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**DATABASE FOR WELLS AND UTILIZATION
OF LOW TEMPERATURE GEOTHERMAL SOURCES**

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ABSTRACT

SQL "Structured Query Language", a relational database language, was used to design suitable database tables for the management of all data about geothermal wells in Egypt. These database tables and their corresponding queries, views, and indexes contain information about drilling data, casing design, chemical analysis of water, locations of wells, types of different logs done in each well and detailed lists of measurements. Data from 43 wells located in the Mosfellssveit low temperature field (15 km east of Reykjavik) were organized using the SQL tables. Discussed are some possible direct applications of using low temperature waters in Egypt. These applications include the piping of geothermal fluids, use of heat pumps and fundamentals of space heating design.

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1. INTRODUCTION

The author had the honour to participate in the UNU Geothermal Training Programme, held at Orkustofnun - the National Energy Authority, Iceland between April 30th and October 30th, 1990. The Geothermal Training Programme was designed and executed as follows:

- * Introductory lectures for five weeks, including topics connected with geothermal research, i.e. geology (exploration and borehole), geophysics (exploration and borehole), geochemistry, drilling and reservoir engineering.
- * Specialized training for four weeks including lectures and practical training on geophysics, reservoir engineering and modelling.
- * Visits to some low and high temperature fields in Iceland. Lectures were given about the geothermal development of these fields.
- * In the last two months the author undertook training in two phases: the first was the designing of the database system to manage all data about water wells in Egypt, using dBASE IV and SQL languages; the second phase included selected topics about direct applications, using low temperature water. These topics included transmission of hot water in pipes, use of heat pumps and space heating design.

2. DATABASE STRUCTURE FOR INFORMATION ABOUT WELLS IN EGYPT

2.1 Introduction

Several hundreds of drilled water wells exist all over Egypt and about 25-30 new wells are drilled every year. The depth of these wells varies from 50 m for shallow wells to approximately 1000 m for deep wells. Consequently, the drilling and completion program varies significantly from one well to another. Water from these wells is mainly used in irrigation, for drinking and in some industries.

The main source of thermal water in Egypt is the deep artesian water wells located mainly in the oasis area in the Western Desert region. The average depth of these wells is 650 m; most of them are in free flow.

The General Company Of REsearch and Ground WATER "REGWA" is a national Egyptian drilling company, and is one of the pioneer companies in the Middle East for drilling water wells. It participates in many huge agricultural and research projects in Egypt and other arab countries, like Libya and Sudan.

There is a wide variety of data about drilled wells in Egypt. For example, drilling data contains information about bit sizes, drill string assemblies, rig used, drilling depth, casing and screen design, description of cementation processes and all equipment used upon well completion. Data about locations of wells contain the coordinate values for each well, mostly the elevation above mean sea level and a detailed description of the location. Also available are a lot of data about the chemical analysis of water samples from wells, logging measurements and pumping tests.

2.2 Data organization

The following database tables were created to manage data about geothermal wells in Egypt:

1. The DRILLING table contains information about well identification (well key), bit sizes and the start and finish depth of drilling.
 2. The CASING table contains information about well key, casing and/or screen diameters, and their setting depths.
 3. The CASINGTYPE table describes the materials of the casings (screens) and their properties.
 4. The LOCATION table contains information about well key, well name, the coordinates, elevation above mean sea level, the grid number and a detailed description of the location.
 5. The GRID table defines the boundaries of each grid number (longitudes and latitudes).
 6. The JOB and JOBTYP table include information about all jobs done in the well like drilling, measurements, development, pumping test, work over...etc.
 7. The LOGDONE table (measurements in the well) includes all types of logs done, their numbers, start and completion dates, the equipment used in measurements and the logger name.
- Four tables are extracted from the LOGDONE table:


- . The LOGVAL table contains detailed values measured, the measurement number and measurement depth.
- . The LOGTYPE table describes the log type done and its identification number.
- . The LOGGER table gives the full name of the logger and his identification number.
- . The TOOLS table gives a full description of the equipment used and its identification number.

8. The CHEMISTRY table contains data about cation and anion concentrations in different water samples for each well, however, the ultimate design of this table will be finalized according to the required elements to be analyzed in Egypt.

In designing the above mentioned tables, we tried to satisfy the following:

- no redundant information to avoid update anomalies.
- no repeating of columns to simplify processing.
- minimum number of tables to minimize inter-table navigation.

Figure 1 shows the structures of the designed database tables.

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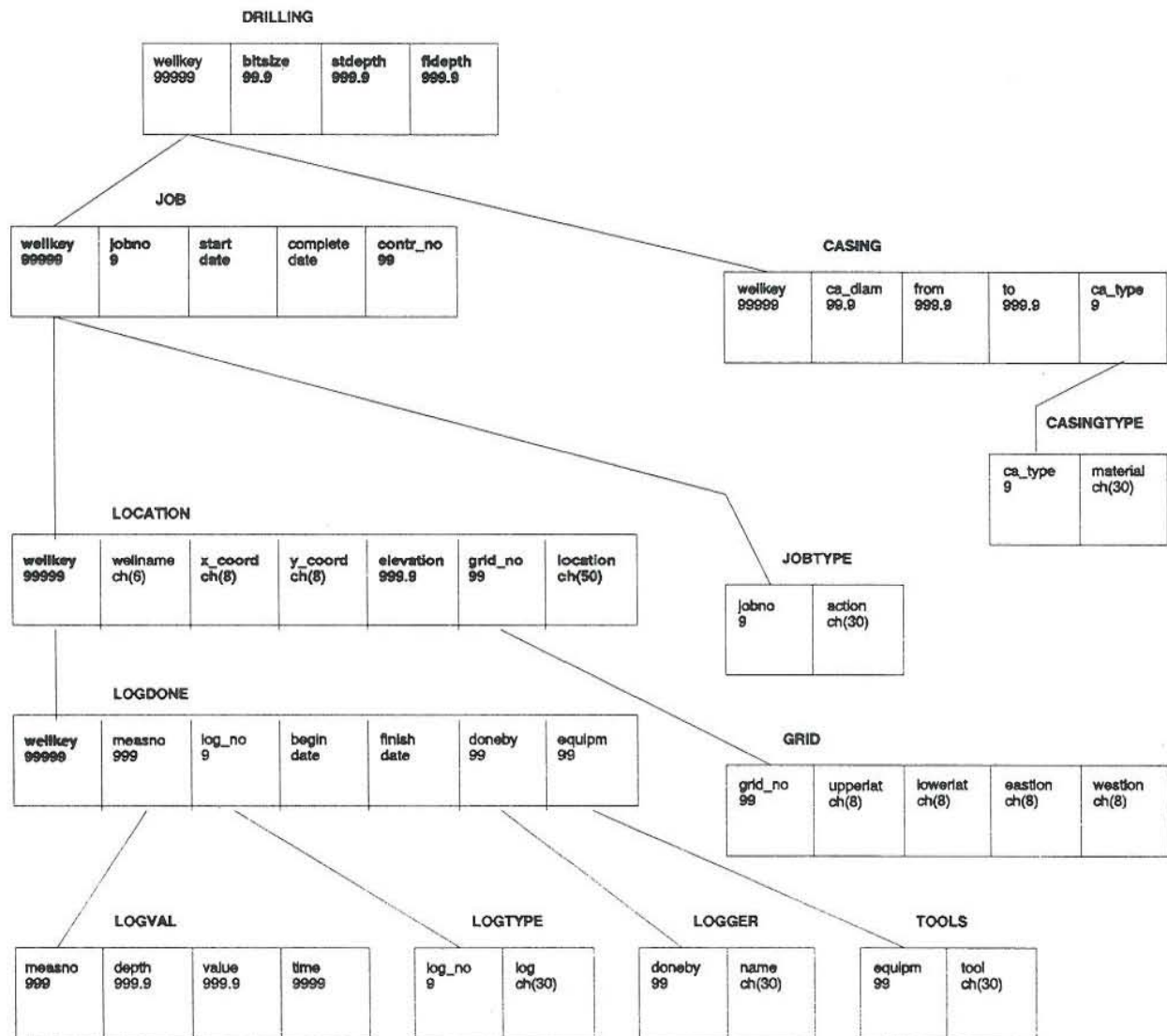


FIGURE 1: Structures of the designed database tables

2.3 Choice of database: relational database, dBASE IV, SQL and PC

In order to store all available types of data about wells and retrieve them in a quicker and more efficient way, it was decided to use **dBASE IV** language (Ashton Gate, 1988) and focus mainly on its embedded **SQL** language.

Data storage, using **dBASE IV** and **SQL** languages gives valuable information about drilling conditions, locations of aquifers, approximate well design and expected productivity. It also saves a lot of effort and money in drilling and exploring new wells.

dBASE IV is a database management system, a powerful tool for managing data. Electronic data processing means that vast amounts of information can be stored, related, manipulated and retrieved. This is usually accomplished by designing the **database files** and their corresponding **forms**, **queries** and **reports**.

SQL is an advanced relational database language that operates on data entirely as logical sets called **tables**. **SQL** has a small and concise set of commands able to display, define, update and print the information contained in way of **what** to do not **how** to do. An **SQL** database table is expressed as a collection of rows and columns. The intersection between each row and column contains a data value. An **SQL** view is a subset of rows and columns of one or more existing database tables. An **SQL** query is a normal **SQL** table which can display all or specific columns of a table in any order and even specific information (rows) can be selected within each column. **SQL** indexes provide a quicker and efficient retrieval of data from tables (see Sayles and Kerr, 1989).

A set of **dBASE IV** commands can be used to enhance the performance of **SQL**.

2.4 Design of **SQL** database tables

2.4.1 Creating a database

This is the first step in designing **SQL** tables and is performed by using the **CREATE DATABASE** command. When a database is created, a subdirectory of the database name is created and a set of catalog tables are created in this directory.

2.4.2 Creating tables

After creating or specifying the database name in which the table to be created will exist, the **CREATE** command is used to specify each column name and the type of data that will be included in this column. The data type may be an integer, decimal, numeric, character, date or logical.

2.4.3 Inserting data into created tables

This is done by either using the **INSERT** command or the **LOAD** command to add new rows (fields) to the tables. Using the **INSERT** command we specify particular values to be inserted into the columns of a table, or insert data from specified rows qualified by a **SELECT** statement. The **LOAD** command appends data from an external file to an existing **SQL** table.

This external file may be either a database file (.DBF), framework II database file (.FW2), delimited format ASCII file (DELIMITED), system data format ASCII file (SDF), Visicalc format files (DIF), or Lotus format file (WKS). Appendix A shows the LOCATION database table with inserted data using the LOAD command.

2.4.4 Creating indexes

This is done by using the CREATE INDEX command in one or more columns, called the index keys.

2.4.5 Creating views

The CREATE VIEW command is used to specify the optional columns to be displayed from one or more tables.

2.4.6 Performing queries

Queries act as views but the result is not stored as in the case with views. SELECT is the basic command used to perform queries. Other commands are specified with the select command to build search or multi-search conditions with the aid of arithmetic, logical and relational operators. A complete syntax of a query may include the clauses: SELECT, FROM, WHERE, GROUP BY, HAVING, ORDER BY and SAVE TO TEMP.

Updating and deleting data in a table or a view is available by using the UPDATE and DELETE commands, respectively. UPDATE command replaces the old rows with the new specified conditions. DELETE removes rows in a similar way. Also the updating and deleting of tables is accomplished by using the ALTER command (to add a new column) and the DROP command to delete the table and its corresponding indexes, views and synonyms.

2.4.7 Plotting graphs

By exporting a report file to an ASCII file, it is possible to append this file to any graphical computer program and perform the required graphs. Figure 2 shows a contour temperature map (in °C) at 100 m depth for the Mosfellssveit low temperature field.

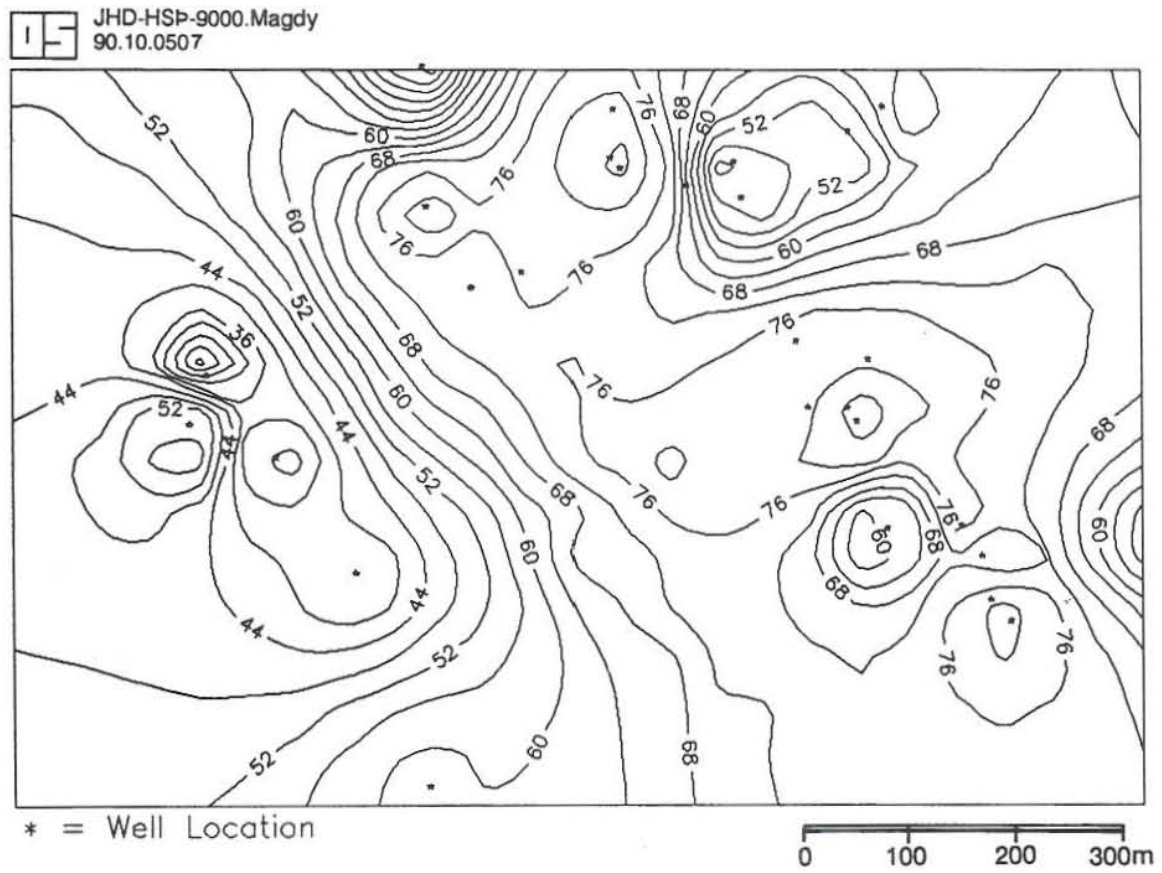


FIGURE 2: Temperature map at 100 m depth for the Mosfellssveit low temperature field

3. UTILIZATION OF A LOW TEMPERATURE GEOTHERMAL SOURCE

3.1 Introduction

Since geothermal water in Egypt is generally characterized by very low temperature fields (30 - 45°C), the possible direct uses of this water are limited. However, the use of heat pumps would probably widen the spectrum of those direct uses, since it provides the necessary temperature boost for a low temperature water source. Figure 3 illustrates the possible direct uses suitable for the conditions of water temperature in Egypt.

In the following sections we are going to briefly describe hot water transmission in pipes, the use of heat pumps and the fundamentals of space heating design.

3.2 Hot water transmission

There are several factors controlling the design of a piping system for hot water transmission. The basic factors are the pipe material, dissolved chemical components in water, size, installation method, head loss and pumping requirements, as well as insulation effect.

Piping materials are of numerous types. The most common materials are carbon steel, ductile iron, fiber glass, (RTRP), asbestos cement (AC), polybutylene (PB), chlorinated polyvinyl chloride (CPVC), polyvinyl chloride (PVC) and polyethylene (PE).

Geothermal fields in Egypt are low temperature fields (35 - 50°C). Water from most wells contains a slightly higher concentration of ferric oxides (0.5 mg/l). Polybutylene pipe is recommended for transmitting thermal water from wells. This is because polybutylene is virtually

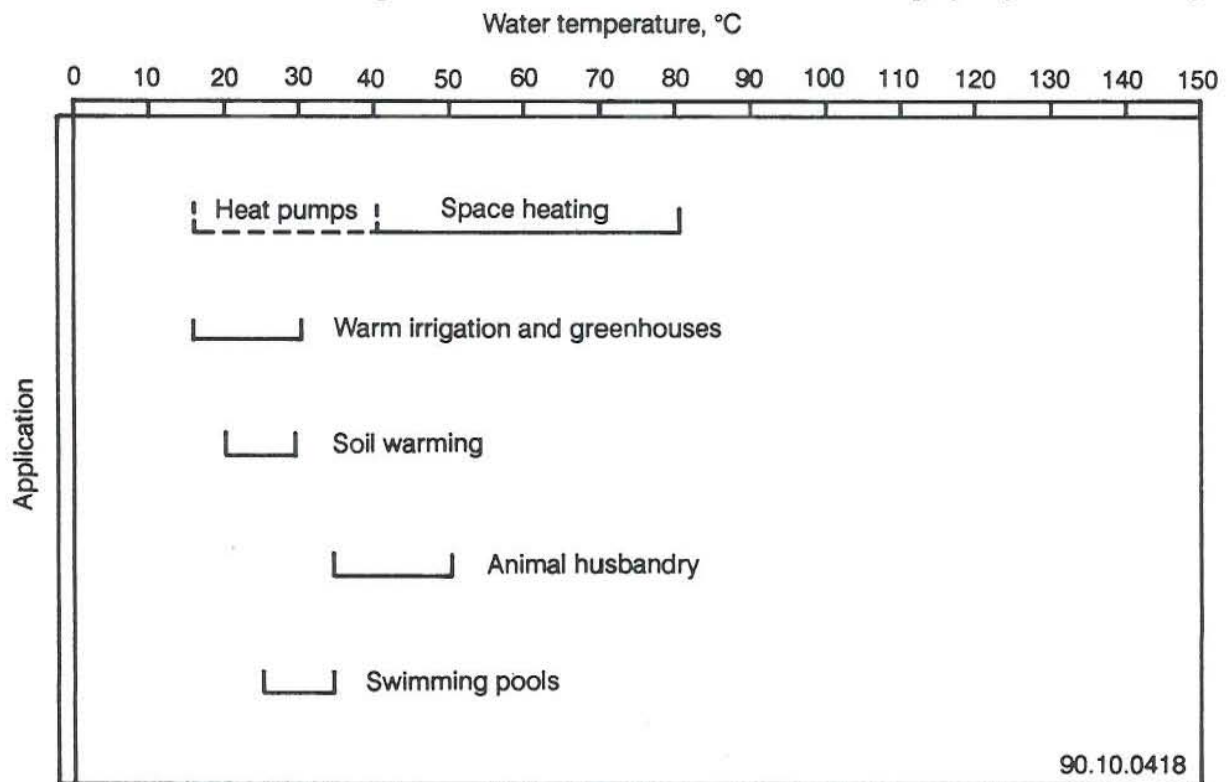


FIGURE 3: Possible direct uses of thermal water in Egypt

impervious to most chemicals in water, lighter in weight than metallic pipes and less expensive in price and installation cost (6 US\$/ft). This type of piping is available in sizes ranging from 2 - 18 inches.

3.2.1 Calculating pressure drop through a pipeline

In a single phase flow liquid, the pressure drop dp (m of water) through a circular pipe of a diameter d (m) and length l (m) resulting from a uniform flow rate m (kg/s) can be expressed by the following formula (see e.g. Kjartansson, 1984):

$$dp = 2 flv^2 / gd, \quad (3.1)$$

where:

- dp = pressure drop, m of water,
- f = friction factor, dimensionless,
- l = pipe length, m,
- d = inside pipe diameter, m,
- g = acceleration due to gravity, 9.8 m/s^2 ,
- v = fluid velocity, m/s.

Reynolds number (Re) is defined as follows:

$$Re = yvd/\mu = 4m/\pi d\mu,$$

where:

- y = fluid density, kg/m^3 ,
- m = mass flow rate, kg/s,
- μ = dynamic viscosity, kg/ms.

For rough pipes the coefficient of friction f could be calculated from the Colebrook equation:

$$1/\sqrt{f} = -2 \log 2.51/(Re\sqrt{f}) + 0.27 \epsilon/d, \quad (3.2)$$

where:

- ϵ = average pipe roughness height, mm.

Substituting the value of f obtained from Equation 3.2 in Equation 3.1, the value of dp can be calculated. Other methods for calculating dp include charts and the computer program PRESSURE (see Appendix B).

Figure 4 shows the results of calculating the pressure drop through three different pipes of diameters 200 mm, 240 mm, and 320 mm, respectively, assuming a flow rate of 25 l/s hot water (45°C) and a roughness height of 0.005 mm.

3.2.2 Temperature losses through pipes

Consider a constant flow of thermal water passing through a polybutylene pipe buried in the soil at depth h (m) from ground surface as shown in Figure 3.3, where r_1 = inner radius of pipe, r_2 = outer radius, and r_3 = insulation radius, (m).

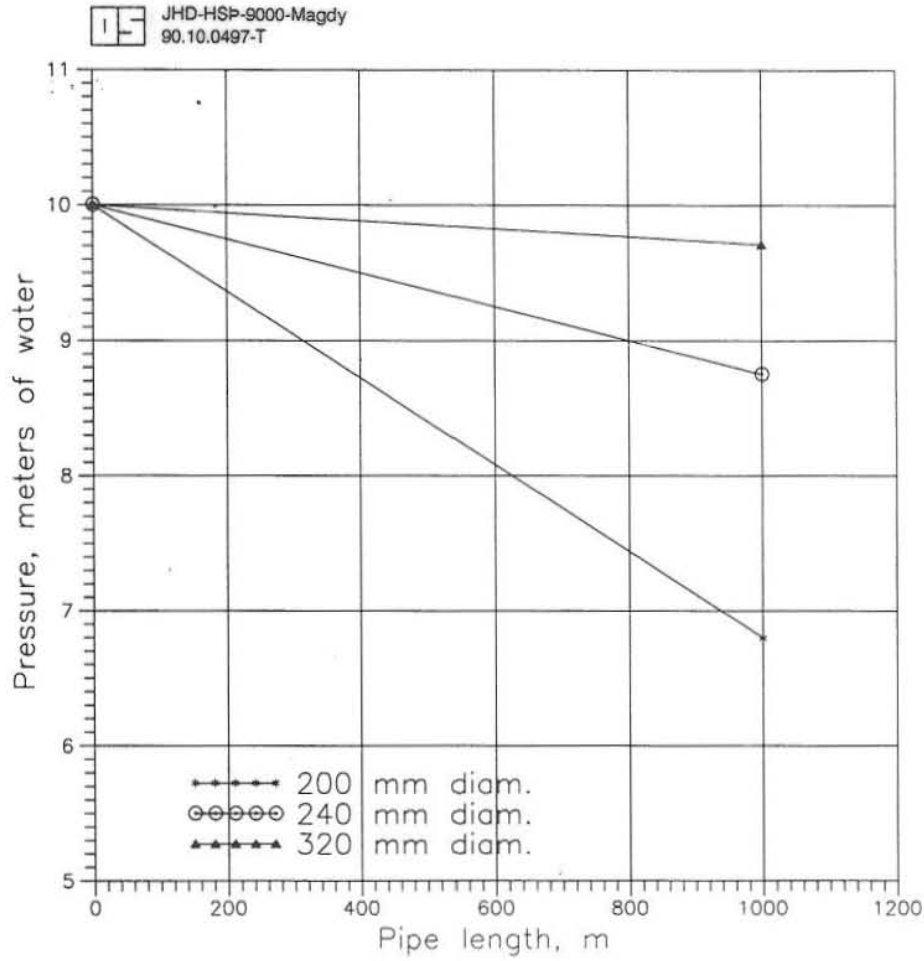


FIGURE 4: Pressure drop through pipelines

The temperature T of hot water passing through a pipe at any length l (m) is described by the following equation (for h/r_3 greater than 1.5) (see Björnsson, 1980; Holman, 1989):

$$T = T_{ao} + (T_i - T_{ao}) \exp(-kl/mc_p), \quad (3.3)$$

where:

T = temperature of water at length l , °C,

T_{ao} = outer air temperature, °C,

T_i = inlet water temperature (at $l = 0$), °C,

k = thermal conductivity of the piping system, W/(m°C),

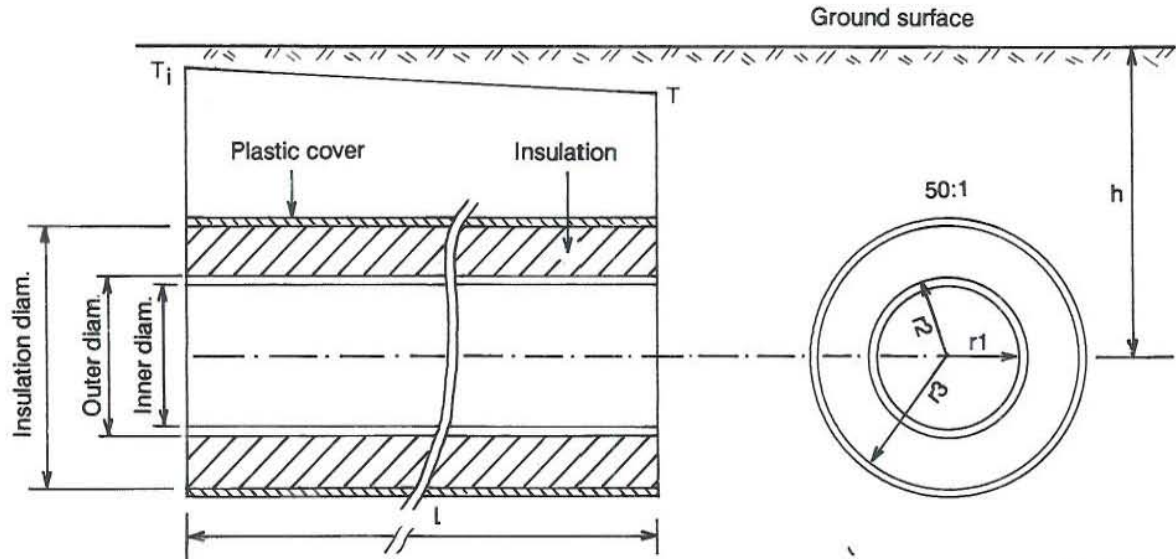
m = mass flow of water, kg/s,

c_p = specific heat capacity at inlet water temperature, J/(kg°C).

We have to determine the value of k in order to solve Equation 3.3 for T . The thermal conductivity of the piping system k is the reciprocal of R , the thermal resistance of the piping system (m°C/W). R , in turn, can be expressed as follows:

$$R = R_p + R_i + R_s \quad (3.4)$$

where the subscripts p , i , s indicate the thermal resistances in pipe, insulator, and soil



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FIGURE 5: Use of isolated pipes in hot water transmission

respectively and:

$$R_p = \ln(r_2/r_1)/2\pi j_p \quad (j_p = \text{thermal conductivity of pipe material, W/m}^\circ\text{C}),$$

$$R_i = \ln(r_3/r_2)/2\pi j_i \quad (j_i = \text{thermal conductivity of insulator, W/m}^\circ\text{C}),$$

$$R_s = (\ln 2(h+r_3)/r_3)/2\pi j_s \quad (j_s = \text{thermal conductivity of soil, W/m}^\circ\text{C}).$$

Values of j_p , j_i , j_s are taken from tables, and they depend on the materials used.

Solving for the above values of R and substituting in Equation 3.4 we get R (piping thermal resistance) and the reciprocal of R is the value of k . Substitute in Equation 3.3 with the value of k and assuming different values for l (pipe length in m) we get the corresponding temperature T .

Figure 6 shows the results of calculating the temperature drop across a 4 inch polybutylene pipe both with insulation and without insulation, assuming the following values:

$$r_1, r_2, r_3 = 0.0974, 0.11, 0.18 \text{ m respectively,}$$

$$T_i, T_{ao} = 45^\circ\text{C}, 0^\circ\text{C} \text{ respectively,}$$

$$m = 8 \text{ kg/s,}$$

$$c_p = 4182 \text{ J/kg}^\circ\text{C,}$$

$$j_p, j_i, j_s = 0.4, 0.026, 0.6 \text{ (W/m}^\circ\text{C}).$$

3.3 Use of heat pumps to upgrade a low temperature source

They are special kinds of pumps which provide the necessary temperature boost to concentrate the heat from a low temperature source (see e.g. Lienau and Lunis, 1989; McMullan and Morgan 1981).

In a heat pump cycle the heat from low temperature water is absorbed into the heat pump's evaporator by the working fluid, which is then increased in temperature and pressure by the compressor. From there it goes to the condenser where this heat is transferred to the hot water for providing heat up to 110°C . Figure 7 shows a schematic diagram of a heat pump using a condensable vapour as a refrigerant (vapour compression cycle).

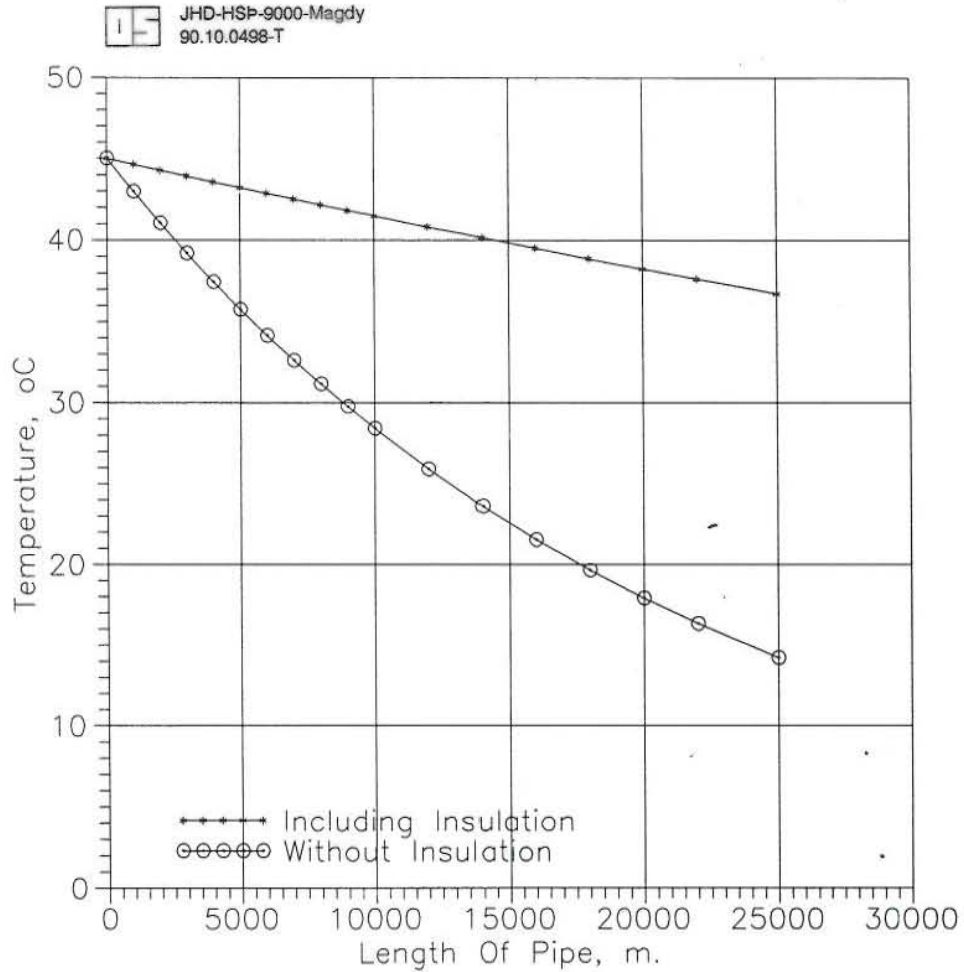


FIGURE 6: Temperature drop in hot water pipes

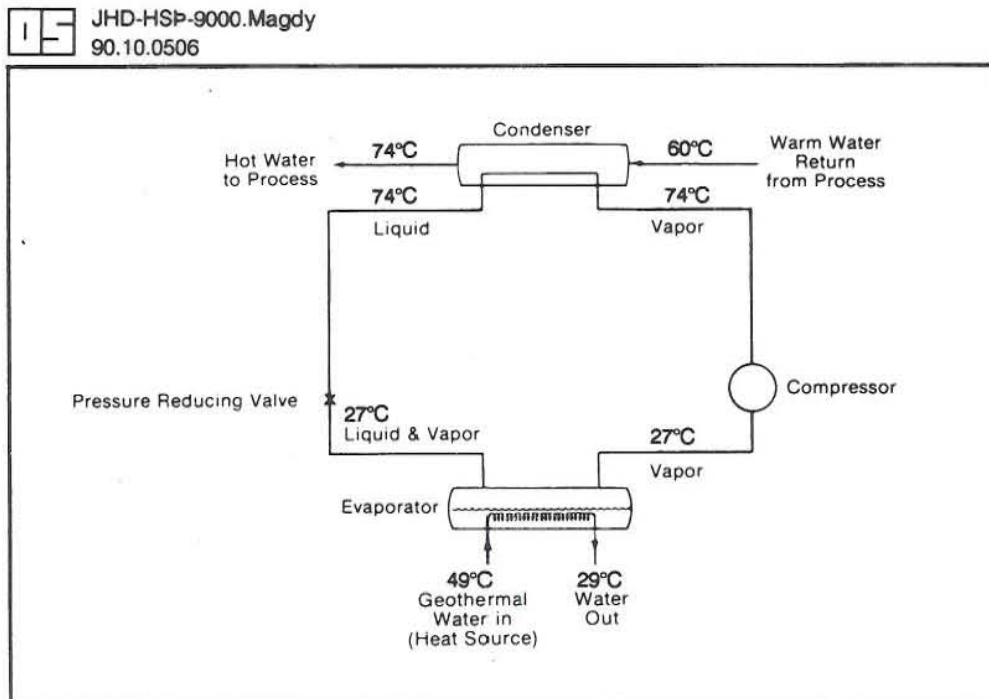
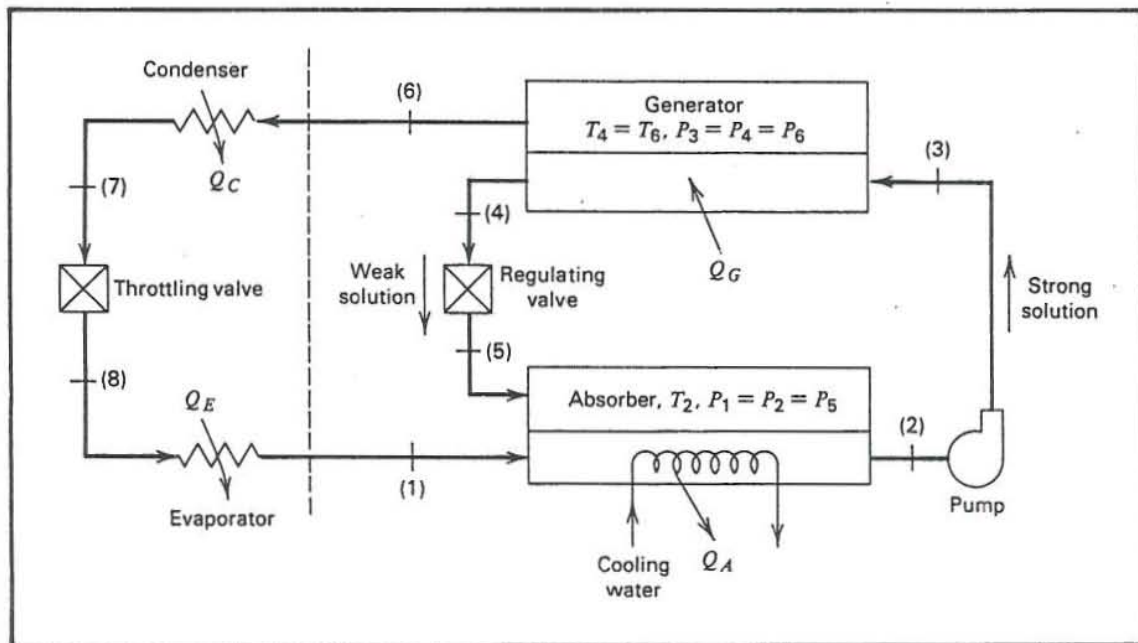


FIGURE 7: Heat pump schematic diagram (Modified from Niess, 1982)



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FIGURE 8: Schematic diagram of an absorption refrigeration cycle (Wark, 1988)

In an absorption refrigeration cycle the compressor is replaced by an absorber, a pump, a generator and a valve as shown in Figure 8. A secondary fluid or absorbent is used to circulate the refrigerant. When using ammonia as a refrigerant, water is considered the absorbent medium. When water is used as a refrigerant, lithium bromide is used as an absorbent medium. The measure of efficiency of a heat pump, called the coefficient of performance (COP), is shown in Figure 9. This is the ratio of the upgraded heat output to the thermal equivalent of the heat pump electrical input (COP) and ranges roughly from 3 to 7. An industrial water-to-water heat pump provides both heating and cooling.

Since geothermal fields in Egypt are referred to as low temperature reservoirs (temperatures range from 35-50°C, by applying the principals of heat pumps, it is possible to widen the temperature diagram and possible direct applications. There are two basic configuration sizes available commercially: reciprocating and centrifugal. Centrifugal machines are used for the largest applications while reciprocating are used for smaller capacities.

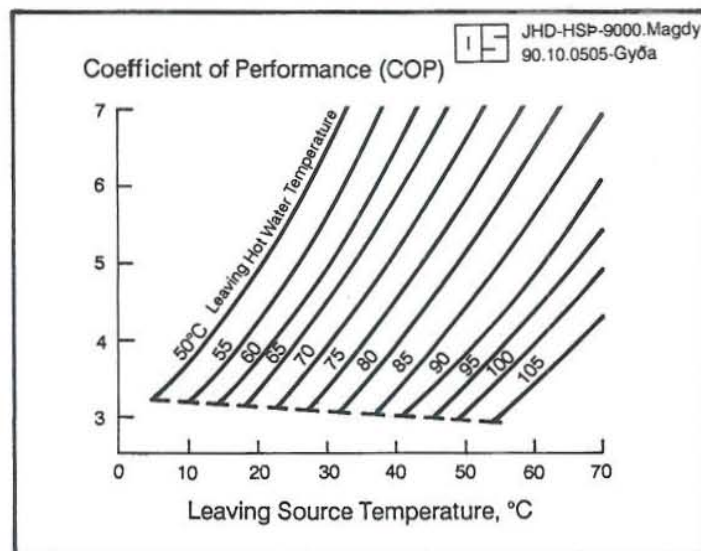


FIGURE 9: Coefficient of performance (Niess, 1982)

3.4 Space heating design

3.4.1 Introduction

Oasis areas, located in the Western Desert of Egypt, are considered the main sources of geothermal water. More than 250 wells exist in the oasis area and the temperature of water ranges from 35 - 50°C. Water is mainly used for irrigation and bathing.

Oasis areas are characterized by a dry arid climate. During the summer, for example in July, a maximum temperature of 45°C during the day and a minimum of 22°C at night is measured. In winter, for example in January, a maximum of 18°C and a minimum of 0°C is measured. During the colder months the source of heat for a farmer's house is mainly via stoves and gas, which are very inconvenient. Big buildings like hospitals, schools and governmental buildings suffer a lack of heating. Hot water coming from wells in such areas could be used as a heat supplying source for large buildings, houses, schools and factories.

The power demand for a space heating system depends on different factors, like wall construction and isolation, air infiltration and the difference between indoor and outdoor air temperature. For a given building, these factors can be calculated and summed up to give the total power demand in kW. Doing such calculations is out of the scope of this report. Instead an estimated value for the power demand per cubic meter of house volume is used. In Iceland, a value of 30 W/m³ is often used for houses with good insulation, with an indoor and outdoor temperature difference of 35°C. With reference to M. Rachedi (1989), a value of 66 W/m³ was calculated for houses with poor insulation, assuming a difference of 20°C between indoor and outdoor temperatures. Here, the power demand is estimated to be 50 W/m³.

To demonstrate the main steps in designing a space heating system, we consider a house with a floor area of 100 m² and a wall height of 3 m, thus giving a house volume of 300 m³. The power demand is, therefore, 50 x 300 = 15 kW. Now we have to choose the heating equipment. Because the temperature of geothermal water is low, using radiators is not suitable. Instead we choose floor heating (panel heating), that is heating from a piping system in the floor which carries the hot geothermal water.

Because of the limitations on the allowable floor surface temperature, we need supplementary equipment to fulfill the heat demand. A combined air heater and blower is chosen as a secondary heating system. An air heater takes a mixture of outer air and recirculated indoor

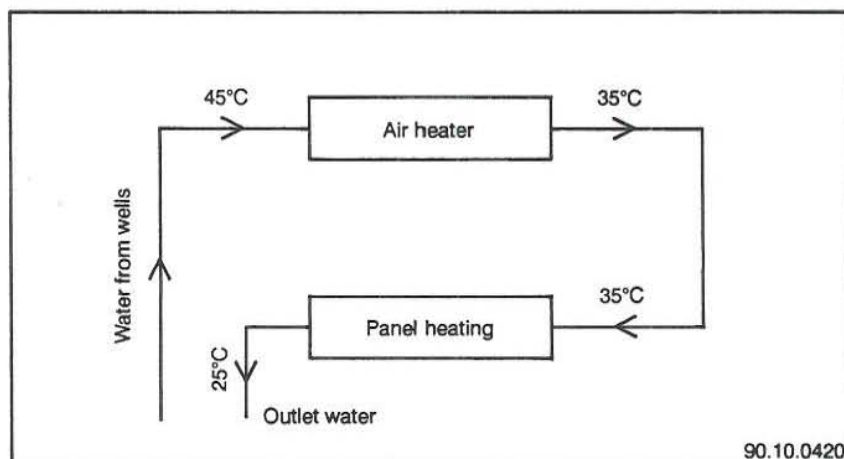


FIGURE 10: Schematic diagram of combined panel heating and air heater systems

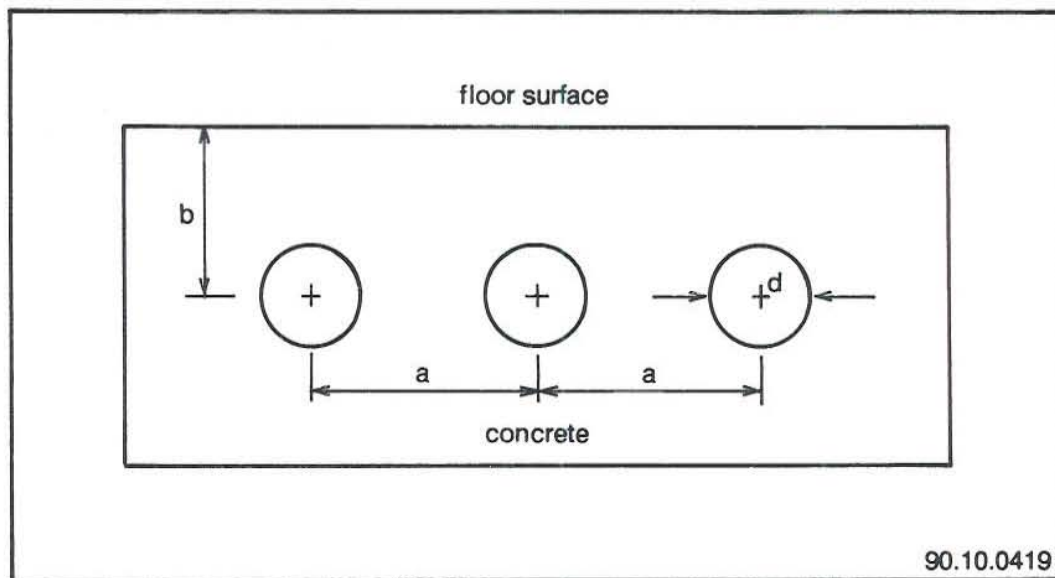


FIGURE 11: A cross-section through a panel heating system

air, heats it up and blows it into the room using a fan. The geothermal water is cooled down in the air heater to a temperature suitable for entry into the floor heating system. Thus, the geothermal water runs serially through both heating systems, as shown in Figure 10.

3.4.2 Design of panel heating system

3.4.2.1 Main design parameters

A cross-section of a floor with panel heating is shown in Figure 11. The pipes are made of plastic, either polybutylene or polypropylene. Two possible pipeline distributions are shown in Figure 12.

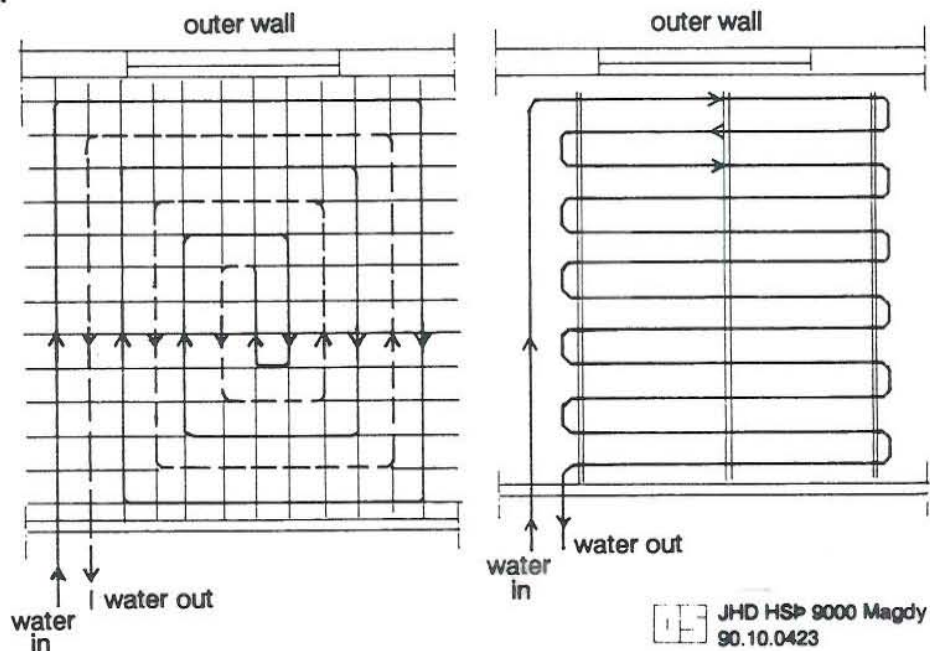


FIGURE 12: Pipeline distribution through a panel heating system

The main design parameters for our panel heating design as seen from Figure 11 are:

pipe outer diameter d , 20 mm,
 spacing between pipe centres a , 200 mm,
 buried depth of pipe (to the centre) δ , 40 mm,
 total pipe length l , 500 m,
 thermal conductivity of concrete k , 1.5 W/m°C,
 inlet water temperature T_p , 35°C,
 floor surface temperature T_f , 26°C,
 indoor air temperature T_{ai} , 20°C.

3.4.2.2 Calculation of heat flow

The maximum floor surface temperature T_f has been chosen as 26°C. With this design condition, the heat flow from the panel heating system in Figure 11 can be calculated as follows:

$$Q_f = h A (T_f - T_{ai}), \quad (3.5)$$

where:

Q_f = heat flow from the floor, W,
 h = heat transfer coefficient, W/m²°C,
 A = floor surface area, m².

In general, the heat transfer coefficient h depends on the geometry of the heat flow surface and on the temperature difference ($T_f - T_{ai}$). It can be taken from tables or calculated by empirical formulas.

With $h = 9$ W/m²°C, the heat flow from Equation 3.5 is:

$$Q_f = 9 \times 100 \times (26-20) = 5400 \text{ W} = 5.4 \text{ kW}.$$

3.4.2.3 Calculation of mean water temperature and outlet temperature

The thermal insulation under the floor is assumed to be so good that the heat flow downwards from the pipes can be neglected. Accordingly, the up heat flow can be described by the following equation (Halldorsson and Sigurjonsson, 1987):

$$Q_f = A dT_m / [(1.15 a / \pi k \cdot \log a/\pi \cdot d) + R], \quad (3.6)$$

where:

dT_m = mean temperature difference between water temperature and indoor air temperature, °C,
 k = thermal conductivity of concrete, 1.5 W/m°C,
 R = thermal resistance above the pipe, (m²°C/W).

The thermal resistance R is composed of two parts: heat conduction from the pipe centre to the floor surface and heat convection from the floor surface to the air. It can be calculated as follows:

$$R = \delta/k + 1/h = 0.04/1.5 + 1/9 = 0.138 \text{ m}^2\text{°C/W}$$

The heat transfer calculated from Equation 3.5 must be equal to that calculated from Equation 3.6, thus dT_m from Equation 3.6 is 9°C .

Now the outlet water temperature T_o can be calculated from the equation:

$$dT_m = (T_i - T_o) / \log [(T_i - T_{ai}) / (T_o - T_{ai})]. \quad (3.7)$$

And we find that $T_o = 25^\circ\text{C}$.

3.4.2.4 Calculation of hot water mass flow required

Assuming m is the mass flow required (kg/s) to produce an upheat flow Q_f , then:

$$Q_f = m c_p dT, \quad (3.8)$$

where:

$$\begin{aligned} Q_f &= \text{upheat flow, } 5400 \text{ W,} \\ c_p &= \text{specific heat capacity of water at inlet, } 4182 \text{ J/kg}^\circ\text{C,} \\ dT &= T_i - T_o = 35 - 25 = 10^\circ\text{C.} \end{aligned}$$

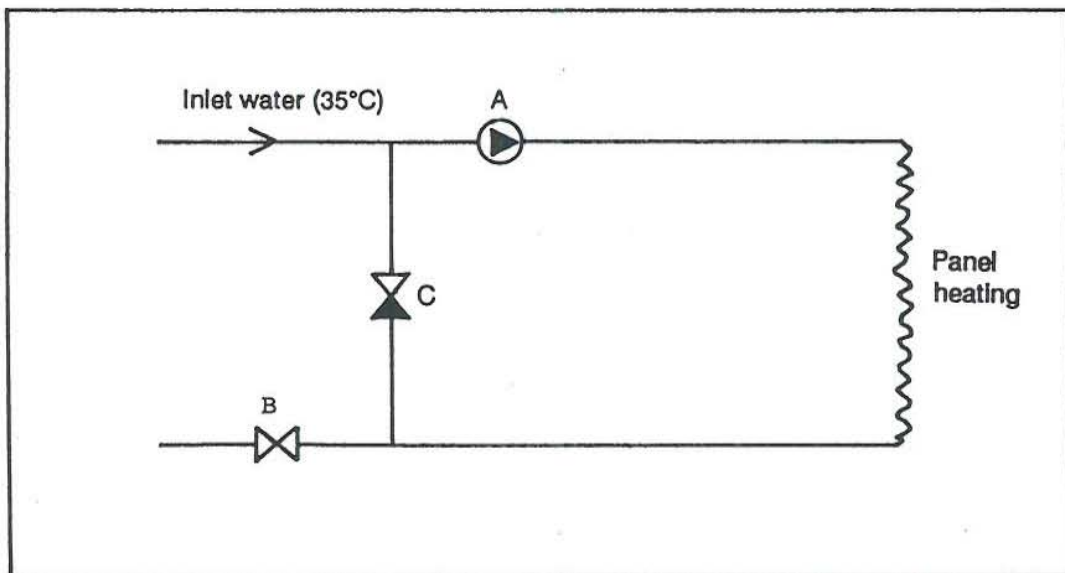
Substitute with the above values in Equation 3.8 and we get $m = 0.11 \text{ kg/s}$.

3.4.2.5 Calculation of pressure drop through heating pipes

The length of the plastic pipes required for the design of a panel heating system as shown in Figure 11 is about 500 meters. So far we have calculated the flow rate through the plastic pipe (0.11 kg/s) and the pipe length (500 meters). Using the computer program PRESSURE described in section 3.2.1, the value of pressure drop (dP) is found to be 12.6 m of water (see Appendix B).

3.4.2.6 Regulation of floor temperature in the panel heating system

When using a combination of a panel heating system and an air heater system, a breakdown or failure in the air heater system sometimes occurs. Thus, the inlet temperature for panel heating T_i becomes much higher than the designed value (35°C), as the water entering the air heater system is not cooled (Figure 10). Therefore, it is necessary to use a control system to maintain the designed inlet water temperature to the panel heating system. Figure 13 shows a schematic diagram of a simple control system, and as shown, returned water is partially thrown away through the control valve (B) and partially recirculated through the non-return valve (C). If the inlet water temperature is too high, the control valve (B) will close partially and more water will be circulated. This circulated water will lower the water inlet temperature. If the water inlet temperature is too low, the control valve (B) will open and the water inlet temperature will increase.



A: Circulation pump

B: Control valve

C: Non return valve

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FIGURE 13: Control system in panel heating

3.4.3 Design of an air blower heating system

An air heater is actually a heat exchanger where hot water is cooled as it flows through pipes located in the heater. Air is heated as it is blown over the pipes by a fan as shown in Figure 14. Inlet air to the heater can be taken from the room or can be a mixture of room air and outdoor air as shown in Figure 15.

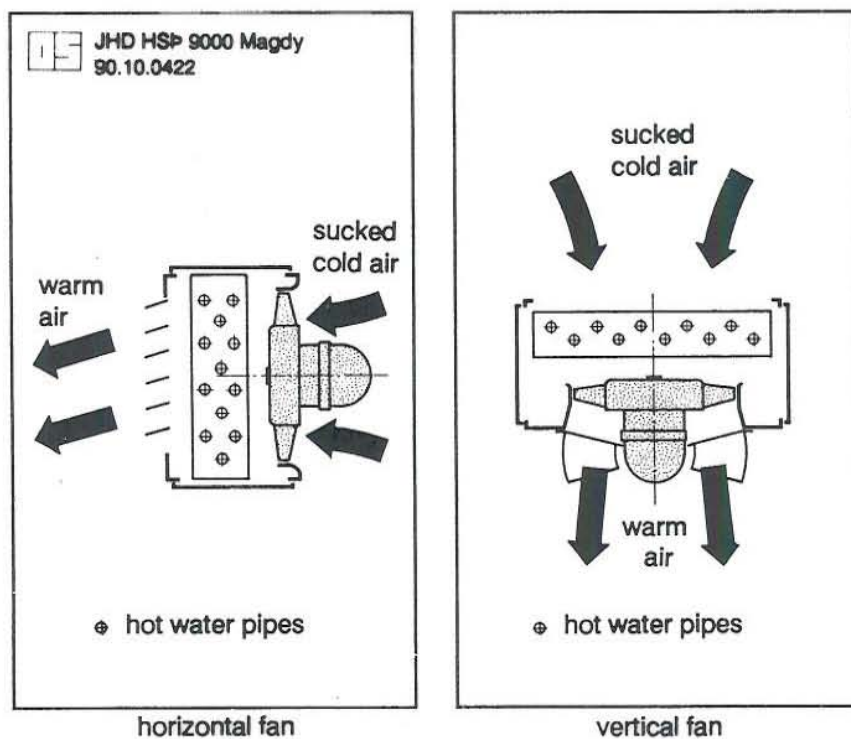


FIGURE 14: A simple design of an air heater

Air heaters (blowers) are commercially available. The designed power of the air heater, inlet water temperature T_i , and outlet water temperature T_o are the necessary parameters for choosing a suitable air heater type from catalogs. Catalogs also give the value of air temperature at inlet and outlet of the heater, the volume of air circulated, and the fan speed in r.p.m.

The inlet air to the heater is actually a mixture of the indoor room air (recirculated) and the outdoor air. Usually in an air heater design, ventilation (mass of ventilated air/hour) is assumed double or triple the volume of the space to be heated.

So far we have calculated the following for our designed heating system:

The total power demand, 15 kW (see section 3.4.1);

The power required for panel heating system, 5.4 kW (Equation 3.5).

Thus, the designed power for the air heater system is:

total power demand - power required for panel heating = $15 - 5.4 = 9.6$ kW.

Now we have the following parameters from which to choose a suitable air heater design from readily available commercial types:

Power required = 9.6 kW,
inlet water temperature = 45°C ,
outlet water temperature = 35°C .

For example, using the catalogs of NOVENCO air heaters published in November, 1989 we can easily choose type VNA - 82, which satisfies the above assumptions. From the catalog we can also find the value of the air temperature out of the heater and the value of the air temperature at inlet, in this case, 24°C and 15°C respectively.

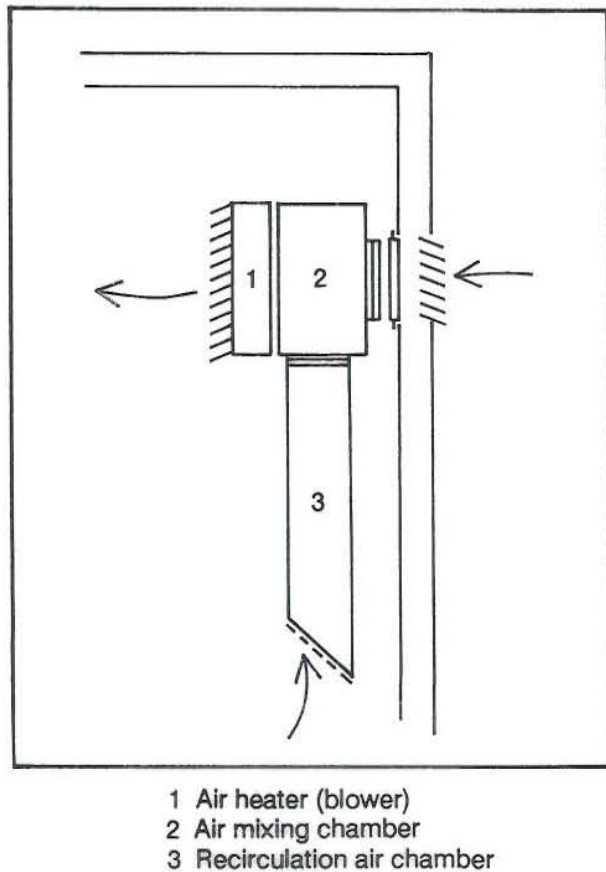


FIGURE 15: Basic components for circulating and heating of cold air

4. CONCLUSIONS AND RECOMMENDATIONS

1. Management of data about geothermal wells in Egypt is of great importance, particularly in carrying out geothermal research and exploring new drilled wells. dBASE IV and SQL languages are powerful tools for managing all available data providing quicker, efficient ways to retrieve these data.
2. Geothermal studies of Egypt are few. An intensive study is recommended to cover the oasis areas (Western Desert of Egypt). A similar study is recommended in the Eastern Desert along the Red Sea coast and in the Sinai Peninsula. The purpose of this study is mainly to determine the best potential areas for geothermal water. This is accomplished by estimating the average value of the heat flow and the geothermal gradient for the recommended areas of study. Also, in addition to a microseismic study, a geochemical study is recommended to estimate the reservoir base temperature.
3. Heat pumps are recommended to provide the necessary temperature boost for a low temperature water source. Water-to-water heat pumps are also recommended to provide both heating and cooling effects.
4. Hot water from wells in the oasis areas can be used for space heating of large buildings such as hospitals, schools, and factories. This can be done by transmitting the hot water from wells through isolated pipelines and by combining panel heating and air heater systems.
5. Other possible direct uses of geothermal water in Egypt may include the use of hot water in soil warming, greenhouses, warm irrigation, animal husbandry and swimming pools.

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NOMENCLATURE

A:	floor surface area (m^2)
c_p :	specific heat capacity of water ($\text{J/kg}^\circ\text{C}$)
d:	pipe inside diameter (m)
dT_m :	mean temperature difference ($^\circ\text{C}$)
dp :	pressure drop (meters of water)
f:	friction loss factor (dimensionless)
g:	acceleration due to gravity (9.8 m/s^2)
h:	heat transfer coefficient ($\text{W/m}^2\text{C}$)
j_i :	thermal conductivity of insulating material ($\text{W/m}^\circ\text{C}$)
j_p :	thermal conductivity of pipe material ($\text{W/m}^\circ\text{C}$)
j_s :	thermal conductivity of soil material ($\text{W/m}^\circ\text{C}$)
k:	thermal conductivity of piping system ($\text{W/m}^\circ\text{C}$)
l:	pipe length (m)
m:	water mass flow (kg/s)
Q_f :	heat flow (kW)
R:	thermal resistance of an isolated piping system ($\text{m}^\circ\text{C/W}$)
R:	thermal resistance above the pipes in a panel heating system ($\text{m}^2\text{C/W}$)
R_i :	thermal resistance of insulating material ($\text{m}^\circ\text{C/W}$)
R_p :	thermal resistance of pipe material ($\text{m}^\circ\text{C/W}$)
R_s :	thermal resistance of soil material ($\text{m}^\circ\text{C/W}$)
r_1 :	inner pipe radius (m)
r_2 :	outer pipe radius (m)
r_3 :	insulation radius (m)
T_{ai} :	indoor air temperature ($^\circ\text{C}$)
T_{ao} :	outdoor air temperature ($^\circ\text{C}$)
T_f :	floor surface temperature ($^\circ\text{C}$)
T_i :	inlet water temperature ($^\circ\text{C}$)
T_o :	outlet water temperature ($^\circ\text{C}$)
v:	fluid velocity (m/s)
y:	fluid density (kg/m^3)
δ :	buried depth of pipes in a panel heating system (m)
ϵ :	average roughness height in pipes (mm)
μ :	dynamic viscosity (kg/ms)

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APPENDIX A: The LOCATION database table

Well Key	Well Name	X-Coordinate	Y-Coordinate	Elevation m a.s.l.
13724	SR-23	1754.433	1754.433	58.8
13721	SR-20	1751.803	1751.803	57.5
13710	SR-09	1761.222	1761.222	57.2
13711	SR-10	1579.149	1579.149	57.3
13727	SR-26	1823.369	1823.369	56.9
13709	SR-08	1867.090	1867.090	57.9
13708	SR-07	1868.886	1868.886	57.0
13707	SR-06	1874.090	1874.090	56.1
13706	SR-05	1974.372	1974.372	62.9
13705	SR-04	1990.028	1990.028	64.7
13704	SR-03	1999.048	1999.048	65.0
13703	SR-02	2006.665	2006.665	65.2
13702	SR-01	2043.574	2043.574	69.9
13719	SR-18	1668.542	1668.542	55.5
13452	SR-30	1621.617	1621.617	44.8
13712	SR-11	1621.015	1621.015	55.5
13714	SR-13	1758.936	1758.936	53.5
13725	SR-24	1924.750	1924.750	50.4
13726	SR-25	1901.703	1901.703	50.4
13728	SR-27	1981.655	1981.655	49.2
13729	SR-28	1972.839	1972.839	49.0
13730	SR-29	1990.080	1990.080	49.5
13723	SR-22	2009.876	2009.876	47.4
13720	SR-19	2079.651	2079.651	46.0
13722	SR-21	2099.086	2099.086	45.6
13453	SR-31	2107.486	2107.486	45.0
13454	SR-32	2126.324	2126.324	44.6
13731	SR-33	2161.618	2161.618	45.0
13732	SR-35	2252.881	2252.881	56.4
13485	SR-37	2344.099	2344.099	55.1
13733	SR-39	1992.511	1992.511	54.0
13734	SR-42	1964.062	1964.062	57.0
12851	SR-40	1935.947	1935.947	49.8
13458	SR-41	1511.810	1511.810	56.0
13456	SR-36	1580.282	1580.282	57.0
13455	SR-34	1603.132	1603.132	56.2
13713	SR-12	1575.806	1575.806	61.0
13459	SR-43	1191.327	1191.327	62.0
13716	SR-15	1327.826	1327.826	57.6
13717	SR-16	1437.277	1437.277	56.1
13718	SR-17	1374.337	1374.337	56.9
13457	SR-38	1356.290	1356.290	57.3
13715	SR-14	1371.751	1371.751	54.7

APPENDIX B: An output example of the PRESSURE program

PRESSURE DROP IN PIPES

Pipe outside diameter	(mm)	20.0000
Pipe wall thickness	(mm)	1.8000
Pipe length	(m)	500.0000
Pipe roughness	(mm)	0.0100
Water temperature	(°C)	35.0000
Water flow rate	(l/s)	0.1100
Water density	(kg/m ³)	994.0815
Water viscosity	(poise)	0.0072
Water velocity	(m/s)	0.5207
Reynolds number	-	11798.3242
Friction factor	-	0.0306
Pressure drop	(mm H ₂ O)	12561.7949 = 12.6 (mH ₂ O)
