixty-three million USD worth of fuel oil will be saved as a result of this investment each year. In addition to the CO_2 mitigation effect, dependence on imported oil will be decreased. The cooling that could be accomplished is an extra benefit that makes the harvest period longer.

Table 6 Comparison of CO_2 emissions reductions for different fuel alternatives

	CO_2 tonne/year		
Fuel replaced*	*Coal*	*Oil*	*N. gas*
ATES for supermarket	113	85	50.3
ATES for greenhouse	34	26	19
Microencapsulated PCMs for test cabin	0.5	0.4	0.3

Note: * Fossil fuel used for electricity generation.

According to recent statistics based on 3066 municipalities, there are 15 million housing units in Turkey.[2] Microencapsulated PCMs as described in the third project can be used in buildings where there is a difference in day and night temperatures. The climate conditions in Turkey are suitable for PCM applications. If PCM was used to reduce the heating and cooling demand of these buildings and assuming the average floor area of the buildings is 25 m^2, CO_2 emissions will be reduced by 50 million tonnes/year with an extra investment of 10.3 billion USD. An amount of 1.6 billion USD worth of coal and 1.8 billion USD worth of electricity will be saved each year and the investment will be paid back in three years. The 18 000 GWh of electricity that will be saved is equivalent to twice the annual production capacity of Ataturk Dam in Turkey and about half of the total electricity consumed by households in Turkey in 2006.[3]

The impact of the application of ATES in supermarkets is not given, because there are no statistics available for the number of supermarkets and their energy consumption in Turkey.

The value of CO_2 emissions from fuel combustion in Turkey is 218.93 million tonnes as of 2008.[4] The total CO_2 emissions reductions potential estimated for widespread applications of the ATES in greenhouses and PCMs in building projects is about 55 million tonnes. If all of that potential can be exploited, one-fourth of the annual CO_2 emissions can be eliminated each year.

5 Conclusions

Heating and cooling are the main energy-consuming sectors in many countries. Any reduction of energy in these sectors will have a significant impact on CO_2 mitigation and hence global warming. TES provides flexible solutions to replace fossil fuels in heating and cooling applications. Three projects that are using ATES for heating and cooling of a greenhouse, ATES for heating and cooling of a supermarket and PCMs for heating and cooling of a test cabin were shown as examples of the mitigation effect of TES technologies. The results show that significant reductions in CO_2 can be achieved with payback time on investments in the range of – zero to three years. Widespread application of TES systems in Turkey can decrease consumption of fossil fuels and electricity, thus providing economic and environmental benefits. Moreover, utilisation of local energy resources through TES decreases the dependence on imported fuels.

The CO_2 reduction potentials estimated here is calculated based on the three projects described. For a more precise evaluation of the technical potential of CO_2 reduction by TES, it is necessary to determine the applicability of TES systems based on local conditions.

Previously, a Clean Development Mechanism (CDM) project proposal for a CO_2 reduction potential for cooling of telecommunication stations with BTES systems was prepared (Paksoy, 2005) but could not be realised, because Turkey had not signed the Kyoto Protocol at that time. Since Turkish Parliament has recently ratified the Kyoto Protocol, such projects can be prepared to assess CO_2 reductions by TES and get funding for realisation.

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Nomenclature

ATES	Aquifer Thermal Energy Storage
BTES	Borehole Thermal Energy Storage
CDM	Clean Development Mechanism
COP	Coefficient of Performance
CTES	Cavity Thermal Energy Storage
E	Energy (J)
PCM	Phase Change Material
T	Temperature
TES	Thermal Energy Storage
UTES	Underground Thermal Energy Storage

Subscripts

c Consumed

r Recovered

Superscripts

* Reference condition

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Notes

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2 www.tuik.gov.tr

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