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OPTIMAL UTILIZATION OF GEOTHERMAL ENERGY AT THE UNIVERSITY OF ORADEA, ROMANIA

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ABSTRACT

The University of Oradea and the National Geothermal Research Centre, as part of the university, plan to create a national demonstration and research geothermal power plant emphasizing on geothermal energy utilization and control engineering. This paper proposes a way to achieve this aim in two steps. In the first step, the existing geothermal installation will be modernised by installing a deep well pump, programmable logic controllers (PLC) and a Supervisory Control And Data Acquisition System (SCADA). In the second step, a solution for cascaded use is proposed, in order to increase the utilization efficiency. Based on the technical calculations presented, it is possible to estimate the behaviour of the whole geothermal system from the point of view of geothermal energy consumption. By using SCADA control system and its data collection facilities, it is possible to search for the optimal strategy for the geothermal utilization.

1. INTRODUCTION

One of the main geothermal reservoirs exploited in Romania is located in the western part of the country. The reservoir is in Triassic limestones and Dolomites and Pannonian sands and sandstone layers which include a section of the Pannonian depression. The Oradea reservoir is an integrated part of this main reservoir. It is situated under the city of Oradea. The extraction history shows that it is an open reservoir. The natural recharge originates in the Apuseni Mountains, located about 80 km to the east of Oradea city. The water is about 20,000 years old.

Thirteen geothermal wells have been drilled into the Oradea reservoir. One of them is used for reinjection in a doublet type of system. Wellhead temperatures are between 70-105°C and the wells flow at artesian rates of 5-30 l/s. The total artesian flow rate is 150 l/s. Draw-down became significant only when the flow rate was increased to the present value. To increase the production rate by pumping means that all the extracted water will have to be reinjected, not only to provide a pollution free disposal method, but also to sustain the reservoir pressure (Rosca, 1993). Present production is about 540 TJ per year and the total installed capacity is 35 MW_t. The geothermal water is used for space and greenhouse heating, domestic hot water, preparation of industrial hot water, balneology and recreational facilities.

2. THE PRESENT GEOTHERMAL SYSTEM AT THE UNIVERSITY

2.1 Presentation of the existing geothermal utilization at the university

The University of Oradea was established as a state university in 1990, on the basis of the Higher Education Institute founded in 1963. It comprises twelve schools in many different fields. Those related to geothermal energy are mechanical engineering, electrical engineering, energy engineering, environmental protection and medical sciences. Inside the university campus a geothermal well was drilled in 1981. The initial artesian flow rate was about 35 l/s with a well head temperature of 87°C. At present, the flow rate is about 30 l/s and the well head temperature is 85°C. The well has a 9 5/8" production casing down to 550 m, a 7" casing between 362-1,991 m and a liner from 1,888 m down to the bottom at 2,991 m. The liner is slotted in the 2,000-2,914 m depth interval for production. All casings are cemented.

The geothermal water is used for district heating of the university buildings, to provide them with hot tap water and to produce electricity in a pilot binary power plant using carbon dioxide as a working fluid. The power plant is an experimental installation and has therefore been used for testing, usually during the warm season, when geothermal water is available for the plant. At present a renovation of the pilot power plant is under construction. The schematic diagram of these users of geothermal water is presented in Figure 1. A storage tank (T) and a pump station building (P) exist, but they have not yet been connected to the geothermal installation system. The used geothermal water is discharged into a river close to the university campus.

The university campus area is about 143,000 m^2. There are at present 24 buildings with a total volume of 144,000 m^3. Part of the existing buildings are rather old. The total volume of these old buildings is

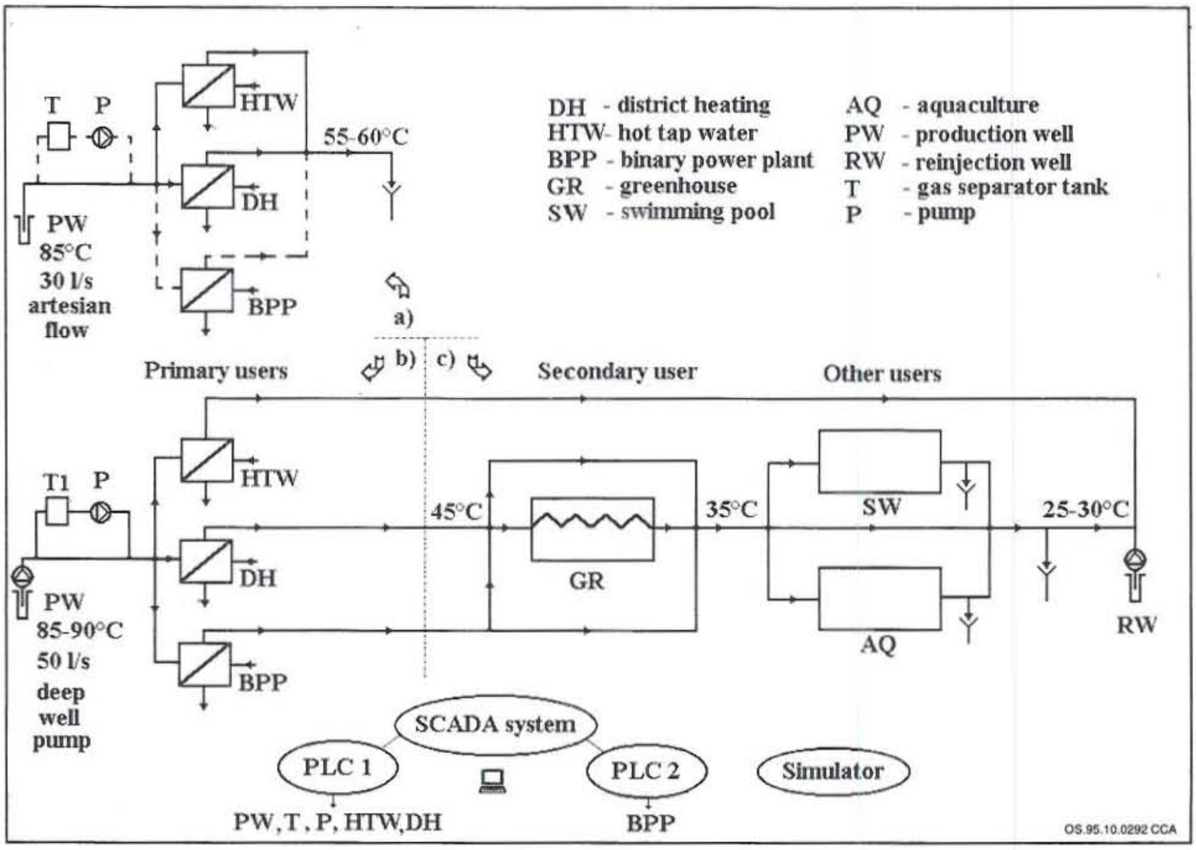

FIGURE 1: The university geothermal installation system diagram, a) existing, b) future step 1, and c) future step 2

about 69,000 m^3 and the total volume of the new existing buildings is about 75,000 m^3. Mainly, there are three buildings with class rooms, laboratories and offices, one building with laboratories and workshops, two hostels, a canteen, two gymnasiums and a number of smaller ancillary buildings.

It is worth mentioning that in 1992 the National Geothermal Research Centre was established in Oradea as part of the university. The head-quarters of the Romanian Geothermal Association are located there.

2.2 Expansion of the university facilities

A new building, with a total volume of 29,000 m^3, is already under construction and will be finished in 1996. Other new facilities are planned to be developed in the future, for instance a new and modern library for about 11,000 students which is in the designing phase, three student hostels with 1,000 places, a physio-kineto-therapy facility, a swimming pool with geothermal water and a greenhouse for training in horticulture.

To obtain the needed thermal energy for these new facilities there are plans to increase the production of the existing geothermal well, by installing a deep well pump. Also, it is planned to modernise and develop the existing geothermal installation system, in order to create a national demonstration and research plant with respect to geothermal energy utilization (Maghiar and Rosca, 1995). For this aim, the university is already taking part in a Eureka project in collaboration with the Icelandic Geothermal Engineering Ltd. company.

3. MODIFICATION OF THE EXISTING INSTALLATION SYSTEM

3.1 Main objectives for the modification

At present, the geothermal water is discharged at the relatively high temperature of 55-60°C into the river which runs just outside the university campus without further utilization. Moreover, when the heating system is turned off, the geothermal water is used only to provide hot tap water. Therefore, the well potential is poorly utilized. On the other hand, during the heating season, the heat production is regulated by modifying in steps the geothermal water flow rate through the plate heat exchangers, i.e. by placing diaphragms with different orifices on the geothermal water pipe. This operation is made manually, 3 or 4 times during the heating season. In this way it is not possible to keep constant temperature inside the buildings, and this causes an uncomfortable situation and waste of energy. In the rooms, the radiators are equipped with manual valves for regulating the heating water flow rate according to the indoor temperature, but these valves are old and prone to sticking and leaking, so it is usual to keep them fully open all the time. When the indoor temperature is too high, the windows are used for regulating the indoor temperature.

The objectives for the modifications of the present heating system are to deal with these shortcomings. Thus, the main objective is to utilize, as efficiently as possible, the thermal energy from the geothermal water and to discharge it into the river at as low temperature as possible. Another objective is to increase the production capacity of the well by installing a deep well pump. In order to maintain the pressure potential of the reservoir it will be necessary to reinject part of the used geothermal water. Another objective is to save energy, i.e. utilization of geothermal water by permanent regulation of geothermal energy supply according to the demand. According to this aim, all the heating system will be controlled and monitored by utilizing two programmable logic controllers (PLC2 for the binary power plant and PLC1 for the other users) which will be connected to a common central SCADA system (Supervisory Control And Data Acquisition). Also, by utilizing SCADA system and its data processing facilities for a longer period of time, it is possible to find the optimal strategy for utilization of the geothermal energy.

3.2 System overview

Relying on the diagram presented in part a of Figure 1, referring to the present utilization of the geothermal water and having regard for the objectives presented in Chapter 3.1, parts b and c propose the following scheme for utilizing the thermal energy from the geothermal water. The geothermal water is extracted from the production well, PW. For increasing the production capacity, a deep well pump and relevant equipment will be installed. The present capacity of the well is 30 l/s artesian flow rate at a temperature of 85°C. By installing the deep well pump, it is planned that the flow rate increases to approximately 50 l/s. Geothermal water temperature will probably increase with higher flow rate, possibly up to 90°C. In this report it is assumed, to be on the safe side, that the temperature remains constant at 85°C. The geothermal water is then directed to a storage and degassing tank T1. From there, through the pump, P, the water is pumped to the heat station and binary power plant, BPP, located approximately 400 m from the well station and pump station. The geothermal water is transported through a steel pipe (200 mm diameter) insulated with rock wool and protected by a zinc-covered sheet. Heat loss through the pipe is less than 15 W/m during the worst weather, that is equivalent to 0.03°C temperature decrease. In the binary power plant the geothermal water is the energy source in a binary thermodynamic cycle by which the thermal energy of the water is transformed into mechanical energy and then into electrical energy. Carbon dioxide is the working fluid which runs in a closed loop in the plant. The cold source for this thermodynamic cycle is cold water from the nearby river and fresh water produced by several shallow wells. In the heat station, the geothermal water is used for space heating and hot tap water production in stainless steel plate heat exchangers. The return temperature from the hot tap water heat exchanger is about 12°C and it is discharged into the reinjection well, RW, as it is unsuitable for further utilization.

The return temperature of the geothermal water from the binary power plant and from space heating heat exchangers is 35-45°C, depending on the outdoor temperature. For this thermal potential cascaded usage is proposed. In this way, geothermal water is transported to a greenhouse complex which comprises of 3 greenhouses, each 10 x 70 m^2. Geothermal water is used for heating the greenhouses during the cold season, about 7 months per year, by a combined solution for heating which will be presented in Chapter 4.2. The geothermal water temperature outflow from the greenhouses is 30-35°C, depending on the outdoor temperature. Further on, a part of the geothermal water is used for recreational, health bathing and didactic activities in 2 swimming pools, during the cold season an indoor swimming pool of 100 m^2, with water temperature in the pool 37°C and, during the warm season, an open-air swimming pool of 12.5 x 25 m^2, and with water temperature in the pool 28°C. It is proposed that the indoor swimming pool be built with glass walls which will be opened during the warm season. Another fraction of the geothermal water flow rate will be used for growing fish in two basins. One of them, which will be running all year round, is 400 m^2 with water temperature of 26°C. The other one is 400 m^2 with water temperature of 17°C and will operate 6-8 months per year, during the cold period. In order to compensate for the increase of the well production and to avoid a reservoir pressure drop, a part of the return geothermal water, after all the utilizations presented above, will be piped to an accumulator for a reinjection well, located approximately 1,000 m from the university campus.

All the modifications and other proposed facilities will be implemented based on the existing system and with minimum changes in existing components. This new system will be built in two steps. The first step includes installation of modern monitoring equipment connected to a process computer PLC on the existing components in the system presented above. In the second step, based on the experience gained during the running of the modernized system, a final system will be built which will include cascaded usage facilities.

3.3 Description of the different subsystems

3.3.1 Direct usage

Well station. As mentioned in Chapter 3.2, in order to increase the production capacity of the well from 30 to 50 l/s, it is proposed to install a deep well pump and relevant equipment. In this respect, well measurements where done to find its artesian production characteristics and to estimate its response to pumping in order to find the necessary length and thrust capacity of the deep well pump. The production characteristics, wellhead pressure vs. flow rate, are presented in Figure 2. For the needed flow rate it is necessary to install the deep well pump at the depth of 50-80 m.

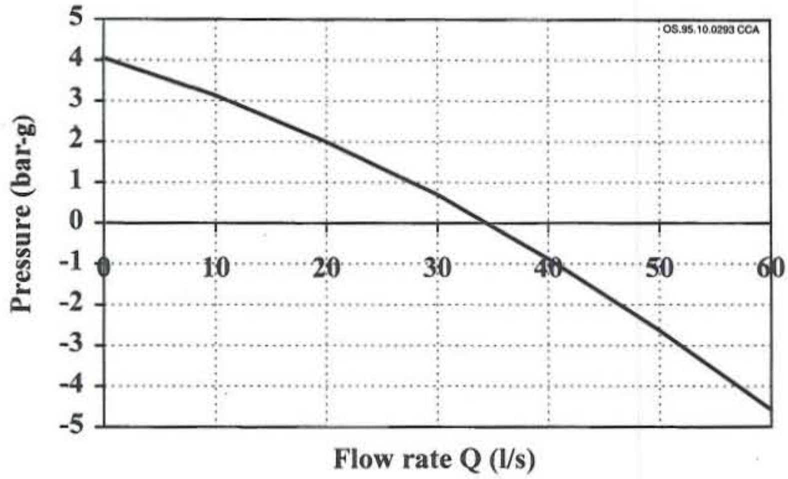

FIGURE 2: The production characteristics of the university well

The deep well pump and its accessories are presented in Figure 3. The geothermal water is transported through the main pipe, diameter 150 m, to a tank with 300 m^3 capacity. To avoid corrosion, the pressure in the tank is higher than the atmospheric pressure, to prevent oxygen from entering the water. This also avoids calcite scaling by keeping part of the carbon dioxide in solution. The water lubrication system for the lineshaft bearings of the deep well pump mainly comprises of a small degassing vessel, a pump, a filter and a flowmeter. A flowmeter, FT1, temperature transmitter, TT1, pressure transmitter, PT9 and control valve, CV0, are installed on the main discharge pipe and connected to the PLC. The deep well pump motor is operated by the variable speed drive, VSD1.

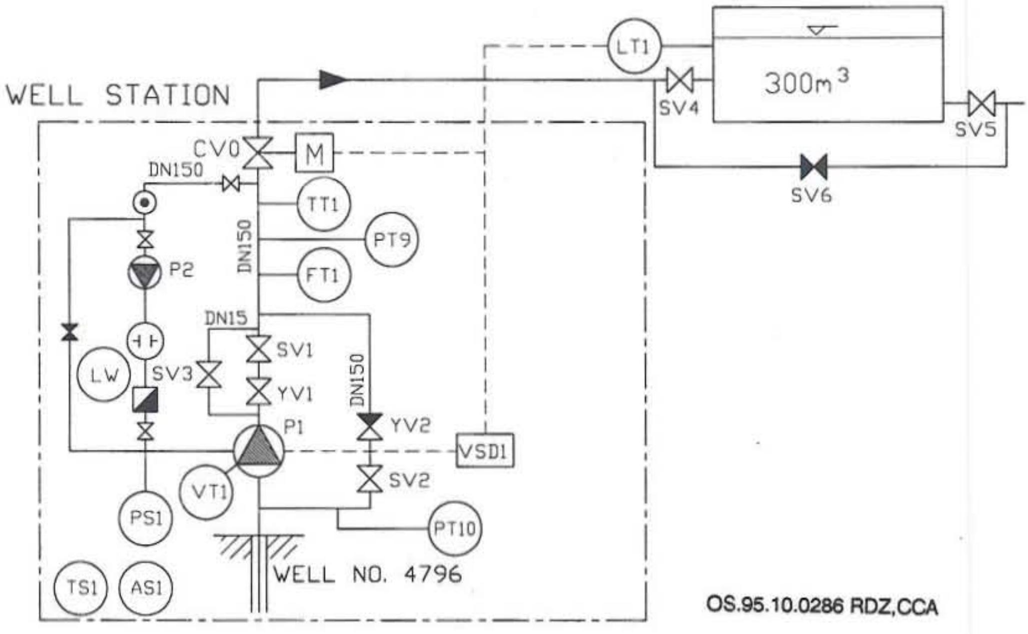

FIGURE 3: Diagram showing the well station and the storage tank

The function of the tank is to be a buffer between the well production and the geothermal water demand from the consumers, to degass the geothermal water and to increase the short time peak load production capacity of the system. The regulating function of the well station is to keep water level in the tank constant. In this way, the water flow rate delivered by the well is variable, depending on the demand for hot water. There are two modes of operation. One of them utilizes the variable speed drive VSD1 by varying the speed of the deep well pump's motor. The other one utilizes the control valve CV0 to regulate the flow rate from the well when the pump is not running, i.e. when there is an artesian flow from the well or when the VSD1 is out of order.

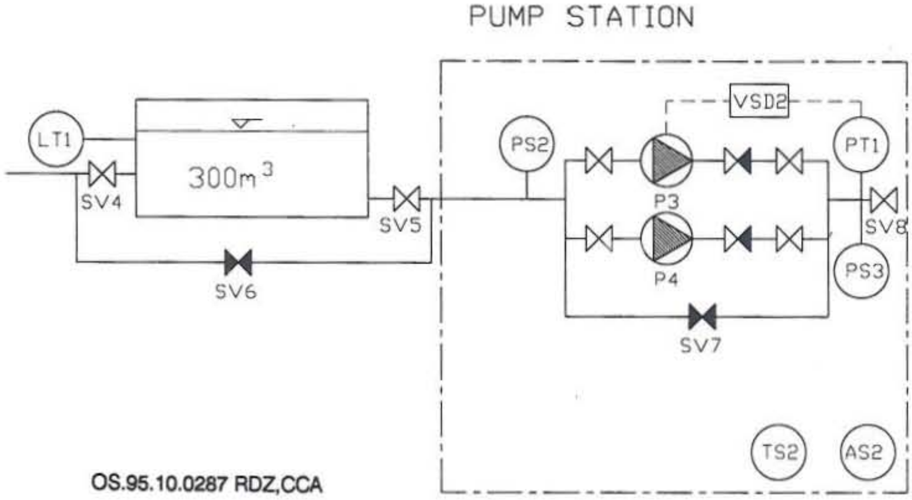

FIGURE 4: Diagram showing the pump station

Pump station. The pump station, located near the well station, comprises mainly of two booster pumps, P3 and reserve P4, variable speed drive, VSD2, and pressure transmitter, PT1 (see Figure 4). The function of the pump station is to supply the geothermal water to the consumers at constant pressure in the main distribution network. The variable speed drive keeps the pressure constant at different fixed set points by varying the speed of the pump's motor.

Heat station. The heat station is located about 400 m from the well station, close to the binary power plant building. The present configuration of the heat station was recently finished, respecting Romanian standards. So, the purpose is not to do large changes in the present configuration and operating strategy but to install modern sensors, control devices and actuators which are connected to the PLC 1 and SCADA system. It is easy to make changes in control strategies in the PLC. This will be utilized to process recorded operational data in the SCADA, and to make necessary changes in order to optimize the operation of the heat station.

The function of the heat station is to supply thermal energy for heating the buildings of the university and to provide them with hot tap water. The geothermal water is not used directly in the district heating and hot tap water network. The thermal energy is transferred from the geothermal water to the space heating water and the fresh water in two independent groups of stainless steel plate heat exchangers. The configuration of the heat station is presented in Figure 5.

The hot tap water, according to Romanian standard, has to be delivered at the temperature of 60°C. The fresh water average inflow temperature is 10°C and it is provided from a storage tank at constant 4 bar-g pressure. The storage tank is fed from the municipal fresh water network. The function of the tank is to compensate the daily variations in demand and to supply necessary pressure for the hot tap water system and cold water system for all the buildings. For the heat transfer two stainless steel plate heat exchangers are used, one of which is reserve. In operation, the inflow rate of geothermal water into the heat exchanger is regulated by using the control valve, CV3, in order to keep constant supply temperature of the hot tap water. The reason for installing the control valve CV5 is to keep the differential pressure between the geothermal water and hot tap water less than 2 bar-g. This restriction is stipulated by the heat exchanger manufacturer. This system runs continuously all year round.

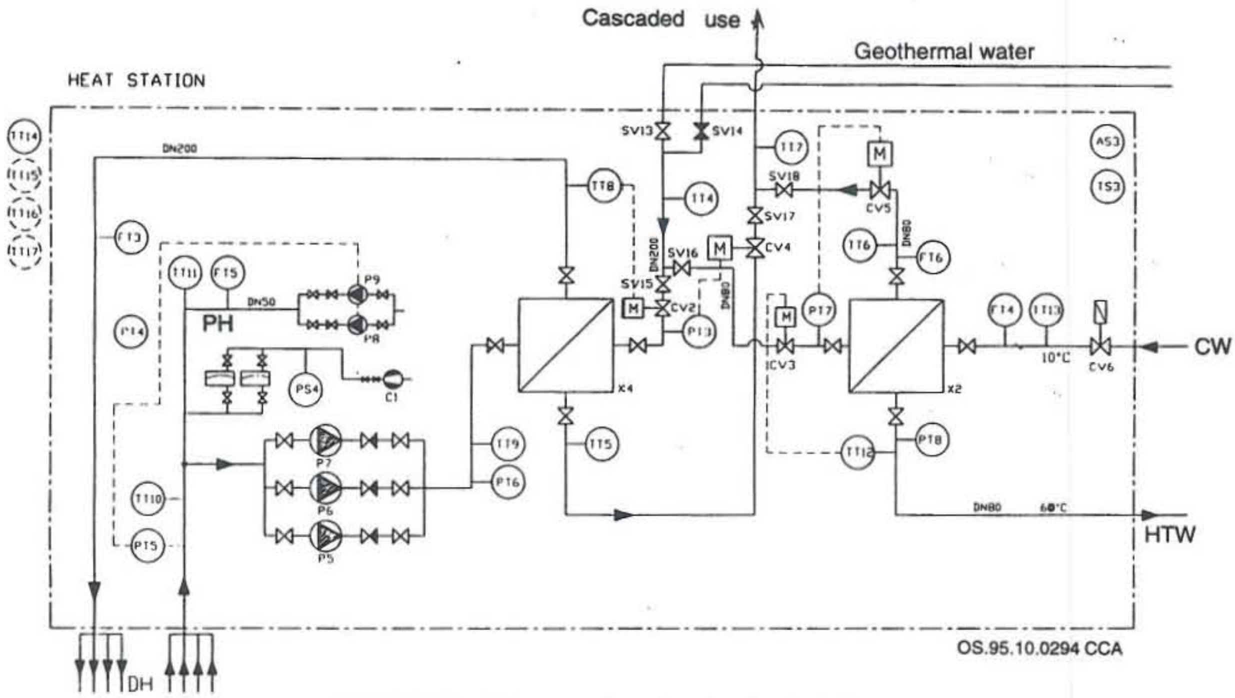

FIGURE 5: Diagram showing the heat station

The district heating network is a closed system, directly connected to the room radiators. The stainless steel plate heat exchangers are used for the heat transfer from the geothermal water to the district heating water. There are four heat exchangers, whereof one is reserve. The existing strategy used to heat the buildings is, as is common in Romania, to modify the inflow temperature of the heating water into the radiators while keeping the flow rate constant. According to this strategy, the circulation pumps P5 and P6 (P7 is reserve) are running all the time at constant speed maintaining the district heating water at constant flow rate. To keep a certain water supply temperature according to the outdoor temperature, it is necessary to vary the geothermal water flow rate through the heat exchangers. This operation will be done by varying the opening of the control valve CV2 according to the temperature TT8. Like above, the reason for installing the control valve CV4 is to keep the differential pressure between the geothermal water and the district heating water less than 2 bar-g.

In order to replace the water lost in the district heating network, due to leakage, and to maintain a constant return pressure PT5, it is necessary to install the make-up water pumps P8 and P9, one is reserve. The reason for installing the pneumatic dampers PH is to avoid pressure transients in the district heating network when the circulation pumps are started and stopped. The air pressure in the pneumatic damper is provided by the compressor, C1, and monitored by the pressure switch, PS4. The other devices installed in the district heating area are used for data monitoring. As usual in Romania, the room radiators used at the university are standard cast iron radiators. The standard indoor design temperature is 20°C. The design outside air temperature for Oradea area is -12°C. Usually the central heating system in Romania is turned off when the daily mean temperature of the outside air is above 10°C for three days in a row. Therefore, the heating system is only running during the cold season, 172 days each year according to statistical data or approximately during the period 15 October-15 April.

3.3.2 Electric binary power plant

The University of Oradea initiated a research program for producing electricity by using geothermal energy. Due to the fact that the geothermal water temperature is less than 100°C, only a binary cycle could be considered for power generation. According to Maghiar (1995), the first pilot power plant was completed and tested in 1984 and had an installed capacity of 100 kW. The research program continued and two other pilot power plants were designed and completed, one 2 x 250 kW in 1986 and the other 1 MW in 1988. Based on the experience gained and the encouraging results obtained with these pilot plants, the research programme has been increased and, at present, a team of researchers and teachers are in the process of designing a new pilot power plant with increasing output capacity. It will be controlled by a programmable logic controller (PLC2), connected to the SCADA system.

The binary power plant transforms the thermal energy of the water into mechanical energy and then, by a generator, into electric energy. Basically, the working fluid runs in a closed circuit according to a thermodynamic motor cycle, between two heat sources, water at high temperature and cooling water. Usually, the working fluid is hydrocarbon, such as isopentan, or refrigerant, such as R12. For environmental reasons, the working fluid used at this binary power plant is carbon dioxide. There are some advantages in using it, such as no explosion danger, it is non-inflammable, non-toxic and available at low cost. In Figure 6 the thermodynamic cycle of CO_2 in a pressure-enthalpy diagram is presented. Line 1-2 corresponds to the flow of the working fluid in the engine, 2-3 is the evolution for transferring heat from CO_2 to the cold water, 3-4 shows the passage of the working fluid through the piston pump for increasing the pressure of CO_2 and 4-1 shows the flow through the shell and tube heat exchangers where geothermal water transfers heat to the working fluid.

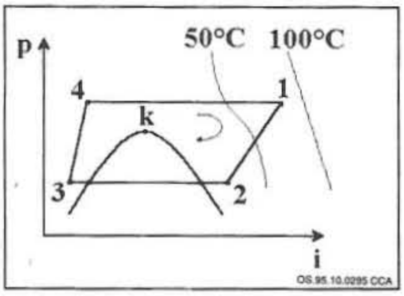

FIGURE 6: The carbon dioxide thermodynamic cycle in pressure-enthalpy diagram

In order to obtain maximum rated power it is necessary to maintain the optimal thermodynamic cycle for every operation regime of the power plant and it is necessary to maintain optimal CO_2 parameters when disturbances occur. In a certain steady state operation regime of the power plant some disturbances may occur resulting in changing of CO_2 parameters. These changes can be due to fluctuations in geothermal and cold water parameters and geothermal engine parameters (i.e. pressure and temperature fluctuations of CO_2, flows and temperature fluctuations of the geothermal water and cooling water and variations of geothermal engine speed, etc.). To maintain this optimal thermodynamic cycle an automation of the power plant is required. As mentioned above, this will be accomplished by using a process computer, PLC2.

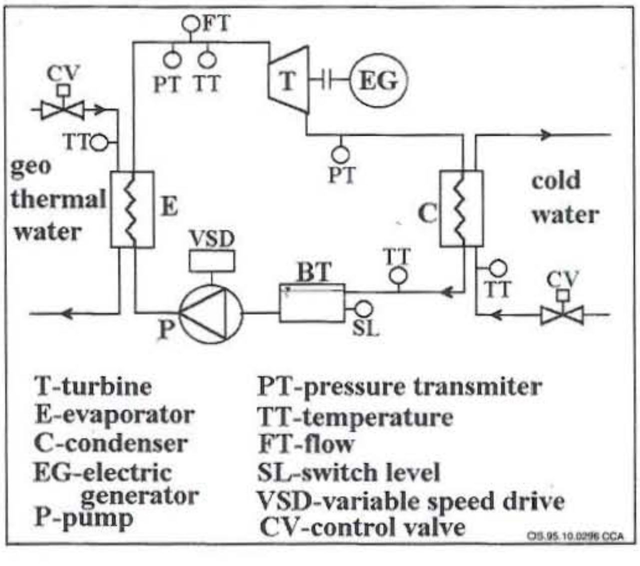

FIGURE 7: Diagram showing the binary power plant

The schematic diagram of the binary power plant is presented in Figure 7. Corresponding to the thermodynamic cycle presented above, it comprises a turbine (T), a condenser (C) with a buffer tank (BT), a pump (P) and an evaporator (E). In order to maintain the optimal thermodynamic cycle, sensors and devices were installed, such as pressure transmitters (PT), temperature transmitters (TT), flow transmitter (FT) and control valves (CV).

3.4 Process computer system (PLC)

The regulation of the heat supply for buildings is presently done manually by modifying the geothermal water flow rate through the plate heat exchangers in steps with orifices. There are many people involved in this process, so it is very hard to control the operation of the system. Hence, it is necessary to implement an overall automatic control system for the whole geothermal installation. This aim can be achieved by installing sensors and control devices and connecting them to a programmable logic controller (PLC1).

A TI-305 PLC2 already exists at the university, but it is too small for the whole installation. Therefore the PLC2 will control the running of the binary power plant. The new Allen Bradley PLC1 will be installed in order to connect all the other users presented in part c of Figure 1. Because the cascaded users are not yet defined, the PLC1 will in the first step only be connected to the users mentioned in part b of Figure 1, i.e. the existing users. In the second step, based on gained experience, the cascaded users will also be connected to the PLC1. At present, a team of engineers from Iceland and the University of Oradea are designing the program for both PLCs.

3.5 SCADA system

Usually, a PLC has facilities to monitor the status of the main process parameters. But the common operator is not able to change the initial program. Only PLC programmers are able to change this. By using a supervisory control and data acquisition system (SCADA), it is possible to provide a very user-friendly graphical man machine interface between the plant and the operator. Not only is it possible to monitor the plant parameters but also to operate all pumps and regulators in the system using this interface. In this way, the operator can use the SCADA directly in real time operation of the plant.

SCADA man-machine interface consists of several process graphics displayed on a PC computer screen by using InTouch software. These pictures show the schematic diagrams of the plant depicting its main items. These pictures are linked to the PLC for commands and information from the operator to reach the plant processes and vice versa.

Thus, one of the advantages in using SCADA system is that an automatic control and monitoring of the plant is achieved. Another advantage is the possibility to collect and store data from the operation of the plant. By processing this recorded data, the SCADA system makes it possible to do trend analysis for different parameters of the plant and to search for better operational strategies.

3.6 Training simulator

A computer simulator for the geothermal installation is under development. The simulator is a software programme which allows the operation of the whole geothermal installation to be simulated, including the power plant, the PLC and SCADA system. Computer simulation is useful for engineers, plant operators and engineering students. It can be used as a tool in design and testing of control system hardware and software, and as an operator's training simulator.

The operation of the geothermal power plant is simulated based on mathematical models of each part of the plant, for example production well, pipes, control valves, heat exchangers, pumps, etc. The user interacts with the simulator through a graphic display that shows all critical variables as well as control functions.

For a complex geothermal installation system, the simulator can be used to find the optimal operation strategy. In this way, based on technical calculations presented in this report and other existing mathematical models, it is possible to create a mathematical model for the whole system. Further, by using the simulator, it is possible to analyse various process design alternatives, to develop and analyse different control strategies and to optimize the operational strategies.

4. CASCADED USE

4.1 General aspects

The second step of the modifications of the present installation system is to find other possible uses of geothermal water by using it in cascades. The classical Lindal diagram is a starting point to define possible cascaded uses. Figure 8 presents only the part of the diagram that is relevant for the studied case. When the water temperature is above 85°C, according to Dickson and Fanelli (1990), generation of electric energy in binary cycle plants can be added. The lower limit of 20°C is exceeded only in very particular conditions or by the use of heat pumps. Due to the fact that cascaded usage does not exist yet at the university, what is presented in this report are only proposals. These proposals will not be studied deeply, they are only approaches concerning the type, thermal energy demand and size. It will in all cases be necessary to make detailed studies or look for other possible cascaded uses.

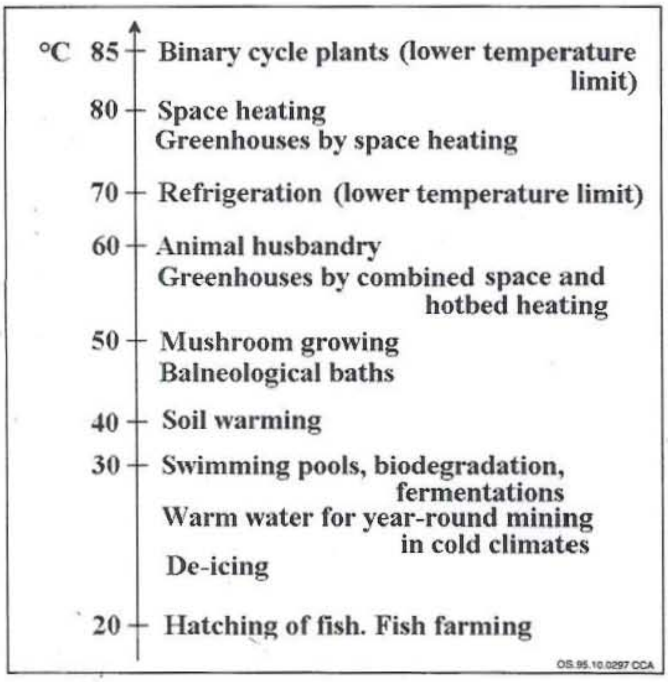

FIGURE 8: The Lindal diagram (partial)

Technical calculations used to define the cascaded uses will be presented in Chapter 5. The proposed cascaded usage flow diagram is presented in part c of Figure 1. It comprises a complex of greenhouses, two swimming pools and two aquaculture ponds. The types of the cascaded users where chosen for educational and research reasons. The size of the installations was calculated according to the available thermal energy from the direct users, i.e. return geothermal water temperature and flow rate from the district heating system and electric binary power plant.

4.2 Greenhouse heating

On the first level of the cascaded usage, the available geothermal water temperature is in the 35-45°C range, depending on the outdoor temperature. For this level it is proposed to use it in a greenhouse by combined space and hotbed heating. Hotbed heating should not be considered solely as a heating system, but as a growing technology consisting of a specific way of plant heating. This way, the greenhouse will be useful for the students from the horticultural department of the university. An additional advantage is that the greenhouse production can be delivered to the university's canteen or sold on the market.

Due to the fact that the available geothermal water temperature for this usage is less than specified in the Lindal diagram (60°C), there are two possibilities. One is to mix the return water with geothermal water at well head temperature in order to increase the water temperature to 60°C. This additional flow might be taken from the binary power plant, which will, consequently, run at a lower power. The other possibility, which will be looked at here, is to use the available geothermal water without mixing. At this low level temperature, it is possible to use the geothermal water at partial load combined with other heating solutions. But it might also be possible to cover the total heat demand combining different heating solutions. In this way, Popovski (1993) presents heating solutions with geothermal water at low temperature. In this report it is proposed to combine two heating solutions, namely soil heating and convectors and induced air flow.

Soil heating installation, is presented in Figure 9. It comprises a system of pipes, located 30-50 cm below the soil surface and 15-40 cm apart. Pipes are put directly in the soil or cultivation base, but there are variants with heated concrete floor, i.e. pipes in the concrete. The material for the pipe is polyethylene or polypropylene, smooth or corrugated pipes of 20 to 60 mm in diameter. Recommended geothermal water temperature depends on the cultivar in question but usually it is in the 25-35°C range. Due to the small pipe diameters, the geothermal water must be clean, without any particles and inclination to deposition. Influence to greenhouse climate is mainly concentrated to the soil temperature and the air just above the soil surface. The use of soil heating is very positive for many vegetable and bulbous flower cultures and it is convenient for covering minimal heat requirements at outdoor temperatures above 0°C.

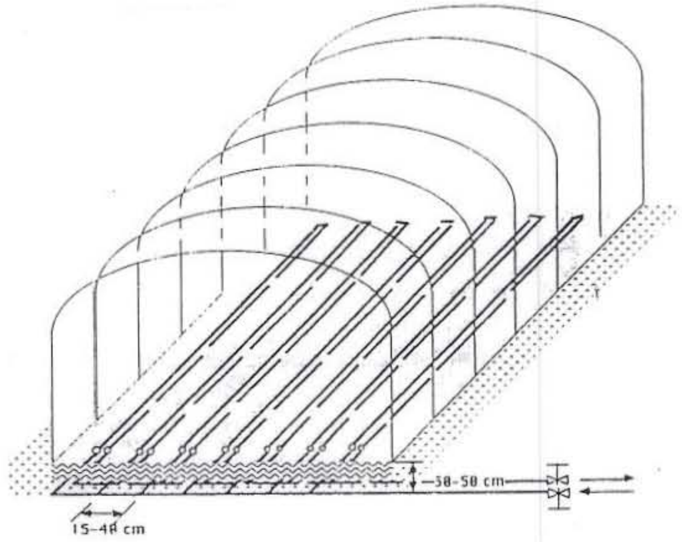

FIGURE 9: A simplified scheme of a soil heating installation in a greenhouse

A heating system with convectors and induced air flow can also be used. This type of system is recommended when temperature of the heating fluid is very low, even below 30°C, and where the heat is free of charge due to the cascaded usage. It comprises convector lines, positioned along the greenhouse side walls or between the plant rows, and with the addition of a pipe line for distributing air below the convector pipes (Figure 10). It is connected to an electrically driven fan. Warm air first flows to the transparent partitions and then to the plants. The convectors are made of copper, carbon steel or aluminium small diameter pipes finned with square plates of the same or different material. Concerning the regulation, there is a good and fast response to changes in internal

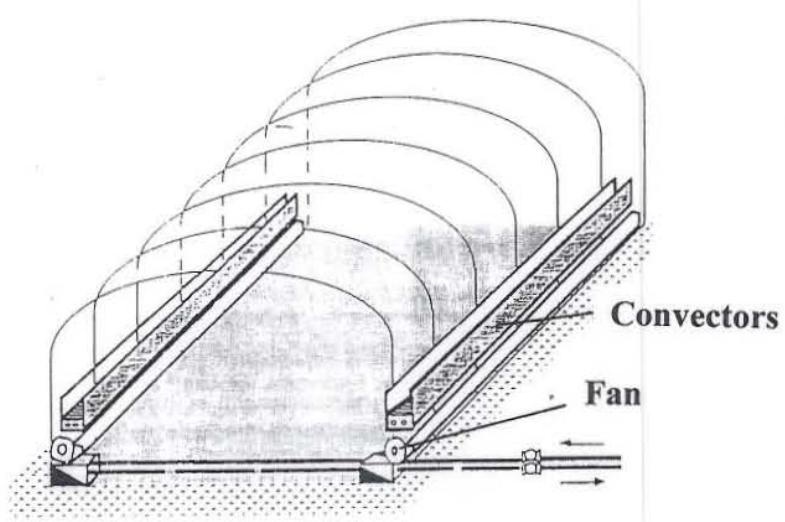

FIGURE 10: Aerial heating installation in a greenhouse with inductive air movement

and external climate conditions. The air temperature profile in the greenhouse is very even between 0.5 and 1.5 m above the floor surface. Below the roof, temperatures are higher than at the plant level, and much higher than at the level of soil surface. This type of heating system is very positive for most of the vegetable and flower cultures. The system eliminates any shading caused by the presence of heat exchangers in the growing area, and combined with the previous, may cover the total heat demand. At partial load, the induced air flow system may be turned off.

4.3 Swimming pool

The geothermal water outflow temperature from the greenhouse is in the range 30-35°C, depending on the outdoor temperature. According to the Lindal diagram, there are some possible cascaded usages. In this report two types are proposed.

The first one is to use the geothermal water in two swimming pools, one indoor and the other open-air. This could be beneficial for the university. The open-air swimming pool could be useful for the students from the sports department, while the indoor swimming pool could be useful for the students from the kineto-therapy department, where they could apply in practice their theoretical knowledge. Last but not least, these two swimming pools would be a very good recreation for all the students in their free time.

The open-air swimming pool is proposed to be open only during the warm season (about 6 months each year). In Romania the people are not familiar with Icelandic custom of using the swimming pool at relatively low temperature (28°C) during the winter. In Romania, the temperature would be at about 37°C. Anyhow, the Icelandic custom, using small hot pots with high water temperature for warming and then swimming in a large swimming pool for exercise must be taken into consideration and it is a proposal for a future study.

According to the aim of the open-air swimming pool presented above, a school pool was chosen, which will be constructed as a part of the sport facilities. Suggested dimensions for this type of swimming pool are, according to Perkins (1988), 25 m length and 12.5 m width, and might be good for the dual use of school and student recreation. The minimum water depth is 0.9 m and the maximum 3 m. The water temperature in the pool is proposed to be, according to the Icelandic experience, about 28°C. For the indoor swimming pool, and according to Romanian recommendations, a pool was chosen with a 100 m^2 surface, 120 m^3 volume and water temperature at 37°C. For this temperature it is necessary to mix the geothermal water outflow from the greenhouse with geothermal water at well head temperature. But, for this size of pool, the needed flow rate at high temperature is less than 0.8 l/s, i.e. 2% from the maximum well capacity. It will operate all year round. It is proposed to locate this indoor pool close to the open-air swimming pool, enclosed by glass walls and to use it during the warm period by opening the glass walls. Both pools will share the needed infrastructure like dressing rooms, showers etc.

Usually, the geothermal water is used for direct heating of the swimming pool water. Due to the low geothermal water temperature available at this level (30-35°C), the heat transfer surface for the heat exchangers is high and, probably not justified economically. According to the international recommendations for drinking water and the available data for the composition of the geothermal water (see Table 1), this water is suitable to be used directly in the swimming pool. The experience gained at Felix Spa (8 km from the university), proves that using geothermal water directly in the pool is beneficial for the health.

The design of the swimming pool must take into account some services, such as water supply, drainage, power needed for maintaining the water temperature, water treatment and disinfection. For the indoor pool, additional services would include heating , ventilation, lighting etc. It is important to include the

TABLE 1: International recommendations for different water usages and the concentration of the chemical substances in the geothermal water from the university's well

	Geothermal water, data for the university's well	**Drinking water, EU guideline values (max. admiss. conc.)**	**Aquatic life, FAO guideline values**
Temperature (°C)	85	25	-
pH	6.0	9.5	7.0-8.5
Total dissolved solids (TDS)	1200.0	1500	450-2000
Calcium (Ca)	230.7	-	-
Magnesium (Mg)	42.4	50	-
Potassium (K)	5.0	12	-
Sodium (Na)	20.0	150	70-200
Chloride (Cl)	70.9	200	100-350
Fluoride (F)	0.0	1.5	1.0
Hydrogen sulphide (H_2S)	0.0	0.2	-
Free carbon dioxide (CO_2)	157.1	not aggressive	-
Aluminium (Al)	0.0	0.2	5.0
Arsenic (As)	0.0	0.05	0.1
Boron (B)	0.0	-	0.5

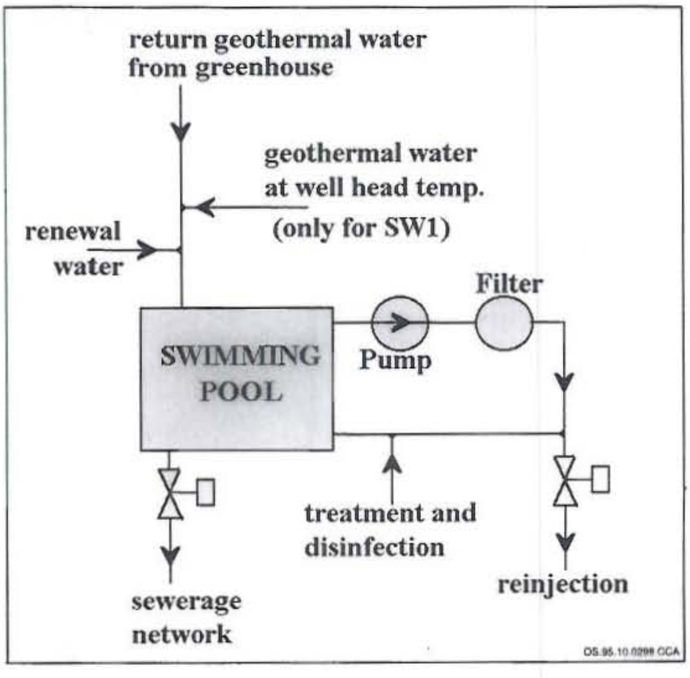

FIGURE 11: A schematic diagram of a swimming pool

necessary equipment for the treatment and purification of water in the swimming pools. The turnover period is one of the most important factors in the operation of a swimming pool and is the time needed to circulate all the water in the pool from the outlets, through the filtration facilities and back to the pool inlets. For the indoor pool, typically, the turnover period is 2-3 hours and for the open-air swimming pool 3-6 hours depending on the number of visitors. A proposed basic layout of some major equipment is shown in Figure 11. The heat demand to keep constant water temperature in the pool is covered by the geothermal water, but the flow rate is variable, depending on the outdoor temperature. When the return geothermal water flow rate is low, it is necessary to add fresh water instead. According to some available Icelandic data, the amount of renewal water needed is about 10% per day of the total volume of the water in the pool. Anyhow, the renewal water flow rate is less than the geothermal water flow rate needed for the heat demand, except for a short period when the heat demand is low. This means that almost all the period, the geothermal water replaces the needed renewal water. When the geothermal water flow rate is less than the flow rate needed for the turnover period, it is necessary to recirculate and filter the water. The used water in the pool has to be discharged. It is proposed to discharge it into the sewerage network or, after filtering, to send it to the reinjection station.

4.4 Aquaculture

The second proposal for using the outlet geothermal water from the greenhouse is for aquaculture, which is the controlled breeding of aquatic forms of life. The aquaculture will be useful for the students in practical training and for researches and the production can be delivered to the university's canteen or be sold to the market. By maintaining an optimum temperature it is possible to breed more exotic species, improve production and in some cases even double the reproductive cycle. According to Dickson and Fanelli (1990), the temperature required for several aquatic species is generally in the 20-30°C range. The size of the installation used will depend on the temperature and flow rate of the available geothermal water, the temperature required in the fish ponds and the heat losses from the latter. In Table 2 the temperature requirements and growth periods for some aquaculture species are presented.

Here, two aquaculture species are proposed for breeding. One of them is Penaeid Shrimp Pink which has an optimum growth temperature in the 24-29°C range and growth period to market size of 6-8 months. It can be breed over a large range of temperatures (11-40°C) and at present is is imported. Trout breeding is the second species with optimum growth temperature 17°C, tolerable extremes 0-32°C and growth period to market size 6-8 months. Carp breeding with a 20-32°C temperature range might also be suggested as it is very common in Romania. The size of the ponds and other factors will be presented in Chapter 5, basically utilizing all available return geothermal water.

According to international standards presented in Table 1, the geothermal water from the university's well is suitable for aquatic live. For this reason, the geothermal water should be used directly in the ponds. This solution decreases the investment costs and, in some cases, reduces the need for renewal water. The available geothermal water temperature and flow rate at different outdoor temperatures are variable. In order to maintain constant temperature in the pond when the heat demand is low, the geothermal water flow rate will be low. For maintaining a constant flow rate for the renewal water, geothermal water would have to be mixed, in this case, with fresh water.

TABLE 2: Temperature requirements and growth period for some aquaculture species (from Rafferty, 1990)

Species	Tolerable extremes (°C)	Optimum growth conditions (°C)	Growth period to market size (months)
Oyster	0-36	24-26	24
Lobster	0-31	22-24	24
Penaeid Shrimp Kuruma	4-?	25-31	6-8
Penaeid Shrimp Pink	11-40	24-29	6-8
Salmon (Pacific)	4-25	15	6-12
Freshwater Prawn	24-32	28-31	6-12
Catfish	2-35	28-31	6
Eel	0-36	23-30	12-24
Tilapia	8-41	22-30	-
Carp	4-38	20-32	-
Trout	0-32	17	6-8
Yellow Perch	0-30	22-28	10
Striped Bass	?-30	16-19	6-8

A proposed basic layout for the ponds may be considered the same as for the swimming pools presented in Figure 11. Due to the fact that the swimming pool water is recirculated through a filter, it is possible to have a large amount of geothermal water available for reinjection in stead of discharging it into the city's sewerage network.

4.5 Reinjection

In order to compensate the increasing of the well production, reinjection is needed to supplement the fluid to maintain the reservoir pressure. A part of the spent geothermal water will be sent through an accumulator to a reinjection well, probably an abandoned production well located approximately 1 km from the university campus. Before the strategy for reinjection will be decided, a specialized study must be done. This report deals with only a few of its aspects.

According to Sigurdsson et al. (1995), a reinjection project should be designed to maximize the thermal sweep of the reservoir. The design should place greater emphasis on thermal sweep than pressure maintenance. The general rule is that the temperature should be high enough to avoid scaling and precipitation of chemicals in or around the reinjection well. If a cold fluid reinjection is selected the geothermal fluid may need some treatment to be suitable for reinjection. The travel rate of the thermal front is the same for cold and hot fluid injection, but the front is sharper in the case of cold injection. Both production and reinjection wells, must have good permeability and be in good connection with the reservoir. It will be necessary to make tracer tests between the wells.

In order to achieve pressure maintenance in reservoirs with low permeability, reinjection may need to be started near the production area. At later stages, preferably before thermal breakthrough, the location of reinjection is moved to greater distances from the production area.

5. UTILIZATION STRATEGY

5.1 Technical calculations

The purpose of this chapter is to

- define the size and configuration of the cascaded users based on available geothermal water after being used in the heat station and the binary power plant;
- calculate the behaviour of the global system at peak and partial loads in order to estimate the annual energy consumption of each user.

Each user has a different energy demand as a function of the time of year and outdoor conditions and they are all interconnected. Demand calculations applied here are based on climatic conditions during a statistically representative year. The calculations are not very detailed but accurate enough to give an overview of the geothermal energy utilization. Generally they follow the guidelines developed by Eliasson et al. (1990), Harrison et al. (1990), Karlsson (1982), Popovski (1993) and Ragnarsson (1995). The calculations will be presented separately for each type of user at maximum design load and partial loads. For each case the main assumptions and relevant heat transfer calculations will be presented. Nomenclature used is explained at the end of the report.

5.1.1 District heating

Here, the heat losses in the network and incidental heat gains from external sources, such as solar radiation and human activities, are omitted. The heat transfer calculations are based on the diagram presented in Figure 12, which illustrates, in a simplified way, the transfer of the heat from the geothermal water to the buildings.

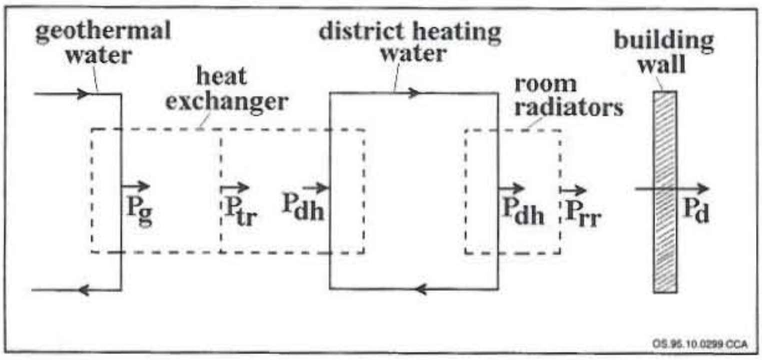

FIGURE 12: Heat flow diagram for the district heating system

For maintaining constant design indoor temperature in the rooms (T_{ind}=20°C), it is necessary to compensate the thermal power losses through the building walls (P_d) by the geothermal power (P_g). The thermal losses in the distribution network are here, for simplicity, included in the power demand for the houses. The equations are as follows:

$$P_g = P_{tr} = P_{dh} = P_{rr} = P_d \tag{1}$$

or in details

$$M_{gdh} * C_{pg} * (T_{wh} - T_{godh}) = U * A * LMTD_{dh} = M_{dh} * C_{pdh} * (T_{dhspl} - T_{dhret}) =$$

$$= P_{rrdes} * (LMTD_{rr} / LMTD_{rrdes})^{4/3} = V_b * G_b * (T_{ind} - T_{out}) \tag{2}$$

$$LMTD_{dh} = [(T_{wh} - T_{dhspl}) - (T_{godh} - T_{dhret})] / \ln[(T_{wh} - T_{dhspl}) / (T_{godh} - T_{dhret})] \tag{3}$$

$$LMTD_{rr} = (T_{dhspl} - T_{dhret}) / \ln[(T_{dhspl} - T_{ind}) / (T_{dhret} - T_{ind})] \tag{4}$$

$$LMTD_{rrdes} = (T_{dhspldes} - T_{dhretdes}) / \ln[(T_{dhspldes} - T_{ind}) / (T_{dhretspl} - T_{ind})] \tag{5}$$

Variables and indices are explained in nomenclature. At peak load conditions, all the parameters in Equations 2, 3 and 4 are known. The calculations were done for the geothermal water well head temperature T_{gwh} = 85°C, the total volume of the buildings V_b = 173,000 m³, the volumetric heat loss coefficient G_b = 0.97 W/m³ °C, the overall heat transfer coefficient at peak load condition U_{des} = 2159 W/m² °C, the total heat surface A = 495 m² and the district heating water flow rate M_{dh} = 31.9 l/s. At partial loads, the overall heat transfer coefficient, U, is unknown, except in the case when available data from the manufacturer exists. Due to this, there is, at partial load, one unknown parameter more than the number of equations. The equation system can in this case be solved assuming constant overall heat transfer coefficient, U. But in reality, it is variable. The following equation (Shah and Wanniarachchi, 1991) is proposed to calculate the coefficient U for plate heat exchangers at partial loads:

$$U = \frac{2\,U_{des}}{1 + (M_{dh} / M_{gdh})^x} \tag{6}$$

The equation is not exact but gives more accurate results instead of assuming a constant value for U. To find the best value for the coefficient x and to check the accuracy, the relation was checked by comparison with available data from some manufacturers. By selecting x = 0.75, the error is in 0-2%

range, when the value of the ratio M_{dh} / M_{gdh} is in the 1-4 range.

The existing strategy for regulating the heat supply at partial loads is the so called constant flow-variable supply temperature strategy. The district heating water is pumped through the network at constant flow rate and the heat demand at partial loads is regulated by the supply temperature.

For this operational strategy the author uses two equations to calculate, at partial loads, the district heating water supply temperature (T_{dhspl}), respectively district heating return water temperature (T_{dhret}). Equation 7 is derived from Equations 1 and 2:

$$M_{dh} * C_{pdh} * (T_{dhspl} - T_{dhret}) = P_{rr} = P_{rrdes} * (LMTD_{rr} / LMTD_{rrdes})^{4/3} \qquad (7)$$

Solving Equations 4, 5 and 7 together gives Equation 8 for T_{dhsup} and T_{dhret}

$$T_{dhret} = T_{ind} + \frac{A}{e^{A/B} - 1} \quad ; \quad T_{dhspl} = T_{ind} + \frac{A}{e^{A/B} - 1} * e^{A/B} \qquad (8)$$

where

$$A = \frac{P_{dh}}{M_{dh} * C_{pdh}} \quad ; \quad B = LMTD_{rrdes} * \left(\frac{T_{ind} - T_{out}}{T_{ind} - T_{outdes}}\right)^{3/4} \quad ; \quad P_{dh} = V_b * G_b * (T_{ind} - T_{out}) \qquad (9)$$

In Equation 2, the outdoor temperature (T_{out}) is the parameter which determines the power demand of the geothermal installation. As the main objective of the calculations is to estimate the annual geothermal energy consumption, the calculations have been done for a statistically representative year. In this way, statistical data of daily outdoor temperature for the Oradea geographic area are used. The available data for the Oradea area are presented in Figure 13. The curve T_{out} - Days is the so called temperature duration curve.

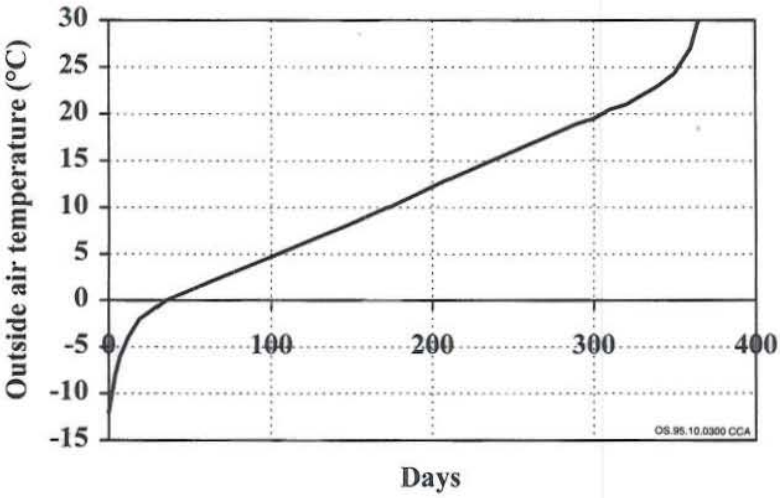

FIGURE 13: Statistical variation of the annual outside air temperature for the Oradea area

5.1.2 Hot tap water

The calculations are done for the average daily water consumption M_{htp} = 4.14 l/s. The consumption fluctuations for the needed geothermal water flow rate within the day will be taken up by the deep well pump and its accumulator or the production of the binary power plant will be reduced. The deep well pump will be operated at maximum capacity around the year or 50 l/s. When the cascaded users have been selected and sized the production in the binary power plant will be varied in order to keep the maximum demand for geothermal waterS at the constant rate of 50 l/s. The equations to calculate the geothermal energy consumption for the production of hot tap water are the following:

$$P_{htp} = M_{ghtp} * C_{pg} * (T_{wh} - T_{gohtp}) = M_{htp} * C_{phtp} * (T_{ihtp} - T_{ohtp}) = A * U_{htp} * LMTD_{htp} \quad (10)$$

5.1.3 Binary power plant

The calculations are based on available but unpublished data from the university, concerning the return geothermal water temperature in the binary power plant (T_{goe}). The values for this parameter will be presented in Chapter 5.2. The calculations for the geothermal energy consumption are based on the following equation:

$$P_{ge} = M_{ge} * C_{pg} * (T_{wh} - T_{goe}) \quad (11)$$

5.1.4 Cascaded users

According to the cascaded use diagram presented in Figure 1, it is necessary to define the geothermal water which is available for the cascaded use. In this way it is necessary to calculate the geothermal water flow rate and temperature at some specific points in the diagram. The calculations are based on the general law of mass and energy conservation, when two or more water flow rates are mixed. To calculate the available geothermal water flow rate and temperature for the swimming pools and the aquaculture ponds ($M_{gswaqav}$ and $T_{gswaqav}$) the following equations are used, depending on from where the geothermal return water comes:

a) From the district heating system, binary power plant and greenhouses:

$$T_{gswaqav} = \frac{M_{gdh} * \dfrac{(M_{gdh} - M_{gr}) * T_{godh} + M_{gr} * T_{gogr}}{M_{gdh}} + M_{ge} * T_{goe}}{M_{gdh} + M_{ge}} \quad ; \quad M_{gswaqav} = M_{gdh} + M_{ge} \quad (12)$$

b) From the binary power plant and the greenhouses:

$$T_{gswaqav} = \frac{(M_{ge} - M_{gr}) * T_{goe} + M_{gr} * T_{gogr}}{M_{ge}} \quad ; \quad M_{gswaqav} = M_{ge} \quad (13)$$

c) From the binary power plant only:

$$T_{gswaqav} = T_{goe} \quad ; \quad M_{gswaqav} = M_{ge} \quad (14)$$

5.1.5 Greenhouse heating

The calculations roughly estimate the size of the greenhouse and the geothermal energy consumption. The size of the greenhouse, in this report, means the number of greenhouse modules. A module was chosen as a typical size for a greenhouse in Iceland, i.e. 70 m length and 10 m width. The greenhouse's heat demand was approximated by the heat demand of a room with glass walls. Detailed calculations are presented by Popovski (1993). Based on the assumptions presented above, the equations are similar to Equation 2 used for heating the buildings, or as follows:

$$P_{gr} = M_{ggr} * C_{pg} * (T_{ggri} - T_{ggro}) = P_{grdes} * (\frac{LMTD_{gr}}{LMTD_{grdes}})^{3/4} = V_{gr} * G_{gr} * (T_{grind} - T_{out}) \quad (15)$$

$$LMTD_{gr} = \frac{T_{ggri} - T_{ggro}}{\ln \frac{T_{ggri} - T_{grind}}{T_{ggro} - T_{grind}}} \quad ; \quad LMTD_{grdes} = \frac{T_{ggrides} - T_{ggrodes}}{\ln \frac{T_{ggrides} - T_{grind}}{T_{ggrodes} - T_{grind}}} \quad (16)$$

In order to keep constant greenhouse indoor temperature, all the available geothermal water flow rate is not needed all the time. So it will be by-passed for use in other cascaded facilities.

5.1.6 Swimming pool

The calculations assume that the heat losses through pool walls are negligible since they are small in comparison to the heat losses from the water surface. Also, since the renewal fresh water flow rate is very low in comparison to the geothermal water flow rate, as mentioned in Chapter 4.3, the cooling influence of the fresh water to the geothermal water is neglected. The equations used to calculate the heat losses, given by Ragnarsson (1995), are as follows:

$$P_{cv} = A * [0.93 + 0.04 * (T_{sw} - T_{out})] + 0.45 * W * (T_{sw} - T_{out}) * 4.185 \quad (17)$$

$$P_{ev} = A * 1.56 * [0.93 + 0.04 * (T_{sw} - T_{out})] + 0.7 * W * (e_{sw} - e_{out}) * 4.185 \quad (18)$$

$$P_{sw} = P_{cv} + P_{ev} \quad (19)$$

The heat losses according to Equation 20 must be compensated by the geothermal water. For the larger swimming pool (No. 2), the geothermal water flow rate demand is calculated by using the well known equation:

$$P_{sw2} = M_{gsw2} * C_{pg} * (T_{gswaqav} - T_{sw2}) \quad (20)$$

For the smaller swimming pool (No. 1), due to the higher pool temperature, it is necessary to mix the available geothermal water with geothermal water at well head temperature. The calculations are done by using the mass and energy conservation law. It should be mentioned that, according to the size of the pool, the renewal geothermal water flow rate 1 l/s was selected, which is approximately the renewal rate used in Icelandic swimming pools. By fixing the renewal rate the equations can be solved. In this way, the geothermal water flow rates at well head temperature (M_{gsw1h}) and from the greenhouse (M_{gsw1l}), are calculated using the following equations:

$$M_{gswl} = M_{gswlh} + M_{gswll} \quad ; \quad M_{gswlh} = \frac{T_{gswlin} - T_{gswaqav}}{T_{wh} - T_{gswaqav}} \quad ; \quad T_{gswlin} = T_{swl} + \frac{P_{swl}}{M_{gswl} * C_{pg}} \quad (21)$$

5.1.7 Aquaculture

The main assumptions are the same as in the swimming pool case: the heat losses through the pool walls and the cooling influence of the fresh renewal water to be used are neglected. The heat losses in the pond may be calculated by using the relations presented by Rafferty (1990) using SI units, as follows:

$$P_{aq} = P_{aqev} + P_{aqcv} + P_{aqrd} \quad ; \quad P_{aqev} = 1103 \frac{A_{aq} * W * (e_{aq} - e_{out})}{T_{aq} + 273} \quad (22)$$

$$P_{aqcv} = 2.51 * A_{aq} * (T_{aq} - T_{out}) \quad ; \quad P_{aqrd} = 5.35 * 10^{-8} * A * [(T_{aq} + 273)^4 - (T_{out} + 273)^4] \quad (23)$$

Equations 22 and 23 cover the total heat loss, i.e. the loss by evaporation, convection and radiation. The total heat loss in the pond has to be compensated by the geothermal water, according to the following equation:

$$P_{aq} = M_{gaq} * C_{pg} * (T_{gswaqav} - T_{aq}) \quad (24)$$

5.1.8 Reinjection

There are two alternatives for reinjection. One alternative is to use all the spent geothermal water, including the filtered spent geothermal water from the swimming pools and aquaculture ponds and reinject all the geothermal water produced by the well ($M_{reinj1} = M_{gtot}$). Another alternative is to use only indirectly used geothermal water, i.e. the return geothermal water which was not used in the swimming pools and aquaculture ponds (M_{reinj2}). This flow rate is given by the following equation:

$$M_{reinj2} = M_{gtot} - (M_{gsw1} + M_{gsw2} + M_{gaq1} + M_{gaq2}) \quad (25)$$

The reinjection water temperatures in both cases (T_{reinj1} and T_{reinj2}) can be calculated based on the general law of mass and energy conservation when two water flow rates (M_1 at temperature T_1 and M_2 at temperature T_2) are mixed (M_{final} at temperature T_{final}), as follows:

$$M_1 * T_1 + M_2 * T_2 = M_{final} * T_{final} \quad (26)$$

5.2 Results and discussion

The technical calculations have been done for each outdoor temperature (T_{out}), according to Figure 13, at a step of 1°C. Due to the fact that the geothermal water users are interconnected, the calculations were done with the aid of the EXCEL programme. The main results are presented in Table 3.

TABLE 3: Results of technical calculationsfor the geothermal installation at the university

	Outside air temperature T_{out} (°C)								
	-12	**-6**	**+0**	**+5**	**+10**	**+13**	**+20**	**+25**	**+30**
Days	0	7	35	104	172	210	300	350	365
P_{dh}	5350	4347	3344	2508	1672	0	0	0	0
P_{htw}	863	863	863	863	863	863	863	863	863
P_{ge}	3566	5851	7205	8128	8920	10441	10142	9921	9659
P_{gr}	605	491	378	283	189	132	9	0	0
P_{sw1}	107	107	107	107	107	147	110	80	44
P_{sw2}	0	0	0	0	0	222	130	57	0
P_{aq1}	470	453	407	350	280	232	120	32	0
P_{aq2}	223	218	187	144	90	53	0	0	0
T_{godh}	45.0	38.4	35.2	32.7	29.8	-	-	-	-
T_{goe}	25.0	26.4	27.9	29.1	30.2	30.9	32.5	33.6	35.0
M_{gg1}	4.5	7.2	5.1	3.5	2.3	1.1	0.1	0	0
M_{ggrav}	31.9	22.3	16.0	11.4	7.2	46.2	46.2	46.2	46.2
M_{ggrav}/M_{ggr1}	7.1	3.1	3.2	3.3	3.1	44	760	-	-
$T_{gswaqav}$	35.7	29.7	28.4	28.5	29.2	30.3	32.4	33.6	35.0
M_{gsw1+2}	0.46	0.41	0.40	0.40	0.40	23.74	7.40	3.00	1.30
$M_{gaq'}$	3.6	8.4	11.0	9.2	5.7	3.5	1.1	0.2	0.2
M_{gaqav}	45.7	45.7	45.7	45.7	45.7	22.4	38.6	43.2	44.8
M_{reinj1}	50	50	50	50	50	50	50	50	50
M_{reinj2}	34.5	15.2	4.9	12.0	26.2	11.5	37.6	45.6	47.4
T_{reinj1}	31.1	25.6	24.8	25.3	26.6	26.9	30.2	32.1	33.5
T_{reinj2}	33.8	26.4	19.1	24.6	27.3	25.8	30.9	32.3	33.6

In Figure 14 the thermal power duration curves for each geothermal water user and the available thermal power from the well ($P_{ref\,13.5}$) are presented, corresponding to the annual average outdoor air temperature for the Oradea area. It can be seen in this figure that the thermal power curve for the district heating is similar to the characteristic curve in Central Europe. The zone between the total demand power and available thermal power curves represents unutilized power. A detailed study has to be carried out to define other utilization for this energy, but heat pumps might be suggested. In Figure 15 thermal power duration curves for the cascaded users are shown in detail.

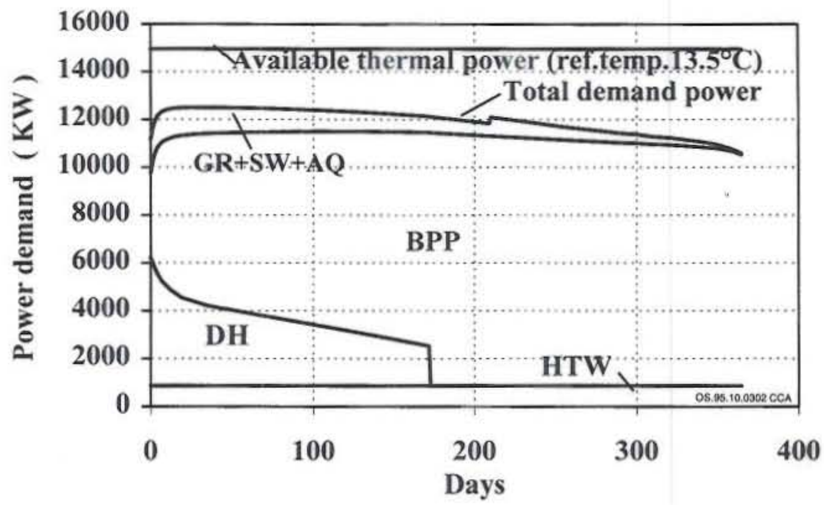

FIGURE 14: Duration of the thermal power demand for the geothermal users; DH - district heating; HTW - hot tab water; BPP - binary power plant; GR - greenhouse; SW - swimming pool; AQ - aquaculture

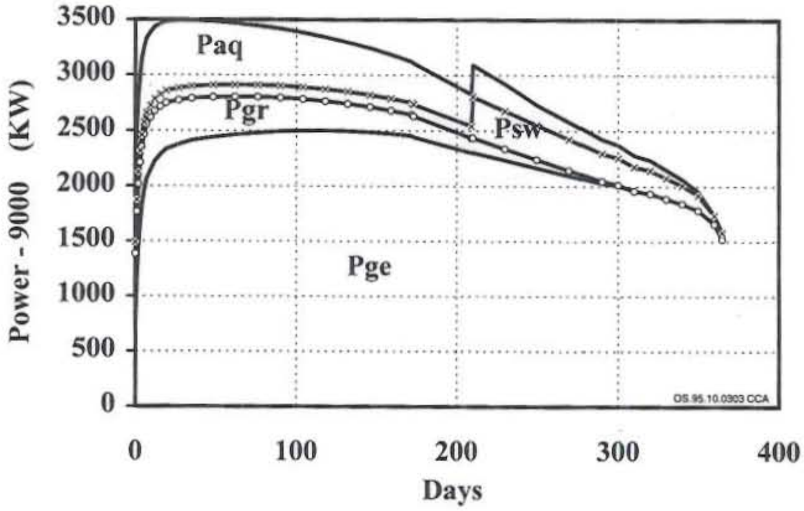

FIGURE 15: Duration of the thermal power demand for the cascaded users; P - power demand; aq - aquaculture; gr - greenhouse; sw - swimming pool; P_{ge} - thermal power demand for the binary power plant

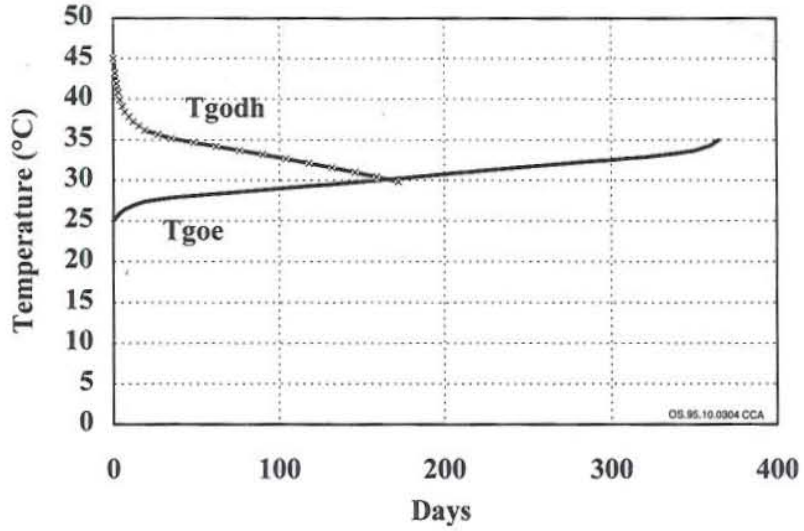

FIGURE 16: Temperature of the return geothermal water from district heating (T_{godh}) and binary power plant (T_{goe})

Generally, it is more economical to install a peak boiler to handle the usually very brief period of peak heat demand than to provide geothermal capacity sufficient for all load situations. But, as can be seen in Figure 14, for the system presented here, it is not necessary to cover the peak load for the district heating with other conventional heating systems due to the strategy of operating the binary power plant. Thus, the geothermal water flow rate to the plant will be varied to keep the total demand of geothermal water at the constant rate of 50 l/s (the capacity of the well). In this way, the total thermal power is quite constant.

The return geothermal water temperature from the hot tap water system is low, 12°C. For this reason, it is sent directly to the reinjection station without being utilized for cascaded use. Therefore only the temperatures for the return geothermal water from the district heating and binary power plant systems are available for cascaded use. In Figure 16, the return geothermal water from these two primary users are presented. It can be seen that, during the heating season, it is better to use the return water from the district heating system for cascaded use, because its temperature is higher.

As seen in Figure 1, the primary geothermal users are district heating, hot tap water and the binary power plant. In order to cover the peak load at design outdoor temperature, T_{out} = -12°C, the type of the heating system was chosen for the the greenhouse complex. The calculations were done for the indoor design temperature T_{ind} = 20°C. This temperature is recommended for growing some usual greenhouse cultures in Romania. The maximum heat demand for a typical greenhouse size (10 x 70 m^2), was calculated as 210 kW (using the volumetric heat loss coefficient G=3 W/m^3 °C). According to Popovski (1993), the power for the soil heating system is 2 kW/m^2. According to the greenhouse surface, this type of greenhouse heating may cover 40 kW (20% of the total heat demand). For the other type of the convector heat exchanger, the power was calculated for a German type of convector, Bidle Vectair E, Type NT275. For the chosen indoor temperature and for the inlet/outlet geothermal water temperatures 45/35°C, the power of one convector is 1.5 kW. The length of one convector is 2.5 m. In order to cover the peak load, (210 - 40) kW/1.5 kW = 113 convectors are needed. Therefore, the total length for the convectors is 2.5 m x 113 = 282.5 m. The length of the greenhouse is 70 m, it follows that 282.5/70 = 4 lines of convectors are needed. These calculations were done for natural air movement. When fans are used the efficiency is higher. In this way it is possible to decrease the number of convectors, but it is left for further study.

The available geothermal water flow rate for greenhouse heating (M_{ggrav}) and the geothermal water flow rate needed for one greenhouse (M_{ggr1}) are plotted in Figure 17. The number of greenhouses may be found in Figure 18, where the ratio is plotted between M_{ggrav} and M_{ggr1}. According to the figure, the available geothermal water flow rate may be used for heating three greenhouses.

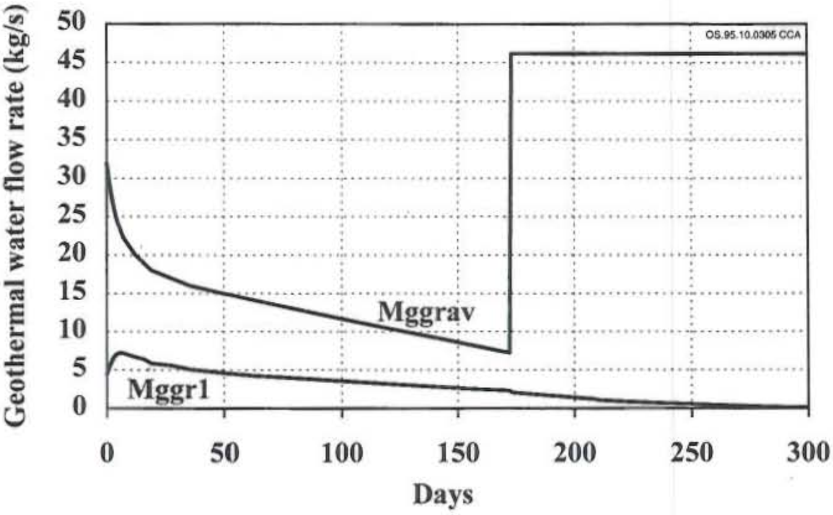

FIGURE 17: The available flow rate of geothermal water for the greenhouse complex (M_{ggrav}) and needed for one greenhouse (M_{ggr1})

The available geothermal water flow rate for swimming pools and aquaculture, is the total return flow rate from district heating and binary power plant systems, i.e. the well geothermal water flow rate minus the flow rate needed for the hot tap water system. The temperature of the water ($T_{gswaqav}$) is presented in Figure 19. The geothermal water flow rate needed in both swimming pools, is plotted in Figure 20. The sizes of the swimming pools presented in Chapter 4.3, were designed according to the relevant size of swimming pools for the university and available geothermal water flow rate.

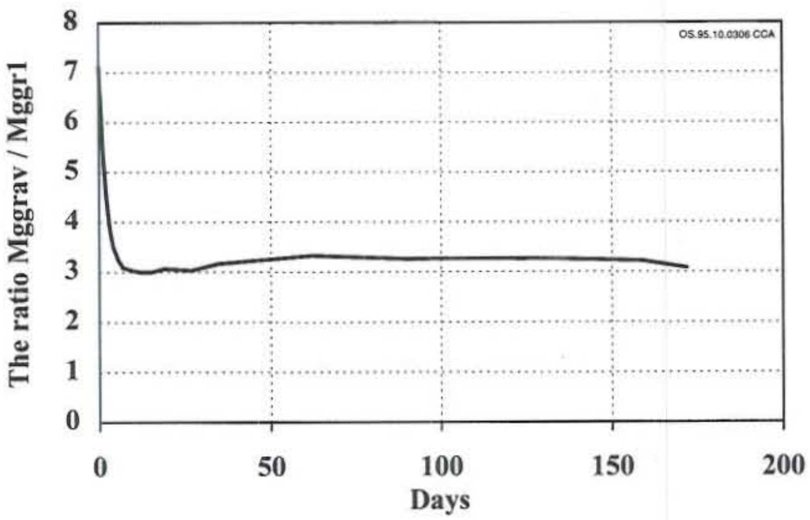

FIGURE 18: The ratio M_{ggrav} / M_{ggr1} for calculating the number of greenhouses

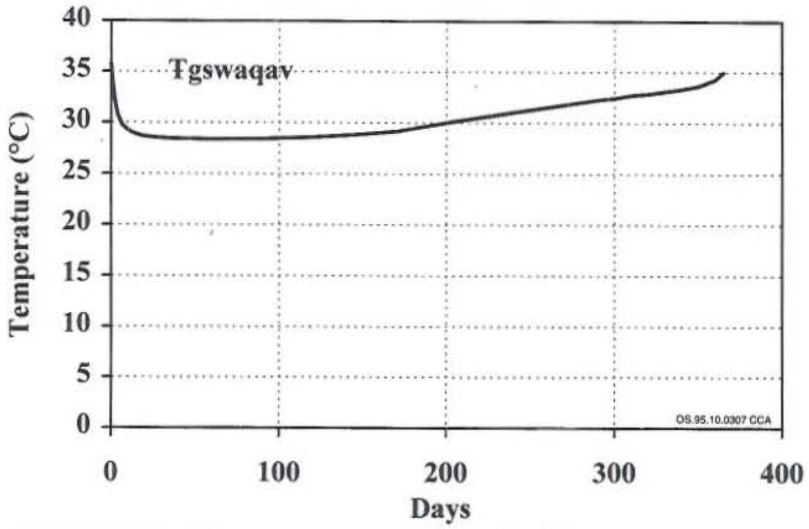

FIGURE 19: The temperature of the available geothermal water for the swimming pools and the aquaculture

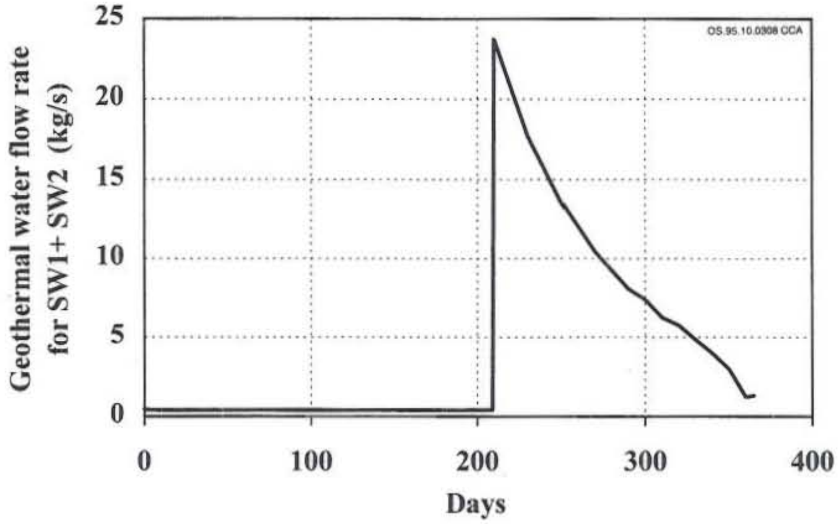

FIGURE 20: The flow rate of geothermal water for the swimming pools (SW1 and SW2)

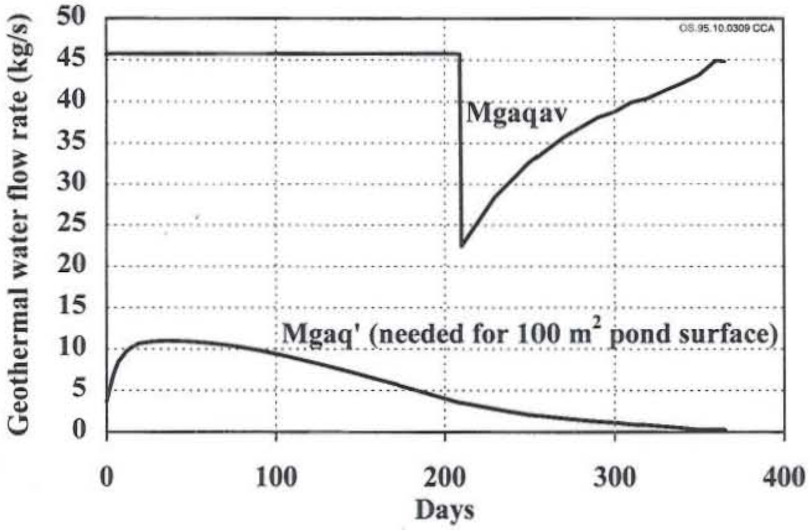

FIGURE 21: Aquaculture, flow rate of available geothermal water (M_{gaqav}) and needed for 100 m² surface pond ($M_{gaq'}$)

The available geothermal water flow rate (M_{gaqav}) for both aquaculture ponds, AQ1 and AQ2 in Figure 1, and the needed geothermal water flow rate for 100 m² surface of aquaculture pond ($M_{gaq'}$) are plotted in Figure 21. The allowed surface of the aquaculture pond may be found by taking M_{gaqav} and dividing into it $M_{gaq'}$. This ratio is plotted in Figure 22. The pond's surface was chosen in order to use completely the available geothermal water when its supply is at minimum. This happens, as can be seen in Figure 22, around the 40th day, that means at 0°C outdoor air temperature condition. The rest of the time, the geothermal water not needed in the aquaculture ponds has to be reinjected or discharged into the river. The calculated surface for each pond is 400 m². The calculations were done for the wind velocity W = 4 m/s.

The spent geothermal water flow rates available for reinjection, in both cases presented in Chapter 5.1, are plotted in Figure 23. In case 2, when only the return geothermal water which has not been used in the swimming pools and aquaculture ponds are available for reinjection, the operation of the reinjection can not be continuous. The break period depends on the reinjection flow rate. The water temperatures are plotted in Figure 24.

In Table 4 the estimated annual geothermal energy consumption for the whole geothermal installation system and for each utilizer are presented. Figure 25 shows the percentage distribution of these values. It can be seen that the binary power plant is the main energy consumer. The annual geothermal water consumption is for the district heating system 574,000 m^3/y, for the hot tap water system 88,300 m^3/y and for the binary power plant 914,500 m^3/y. The total annual geothermal water consumption for these primary users is 1,576,800 m^3/y.

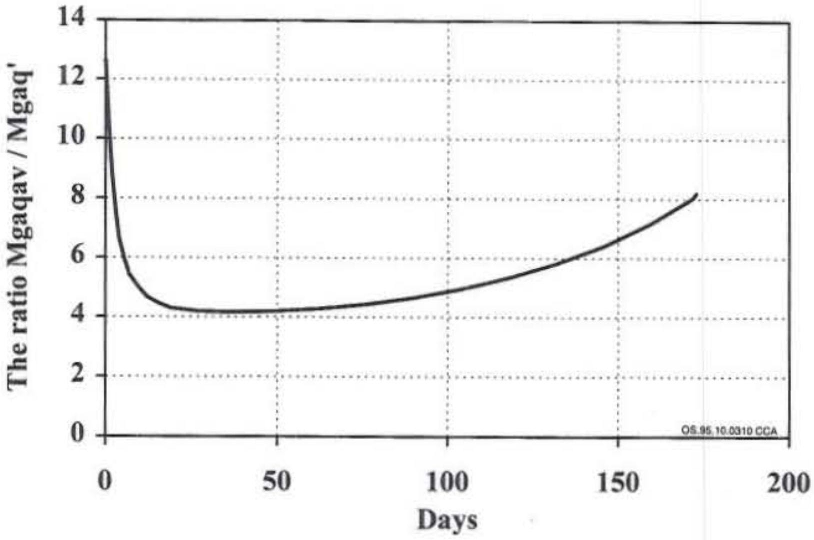

FIGURE 22: The ratio $M_{gaqav} / M_{gaq'}$ for calculating the surface of the aquaculture pond

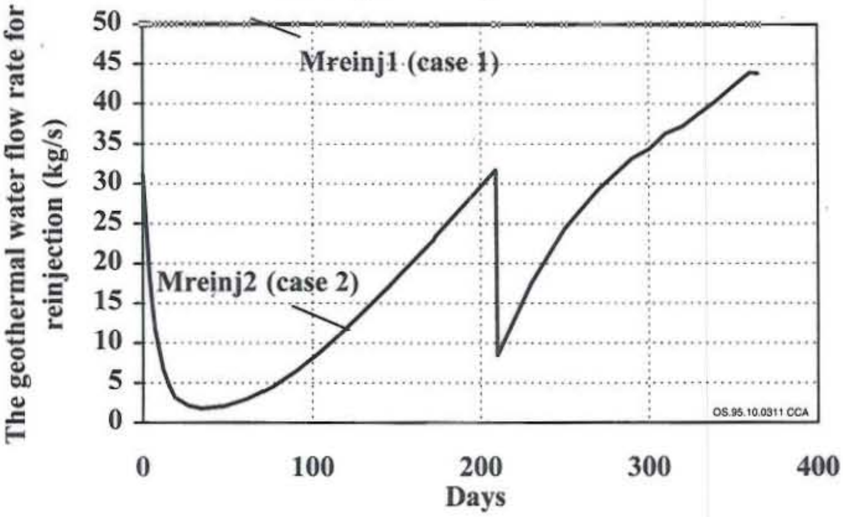

FIGURE 23: Available flow rate of geothermal water for reinjection in case 1 (M_{reinj1}) and case 2 (M_{reinj2})

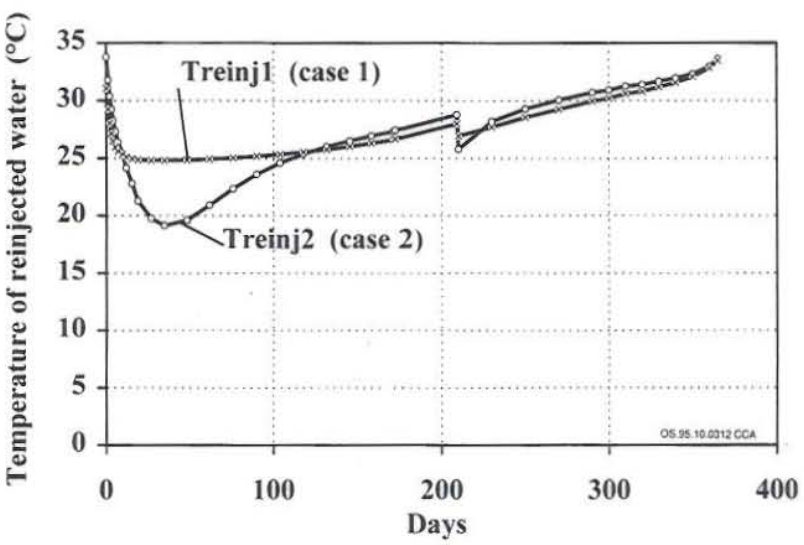

FIGURE 24: Temperature of reinjected geothermal water in case 1 (T_{reinj1}) and case 2 (T_{reinj1})

TABLE 4: Estimated annual geothermal energy consumption

Users	Estimated annual geothermal energy consumption	
	(TJ/y)	(%)
DH - district heating	46.2	15
HTW - hot tap water	21.6	7
BPP - binary power plant	212.5	69
GR - greenhouse	9.1	3
SP - swimming pool	4.7	1.5
AQ - aquacultur	13.9	4.5
TOTAL	308	100

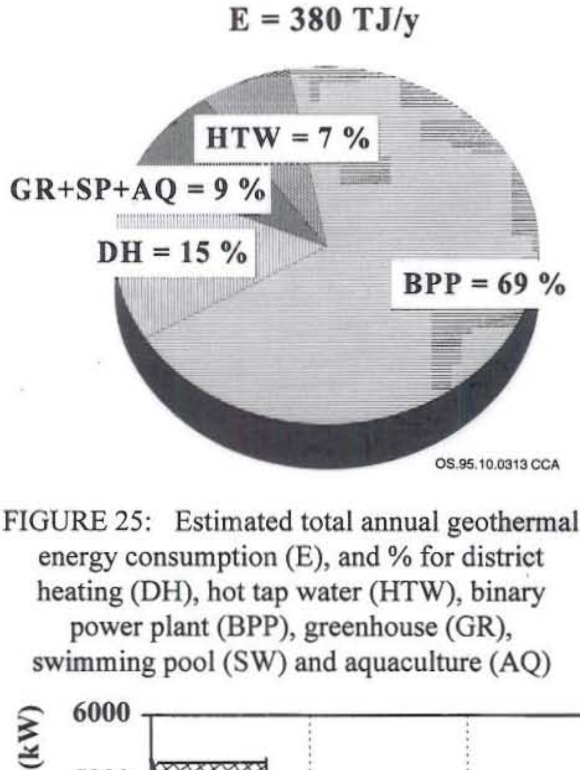

FIGURE 25: Estimated total annual geothermal energy consumption (E), and % for district heating (DH), hot tap water (HTW), binary power plant (BPP), greenhouse (GR), swimming pool (SW) and aquaculture (AQ)

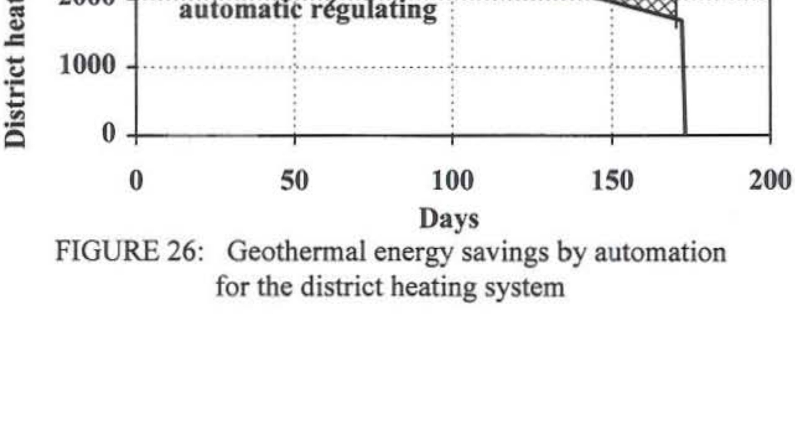

FIGURE 26: Geothermal energy savings by automation for the district heating system

5.3 Economical aspects

The university is a public institution, financed by government funds. The statute of the university is for education and research. In this way, it is hard to estimate the benefits of such a geothermal project in money values. Rather the gain may be found in the rise in educational capacity of the university by using the facilities presented in Chapters 3 and 4. Another gain is achieved by using the products of the greenhouse and aquaculture. Also, these facilities may be used for research in specific domains of study.

The other aspect is increase in the efficiency of the utilization of geothermal water. For example, in Figure 26 the thermal power duration curves for the district heating system are presented, corresponding to the present process regulation in steps and the planned automatic regulation by a PLC. The areas below these curves are the annual energy consumptions. At present, the annual geothermal energy consumption for district heating system is estimated to be 71 TJ/y. By automation, the consumptions are estimated to decrease to 57 TJ/y, i.e. 30% savings. As mentioned in Chapter 5.2, the annual geothermal energy consumption for all the systems presented in this report is 308 TJ/y. This thermal energy corresponds to annual fuel savings of about 37,000 tonnes coal equivalent with a low calorific value of 8,400 kJ/kg.

Concerning the cost of the geothermal project, two general types of cost must be considered in relation to big geothermal installation systems, capital costs and operating costs. Capital costs mainly consist of the cost of purchasing and installing the equipment (pipes, control valves, circulation pumps, automatic equipment, etc.) and, where necessary, modifying existing systems. Capital cost should also include allowances for engineering design and project management fees. The main operating cost for the whole installation is the cost for equipment maintenance and repairs, and for electricity and wages. Based on the technical calculations presented in this report, an economical study might be done in order to estimate the cost of the whole geothermal installation system.

5.4 Environmental aspects

In Table 1 some values for international recommendations for different water usages are presented and the concentration of these polluting substances in the geothermal water from the university's well. It can be seen that harmful substances are low. The concentration of dissolved solids is below the admissible limit for human consumption. For this reason, this geothermal water can be used directly in the swimming pools. For aquatic life, all the polluting substances in the well water are below the allowable limits. Therefore, the geothermal water can be used directly in the aquaculture ponds. It is possible that this geothermal water can be used directly in the district heating and hot tap water systems, as is quite common in Icelandic geothermal district heating systems. For this it is necessary to predict the scaling potential of the different minerals, such as magnesium silicates and corrosion.

From the point of view of chemical pollution, the discharge of the spent geothermal water into the municipal sewage system is possible. Reinjection of water eliminates the possible causes of environmental pollution (thermal and chemical). Reinjection operation should be planned by specialists with a wide experience in this field to avoid pollution of the freshwater aquifers and cooling of the geothermal reservoir.

The geothermal water from the University's well contains CO_2 in a concentration of 157.1 mg/l. The annual amount of CO_2 released into the atmosphere from the geothermal water used by all the users compared to the amount released by coal fired power plants producing the same thermal energy, is presented in Table 5. The calculation was carried out for a perfect combustion of coal with 60% carbon and a low calorific value of 8,400 kJ/kg. In addition, the coal fired power plant releases solid particles and toxic gases (sulphur dioxide, nitrogen oxides) into the atmosphere, not present in the geothermal plant.

TABLE 5: Pollutant emission (in tonnes/year)

Geothermal water	**Coal fired power plant**			
CO_2	**CO_2**	**SO_2**	**NO_x**	**Solid part.**
248	115	164	181	28

7. CONCLUSIONS AND RECOMMENDATIONS

1. A complex geothermal installation can be improved by automation utilizing programmable logic controllers (PLC) and a specialized software system SCADA. This computer system is a powerful research tool for finding the best strategy for geothermal utilization.

2. Using only the return geothermal water from the primary users, the size of the cascaded users is not limited by the minimum outdoor temperature, but other outdoor temperatures, when the available return geothermal power is lowest.

3. By introducing utilization of the geothermal water in cascade it is possible to increase the thermal efficiency of the plant. For cascaded use, there are many possibilities for choosing the type of users and their interconnections. Here, one such alternative is presented.

4. In order to save energy for water pumping and improve indoor temperature control, it is necessary to change the operating strategy for the district heating system. Variable flow-constant supply temperature strategy is recommended instead of constant flow-variable supply temperature strategy.

5. Because the geothermal water of the university well is relatively clean, it is recommended to analyse the possibility to use it directly in the district heating network and the hot tap water system.

6. Before deciding the cascaded users, it is recommended that a thorough study is undertaken on the possibilities both from the technical point of view of and for economical reasons. It is recommended to use SCADA system and the simulator in order to analyse various process design alternatives, to develop and analyse different control strategies and to optimize the operational strategies.

7. Also, it is recommended to pay special attention to the reinjection by doing tests and studies in order to find the optimal reinjection strategy.

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NOMENCLATURE

Variables:

P = Thermal power (W)
M = Mass flow rate (kg/s)
T = Temperature (°C)
A = Surface (m^2)
V = Volume (m^3)
U = Overall heat transfer coefficient (W/m^2 °C)
Cp = Specific heat of water (J/kg °C)
$LMTD$ = Logarithmic mean temperature difference (°C)
G = Volumetric heat loss coefficient (W/m^3 °C)
W = Wind velocity (m/s)
e = Partial steam pressure (mbar)
x = Coefficient

Indices:

dh = District heating
htp = Hot tap water
e = Binary power plant
gr = Greenhouse
$sw1$ = Swimming pool 1
$sw2$ = Swimming pool 2
$aq1$ = Aquaculture pond 1
$aq2$ = Aquaculture pond 2
$reinj$ = Reinjection
g = Geothermal water
wh = Well head
I = Inlet
o = Outlet
ind = Indoor
out = Outdoor
spl = Supply
ret = Return
b = Building
rr = Room radiators
tr = Transferred through the heat exchanger plates
d = Demand
des = Design conditions (at peak load)
cv = Convection
ev = Evaporation
rd = Radiation
av = Available
tot = Total

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