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INVESTIGATION AND DETERMINATION OF THE GEOTHERMAL PARAMETERS OF THE GROUND IN CYPRUS FOR THE EXPLOITATION OF GEOTHERMAL ENERGY AND THE IMPACT OF THE RESULTS IN THE DESIGN OF THE GEOTHERMAL SYSTEMS.

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ABSTRACT

The Energy Service of the Ministry of Commerce, Industry and Tourism has the overall responsibility for Energy matters in Cyprus and specifically for preparing and implementing programmes for energy conservation, the promotion of renewable energy sources (RES) and the development of technologies for the utilization of RES. The Government of Cyprus being aware of the benefits of geothermal energy and in order to increase the share of energy from renewable sources consumed in heating and cooling in 2020, promotes the geothermal energy systems through a Scheme that provides financial incentives for the utilization of RES for heating and cooling. However, the lack of valid data for the ground thermal properties in Cyprus was one of the main obstacles for the design of efficient geothermal systems, the implementation of the Schemes in the field of geothermal energy and the calculation of the share of energy from renewable sources for heating and cooling according to the methodology defined by the E.U in the directive 2009/28/EC. In an effort to identify suitable energy efficient systems for heating and cooling of buildings and the correct calculations of their contribution to the national targets, the Energy Service participated in a project founded by the Research Promotion Foundation of Cyprus to investigate and determine the geothermal parameters of the ground of Cyprus at six representative sites in Cyprus, for use in the design of ground heat exchanger applications and ground thermal storage. The paper presents the importance of the Isothermal map that helps consultants to design efficiently geothermal energy systems, calculate effectively heat losses of buildings to the ground and design the thermal energy storage equipment. The importance's of the results are analyzed by national authorities' experts' point of view for evaluating geothermal applications bridging in this way the gap between technical output and commercial reality.

Keywords: Geothermal, ground temperatures, Cyprus Geothermal Map.

INTRODUCTION

The Energy Service of the Ministry of Commerce Industry and Tourism of Cyprus determines the energy needs of the country, by taking into consideration the obligations that are related to international agreements and European Standards and regulations [7]. Cyprus has considerable potential regarding the Renewable Energy Sources, which includes solar and wind energy, biomass and the use of geothermal of low enthalpy.

In order to assess the geothermal potential of Cyprus, at a specific depth, the Energy Service in cooperation with Cyprus University of Technology (CUT) made

various drillings in areas at Nicosia, Limassol, Larnaca, Paphos and Saitas. The results of this investigation show that the ground temperature varies with depth [1-2]. At the surface, the ground is affected by short term weather variations, changing to seasonal variations as the depth increases (figure 7). At the deeper layers, the ground temperature remains almost constant throughout the seasons and years and is usually higher than that of the ambient air during the cold months of the year and lower during the warm months. The ground therefore is divided into:
a) the surface zone where hourly variations occur
b) the shallow zone, with monthly variations and
c) the deep zone, where the temperature is almost constant.

The final outcome of this paper is to help both consultants to design efficiently geothermal energy systems, calculate effectively heat losses of buildings to the ground and design the thermal energy storage equipment. The final objective is to develop a software tool that will help the end consumer to better understand the coefficients that affecting the system performance comparing with the price of the system.

In parallel, this project provides important information of the structure of the ground at different areas of the island, defines the geothermal characteristics and its layers (thermal conductivity, special weight, and humidity) and the measurement of the temperature in depths up to 200 meters in representative's urban and hilly areas of Cyprus [2]. The creation of a database in order to facilitate the efficient design of geothermal systems for the climate of the buildings and to assist the investigation of thermal energy storage in the ground is also consider and discussed in this paper.

GEOTHERMAL ENERGY IN CYPRUS

The use of geothermal systems for heating in Cyprus had a significant increase in the last few years. The technology is already used in hospital hotels, industrial buildings and households. From evaluations of the installed geothermal systems in Cyprus, it is observed that compared with the use of conventional fuels for heating and cooling, the use of geothermal systems can offer an energy saving between 40-75% depending on the size of the building and the comparable conventional system.

Grants are being provided for climate control systems which exploit the heat from geological formations and from surface and underground water which are installed in buildings of existing and new enterprises.

In the eligible costs the following are included:

1. Cost of buying the geothermal heat pump
2. Cost of drilling if applicable
3. Cost of piping the geothermal heat pump, heat exchangers, pumps the control instruments from the ground to the heat pump
4. Installation costs (labor)
5. Feasibility study cost and measurements if applicable
6. Automation System if applicable

The Grants Schemes in Cyprus are separated in two categories:

a. Support Schemes for individuals and organisations that do not exercise economic activities. Under this support scheme, geothermal systems are supported up to 55% of eligible cost with maximum amount of €20.000 per application.

b. Support Schemes for companies and individuals that do exercise economic activities. Under this support scheme, geothermal systems are supported up to 40[1]% of eligible cost with maximum amount of €100.000 per application.

Table 1: The applications submitted for Grant since 2006 are shown in the table below.

2006	2007	2008	2009	2010
14	13	19	53	55*

*The number will finalized in the beginning of February

Based on the interest shown from the people using Renewable Energy Sources to satisfy their needs in heating and cooling, the Cyprus Government in cooperation with CUT is developing a software model analyzed in this paper to be used by consultants. This will lead to further investments in this technology and in addition it will prove that the theoretical and actual values do not differ significantly.

The support schemes covers the cost for purchasing and installing new equipment as well as the study of the system. The eligible costs and the parts of the equipment that are covered by the scheme are defined in the application forms[2] that are updated on a yearly basis based on the innovation of technology and feedback received from each calendar year's applications.

[1] The difference is support is directly related with the Value Added Tax amount which is 15% in Cyprus.
[2] Cyprus Institute of Energy, (www.cie.org.cy)

It was also observed that the systems installed during the first years of the Grant Scheme had lower performance compared with systems installed in the successive years. This is because both consultants and contractors acquired more experiences during the years by evaluating the installed systems.

GEOTHERMAL CHARACTERISTICS AND MEASUREMENTS IN CYPRUS

The island of Cyprus which is the third largest island of the Mediterranean with surface area of 9251 sq. km is divided into four geological zones: a) the Pentadaktylos (Kyrenia) Zone (b) the Troodos Zone (c) Mamonia Zone or Complex (d) the Zone of the autochtonous sedimentary rocks.

Figure 1: Geological Map of Cyprus with the four representative areas

The studies that were carried out in order to investigate the geothermal properties of the ground in Cyprus were very limited.

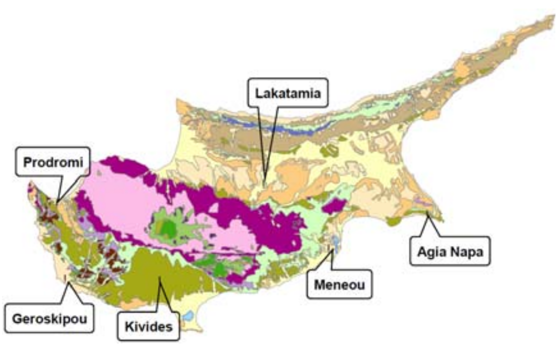

Figure 2: Geological Map of Cyprus with borehole locations done in this project

In 1970s **[4]**, Paul Morgan measured the geothermal gradient of 33 boreholes (figure 5) in Cyprus and CUT in accordance with the Department of Energy of Ministry of Commerce Industry and Tourism and the
Geological Survey Department of the Ministry of Agriculture, Natural Resources and Environment proceed further with the investigation of another 8 boreholes[3].

The results of the above studies showed that:

(a) The temperature of the ground in Cyprus is constant throughout the year and is within the range of ***17°C-24°C.***
(b) The Ground-Coupled Heat Pump (GCHP) operating conditions vary depending on the manufacturer, the country/region or climate conditions aimed for and the purpose to be used. According to the climatic conditions and the thermal characteristics of the ground proper pump selection and sizing should be done.
(c) The data collected until now clearly indicate that there is a potential for the efficient use of GCHPs in Cyprus leading to significant savings in power.
(d) When the thermal conductivity of a borehole is low, using standard heat exchangers could result in long borehole lengths. Therefore one should investigate the possibility of using heat exchangers that will minimize the resistance of the thermal flow between the ground and the heat carrier fluid.
(e) Also it is calculated that the thermal conductivity for Geroskipou is between 1.42 to 1.97 W/mK, for Lakatamia 1.68 W/mK, Agia Napa 1.58 W/mK, Meneou 1.72 W/mK and Prodromi 1.87 W/mK. [5]

GEOTHERMAL MAP

A neural network will be used for the generation of geothermal maps of the temperature at three depths (20, 50 and 100 meters) in Cyprus. Archived data of temperature recorded at 41 boreholes will be used for training a suitable artificial neural network. For eight of the boreholes the temperature was recorded over a period of one year whereas for the rest, data from the Morgan study was used.

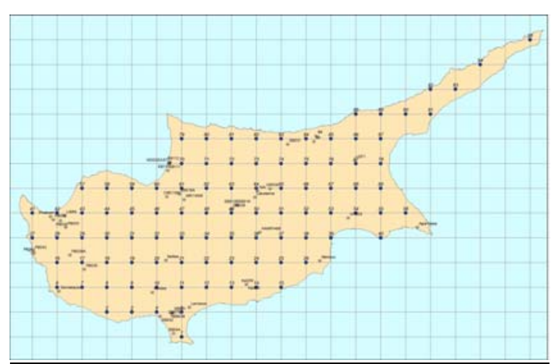

Figure 3: Locations used to extract the simulations

[3] The boreholes at Saitas and Limassol were drilled in a previous project done from the Energy Service.

Various architectures and learning rates will be tested, aiming to establish a network which can yield an acceptably accurate estimation of temperature at any arbitrary location on the island which can subsequently be used for drawing the geothermal maps.

Possible parameters that could be used for the training of the network are;
1) the lithology class at the area of each borehole,
2) the borehole elevation,
3) the mean, minimum and maximum ambient air temperature at the location of the borehole,
4) rainfall at the location of the borehole,
5) the x and y coordinates for each borehole, measured from some reference point,
6) the depth at which temperature is recorded (20, 50 and 100 meters) and
7) the temperature at the particular depth.

Since there are no available data for all 41 boreholes and for all depths, the final patterns will be decided by eliminating the cases where data are not available.

A 10x10 km grid is then drawn (Figure 3) over a detailed topographic map of Cyprus and the lithology class; elevation; mean, minimum and maximum ambient air temperature; rainfall and the x and y coordinates for each borehole, measured from the same reference point will be recorded.
This information will be supplied to the trained network and by doing so the temperature at the same depths as above will be predicted at each grid-point. The x and y coordinates and the estimated temperatures at the three depths for both the original boreholes and the grid-points, as mentioned above, will be then used as input to a specialized contour drawing software in order to draw the geothermal maps.
It is believed that the proposed method of explicitly involving the lithology class, elevation, ambient temperatures and rainfall in drawing geothermal maps realistically will produced valid maps of temperatures at the three depths.

With the knowledge of the thermal behavior of the ground at various locations and depths of Cyprus is valuable for improving the design of geothermal applications in Cyprus and especially the efficiency of the ground coupled heat pumps used for the cooling and heating of buildings.

The structure and physical properties of the soil are factors affecting the temperature, at all zones. The temperature of the ground is a function of the thermal conductivity and the geothermal gradient and water contend and flow.

THE SOFTWARE MODEL

The model shown in Figure 9 compares the system parameters between a conventional (not defined system) and a geothermal system and compares them with a threshold number C_th. When the comparison indicates that the Geothermal System is feasible (economic viable) then the software proceed with the evaluation of the Stage 2. In the comparison model, the following parameters are examined:

- Payback of the System
- Inflation rate
- Interest rate
- Maintenance and operate Cost
- COP & EER of the system
- Cost of Kwh
- Gas purchase price
- Thermal Conductivity
- Ground Parameters

The model is capable of adopting other factors that may affect the system performance and maintenance. A weight also is given to the warranty provided by the manufactures for the equipment used.

From the applications submitted up to date it can be extracted that the most of the systems installed are of closed loop vertical type (figure 4).

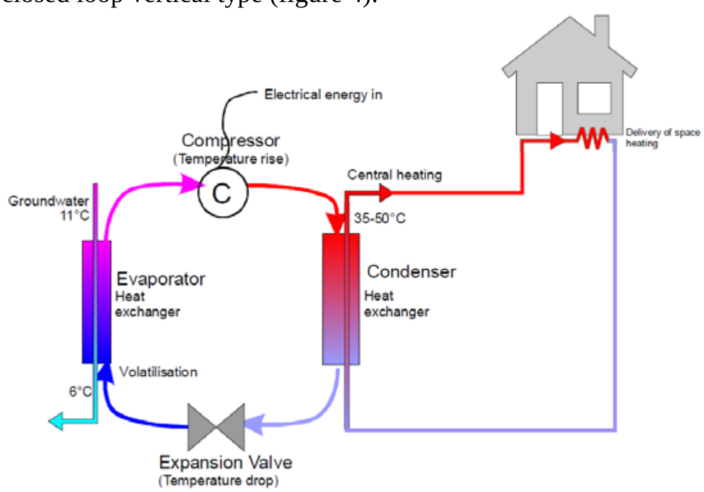

Figure 4: Typical Geothermal System

Based on the applications the distribution of the cost of the systems can be analyzed in two tables. The *table 2* shows the cost variation among the equipments used and the *table 3* indicates the variation of the cost among the works needed to be done for a vertical geothermal closed loop residential project.

Table 2: Cost variation of equipment used in a Geothermal System

Type of Equipment	Range of Percentage
Heat Pump	11-27%
Fan Coils	6-14%
Isolated Tubes and Normal Tubes	6-14%
Water and Buffer Tanks	1-2%
Electrical Components (Switches, MCCBs, Distribution Boards, Electrical cables etc)	4-10%
Water Filters and Cleaning Water System	<1-2%
Different type of Valves (three way valves, expansion Valves)	2-5%
Calorimeter-Thermometer	<1-3%
Monitoring System, Sensors (Flow, Temperature)	3-5%
Chain stack duck	
Circulation Pump	2-6%
Dry Filter,Manometer	1-2%
Betonite	4-14%

Table 3: List of the Major Works of a Geothermal System

Work Description	Range of Percentage
Electrical Works	1-2%
Automation System Design and Installation	1-4%
Drilling works	10-21%
Pipeline Interconnection	2-3%
Study and Application for Grand & Geological tests	2-9%
Fork Lift	1-2%

It can be observed from the above figures that there are huge variations on products and services on the invoiced cost between different companies. It is important though to note that the selection of the GCHP is largely dependent on the geological and thermal characteristics of the site.

The filling of the hole is necessary with bentonite (an absorbent aluminum phyllosilicate – absorbent clay) mostly because the national authorities of Cyprus need to prevent the underground water resources. However the thermal conductivity of such substance is very low comparing the other underground layers (dry bentonite k = 0,8W/m K and liquid 1.2W/m K).
The filling with the bentonite causes isolation to the geothermal system; however the new types and mixtures of bentonite (Potassium bentonite & Calcium bentonite) will help the engineers to overcome the above problem.
The diameter of the hole is of very high significant because the smaller the diameter is the less the filling with bentonite.
The above mentioned parameters are considered in the database of the developing model.

The first database consists of the Conventional System materials and prices found on the local market based on the applications submitted up to date. The prices are compared with the prices of the products over well known internet databases. The labour hours are considered and compared between the different installers and a mean value is considered for the acceptable cost.

The drilling cost will vary according to the geological zones, depth of the hole and diameter of the hole.

By entering data in the software model, the consultant or even the customer will have an indicative idea about the payback of the system and a comparison chart of the savings versus the conventional system under study.

The purpose of the database is to limit the cost variations and compare also the prices for systems installed in other countries taking into account the extraordinary circumstances of Cyprus.

For example in USA[4], a geothermal heat pump system costs about $2,500 per ton of capacity. The typically sized home would use a three-ton unit costing roughly $7,500. That initial cost is nearly twice the price of a regular heat pump system that would probably cost about $4,000, with air conditioning. The cost of drilling can run anywhere from $10,000 to $30,000, or more depending on the terrain and other local factors. The accepted payback period is between 5 and 10 years [7].
In Cyprus the total cost of a typical house of 16KW load is between €30,000 – €35,000 and with the grants given the payback period of a system is between 6-8 years. The saving energy of these systems is in the range of 40-75% per year.

[4] California Energy Commission (http://www.consumerenergycenter.org)

Evaluation of the Applications

Table 4: The applications are evaluated based on the following criteria

No.	Description	Weight of Significance
1	Effectiveness of the capital expenditure	20%
2	Saving Energy	35%
3	Reliability of the proposed technology (Geothermal components that are included in the Eligible List) and the effectiveness of the proposed application.	20%
4	Effectiveness of the supported Scheme in accordance with the use of the system.	10%
5	Enviromental Benefits	10%
6	Third Part Financing	5%

In order for one application to be approved it is necessary to obtain at least 50% score.

The consultants should include the following in their study:

1. Calculation methodology including Cooling and Heating Capacity of the Building under study.
2. Calculation methodology based on the Heating and Cooling capacity in a yearly basis according to the customer needs. (Customer needs to fill up a questionnaire based on which the above studies will be carried out)
3. Estimation of the cost of a conventional system, (Customer needs to approve the conventional system to be used in case the application is not approved).
4. Calculation of the Conventional System for both heating and cooling over a complete calendar year.
5. The consultant should define all the assumptions made (e.g. Price of the Oil, Cost of KWh of the electricity, hours of operations of each building),
6. Correct Collection and sizing of the heat pump.
7. Selection of the type of Geothermal Heat Exchanger
8. Process of the dimensioning of the Geothermal Heat Exchanger.
9. All the data used, and assumptions made in order to end up with the final dimensioning of the system, (here the consultants need to indicate the ground temperature, the thermal diffusivity, etc).
10. Estimation of the Cost of the Geothermal System based on the above assumptions and findings.
11. Calculation of the efficiency of the Heat Pump in both Cooling and Heating Cycle (EER minimum acceptance value B20/W8 and COP with minimum of B20/W40)
12. Annual calculation of the operating cost for both heating and cooling of the system.
13. Calculation of the energy saving based on the above assumptions in an annual base taking into account the efficiency of the heat pump in both cooling and heating cycles.
14. At the final stage the consultant need to calculate the Internal Rate of Return of this investment, the Net Present Value as well as the payback period of the system

The paragraph 9 above seems to be the more difficult to calculate and on the other hand the more critical in the whole outcome of the study. For the consultants to have more precise results, especially in large or commercial systems they have to make measurements for a period of time in order to have an indication about the characteristics of the underground layers. The consultants used to “guess” or get an estimation of the ground temperature based on the Geological Maps and lithology characteristics that were available up to date.

Figure 5: Geographical Locations of the boreholes studied in the project. The Red bullet indicates the boreholes drilled under this project and the blue boreholes were drilled back in 1973 by Morgan.

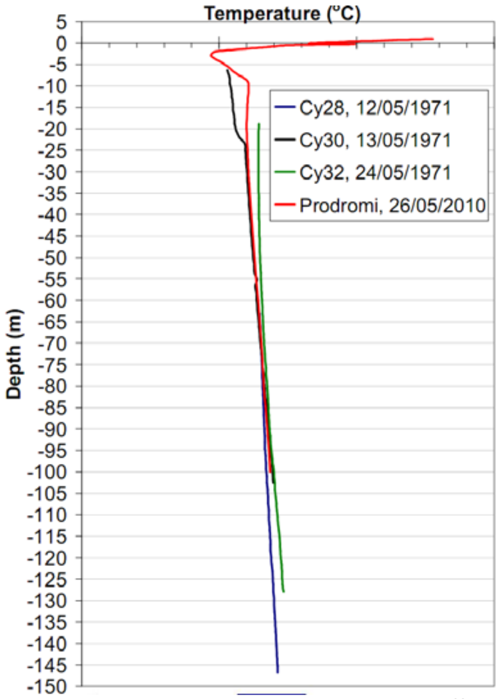

Figure 6: Comparison Chart between the differences in temperatures that were recorded under this experiment in comparison with Morgan in 1973

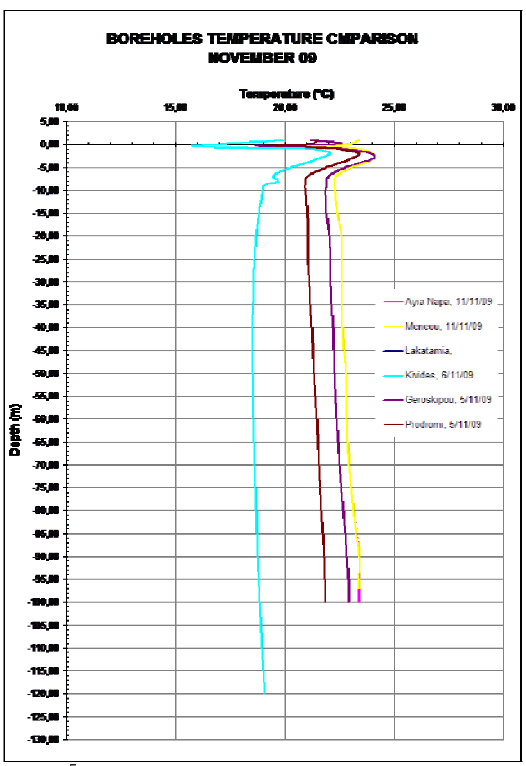

Figure 7[5]*: Graph indicating the ground temperatures for all locations under study for the month of November.*

[5] All the results can be found at http://www.cut.ac.cy/geothermapcy/

With the results of the current study the Consultants will be able to take the values from the Geothermal Map Database that will be included in the developed Software, or use the data and enter them in any of the existing software's (GE2000, glhewin, gchp, EED). This way they can get off complicated calculations and assumptions made to estimate the temperature of the ground and depths between 20-100 meters.

As mentioned above the thermal conductivity Maps along with the temperature maps that will be developed using the methodology of Artificial Neural Networks (ANN). An ANN is in fact a massively parallel distributed processor that has a natural propensity for storing experiential knowledge, making it available for use. In fact the ANNs learn the relationship between the input parameters and the controlled an uncontrolled variables by studying previously recorded data.

The parameters of the methodology used (figure 9) to examine the feasibility cost of a Geothermal System is defined with the following variables:

Gth_cost1 = is the Estimated cost in Euros, of the Geothermal System based on the Geographic location of the residence and the calculated load of the building in heating and cooling.

Conv_cost1 = is the Estimated cost in Euros, of the Conventional System based calculated load of the building in heating and cooling. The conventional systems to be used could be either a conventional system with heat pump or other conventional system from the database.

Dth: is the comparison between Gth_cost1 and Conv_cost1 in relation with COP,EER,IRR and Pay back Period of the system (PP).

Dth_min: is the Threshold value based on which the decision of the program will be made. The values will be defined based on reference scenario that will be updated regularly but is not expected to change substantially from year to year.

Gth_cost2: is the actual cost of the Geothermal System in Euros, based on the Geographic location, Number and Depth of Holes Needed, the EER and COP of the heat pump etc.
All the assumptions used to be made from consultans will be available in the database of the software (Price of the Gas, Cost of KWh of the electricity, Inflation rate, Interest rate, Accepted Lifetime of the system etc).

Th: is the percentage (±) based on the ratio of the cost of an extra hole (loop) Vs the system Cost. It is also taking into account the uncertainty used on the above assumptions.

Gth_final= Gth_cost2 * Th
Is the final cost of the Geothermal System. This step it will not needed to be carried out for small residential systems.

Step 1:

Calculates Dth as a function of payback period (or Internal Rate of Return) of a system (after subtracting the cost of the conventional system), COP and EER of the heat pump. (Data from tables 5a-5c will be used)

Table 5a: Temperature variations at 8 different locations in all over Cyprus at 20m

Location	*20 m (^oC)*		
	Min	*Max*	*Mean*
Agia Napa	*23.17*	*23.45*	*23.31*
Meneou	*22.56*	*22.76*	*22.66*
Lakatamia	*21.86*	*22.71*	*22.29*
Kivides	*18.59*	*18.68*	*18.64*
Geroskipou	*22.04*	*22.34*	*22.19*
Prodromi	*20.75*	*21.08*	*20.92*
Saitas	*17.04*	*17.06*	*17.05*
Limassol	*21.98*	*22.06*	*22.02*

Table 5b: Temperature variations at 8 different locations in all over Cyprus at 50m

Location	*50 m (^oC)*		
	Min	*Max*	*Mean*
Agia Napa	*23.07*	*23.56*	*23.32*
Meneou	*22.36*	*22.94*	*22.65*
Lakatamia	*21.91*	*22.56*	*22.24*
Kivides	*18.39*	*18.50*	*18.45*
Geroskipou	*22.27*	*22.78*	*22.53*
Prodromi	*21.29*	*21.39*	*21.34*
Saitas	*17.47*	*17.48*	*17.48*
Limassol	*21.70*	*21.81*	*21.76*

For the above calculations the consultants will use the same database for all the assumption that were made up to date (cost of the KWh by Electricity Authority of Cyprus, cost of Gas, Inflation Rate, Interest Rates, Period of load if applicable, The maintenance cost will be a function of the cost of the system and the ground parameters).
Define a minimum threshold value (Dth_min) that will be compared with the Dth. The Dth_min is calculated in a way that the payback period of a system is within the thresholds sets from European Requirement Standards.

Table 5c: Temperature variations at 8 different locations in all over Cyprus at 100m

Location	*100 m (^oC)*		
	Min	*Max*	*Mean*
Agia Napa	*23.52*	*23.91*	*23.72*
Meneou	*23.02*	*23.46*	*23.24*
Lakatamia	*22.93*	*23.46*	*23.20*
Kivides	*18.59*	*18.84*	*18.72*
Geroskipou	*22.89*	*23.00*	*22.95*
Prodromi	*21.77*	*21.91*	*21.84*
Saitas	*18.72*	*18.73*	*18.73*
Limassol	*22.43*	*22.57*	*22.50*

The Dth_min will be reviewed every year based on the feedback got from the applications and research of the market prices and products.

Step 2:

If Dth > Dth_min, the software will proceed with the step 2 and the data described above are entered to calculate the Gth_cost2. After the final results obtained then the procedure of step 1 will be repeated only if the Gth_cost2 > Gth_cost1.

Step 3:

Gth_final= Gth_cost2 * Th
This step may be not necessary to be carried out for small residential systems if the depth of the holes is between 20-100m. However in special circumstances and for large systems this step may be carried out in order to indicate if the system is undersized or oversized and decide what is needed to be done:
Option A: **Gth_final > Gth_cost2 * Th**
Drill an extra hole to measure the actual ground parameters and redo the calculations to find how many holes are needed to meet the required capacity for both heating and cooling.
Option B: **Gth_final < Gth_cost2 * Th** Use extra hole (loop) to satisfy the needs of the building without doing further calculations.

CONCLUSION, FURTHER STEPS

The software will be a tool for consultants studying geothermal systems. By using a unique methodology and software the procedures of evaluation will be more just, transparent and comparable.
Also the procedure will be simplified and the time of evaluating an application will be decreased significantly.
In addition, the end user will have a geothermal system that will not be oversized or undersized and the savings in Energy will be known beforehand. The Government can limit the cost of the systems and even more people will use this type of systems from

their cooling and heating requirements since the available funds can satisfy more applications.

The above study is one of the steps that Cyprus need to take to meet the requirements set from EU in the directives 2009/28/EC & 2010/31/EC [8], since the Geothermal Systems are mentioned in both directives for energy efficiency and Renewable Energy Sources.

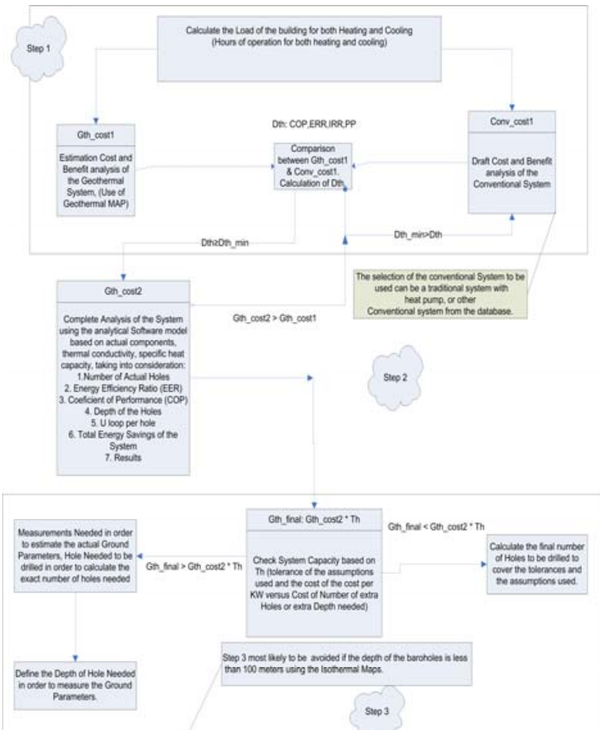

Figure 9: Flow Chart of the Software model

Furthermore, it is expected that through the support schemes, the government will collect more real data in order to improve the accuracy of both isothermal and thermal conductivity maps and provide the appropriate feedback to consultants improving that way the accuracy of the techno-economical studies.

Most Governments are encouraged to have support schemes to encourage RES and innovative technologies. In parallel Government should also provide the necessary tools to facilitate such investments.
At the end the geothermal energy will take its proper rank among the other renewable energy sources.

Acknowledgments

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