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Solar and geothermal heating and cooling of the European Centre for Public Law building in Greece

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Abstract

The European Centre for Public Law in Legraina near Athens in Greece is heated and cooled by a combined solar and geothermal system. The main components of the system are a saline groundwater supplying well, water storage tank for 6 h autonomy, inverter for regulating geothermal flow, heat exchanger, two electrical water source heat pumps placed in cascade, fan coils, air handling units, as well as solar air collectors for air preheating in winter. In addition, hot water is supplied to the building hostel by solar water heaters. Monitoring of the energy system during heating showed excellent energy efficiency and performance.

Keywords: Heat pumps; Solar air collectors; Groundwater; Heating; Cooling

1. Introduction

The European Centre for Public Law is a building complex of a main building and a hostel located at Legraina, *ca* 65 km southeast of Athens on the Saronic gulf coastline. The heating and cooling needs of the buildings are covered by a combined system of geothermal heat pumps and solar air collectors [1]. Solar air collectors seem to play an important role in the energy savings of the preheating of the fresh air, as well as of the heating of the air mixture [2]. CRES played a principal role in the design and supervision of the construction of the system, which was

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2. The heating and cooling system

The overall configuration of the geothermal part of the building heating and cooling system is shown in Fig. 1. In order to minimize the required water flow from the well, two heat pump units (Trane/scroll) have been installed. The two units are connected in cascade in order to maximize the temperature difference (ΔT) of the ground water, and as a result the energy extracted from a given water flow rate. In order to facilitate this configuration within the building heating and cooling system, the thermal and cooling load of the building is split into two parts.

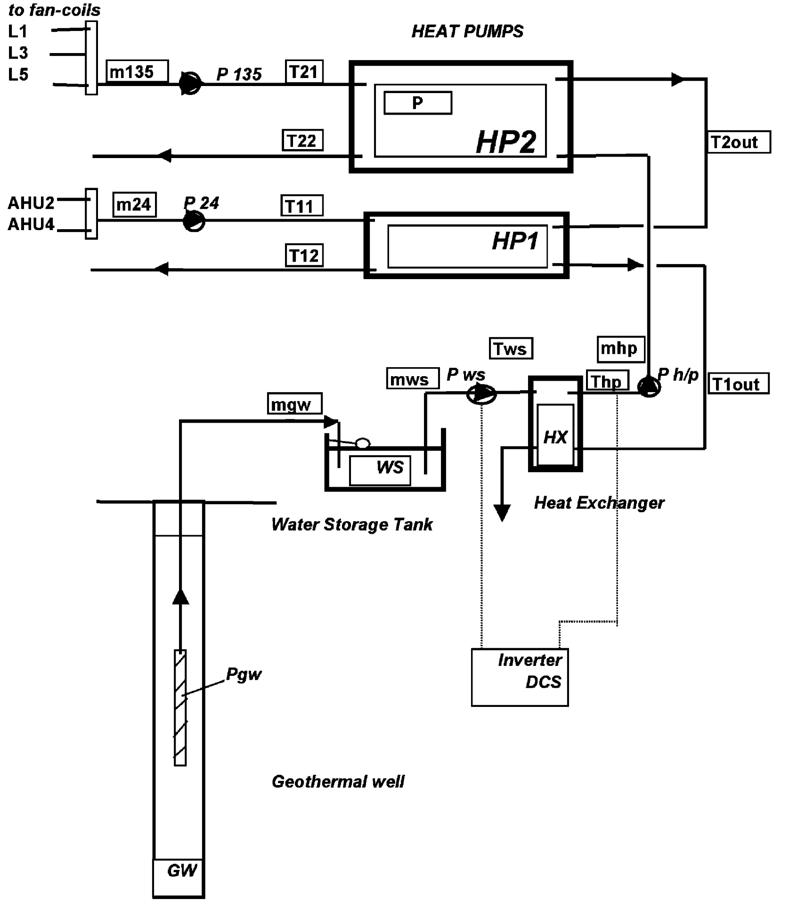

Fig. 1. Layout of geothermal heat pumps system and measuring points.

In addition, the ΔT is monitored and controlled by the control system in order to avoid freezing and overheating conditions.

The two heat pump units, HP1 (of 70 kW nominal capacity) and HP2 (of 100 kW nominal capacity), are both water-to-water type, electrically driven. The first unit (HP1) serves the auditorium and the classrooms of the ground floor of the main building through an all-air system (air handling units). The second unit (HP2) serves the offices and the library facility of the main building, as well as the guest-house (hostel), with the aid of a hydraulic system (fan coils).

The air handling units comprise a return fan section, a double mixing box, a diverting 'solar' mixing box, a coil section with a dual purpose heating/cooling coil, a spray humidifier for winter application, bag filters, a supply fan section, as well as an air to air heat recovery section. Both fans have been designed for two speed operation because winter load is much less than the summer one and winter mode is operated with half airflow rate (the supply air temperature then can take values in the comfort zone).

The diverting 'solar' mixing box is connected to 45 m^2 solar air collectors through a 350 mm insulated air duct for solar energy utilization as well. The solar energy input to the air handling units is presented schematically in Fig. 2. This mixing box diverts the air mixture flow to bypass the collector during summertime. Then relief dampers have been foreseen for the protection of the collector against overheating. During winter, the same diverting 'solar' mixing box regulates the diverting airflow so that the airflow through the collectors achieves positive ΔT.

The source/rejection sides of the two heat pumps (Fig. 1) are connected in series upon a single water loop, in which a plate heat exchanger represents the source of the required amount of thermal energy. An open loop animated by one pump and fed with water from an open concrete and insulated storage tank of 70 m^3 volume, receives the thermal energy of the previous loop for rejection. The tank is also constantly fed by another open loop driven by a submerged stainless steel pump, inside the geothermal well. Both last open loops circulate saline groundwater through the titanium plate heat exchanger. The storage tank is needed for back up reasons. This autonomy rises up to 6 h (at peak load conditions). For water saving reasons, an inverter driven control system (IDCS) reduces the pumping energy consumption at partial load conditions of the system. This same control protects the heat pumps against freezing and overheating, in case wellhead temperature rises above its present value of 24 $^\circ$C after long term production of groundwater.

During wintertime, both heat pumps operate in the heating operation mode, absorbing heat from the source (rejection in summer) closed loop. In order to maximize energy efficiency, the water pump feeding the heat pumps through this water loop, feeds the unit HP2 in priority. As a result, HP2, which is larger and operates more hours yearly, operates with higher COP. Therefore, the HP1 operates with colder evaporator, while HP2 in priority, operates with warmer evaporator and higher COP. Nevertheless, instead of 24 $^\circ$C, the temperature of the water circulating within the closed loop is controlled and kept at a lower temperature. The maximum value of this lower temperature is controlled at 18 $^\circ$C; the water is then supplied to the HP2 entry (scroll compressor technologies of both heat pumps

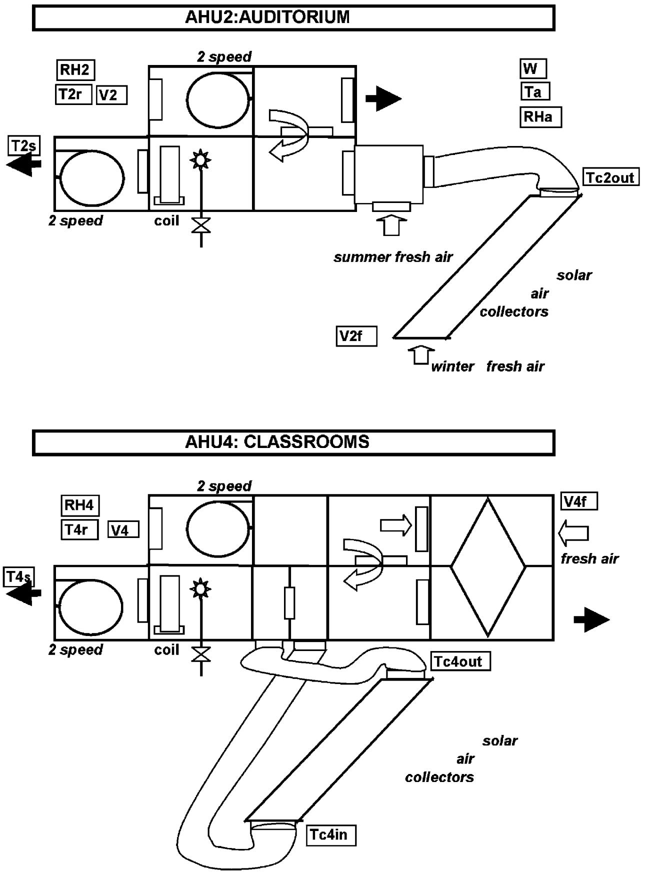

Fig. 2. Layout of air handling units (solar energy input) and measuring points.

cannot afford higher evaporating temperatures). For energy efficiency purposes, the temperature set point during wintertime has been set at the maximum allowable value, which is 18 °C.

During middle-seasons it can happen that both heating is needed in the HP2 system and cooling in the HP1 system, because of the high latent load inside the classrooms and the auditorium. In this case, the closed loop, assisted by the inverter open loop, can integrate opposite thermal loads.

The hostel of the building requires hot water supply, which is provided by solar water heaters.

3. Measuring points and equipment

The measurement points of the heat pumps system (geothermal energy) are presented in Table 1 and their locations in Fig. 1. The ones of the air handling units

Table 1
Measuring points at the geothermal heat pumps loops (see also Fig. 1)

		Same as:
	HP2	
T_{21}	Inlet temperature to HP2, load side	
T_{22}	Outlet temperature from HP2, load side	
T_{2out}	Outlet temperature from HP2, source side	Inlet temperature to HP1, source side
$\dot{m}_{135}$	Water mass flow rate, load side	
P	Electric energy absorbed by all HVAC system components and accessories	
	HP1	
T_{11}	Inlet temperature to HP1, load side	
T_{12}	Outlet temperature from HP1, load side	
T_{1out}	Outlet temperature from HP1, source side	Inlet temperature to the HX, water side
$\dot{m}_{24}$	Water mass flow rate, load side	
	H/X	
$T_{h/p}$	Supply temperature to the heat pumps	Outlet temperature from the HX, water side, inlet temperature to the HP2 source side
$\dot{m}_{h/p}$	Water mass flow rate of the heat pumps, source side	
	WS	
T_{ws}	Temperature of the water storage	Inlet temperature to the HX, groundwater side
$\dot{m}_{ws}$	Groundwater mass flow rate leaving the storage	
$\dot{m}_{gw}$	Groundwater mass flow rate from the geo well feeding the storage	

(assisted by solar and geothermal energy) are presented in Table 2 and their locations in Fig. 2.

From the measuring points described in these tables and figures, the following ones, with the exception of $\dot{m}_{ws}$ and $\dot{m}_{gw}$, present constant values and they have been monitored once a day and periodically throughout the day:

- Group A (water mass flow rates): $\dot{m}_{135}$, $\dot{m}_{24}$, $\dot{m}_{h/p}$, $\dot{m}_{ws}$, $\dot{m}_{gw}$;
- Group B (air volume flow rates): $\dot{V}_2$, $\dot{V}_{2f}$, $\dot{V}_4$, $\dot{V}_{4f}$.

The remaining variables of groups C, D, E and F have been monitored almost real time, namely every 5 min:

- Group C (temperatures): T_{21}, T_{22}, T_{2out}, T_{11}, T_{12}, T_{1out}, $T_{h/p}$, T_{ws}, T_a, Tc_{2out}, T_{2s}, Tc_{4out}, Tc_{4in}, T_{4s};

Table 2
Measuring points at the solar assisted air handling units (see also Fig. 2)

	Ambient
W	Global solar radiation
T_a	Ambient temperature
RH_a	Ambient humidity
	AHU2
Tc_{2out}	Outlet temperature of the solar collector of the AHU2
T_{2r}	Room temperature of the zone of the AHU2
RH_2	Room humidity of the zone of the AHU2
T_{2s}	Supply air temperature of the AHU2
$\dot{V}_2$	Air volume flow rate of the AHU2
$\dot{V}_{2f}$	Fresh air volume flow rate of the AHU2
	AHU4
Tc_{4out}	Outlet temperature of the solar collector of the AHU4
Tc_{4in}	Inlet temperature of the solar collector of the AHU4
T_{4r}	Room temperature of the zone of the AHU4
RH_4	Room humidity of the zone of the AHU4
T_{4s}	Supply air temperature of the AHU4
$\dot{V}_4$	Air volume flow rate of the AHU4
$\dot{V}_{4f}$	Fresh air volume flow rate of the AHU4

- Group D (indoor conditions): T_{2r}, RH_2, T_{4r}, RH_4;
- Group E (power consumption): P;
- Group F (solar energy): W.

The sensor technology applied during the monitoring of the above group of variables is described in Table 3.

4. Results of the energy performance of the system

In order to evaluate energy performance, the system operation was monitored under the following conditions:

Table 3
Measuring equipment technology

Group	Sensor technology	Remarks
Group A	Electromagnetic flow meter	Checks with pumps Δp
Group B	Propeller air flow meter	
Group C	Temperature sensors based Pt100	Via BEMS
Group D	Dual sensor based transistor	Via BEMS
Group E	3Ph energy totalizer	Via BEMS
Group F	Pyranometer	

- One day with heating load was selected among several heating days of continuous monitoring.
- Both HP2 and HP1 operated in the heating mode.
- The HP1 supplied the auditorium operating with the AHU2 facility only.
- The fresh air (AHU2) supply was fixed to <50% of the maximum load.
- The free cooling mode of the AHU2 (from the BEMS menu) was disabled.
- The critical temperature set point of the value $T_{h/p}$ has been set at the default winter value MAT = 18 °C.

The measurements of the constant parameters and of the groundwater mass flow rate $\dot{m}_{ws}$ are listed in Table 4.

The measurements of the input and output temperatures of the air entering and leaving the solar collectors during the selected day of operation are presented in Fig. 3. The thermal power delivered by the solar collectors has been calculated using the equation:

$$P_{solar} = \rho_{air}\dot{V}_{2f}c_{p_{air}}(Tc_{\ 2out} - T_a),$$

where ρ_{air} and c_{pair} are the density and specific heat of the air, respectively. The results are presented in Fig. 4.

The temperatures at the points of measurements of the heat pumps water loops are presented in Fig. 5. The geothermal energy contribution to the heat pumps has been calculated using the equations:

$$P_{HP1} = \dot{m}_{h/p}c_{pw}(T_{2out} - T_{1out})$$

$$P_{HP2} = \dot{m}_{h/p}c_{pw}\left(T_{h/p} - T_{2out}\right),$$

where c_{pw} is the specific heat of the water. The results are presented in Fig. 6.

Overall electricity consumption P including all HVAC equipment, namely the heat pumps, the water pumps and all air fans (air handling units and fan coils), has been measured through the Building Energy Management System (BEMS).

The contribution of solar energy, geothermal energy and electricity to the building energy balance is shown in Fig. 7. The mean daily energy efficiency of the heat pumps expressed as net coefficient of performance (net COP = daily energy output over overall daily electricity input) and of the solar collectors (η = daily energy output over daily solar radiation) are listed in Table 5.

Table 4
Measured values of constant parameters and $\dot{m}_{ws}$

	$\dot{V}_2$	$\dot{V}_{2f}$	$\dot{V}_4$	$\dot{V}_{4f}$	$\dot{m}_{135}$	$\dot{m}_{24}$	$\dot{m}_{h/p}$	$\dot{m}_{ws}$
m^3/h	2.300	1.800	0	0	26.00	15.00	19.50	18.20
kg/s	(0.805)	(0.63)	0	0	7.22	4.17	5.42	5.06

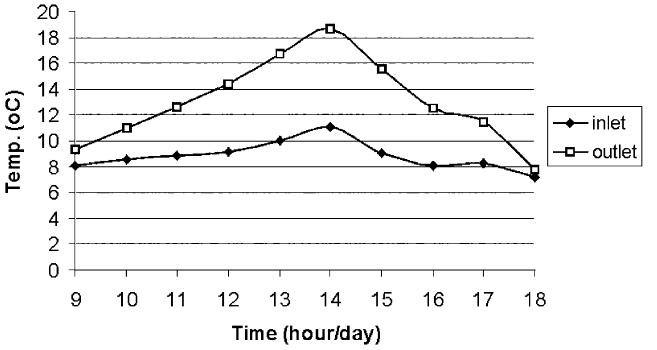

Fig. 3. Hourly solar collectors performance in terms of airflow temperature measurements.

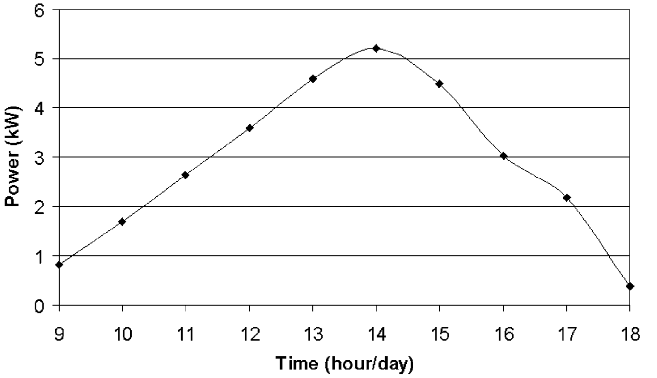

Fig. 4. Hourly energy output of the solar collectors.

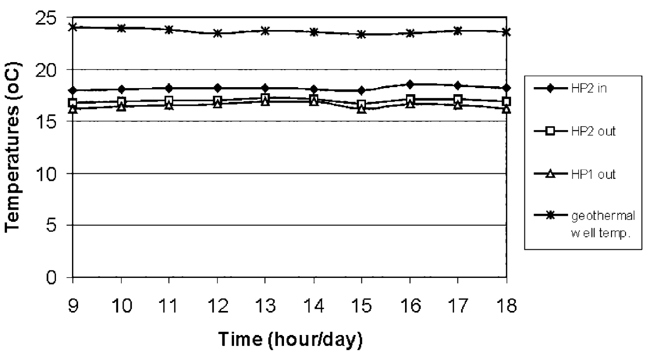

Fig. 5. Hourly temperatures in the heat pumps loop at measuring points.

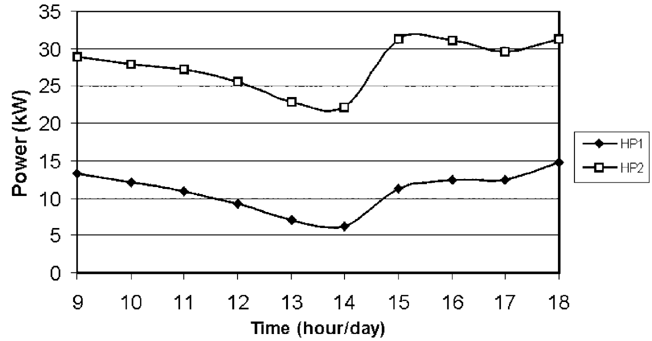

Fig. 6. Hourly geothermal energy input to the heat pumps.

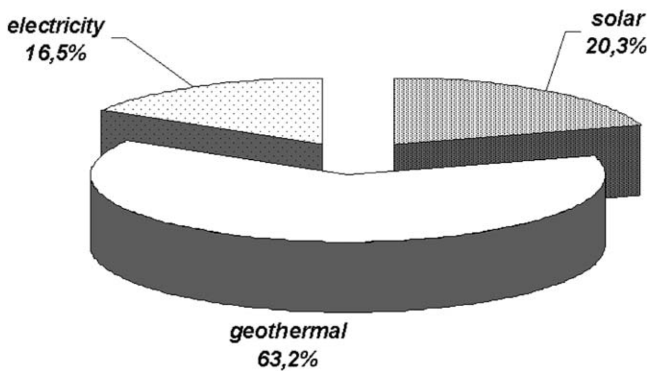

Fig. 7. Share of geothermal energy, solar energy and electricity to the building energy consumption.

Table 5
Energy performance of the heat pumps and the solar collectors

Date	Heat pumps		Solar collectors
	Net COP of HP1	Net COP of HP2	η-meanday
08-02-2001	3.91	4.3	0.395

5. Conclusions

The heating and cooling system of the building of the European Centre for Public Law in Legraina near Athens, Greece, demonstrated the technology of combining solar energy with geothermal energy, in particular the integration of solar air collectors to a geothermal heat pumps system used for the heating and cooling of buildings. Measurements during a winter's day and calculations performed, proved that solar energy can effectively contribute to the energy balance of the building, increasing the overall share of renewable energy use.

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