INTERNATIONAL SUMMER SCHOOL
on Direct Application of Geothermal Energy

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HEATING AND COOLING OF THE MINING – ELECTRICAL ENGINEERING BUILDING AT THE NTUA CAMPUS WITH GEOTHERMAL HEAT PUMPS

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ABSTRACT

The heating and cooling demands of a University building at the National Technical University of Athens (NTUA) Campus in Zografou Athens, amounting respectively at 1000 kW_{th} and 700 kW_C, are partially covered by a geothermal heat pump system (Interklima), which combines heat pumps fed by both groundwater and a field of vertical earth heat exchangers (VEHEs). These systems, respectively, utilize the thermal energy content of the ground water and of the rocks present in the shallow earth adjacent to the building.

The project was supported by the THERMIE programme (Project BU.468.94. HE) with CRES being the project coordinator.

Combining both groundwater and earth heat exchangers, required a special design configuration, which was accomplished through two plate heat exchangers.

The groundwater provides 234 kW_{th} of thermal energy to Heat Pump Unit 2 through the first heat exchanger, plus an additional 62,5 kW_{th} to the water circulating within the VEHEs and the evaporator of Heat Pump Unit 1, through the second heat exchanger. The 13 VEHEs provide 76.5 kW_{th} to the Heat Pump Unit 1.

The Geothermal Heat Pump system provides a total of 526 kW_{th} of heating at the condensers of the heat pumps and 461 kW_C of cooling at the evaporators. Of these 373 kW_{th} of heating is provided through heat exchanging, from the earth during the heating period in the winter, whereas the earth is furnished with 598 kW_{th} during the cooling period of the summer.

Integration of the geothermal heat pumps into the building heating system did not encounter any problems, as the building was already equipped with fan-coils.

After the water leaves the plate heat exchangers, it is either returned into the ground through a reinjection borehole, or it is used for irrigation purposes.

The total energy production and saving achieved by the unit operation is 60 Tonnes Oil Equivalent (TOE)/year produced/substituted for heating and 46,2 TOE/year saved from cooling. The estimated simple payback period of the innovation compared to the conventional systems is 9,11 years.

1. INTRODUCTION

The aim of this project is to provide heating and cooling to a University building in the campus of the National Technical University of Athens by means of water-source heat pumps utilising geothermal and solar energy stored in the shallow earth and provided by groundwater (Ground-source Heat Pump systems GSHPs) and vertical earth heat exchangers (VEHEs - Ground-coupled Heat Pump systems GCHPs).

The main scope of this project is the application of a heat pump system utilizing clean and environmentally friendly ground and solar energy with a rather high energy efficiency at a relative cost effective way. The efficiency of GCHP/VEHE systems is over 50% higher than conventional air-driven air conditioning systems (for heating and cooling) showing Coefficient of Performances (COPs) as high as 4 (compared to average 2.2 for the conventional air conditioning systems).

It has been proven that the temperature of soil or ground water below the earth's surface does not fluctuate significantly through time, although it gradually increases with progressing depth (geothermal gradient). Ground temperatures, a few meters below the surface, have been found to be constant all around the year (at a depth of 5 m fluctuations of only 1°C are very rarely encountered and below the depth of 8 m practically no seasonal variation is further encountered).

In medium latitudes, like our site in Athens, all ground-source heat pump configurations can provide the necessary energy both for heating and cooling.

The heating and cooling demands of a University building at the National Technical University of Athens (NTUA) Campus in Zografou Athens, amounting respectively to 1000 kW_{th} and 700 kW_{th}, will be *partially* covered by a *Geothermal Heat Pump system* which combines a *Ground-source Heat pump system* with a *Ground-coupled Heat pump system*. These systems, respectively, utilize the thermal energy content of the ground water and of the rocks present in the shallow earth adjacent to the building.

A 280m deep productive borehole yielding an optimum of 35m^3/h of groundwater and thirteen (13), 90 m deep, Vertical Earth Heat Exchangers (VEHEs) will supply the necessary thermal energy at a temperature of about 18-22°C, which by means of water - source heat pumps will be transformed to heating (45 to 47°C water) and cooling energy (6°C water) appropriate to *partially* cover the energy demands of the Mining Engineering – Phase 2 (namely Mining - Electrical Engineering Building) of the NTUA, for simplicity mentioned from now on as the "target" Building.

More precisely, the total *Geothermal Heat Pump system* provides 526 kW_{th} of heating to the condensers of the heat pumps and 461 kW_{th} of cooling to the evaporators. Of these

373 kW_{th} of heating is provided, through heat exchanging, from the earth during the heating period, in the winter, whereas the earth will be furnished with 598 kW_{th} during the cooling period of the summer.

The *Vertical Earth Heat Exchanger System* (VEHEs) is designed and constructed in such a way as to create a seasonal ground energy storage disposable for the needs of the building. In other words the earth close and between the VEHEs will act as a heat source during the heating season (winter) and as a heat sink during the cooling season (summer).

2. DESCRIPTION OF THE SITE

The site where the innovative *BU.468.94.HE project* is applied is the Mining Engineering Building phase 2 of the NTUA (known as the Mining – Electrical Engineering Building) for simplicity also mentioned in this report as *the "target" Building.*

The "target" Building is located in the southeast sector of the Campus of the National Technical University of Athens in Zografou. Zografou is a suburb of Athens, located in the Eastern side of Athens (4 km from Athens' center) on the lower slopes of Mt. Imitos (see Photo 1).

3. DESCRIPTION OF THE INSTALLATION

The installations of the BU.468.94.HE project consist of the following parts which will be described in the following paragraphs. The installation consists of the following parts (see FIGURE 1):

1) The ground system, which offers its energy to the building, consisting of the productive borehole (the GSHP system) and the VEHEs (the GCHP system);

2) The water transportation and water collector/distributor system;

3) The water-source Heat pumps;

4) The connecting piping system from the Engine Room to the "target" Building;

5) The Engine-room (40 m south-southeast of the "target" Building) and the

adapted connection with the consumer in the "target" Building.

All parts have been constructed, manufactured, assembled and erected specifically for the BU.468.94.HE project. The entire installation has been thoroughly tested for its correct operation.

3.1. The Ground-source Heat Pump System

The Ground-source system (open-loop) at the NTUA is connected to the production borehole.

This Ground-source Heat pump system utilizes the energy content of the aquifer confined within the Upper Marble formation of Mount Imitos (from the depth of 200 to 270 m). The GSHP system is comprised of the following main parts:

- The production borehole
- The production water pump
- The short length transportation pipe system
- The connection to the Ground-coupled system through Plate Heat Exchanger 1
- Plate Heat Exchanger 2
- The water source heat pump system, Heat Pump Unit 2
- A water tank (for storage during summer irrigation period)
- A reinjection well (future extension)

The technical specifications of the geothermal water pump are given in the following table:

Water pump manufacturer	CALPEDA
Type of pump rotor	8 SDS – SUBMERSIBLE MOTOR PUMP
Nominal Power Consumption of Motor	60 HP
Nominal Head Pressure	262 m
Optimal Capacity	35 m^3/h
Speed	2900 rpm
Water Pump Performance Rate	Approx. 65%

The water transportation piping from the production borehole to the entrance of the Engine-room has a total length of 150m. It is plastic with a diameter of _ 200, withstanding a pressure of 10 atm. The pipe system has been placed in a trench at depths of 0.8 to 1.2 m.

3.2. The Ground-coupled closed loop – VEHE system

The Ground-coupled heat pump system designed and installed for the BU.468.94.HE project is comprised of **13** *Vertical Earth Heat Exchangers* (VEHEs) which have been drilled to a depth of 90m.

Each VEHE is comprised of a 8_" borehole, cutting through marls, sandstones, conglomerates, schists and marble, drilled to a depth of 90m in which a closed loop system has been placed, consisting of 2 plastic High Density Polyethylene of _32 (HDPE 32mm) tubes with nominal pressure of 16 atm, have been placed with a certain configuration inside the VEHE borehole (see Figure 2 and Photo 2).

The space between the U-tube and the borehole walls is filled with a mixture of sand, cement and bentonite for protection and stabilization, as well as for facilitation of heat transfer between the earth and the U-tube. The operation of the VEHE is based in the continuous circulation of a coolant (water plus anti-freeze).

The tubes start from the exit of the distributor in the Engine-room running all the way to the entrance of each VEHE (distances of 10 to approx. 60m, depending on the position of each VEHE in respect to the Engine-room) and continue towards the entrance of the collector system in the Engine-room (collectors/ distributors see Photo 3). The coolant is circulated into each VEHE extracting thermal energy from the ground during the winter (heating season) and providing energy to the ground during the summer (cooling season).

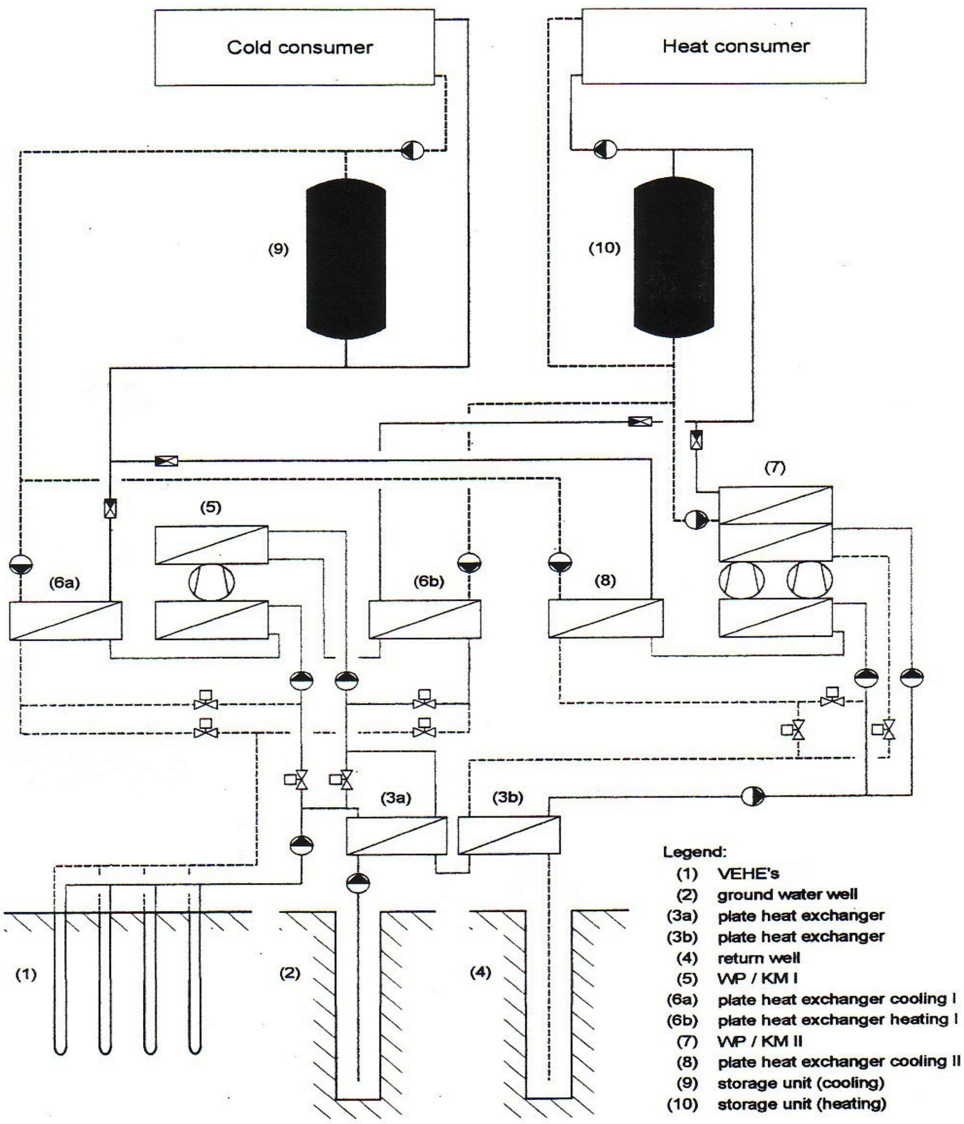

Fig. 1: Schematic diagram of heating and cooling

3.3. The Heat Exchange Stage – Energy produced and/or saved

The most crucial part of the project design and installation is the actual heat exchange which assists the transfer of ground energy (from both systems applied) to the heating/cooling devises of the building. Thus, the heat exchange phase is the interface of the innovative ground source system (groundwater well and VEHEs) with the demonstrative water-source heat pump units and the consumer's heating/cooling units (fan coils).

The transfer of heat from the ground system to the heat pumps, during the heating mode operation, and vice versa during the cooling mode operation is attained through heat exchange.

The media for heat exchange in the installation are two Plate Heat Exchangers (PHE 1 and 2). The primary circuits for both PHEs are the water from the groundwater well and from the circulating water from the VEHEs. The secondary circuits are water circulating closed-loop systems providing energy to the evaporators or condensers of the Heat Pumps.

During the cooling mode operation the entire cycle is reversed, the ground water side operating as the circuit receiving the heat from the condensers of the heat pump and storing it in the adjacent to the "target" Building subsurface. For a total overview of the position of the heat pumps in the Engine Room see Photo 4.

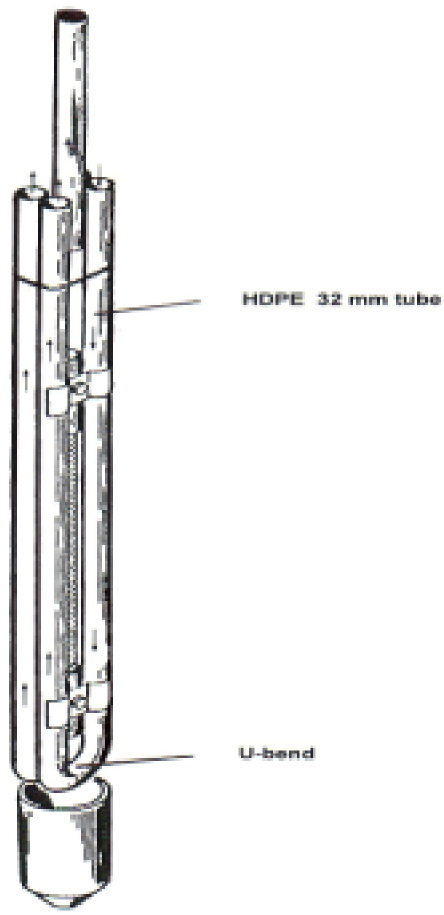

FIGURE 2: The VEHE configuration

Heating mode operation

The decisive parameters for the design and operation of the system are the *temperature difference* between the primary circuit inlet and outlet (not the actual temperature absolute value) and the *flow-rate* of the system. A temperature differentce of 5 to 10^{o}K has been determined as optimal for the operation of both units. The total energy transferred being related directly to this and the flow-rate of the primary water circuit.

The heat exchange in our system takes place as follows, taking in mind that there is a by-pass connecting system from the Ground-source to the Ground-coupled system. The ground-water passes through 2 consecutive stages of heat exchange giving its energy to supplement the heating and water-flow of the VEHES.

Initially, the ground-water gives its energy to *HEAT PUMP UNIT 2* through heat transfer in *PHE-2*. More precisely, in the case of *HEAT PUMP UNIT 2* the design foresees a *35 m^3/h flow-rate* and a *6^{o}K temperature difference* and a *95% heat transfer efficiency* providing, through heat exchange, the unit with approximately *234 kW_{th}* of thermal energy to the evaporator of the heat pump.

After this heat exchange stage (at PHE 2) the ground-water offers part of its remaining energy to the secondary circuit of *PHE 1* providing the *HEAT PUMP UNIT 1* with 45% of its required energy. More precisely, the operation of *HEAT PUMP UNIT 1* is achieved by the heat transfer of 139 kW_{th} during the heating mode, achieved with a *34.5 m^3/h flow-rate and a 4^{o}K temperature difference and a 95% heat transfer efficiency.* Of these 55% or

76.5 kW_{th} are obtained from the energy influx from the 13 VEHEs and 45% or 62.5 kW_{th} from the secondary circuit of PHE 1, providing the necessary energy for the operation of the evaporator of the heat pump.

Cooling mode operation

A temperature difference of 5 to 10°K has been considered as optimal for the design of both HEAT PUMP UNITS for the cooling mode, the total energy transferred being related directly then to the flow-rate of the primary water circuit. However, during the cooling mode operation we provide the earth with energy instead of depleting it from the earth.

More precisely, in our case the operation of *HEAT PUMP UNIT 1* is achieved, during the cooling operation mode, with a *34,5 m^3/h flow-rate* and a *5.7°K* temperature difference providing the earth with approximately *219 kW_{th}* of thermal energy *95% heat transfer efficiency* from the condenser of the heat pump (more than 55% of this thermal energy is provided to the 13 VEHEs and the remaining to the ground-water system through Plate Heat Exchanger 1).

In the case of *HEAT PUMP UNIT 2* the design foresees that a *35 m^3/h flow-rate* and a *9.8°K temperature difference* will be produced and provided to the earth in the case of reinjection or the water disposal system through Plate Heat Exchanger 2 (PHE 2) of thermal energy from the condenser of the heat pump. In this case the total thermal power output of the system is estimated to be approximately *379 kW_{th} with a 95% heat transfer efficiency*.

After the water leaves the plate heat exchanger prime circuits (PHE 1 and PHE 2) outlets it may either be reinjected into the ground (through a well or borehole) or it may be headed to a water tank entering the water supply system for further use, especially in the summer, when 50% of the water pumped from the ground-water borehole may be used for irrigation purposes.

3.4. The Water-source Heat pumps

Both water-source Heat Pumps units have been specifically designed and produced by INTERKLIMA S.A. for the BU.468.94.HE project as follows:

Heat Pump Unit 1:	Connected to the Ground - coupled system (VEHES) and receiving/giving energy from/to PHE 1
Heat Pump Unit 2:	Connected to the Ground - source system (ground water well) receiving/giving energy from/to PHE 2

Heat Pump Unit 1 has been calculated for operation with friendly to the environment refrigerant R407c, whereas Heat Pump Unit 2 has been designed to operate with the usual R22.

Units have been installed, started, tested on site and smoothly operated. Nevertheless, a period of approximately one year is required in order to have a full graph of parameters either in the heating or in the cooling mode.

The main components of the Heat Pump units are:

- Semi - hermetic reciprocating compressors on a special anti-vibrating mounting.
- Shell and Tube, Heat Exchangers either for the Condenser or Evaporator.
- Galvanized Steel structure, powder coated RAL 9002 (thickness 60 to 70 _m).
- Microprocessor control for the fully automatic as well as safe operation of the units with main parameter the water temperature. A lot of other parameters are controlled, such as High refrigerant pressure, low refrigerant pressure, inlet and outlet water temperatures, water flow either in condenser or in evaporator through flow switches, defrost control etc.

The technical specifications for both Heat Pump Units are given in the following table (see next page).

As a general remark, the operation of both units is fully controlled and self protected.

3.5. Other Peripheral Equipment

Our unit consists of various peripheral equipment such as piping, curves, 5 in-line circulator pumps, expansion vessels (of capacities of 150 lit and 200 lit), automated valves and simple valves, storage tanks (of 2.5 m^3 and 5 m^3 capacities), electrical and automation panels, which all assist in the perfect and successful operation of the unit. All piping is based on the following DIN 2448 specifications being PN 16 St 37, with variable diameters depending on the position and the function of the piping from DN 22, DN 50, DN 80, DN 100, DN 125 and finally DN 150+. All piping has been insulated with ARMAFLEX with a thickness of 13mm.

4. RESULTS

4.1. Operating History

The unit has been thoroughly tested for its operation and several minor modifications especially in the automation systems were performed (such as in the automation control panel). The unit has operated in a successful manner and continues to operate and behave normally

Hence, the project is considered a successful one.

4.2. Operating Costs

The only operating costs, when the unit is operating is the electricity consumed by the Heat Pumps, the Borehole Water Pump and the in-line circulators of the Ground-coupled closed loop system and the water transport system.

The total electric potential requirement has been measured adding up to an average of 182 kW_{elec} (for a testing-basic monitoring period of at least 80 days). Since the unit totally provides the “target” Building with 528 kW_{th} for heating and 461 kW_{th} of cooling it means that the “true” COP (including the electricity provided to peripheral units, such as circulator pumps) averages 2.90 for heating and 2.53 for cooling.

Since, the load factor (operation time) of the unit is equal to 17,1% of the year for heating and 8,2% of the year for cooling, the total annual electric energy required for the unit’s operation are *403.363* kWh_{elec}.

4.3. Economic Viability

The Estimated Simple Payback period of the system has been calculated to be 9,11 years with an expected life-time of the unit of 30 years.

The Difference Between Cost of Energy Produced or Saved and Normal Energy Prices

As mentioned before the cost of the thermal kWh_{th} produced from our unit during the thermal mode operation is 0,025 €/kWh. When oil is used the operation cost for the fuel 0,057 €/ kWh_{th}. The difference, for operation in the heating mode is 0,031 €/ kWh_{th}.

For operation during the cooling mode our unit costs 0,029 €/ kWh_{th}. Whereas, the normal electricity price is 0,073 €/kWh_{elec}.

HEAT PUMP UNIT 1

NUMBER OF UNITS	1	
NUMBER OF COOLING CIRCUITS	1	

	HEATING	COOLING
Q_c CONDENSER PERFOMANCE	198 kW	219 kW
HEATING WATER IN-FLOW	41° C	29° C
HEATING WATER OUT-FLOW	47° C	35° C
HEATING WATER QUANTITY	30,6 m^3/h	34 m^3/h
RESISTANCE OF WATER FLOW	20 Kpa	25 Kpa
Q_o EVAPORATION PERFORMANCE	139 kW	170 kW
COLD WATER IN-FLOW	12° C	12° C
COLD WATER OUT-FLOW	6° C	6° C
COLD WATER QUANTITY	21,8 m3/h	26,7 m3/h
RESISTANCE OF WATER FLOW	16 Kpa	23 Kpa
DRIVING FORCE	58,6 kW	48,9 kW

COOLANT	R 407C
PERFORMANCE CONTROL	0/75/100 %

HEAT PUMP UNIT 2

NUMBER OF UNITS	1	
NUMBER OF COOLING CIRCUITS	2	

	HEATING	COOLING
Q_c CONDENSER PERFOMANCE	328 kW	379 kW
HEATING WATER IN-FLOW	30° C	31° C
HEATING WATER OUT-FLOW	45° C	37° C
HEATING WATER QUANTITY	9,4 m^3/h	54,4 m^3/h
RESISTANCE OF WATER FLOW	8 Kpa	27 Kpa
Q_o EVAPORATION PERFORMANCE	234 kW	291 kW
COLD WATER IN-FLOW	10° C	12° C
COLD WATER OUT-FLOW	4° C	6° C
COLD WATER QUANTITY	33,5 m^3/h	41,7 m^3/h
RESISTANCE OF WATER FLOW	24 Kpa	36 Kpa
DRIVING FORCE	94 kW	88 kW

COOLANT	R 22
PERFORMANCE CONTROL	0/37/50/87/100 %

4.4. Energy Saving and Environmental Impact

Total calculated energy production and saving are 60 TOE/year produced for heating and 46.2 TOE per year saved from cooling.

More precisely:

a) The total thermal power input for heating provided to the evaporators of the unit is 373 kW_{th} or 321.200 kcal/h. The operation of the unit in the heating mode has been calculated equal to the 17.1% of the year. This results to an energy production of 481 million kcal/h or 60 TOE (1 TOE = 8.000.000 kcal).

b) The total thermal power output for cooling provided from the condensers of the unit to the geothermal system are 598 kW_{th}.

Since, this energy is stored directly into the ground, within the seasonal ground storage*, it should be obviously considered as a form of energy directly saved by the unit being offered to the ground through the Geothermal Heat Pump system.*

The operation of the unit in the cooling mode has been calculated to be equal to 8.2% of the year or 720 hours annually**.** *This results to a thermal energy saving equivalent to 429560 kWh_{th} or 46,2 TOE (1 TOE = 8000000 kcal/h or 9302 kWh_{th}).*

By the operation of the "target" Building Geothermal Heat Pump unit in the heating and cooling mode it can be estimated that 106,2 TOE of conventional fuels are substituted or saved each year. This results to a direct and significant reduction of CO_2 and other pollutant emissions. More precisely 339,8 Tonnes of CO_2 are not emitted annually (1 TOE of conventional fuel emits 3,2 Tonnes of CO_2) as well as 2,26 Tonnes of SO_2, and 0,75 Tonnes of other harmful pollutants such as NOx, CO etc.

5. Future of the Installation

The unit will be owned and operated by the NTUA which plans to extend the VEHE field in the future and add another heat pump unit to cover the needs of the remainder of the building. It should be stressed that the NTUA is a research institute which will utilize the unit as a research tool in order to improve the concept and further disseminate the product.

CRES also intends to proceed, in co-operation with the NTUA, with numerous dissemination and promotion activities, for further development of the technology in Greece, southern Europe and the Mediterranean region.

The project will contribute to the dissemination of Geothermal Heat Pump Systems (Ground-source and Ground-coupled Heat Pump systems) for heating/cooling of large buildings, as well as dwelling houses, not only in the region of Athens but also in other areas of Greece and the Mediterranean basin, where similar ground and atmospheric conditions prevail. CRES and the NTUA intend to further promote this technology to other applications. The cost savings achieved, even in the case of this pilot unit, will be widely appreciated during the replication of this innovative combination of Geothermal Heat Pump technologies.

6. CONCLUSIONS

Our basic scope, through the implementation of this project, is to show the merits of applying a *heat pump system* connected directly to the *clean and environmentally friendly energy derived from the utilization of the vast energy content of ground-water*, of the earth's surface water bodies such as lakes or the sea and occasionally from the water supply system showing in parallel a rather high energy efficiency at a very cost effective way is the main scope for the utilization of *Geothermal Heat Pumps* (GHPs).

The Geothermal Heat pump system applied for the heating/cooling of the Building at the National technical University of Athens (NTUA) Campus at Zografou has been completed successfully.

The system is comprised of the combination of a Ground-source Heat pump with a Ground-coupled Heat pump systems. A significant amount of conventional fuels is substituted or saved by the application of the technology leading to a direct reduction of pollutant emissions and an amelioration of the quality of life of the surrounding the building areas.A major advantage of the system is that it may be applied even in regions where there is restricted availability of ground-water and/or requirements for water utilization is very strict.

The total energy production and saving achieved by the unit operation are *60 TOE/year produced/ substituted* for heating and *46,2 TOE/year saved* from cooling. The estimated simple payback period of the innovation compared to the conventional systems is *9,11 years* with an expected life-time of the unit of *30 years*.

Considering all of these facts Geothermal Heat pump systems have been proven to be extremely efficient throughout the year virtually in any place or under any climatic conditions. Thus, the replication prospects of this or similar applications are very high.

REFERENCES

ASHRAE, (1995) Chapter 29 – Geothermal Energy – ASHRAE Handbook: Heating, Ventilating, and Air-conditioning Applications, Atlanta Georgia.

ASHRAE (1995) Commercial Ground-source Heat pump systems, Special Edition, 134 pp.

Carella, R., (1993) The Several Uses of Low Temperature Geothermal Energy for Heating, FAST-OPET DGXVII, 25pp.

Federal Energy Management Program (1995) Ground-source Heat Pumps Applied to Commercial Facilities, FDA Bulletin, 41 pp.

Karytsas, C., Fytrolakis, N., and Krikis, N., (2001) Final Report of THERMIE BU.468.94.HE

Pratsch, L.W., (1994) Geothermal Heat Pumps benefit the Consumer, Utility, and Nation, US Department of Energy, Report.

PHOTOGRAPHS

Photo 1: The production borehole head and the “target” Building at a distance.

Photo 2: A VEHE and the U-Tube configuration.

Photo 3: The VEHE system distributors (left) and collectors (right), one of the in-line circulator pumps is also shown.

Photo 4: Heat Pump 2, sub-units 1 and 2 (R 22) shown in the distance.