USE OF GEOTHERMAL ENERGY AND SEAWATER FOR HEATING AND COOLING OF THE NEW TERMINAL BUILDING IN THE AIRPORT OF THESSALONIKI

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INTRODUCTION

Following promising results of the recent geothermal exploration in the region next of the airport "Makedonia" of Thessaloniki, the Civil Aviation Authority of Greece, which is responsible for managing the airport, will drill a deep (up to 800 m) geothermal borehole within the premises of the airport, in order to investigate and exploit local geothermal potential for heating and cooling the new terminal building. The energy needs of the building have been estimated as 8 MW_t and 16,800 MWh for heating (Mendrinos, et al., 2003). The cooling needs of the building may be even higher.

GEOLOGICAL AND GEOTHERMAL BACKGROUND

The airport "Makedonia" is located a few kilometres south of the city of Thessaloniki on the coastline of Thessaloniki's bay (Figure 1), within the basin of Anthemountas, which is a recent tectonic depression filled with younger sediments forming an extension to the wider basin of Thessaloniki-Thermaikos. The extent of the Thessaloniki-Thermaikos basin is shown in Figure 2. According to Fytikas and Papachristou (2003) the stratigraphy of the region comprises: a) volcanic (dounites and peridotites) and/or metamorphic rocks with intense fracturing (Gabbros

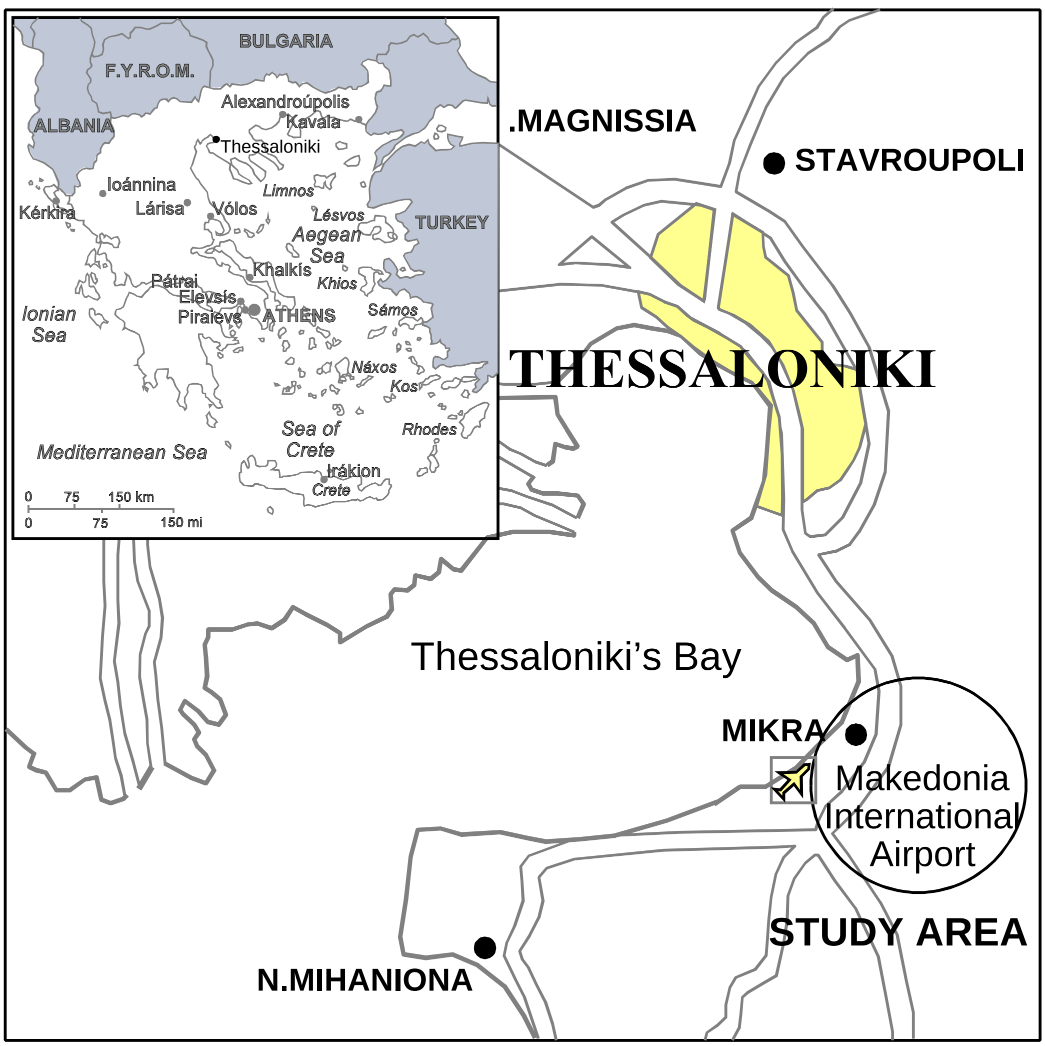

Figure 1. Map of the study area.

and gneiss) of the basement encountered at around 1000 meters depth, b) the base conglomerate, c) Pliocene marine sandstones and green clays with limestones intercalations; river and lake sediments with lenses and layers of sand, silt, sandstones, marls, marly limestones and red-layers, d) Quarternary deposits of red silt, sand, conglomerates and breccias, and e) younger sedimentary deposits of terrestrial origin.

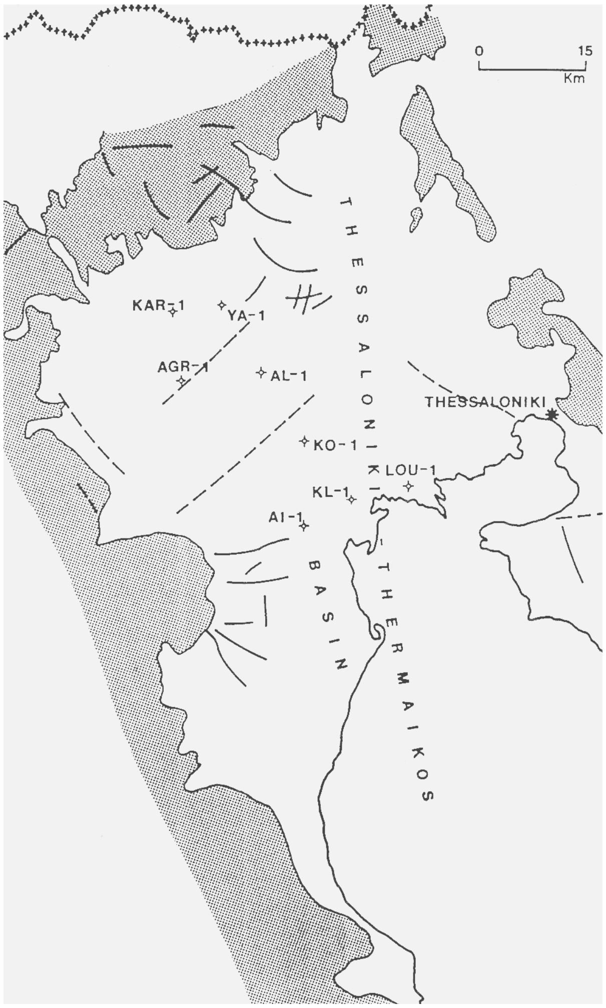

Figure 2. ***Extent of the Thessaloniki-Thermaikos Basin (Karytsas, 1990).***

The geological cross section, corresponding to the upper stratigraphy of the basin, of the slim exploratory well drilled in the vicinity of the airport is presented in Figure 3.

Recent geothermal research in the region undertaken by the Institute of Geological and Mineral Research of Greece indicated the presence of 42ºC artesian water at 550m depth below the ground surface. According to geological and geophysical data, the warm permeable horizons extend between depths of 550 - 1000 m (Fytikas and Papachristou, 2003). As a result, we conclude that a deeper borehole having an 8-in. production casing may well yield a sustainable flow of 75 m^3/h water with temperature of at least 42ºC.

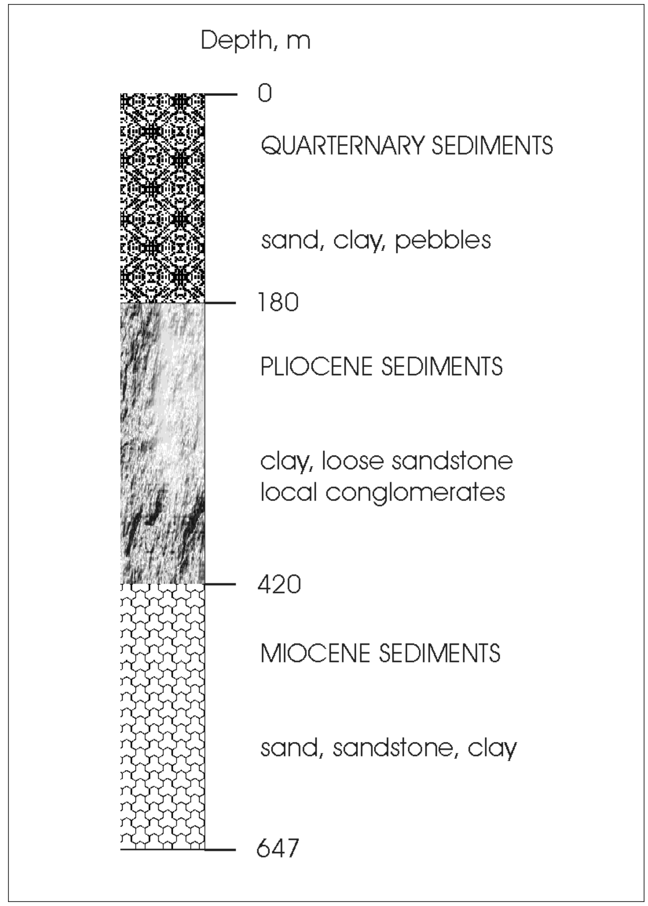

Figure 3. ***Stratigraphy of the area as indicated by deep exploratory drilling in the vicinity of the airport (reconstructed from Fytikas and Papachristou, 2003).***

THE PROPOSED HEATING AND COOLING SYSTEM

Due to the need for providing both heating and cooling to the new terminal building, we propose a hybrid system utilising both seawater and geothermal fluids. Its layout is presented in Figure 4.

In order to maximize temperature drop and geothermal energy output from a given flow rate, we propose the geothermal fluid to feed a water source heat pump. Similar heating and/or cooling systems using groundwater or seawater coupled with water source heat pumps have been constructed or planned for several locations in Greece. These include the heating and cooling of municipal and other public buildings in the Municipality of Langadas (Mendrinos, et al., 2002b), the heating and cooling of the Mining-Electrical Engineering Building of the NTUA campus (Karytsas, et al., 2002). Other buildings include the Educational Centre in Legraina, Attica, the new CRES office building in Pikermi, the office building of Thenamares Ship Management in Kavouri, Athens and the new Concert Hall of Thessaloniki (Mendrinos, et al., 2002a).

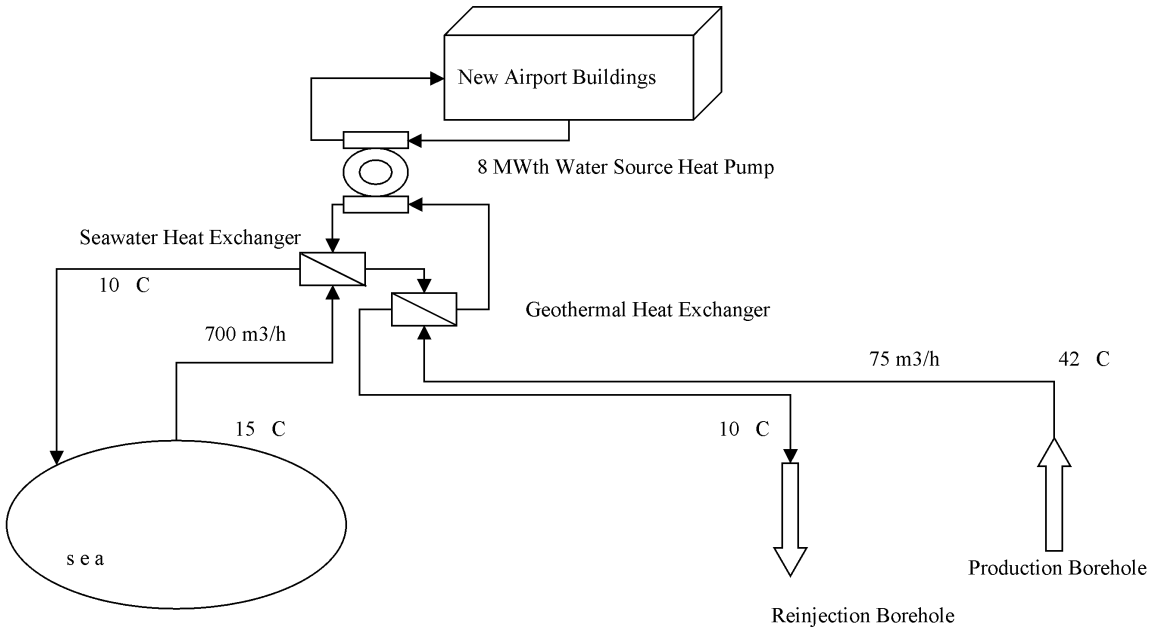

Figure 4. ***Geothermal and seawater system coupled with water-source heat pumps for heating and cooling of the new terminal building of the airport of Thessaloniki "Makedonia." This system can supply the buildings with 8 MWt of heating and 7 MWt of cooling.***

Assuming production temperature slightly over 42ºC for the geothermal water, its direct use from one production borehole would correspond to a maximum 5ºC temperature drop or 435 kW only a very small amount compared with the 8000 kW_t needed for the heating of the building.

Our proposal for the buildings heating and cooling system combines one or more water-source heat pumps of total rated power 8 MW_t, using as heat sources during the winter period both 42ºC geothermal water and seawater of 15ºC. We propose to use one production and one reinjection borehole in order to minimize capital costs associated with the boreholes drilling and completion, and maximize the load factor of the geothermal system. The maximum temperature drop of the geothermal circuit will amount to 32ºC, which corresponds to reinjection temperature of 10ºC at peak load. The energy transfer to the heat pumps by the geothermal water and the seawater will take place with the aid of two separate plate heat exchangers. The heat pumps will be fed by the geothermal water in first, in order to maximize water input temperature at the evaporator of the heat pumps and as a result, their energy performance.

During the summer period, the water-source heat pumps will provide cooling and will use 25ºC seawater as a heat sink.

The geothermal fluid supply system components will include one production and one reinjection well, each one 800 m deep with about an 8 inch inner casing, insulated buried transmission piping of 10-in. diameter, plate heat exchanger, submersible production pump of 70 hp producing 75 m^3/h flow from 100m water level within the production well, frequency modulator (inverter) and temperature sensors for flow regulation.

The seawater supply system may include 60 - 120 shallow wells each 10 - 20 m deep, or alternatively two trenches 400 m^3 each excavated within the sand at 1 m distance from the waterside, equipped with pumps of total power of 100 hp for 700 m^3/h total flow, buried transmission lines, plate heat exchanger, as well as inverter(s) and temperature sensors for flow regulation. During the cooling mode, the geothermal system will remain out of operation, with seawater only serving as the heat sink for the heat pumps. In that case, the seawater can absorb all 8 MW of heat rejected by the heat pumps, which corresponds roughly to 7 MW of cooling within the buildings. The temperature difference of the seawater will be approximately 5ºC in heating mode during winter and 10ºC in cooling mode during summer.

In the peak heating mode, the water circuit feeding the evaporators of the heat pumps, will gain 3.4ºC from the seawater heat exchanger and 2.2ºC from the geothermal heat exchanger and will enter the evaporators at 10ºC. The corresponding flow rate will be approximately 1100 m^3/h requiring water pumps of power equal to 150 hp. In all other cases of the heating mode, the automation controls will ensure that the geothermal system operates at full power and that only the additional energy required will be provided by the seawater. In that case, the temperature of the evaporators circuit can be relaxed to higher values close to the upper limits allowed by the heat pump manufacturer (e.g., 18ºC), in order to increase the energy efficiency of the heat pump. The water circuit connected to the heat pumps condensers will require flow rate of 1,250 m^3/h and pumps of 170 hp.

A power substation able to supply 2.6 MWe of useful electricity should be installed, in order to supply the electricity needed for the heat pumps, the pumps, the fan-coils and the fans of the heating and cooling system.

ENERGY BALANCE

One geothermal production borehole yielding 75m^3/h and 42ºC corresponds to 3.25 MW$_{th}$ heat pumps output in heating mode and can cover 12,960 MWh of heating, or 77% of heating needs. The remaining 3,840 MWh, or 23% of heating needs will be provided to the heat pumps by the seawater, which will cover the peak loads. The energy output of the heat pumps in the heating mode corresponding to geothermal water and seawater is presented in Figure 5.

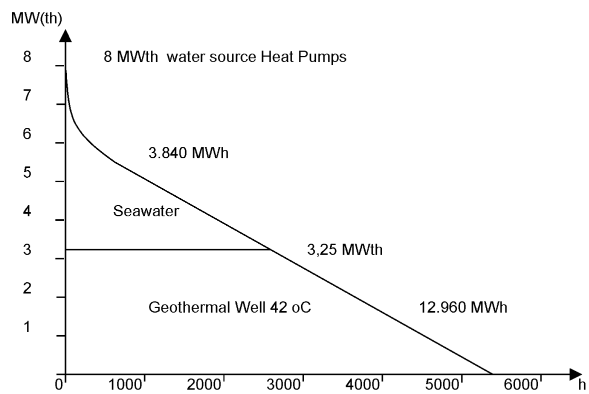

Figure 5. Energy output of the water-source heat pumps for heating throughout the year according to the heat source (geothermal water or seawater) feeding the heat pumps.

The main energy sources for the heating of the new terminal building are: a) geothermal energy included in the 42ºC groundwater, b) thermal energy released by seawater while dropping its temperature from 15 to 10ºC, and c) electricity supplied to the water source heat pumps. During summer, seawater serves as the heat sink of the thermal energy pumped out of the buildings. The main operating parameters are summarised in Tables 1 and 2 and the resulting energy balances are presented in Tables 3 and 4. The corresponding load factors are shown in Table 5.

The higher COP of the heat pumps during cooling operation is attributed to the prevailing lower temperature difference between the temperatures of the evaporators and the condensers. The net SPF (seasonal performance factor) of the system for all-year-round operation, taking into consideration the electricity consumed by the geothermal and seawater supplying submersible pumps, the water circulating pumps in the heat pumps and building loops, and the fans of the air handling units and the fan coils has been estimated at SPF=4.3. This value is approximately 50% higher than that of an air-source heat pumps. Electricity consumed by the heat pumps corresponds to 95% of electricity input and the remaining 5% corresponds to all pumps and fans. The prerequisite for this low power consumption to the pumps and fans is flow control by frequency modulators (inverters) and centralized energy management system.

Net annual energy savings of the geothermal-seawater energy system correspond to 13,150 MWh for heating (1,400 TOE), plus 7,500 MWh for cooling (800 TOE), totalling 2,200 TOE each year. The corresponding CO_2 emissions reductions have been estimated as 7,040 tons annually.

EXPECTED FINANCIAL PERFORMANCE: ENERGY COSTS TO THE END USER

The cost estimation of the proposed investment and its breakdown to major components of the project are presented in Table 6. Geothermal production network corresponds to 9% of the overall investment, the reinjection network to 8%, the seawater supply to 18%, the heat pumps to 35% and the building heating and cooling system to 31%.

The financial analysis of the project in terms of final energy (both heating and cooling) delivered to the end user, with or without reinjection, is presented in Table 7. The assumptions for the calculations are 5% cost of money (discount factor), and 20-yr amortization period of the investment.

Three different costs of energy have been calculated averaging both heating and cooling delivered to the building. The first one (0.0323 - 0.0337 $/kWh) corresponds to overall system costs including the amortization of the low-temperature heating and cooling system within the building itself.

Table 1. Heating and Cooling System of the New Terminal Building: Operating Parameters in Heating Mode

	Tin ºC	Tout ºC	Max. Flow m^3/h	Averave Flow m^3/h	Hours of Operation
Geothermal	42	10	75	58	5400
Seawater (winter)	15	9.64	700	212	2600
Evaporators	10	4.5	1119	434	5400
Condensers	45.5	40	1255	487	5400

Table 2. Heating and Cooling System of the New Terminal Building: Operating Parameters in Cooling Mode

	Tin °C	Tout °C	Max. Flow m^3/h	Averave Flow m^3/h	Hours of Operation
Evaporators	12.5	7	1119	559	2700
Condensers	39	33.5	1243	621	2700
Seawater (summer)	25	34.77	700	350	2700

Table 3. Heating and Cooling System of the New Terminal Building: Energy Balance in Heating Mode

	Power kW	Energy MWh	Energy %	Equivalent Energy MWh
Geothermal	2,787	11,551	62	12,960
Seawater	4,356	3,424	18	3,842
Geothermal & Seawater (approximately equal to the evaporators circuit)	7,143	14,975		16,802
Electricity	1,742	3,653	20	
Total Energy Input	8,885	18,826	100	
Thermal Losses	-871	-1,826	-10	
Heat Delivered to the Buildings (condensers circuit)	8,014	16,802	90	
Heat Pumps COP	4.6	4.6		

Table 4. Heating and Cooling System of the New Terminal Building: Energy Balance in Cooling Mode

	Power kW	Energy MWh
Cooling Energy Delivered to the Building (evaporators circuit)	7,143	9,643
Electricity	1,587	2,143
Thermal Losses	-794	-1,071
Condenser Circuit	7,937	10,715
Seawater	-7,937	-10,715
COP	5.0	5.0

Table 5. Load Factors of the Geothermal System, The Seawater System and the Heat Pumps

	Geothermal	Seawater	Heat Pumps
Heating	0.47	0.09	0.24
Cooling	-	0.15	0.15
Total	0.47	0.24	0.39

Table 6. Geothermal & Seawater Heating and Cooling System of the New Terminal Building: Capital Costs

	Amount	Cost Euros
Geothermal Energy Network		
Production Well	800 m depth, 8 in.	296,000
Piping and Fittings	2,000 m	180,000
Pumps and Inverters	1 submersible 70 hp	17,500
Miscellaneous *	10%	49,350
Total Without Reinjection		**542,850**
Reinjection Well	800 m depth, 8 in.	296,000
Piping and Fittings	1,000 m	90,000
Heat Exchangers	Ti Plate 100 m^2	45,000
Miscellaneous *	10%	43,100
Total With Reinjection		**1,016,950**
Seawater Network		
Seawater Wells	10 - 20 m each, 1,200 m depth total	162,000
Piping and Fittings	2,000 m	540,000
Pumps and Inverters	1 per well, 100 hp total	115,000
Heat Exchangers	Ti Plate 400 m^2	180,000
Miscellaneous *	10%	99,700
Total		**1,096,700**
Heat Pumps		
Heat Pump Units	8,000 kW	1,600,000
Pumps, Inverters, Etc.	Centrifugal 150 hp	37,500
Power Supply	2,600 kW net	65,000
Civil Engineering	Engine house 400 m^2	240,000
Miscellaneous *	10%	194,250
Total		**2,136,750**
Low-Temperature Heating & Cooling System of the Building		
Fan Coils, AHUs	8,000 kW	840,000
Piping and Fittings	40 km	800,000
Pumps, Inverters, Etc.	Centrifugal 170 hp	42,500
BEMS	100 units	80,000
Miscellaneous *	10%	176,250
Total		**1,938,750**

* Design study, works supervision and administration expenses

Table 7. Geothermal & Seawater Heating and Cooling System of the New Terminal Building: Energy Costs

(Euros)	Without Amortization	External Networks & Heat Pumps		Overall, Including Indoor System	
Reinjection		YES	NO	YES	NO
Investment	-	4,250,400	3,776,300	6,189,150	5,715,050
Operation & Maintenance	395,750	395,750	395,750	395,750	395,750
Amortization	-	341,063	303,020	496,633	458,590
Energy Costs $ per kWh	0.0150	0.0279	0.0264	0.0337	0.0323

The second includes only the amortization of the external system delivering heat or cool to the building, including the heat pumps and excluding fan-coils, air handling units (AHUs), air ducts, piping, etc. These values of 0.0264 $/kWh (without reinjection) and 0.0279 $/kWh (with reinjection) are competitive to natural gas and diesel sale prices prevailing in Greece. The corresponding energy costs for about a 10 MW_t district heating system of more than 1,000 dwellings in Traianoupolis near Alexandroupolis in North Greece utilising geothermal fluids of 53 - 92ºC temperature, have been estimated as 0.024 US $/kWh by Karytsas, et al. (2003).

The third value of 0.0150 $/kWh, which corresponds to the running costs of the system comprising mainly of the electricity consumption of the heat pumps, is approximately 40% lower than the sale price of natural gas and diesel oil in Greece.

CONCLUSIONS

A combined geothermal and seawater system coupled with water-source heat pumps can effectively provide heating and cooling to the new terminal building of the airport of Thessaloniki "Makedonia." The system is characterised by high energy efficiency and competitive costs.

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