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GEOTHERMAL DISTRICT HEATING MODELLING, NOWOGARD TOWN, POLAND

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ABSTRACT

Nowogard town is located in northwest Poland, near the Baltic Sea and the German border. The town borders good geothermal water resources in Poland. Water temperature in the Nowogard's aquifer is estimated to be close to 80˚C with a flow rate of up to 80 l/s. Nowogard has no district heating system. Presently, 84 boilers supply heat for local customers. The majority of the boilers are coal boilers causing huge air pollution. Modelling based on a totally new district heating design gives alot of interesting results. Simulations of a district heating operation seem reliable and could be a good starting point for a real project.

1. INTRODUCTION

The heating demand in Poland is much higher than present geothermal exploitation. However, available geothermal resources are much greater than what is utilized. Recently a number of efforts have been made to develop a technology for the utilization of low-enthalpy geothermal resources for district heating. Now 4 plants are in operation, all of which provide sufficient energy to their customers. There have been no major problems in plant operations due to insufficient technical solutions for possible difficulties based on underground properties. Observed problems are mainly failures in the district heating system, the surface installation of the plant or at the subsurface water pumps. There still exists a great potential for new geothermal investments. Town like Nowogard, with good geothermal conditions and huge air pollution caused by coal boilers, are common in Poland. So there is still much to do, to provide geothermal energy and its benefits to customers. This project is a small step, towards starting geothermal investment in Nowogard Town, but hopefully this step will lead to others.

2. NOWOGARD TOWN

Nowogard is a small town with 17,000 inhabitants located in NW-Poland (Figure 1). It lies near to Szczecin City and also near the German border and Baltic Sea, and has thus a large tourist aspiration. It is a town of mainly agricultural activities and some consumer industry. A district heating system does not exist in Nowogard town. Many individual coal fired boilers heat buildings. They consume a large amount of coal, and are the reason for substantial air pollution.

The intensified degradation of the human natural environment has roused a growing anxiety. The problem is recognized more and more clearly in the local society of the town. To correspond with those facts, the local council has started ecological investments. One of them is a project of a wind power station. They also plan to replace local boilers with a new ecological heat source. It could be a geothermal heat plant.

FIGURE 1: Map of Poland showing Nowogard town

2.1 Population trends

When a new district heating system is designed it is expected to be in operation for a number of years. Therefore it is necessary to study how the population of the district has developed in the past to be better able to forecast future developments as the design of some major components of the system such as a supply mains and distribution trunk lines are often based on 15-20 years projected future needs. On a statistical research basis, the population is expected to remain rather steady in number in Nowogard, but for the next 10 years there is a predicted 10% growth rate. These factors must be taken into consideration when a district heating system is being designed.

2.2 Geothermal conditions

The northwest part of Poland, the Szczecin region, has good conditions for using geothermal water for heating purposes. Geothermal water occurs there at a depth of 1600-2200 m and with temperature of 50-90°C. These strata consist of grey sandstone with high porosity and thickness up to 200 m (the so-called lias formations). Each square kilometre of the terrain contains at depth about 4.3×10^6 m^3 of geothermal water. The corresponding energy may be compared to about 160,000 tons of coal.

The Szczecin region with Nowogard town is a part of the large Szczecinsko-Lodzkie sinclinorium, considered one of the best geothermal water sources in Poland (Figure 2). The sinclinorium area is about 67,000 km^2. The estimated recoverable volume of sub-artesian and artesian geothermal water is 2854

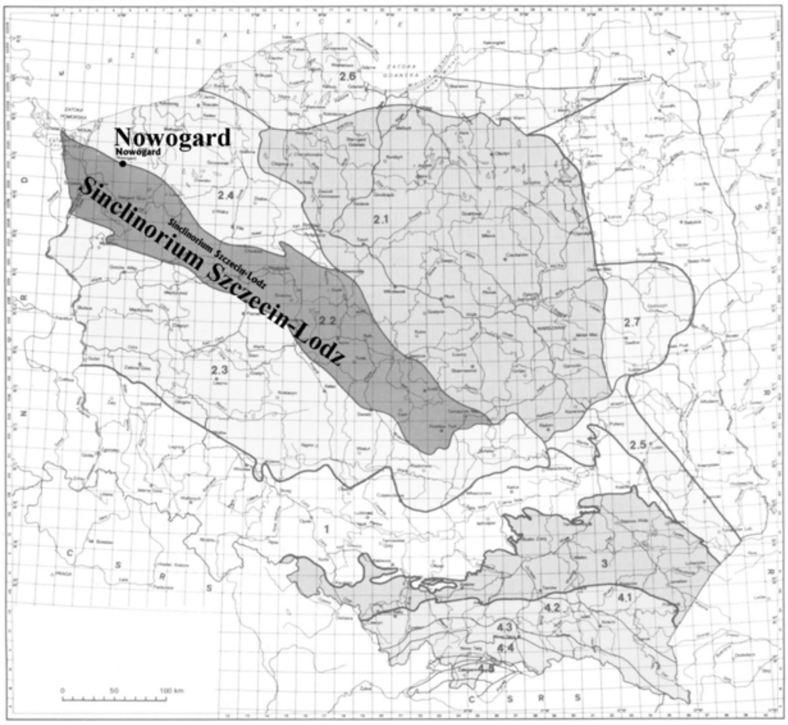

FIGURE 2: The Szczecinsko-Lodzkie sinclinorium, a large source of geothermal energy

km^3 amounting to 18,812 millions toe (tons oil equivalent). On average it amounts to 42 million m^3 of water or 280,800 toe per square kilometre.

Pyrzyce town is located on the borders of the same sinclinorium, very close to Nowogard town. A few years ago the situation there was similar, with many local boilers and good geothermal conditions adding a similar number of inhabitants. Pyrzyce is a good example of professional progress. Coal boilers were the main source of air pollution in the city. One of the most important criteria in choosing an ecological heat source was the aspiration of the local government to limit the emission of damaging combustion products. They chose an ecological heat source, building a geothermal heat plant assisted by gas boilers. The task of the geothermal heat plant in Pyrzyce and the district-heating network, which was built at the same time, was to replace 68 local coal boilers in use and increase efficiency.

Since 1997 they have operated a modern 50 MWt heat plant, utilizing 340 m^3/hr of 68°C geothermal fluid as a base load, adding two 10 MWt heat pumps to heat the fluid for the customers to 90°C. As an emergency and peak heat source they use 22 MWt gas boilers. The main effect of the operating plant is extreme limitations of pollutant emissions. The objective was attained - a trail was blazed (Meyer and Kozlowski,1995).

From geological and geophysical surveys, and existing wells in the Szczecin basin area, one can estimate the following data for geothermal fluid accessible in the Nowogard area:

- Temperature of geothermal fluid: T_{MAX} = 75°C;
- Aquifer depth: D = 1.5 - 2.0 km;
- Flow rate: V_{Gmax} = 150 m^3/hr and V_{Gmin} = 50 m^3/hr;
- Average density of geothermal fluid: ρ_G = 1.08 kg/m^3;
- Average specific heat at the constant pressure of geothermal fluid: $c_{pG} \cong$ 3.8 kJ /kgK.

On the basis of operation of the Pyrzyce geothermal heat plant, and a chemical survey it is known that the geothermal water from the Szczecin Basin is very aggressive. The reason for this is high mineralization – high content of salts (with NaCl-type water and mineral content of 112 g/l). This fact should be taken into consideration during selection of specific materials and devices. For example, the main plate heat exchangers should have a surface covered with palladium or titanium as well as the main pumps, used for pumping water from the well or the heat pumps.

Also it is worthwhile to note that there could be another danger called microbiological corrosion. Salt and hot geothermal water can be a good environment for bacterial growth. The bacteria if injected into the bedrock can silt it up (stick up) making the flow impossible. Therefore, one should avoid contact of the geothermal water with atmospheric air.

2.3 Weather data

Nowogard's location - Northwest Poland - is characterized by a mild climate. There are no cold winters and 84% of the days in a year enjoy temperatures above zero (Figure 3). Minus 15°C was the coldest

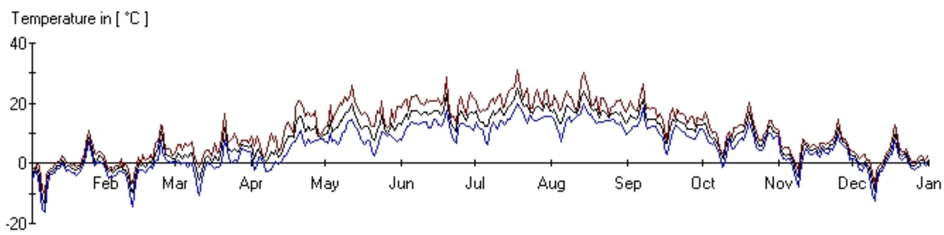

FIGURE 3: Air temperature, Nowogard, Poland

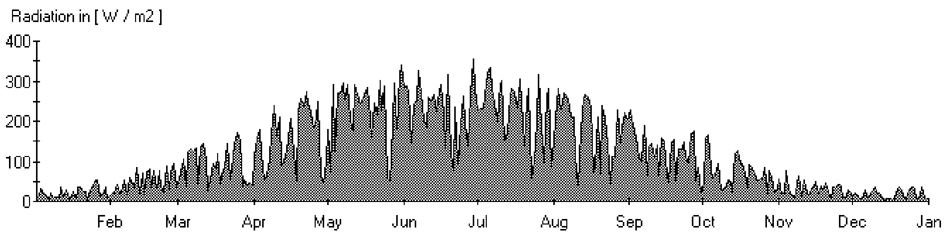

FIGURE 4: Sun radiation in Nowogard, Poland

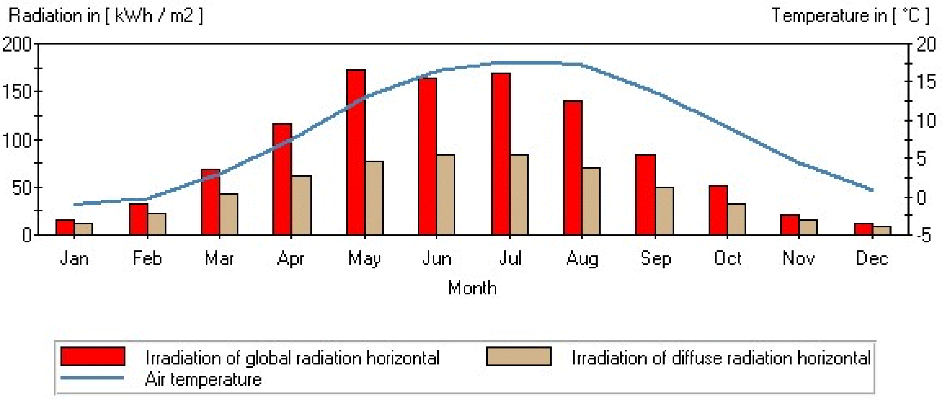

FIGURE 5: Sun radiation and average air temperature, Nowogard, Poland

temperature measured during the last 20 years. Because air temperature affects indoor climate through heat conduction in the outer walls and windows, this factor needs to be taken into consideration in a district heating study. Sun radiation (Figures 4 and 5) is also an important factor, influencing indoor climate in a house. For the heat dynamics of buildings, it is important to distinguish between direct and diffuse radiation, since the angle of incidence is needed to calculate the amount of penetrating radiation at any orientation of the windows (Emeish, 2001).

3. THERMAL POWER DEMAND STUDY

3.1 Present situation

At present there are 84 working boilers, providing heat and tap water for Nowogard town. There is no existing district heating system. Each boiler provides heat and tap water to consumers by it own pipe system. Most of these pipe systems are in very bad condition, and it is necessary to replace them as quickly as possible.

The total thermal power of all working boilers in Nowogard is about 56,202 MWt. Also it is worth mentioning, that the boilers have very different installed thermal power capacity, from 22 kW to 4480 kW (Table 1).

During the last few years, some of boilers have been modernized, more efficient gas boilers replacing coal boilers. But this only applies for some small capacity boilers and most of the big coal boilers are still in operation. These boilers, in most cases, operate with low efficiency because of over estimation of heat requirements.

TABLE 1: Number and type of boilers in Nowogard

Thermal power capacity	Fuel			
	Coal/ coke	Natural gas	Oil	Firewood
Up to 100 kW	4	9	4	1
101 - 200 kW	3	13	3	2
201 - 500 kW	8	2	4	-
501 - 1000 kW	7	1	-	-
Above 1000 kW	15	5	2	1
Altogether	37	30	13	4

TABLE 2: Different fuel type participation in thermal power production in Nowogard City

	Fuel			
	Coal/ coke	Natural gas	Oil	Firewood
Heat production [MW]	38,444	11,664	4,551	1,543
Percentage [%]	68.40	20.75	8.10	2.75

The result of coal and coke providing nearly 70% of the heat production (Table 2) is a huge emission of air pollutants. It is estimated that the coal and coke boilers in Nowogard emit into the atmosphere, relative to the total emission:

- 97% of SO_2;
- 89% of N_2O_5;
- 99% of CO; and
- 95% of the ashes.

Taking these numbers into consideration, and with no existing district heating system, it is necessary to think about a new, clean, and economical heat source for the town.

3.2 Heat requirements

The heat requirement estimation methods can include

- Cataloguing existing boilers. Very quick but error abound, as some of the boilers are over estimated;
- Cataloguing building data. Heat requirement estimates for actual building data, and for buildings after thermo modernization.

A more accurate heat requirement estimation method is to collect data for all the building and population. In this work, data from Hydro-Sanitary Enterprise in Nowogard town was used. They catalogued the following data:

- Number of flats;
- Number of inhabitants;
- Number of industrial plants;
- Living space;
- Construction year;
- Wall type;

- Building type;
- Thermal modernization at present and in the future;
- Predicted building development.

Primarily, the heat requirement for each building was determined by using the norms of Polish National Agency of Energy Savings (Table 3). These norms did not take into consideration building types, so it was decided to also use German norms, specified for East Germany (Table 4).

TABLE 3: Heat requirement according to the norms of Polish National Agency of Energy Savings

Year built	**Before 1967**		**1967 - 1985**		**1986 - 1992**		**1993 - 1997**		**Since 1998**	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Heat requirement [kWh/m^2a]	240	350	240	280	160	200	120	160	90	120

TABLE 4: Heat requirement according to German norm

Year built		**No. of floors/ stories**	**0 Building type**	**Code type**	**Heat requirement [kWh/m^2a]**
From	**To**				
-	1918	1 - 2	Detached house	BWJ A	325
-	1918	1 - 2	Detached house	BWJ B	325
1919	1945	1 - 2	Detached house	BWJ C	250
1946	-	1 - 2	Detached house	BWJ D	250
1961	1970	1 - 2	Detached house	BWJ E	250
1971	1980	1 - 2	Detached house	BWJ F	180
1981	1985	1 - 2	Detached house	BWJ G	180
1986	1990	1 - 2	Detached house	BWJ H	180
1991	1999	1 - 2	Detached house	BWJ	140 (*110)
-	1918	3 - 4	Small terrace house	BMW A	200
-	1918	3 - 4	Small terrace house	BMW B	180
1919	1945	3 - 4	Small terrace house	BMW C	180
1946	1960	3 - 4	Small terrace house	BMW D	180
1961	1990	3 - 4	Small terrace house	BMW E-H	180
1991	1999	3 - 4	Small terrace house	BMW I	110
-	1918	5 - 8	Big terrace house	BDW A-B	190
1919	1945	5 - 8	Big terrace house	BDW C	190
1946	1960	5 - 8	Big terrace house	BDW D	145
1961	1970	5 - 8	Big terrace house	BDW E	200
1971	1980	5 - 8	Big terrace house	BDW F	170
1981	1990	5 - 8	Big terrace house	BDW G-H	160
1991	1999	5 - 8	Big terrace house	BDW I	110
1961	1970	9 - 99	Tower block	BW E	150
1961	1970	9 - 99	Tower block	BP E	130
1971	1990	9 - 99	Tower block	BW F	130
1971	1990	9 - 99	Tower block	BP F-H	110
1991	1999	9 - 99	Tower block	BP I	110

To calculate thermal power demand for each flat, it is necessary to multiply a specific norm coefficient of heat requirement by flat area - obviously taking into consideration the type of building. Calculations were done according to Polish and German norms. In the case where some thermal modernization had been done (or will be done) the results of thermal power demand were modified by a specific coefficient, according to Polish National Agency of Energy Savings norm (Table 5).

TABLE 5: Reduction of heat demand relative to initial state after thermal modernization

	Reduction of heat demand relative to initial state
Modernization of thermal centres + weather automation	5 - 10%
New pipe isolation + thermostatic valves	15 - 20%
Installation of heat meters	Up to 10%
Installation of screens behind the radiators	Up to 5%
Windows and door sealing	3 - 5%
Installation of 3-partition windows	10 - 15%
Wall insulation	10 - 25%

Thermal power demand for tap water preparation, was calculated by multiplying the number of tenants in each flat by a special coefficient according to Polish and German norms. The coefficient value is 0.5 MWha/person.

Total heat demand due to heating and tap water preparation was obtained by adding all the component results (heat requirements for each flat, building, and industrial plant). Results are presented in Table 6.

TABLE 6: Thermal power demand according to German and Polish norms

	East German norm (D)	**Polish norm min (PL_{min})**	**Polish norm max (PL_{max})**
For preparing tap water [MWh/a]	12,750	12,750	12,750
For space heating [MWh/a]	83,167	98,416	127,124
Total thermal power demand [MWh/a]	95,917	111,166	139,874
Poland/Germany ratio (PL/D)	-	116%	146%

Analysing the data in Table 6, it is ease to notice that total thermal power demand calculated according to the Polish norm is almost 16% greater than the German norm in the minimum heat requirement case, and nearly 46% greater according to maximum heat requirement.

Table 7 includes results of comparing necessary total thermal power, calculated according to the norm, and related to present installed thermal power. Calculations were made with the following assumptions:

- Tap water requirements – 365 days/a, 8760 hours/a;
- Heat for space heating requirements – 182 days/a, 4368 hours/a;
- Transmission of heat energy, average efficiency – 65%;
- Conversion energy, average efficiency – 80%;
- Presently installed thermal power – 56,202 MW.

TABLE 7: Presently installed total thermal power related to calculated thermal power according to norms

	East German norm (D)	**Polish norm min (PL_{min})**	**Polish norm max (PL_{max})**
Necessary thermal power to prepare tap water [MW]	1,456	1,456	1,456
Necessary thermal power for space heating [MW]	19,040	22,531	29,103
Total necessary thermal power [MW]	20,496	23,987	30,559
Total necessary thermal power [MW] with transmission efficiency 65%	31,532	36,903	47,014
Total necessary thermal power [MW] with conversion efficiency 80%	39,415	46,129	58,767
Comparison with installed thermal power [%]	143%	122%	96%

The deficit of about 4% of installed thermal power relative to the maximum heat requirement case is in reality covered by heat sources not included in this study. It is also worth mentioning the large over-sizing of actual working heat sources. Compared to the German norm, there is 43% more thermal power installed in the town than needed. This is due to various reasons. Thermal energy saving operations have been carried out in East Germany for the past 20 years. Installing pre-insulated pipes in district heating systems, insulation of external walls, montage of good windows and doors, all these facts have an influence on thermal power demand. It is clear that similar steps need to be undertaken in Nowogard. There already exists a Polish energetic law, and several legal acts standardizing building parameters (Table 8). Due to these it can be supposed, that in the near future buildings and piping heat losses will be reduced and the total thermal power demand for the town decreased.

TABLE 8: Building normative parameters

Date of introduction	**Norm no. valid from date**	**Heat transfer coefficient, k for external walls**	**Thermal power demand for space heating, E**	**Thermal power demand for space heating, E_o**
		[W /m²K]	**[kWh/m²a]**	**[kWh/m³a]**
Up to 1966	No norm	-	240 - 400	-
1967-85	PN-64/B-03404 since 01.01.1966 PN-74/B-03404 since 1.1.1976	1.16	240 - 280	-
1986-92	PN-82 B-02020 since 1.1.1983	0.75	160 - 200	-
Since 1993	PN-92 B-02020 since 1.1.1992	0.55	120 - 160	37.4 - 49.6
Since 1998	PN-98 B-02025 PN-EN ISO 6946 PN-EB ISO 10211-1 since 29.04.1998	0.45	90 -120	29.0 - 37.4

4. THE NETWORK

4.1 Network design based on the town plan

A geothermal district heating system is defined as the use of one or more production fields as sources of heat to supply thermal energy to a group of buildings. Services available from a district heating system are space heating, domestic water heating, space cooling and industrial process heat. A district heating system is not limited to a particular type of heat source. Heat sources that could be used for a district heating system include co-generating power plants, conventional boilers, municipal incinerators, solar collectors, heat pumps, industrial waste heat sources and geothermal fields. Depending on the temperature of the geothermal fields, it may be advantageous to develop a hybrid system including, in addition to geothermal, a heat pump and/or conventional boiler for peaking purposes. A geothermal district heating system comprises three major components, as shown in Figure 6.

- The first is heat production, which includes the geothermal production and recharge fields, conventional fuelled peaking station and wellhead heat exchanger (Lienau, 1981).
- The second is the transmission/distribution system, which delivers the geothermal fluid or heated water to the consumers.
- The third includes central pumping stations and in-building equipment. Geothermal fluids may be pumped to a central pumping station/heat exchanger. Thermal storage tanks may be used to meet variations in demand.

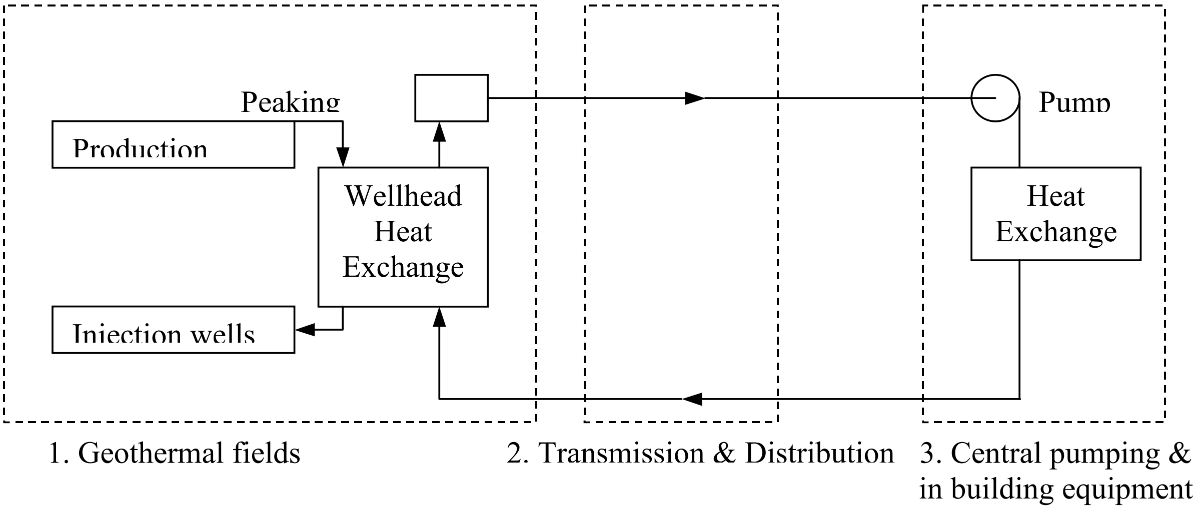

FIGURE 6: District heating system for Nowogard town

A sketch of a new district heating system was made on a town plan or street map of Nowogard (Figure 7). During its creation, several simplifications were made. The customers were grouped according to street, and for every street the heat demand was summarized. A pipe system was made only to supply heat for every street; there is no return system. There are no storage tanks and expansion devices. It might be mentioned that the created sketch of the district-heating system is not a professional design. It has been designed for simulation, and calculation of main district heating parameters and pipe costs. A geothermal heat plant is the central point of a district heating system. On Figure 7 it is indicated by a pentagon. No wells exist in Nowogard town, so the orientation of the geothermal heat plant is made on an assumption basis.

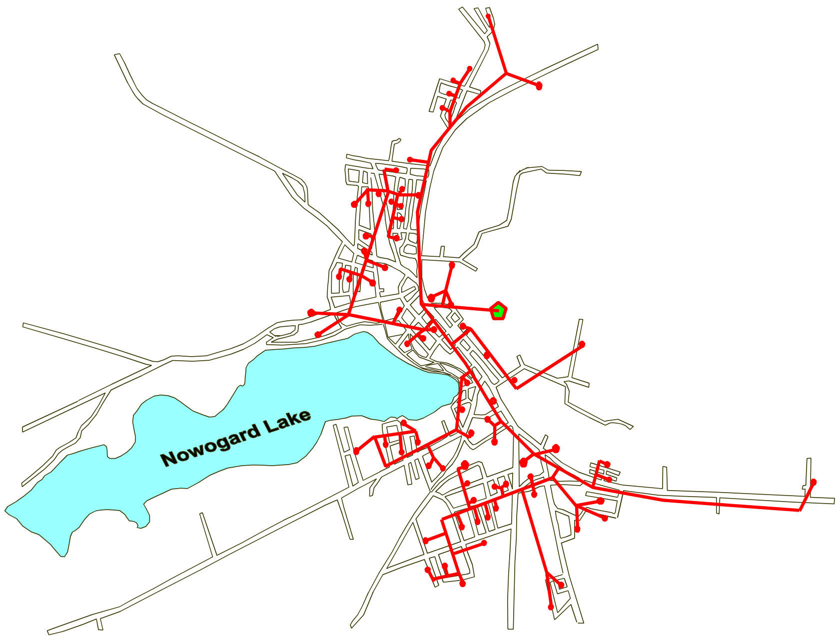

FIGURE 7: District heating system for Nowogard town

The designed district heating system was used to establish the location of all streets according to the location of the central point (heat plant) of the system. Knowledge of the location of every characteristic point of the system was used to prepare input files for calculation of all district heating parameters.

5. SIMULATION

To simulate operation of a district heating system, the software "Pipelab" was created under Matlab – The Language of Technical Computing. To start the simulation it was necessary to create two input files. The first one with xyz coordinates of every node (based on the district heating design, Figure 7), the second

FIGURE 8: Sketch of a district heating net created in Pipelab software

with length, diameter, roughness and heat loss of every pipe in the system. The second part of this file includes necessary water flow to every part of the system and the pressure head at the starting point of the system. The files can be seen in two appendices at the end of the report. Based on these two files, the drawing of the distribution network (Figure 8) was done and all the calculations carried out. The method for the calculations is found in Valdimarsson (1993).

Necessary water flow was calculated on the basis of a 40˚C radiator gradient assumption and heat requirements for each street. To cover all the heat requirements of the town an additional heat source is needed. Estimated possible discharge from the Nowogard aquifer is about 40 kg/s of 75˚C geothermal water. So it is clear that the rest of the needed water must be prepared with the aid of a boiler or a heat pump.

5.1 District heating main parameters

The Pipelab software gives a lot of district heating parameter results. Below are presented the main results of Nowogard district heating simulation. During calculation of the optimized basis, some pipe diameter selection was made. Specifications of the diameter of every pipe used in the system can be found in the Appendix II. Figure 9 shows the results in plot format. Because optimisation was done on the norm pipe diameter, the system includes only standard pipes. The biggest diameter used in the system is 0.4 m, and this is pipe directly from the geothermal heat plant.

Figure 10 shows the pipe head gradient. A two bar gradient in a majority of the pipes is acceptable.

The pipe head gradient in the whole system is shown in Figure 11. Head difference of around 2 bar between the highest and lowest user is a good result. Straight proportional decreasing of a head gradient in the whole system is a good result.

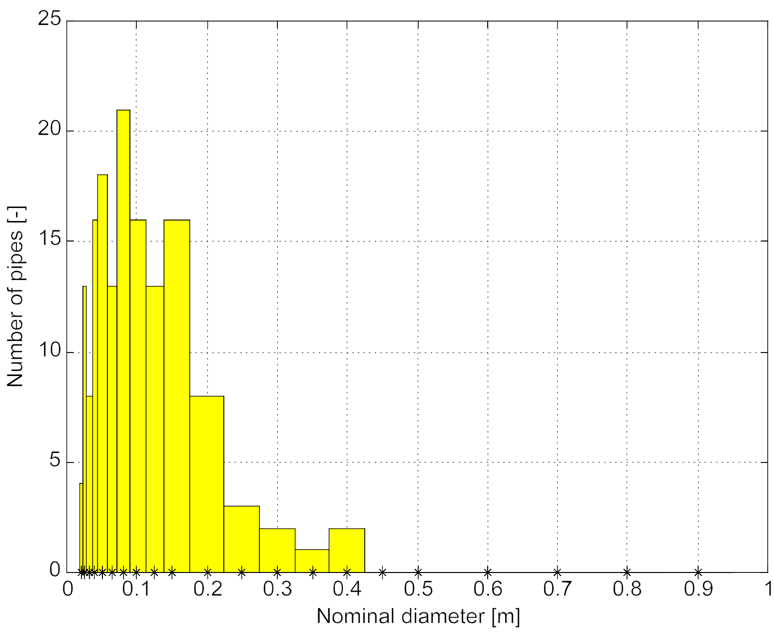

FIGURE 9: Pipe diameter histogram

The largest group of customers are served with a pressure head at 6.5-7 bars, as seen by analysing Figure 12. Diameters of the longest pipes used in the net are between 0.05 and 0.15 m (Figure 13). Velocity of 0.2-0.5 m/s occurs in the majority of the pipes (Figure 14). It is quite logical, because the majority of the pipes are the pipes to the consumers, with the smallest fixed diameter of 0.02 m.

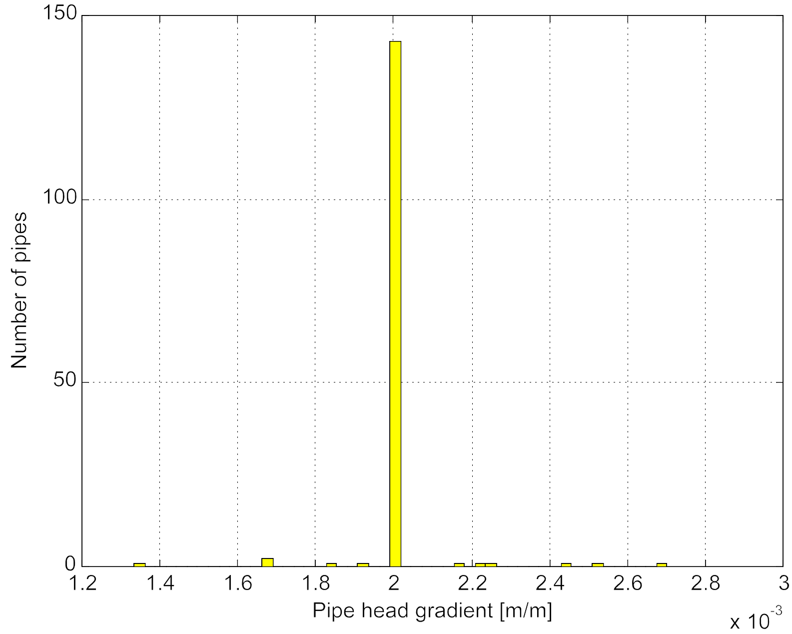

FIGURE 10: Pipe head gradient

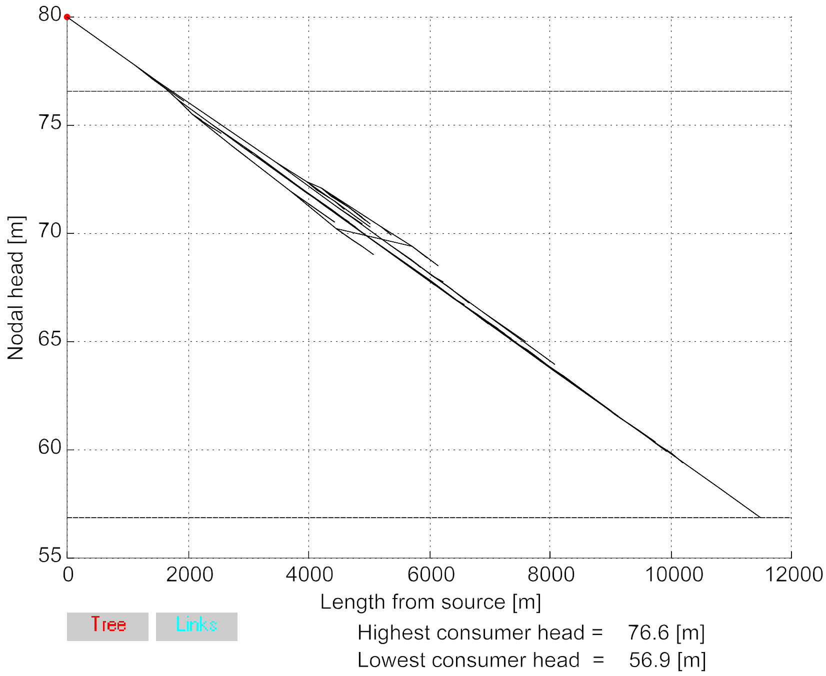

FIGURE 11: Pipe head gradient in the whole system

5.2 Estimated cost of the new system

Estimation of the new system's costs were done on the Dutch market basis. Specification of every pipe used in the system, length of these and prices are part of the Pipelab database. After designing a new system for Nowogard town and running simulation, there was available a roughly estimated price of all the pipes used in the system. In the case of Nowogard, the approximate total costs of the new system (only supply net) is 2.4 million US dollars (Table 9).

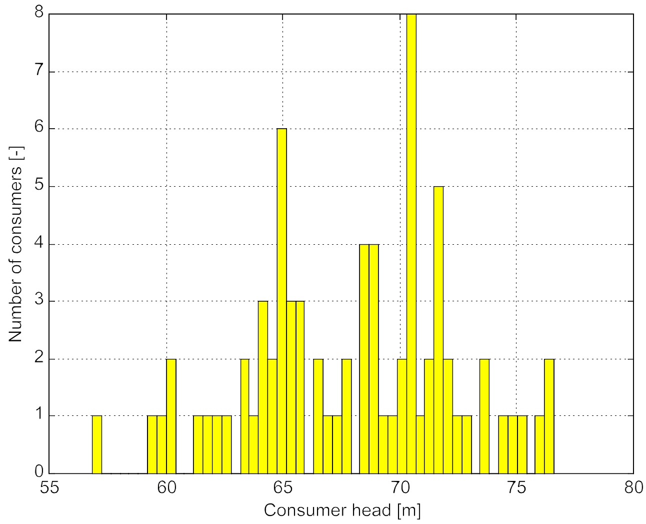

FIGURE 12: Distribution of consumer head

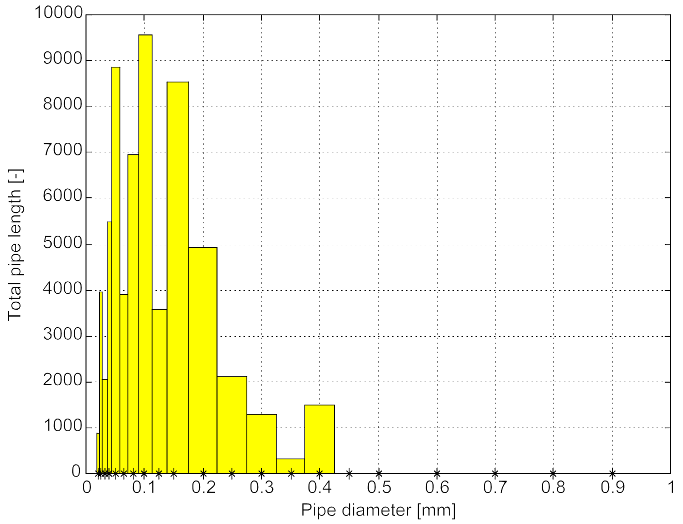

FIGURE 13: Length and diameters of pipes used in the network

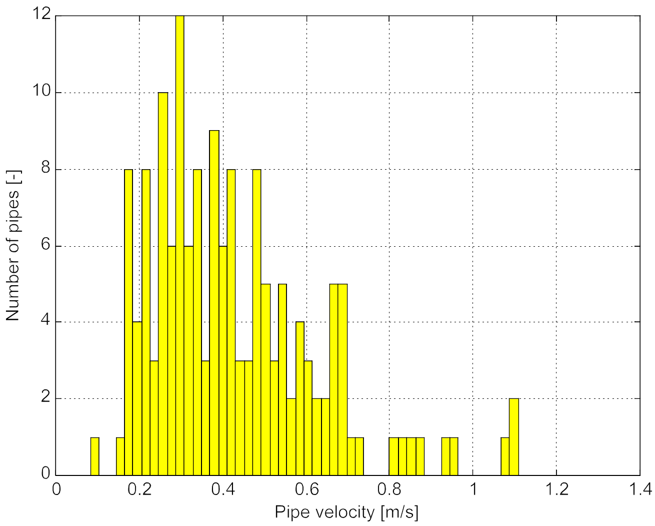

FIGURE 14: Pipe velocity vs. number of pipes

TABLE 9: Costs of pipes, Nowogard district heating

Nominal diameter [mm]	Length [m]	Cost	
		Dutch Guilder [fl]	US Dollar [USD]
20	2196.04	91882.47	36952.37
25	2087.03	87321.42	35118.06
32	1718.88	77693.16	31245.86
40	6180.28	279348.77	112345.7
50	9035.27	469111.25	188662.5
65	3896.10	228467.15	91882.63
80	6945.06	453929.27	182556.7
100	9567.09	786128.19	316157.2
125	3571.36	341457.93	137324.1
150	8520.98	986474.73	396730.5
200	4921.98	751734.73	302325.2
250	2115.07	443868.19	178510.5
300	1279.07	332890.03	133878.4
350	314.27	93410.38	37566.85
400	1509.49	545031.54	219195.3
Total pipe costs		**5,968,749**	**2,400,452**

6. SYSTEM DESIGN

Possible discharge from the Nowogard reservoir is estimated at about 40 l/s of 80˚C. Therefore, an additional heat source is needed in the system to cover all heat requirements in the town. Two alternatives will be taken into consideration, using a heat pump, or a gas boiler. Simulation and determination of the main district heating parameters were done on a 25 MW total power demand basis (not including transmission losses and efficiency of the heat source). Hence, the system design will be done on the same basis.

6.1 Heat pump concept

The first alternative assumes using a heat pump driven by a diesel engine. The supplementary water is preheated by a heat pump and finally heated by a diesel engine (Figure 15). This water runs in a closed loop. Instead of using a diesel engine, it is possible to use different power and heat source such as natural gas.

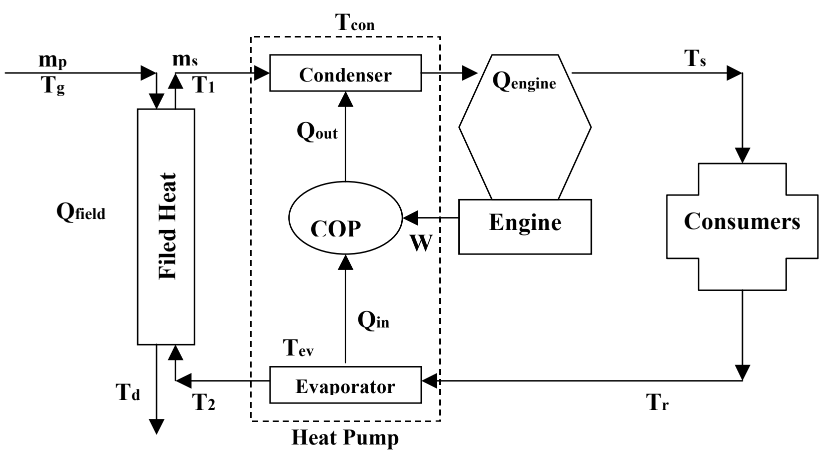

FIGURE 15: Additional heat provided by heat pump

The following numbers present the results of calculations of the main district heating parameters. These values only give a rough idea of the possible operation of the Nowogard's district heating system.

T_g = 80°C - geothermal water temperature;
T_d = 8°C - discharge (reinjected) water temperaure;
T_1 = 24°C - temperature of water from heat exchanger;
T_2 = 5°C - temperature of water to heat exchanger;
T_{CON} = 77°C - condenser temperature;
T_{EV} = 2°C - evaporator temperature;
T_r = 45°C - return temperature;
T_S = 85°C - supply temperature;
m_p = 40 l/s - preliminary flow, geothermal water;
m_s = 149 l/s - secondary flow, water to town;
W = 6.7 MW - engine work;
COP = 4.65 - coefficient of performance;
Q_{engine} = 6.7 MW;
Q_{in} = 25 MW;
Q_{out} = 31 MW;
Q_{field} = 12 MW;
Consumers, Q = 25 MW.

6.2 Gas boiler concept

Another approach to the problem could be the use of a gas boiler as an additional heat source (Figure16). The supplementary water can be preheated with the aid of geothermal energy and finally heated by a gas boiler.

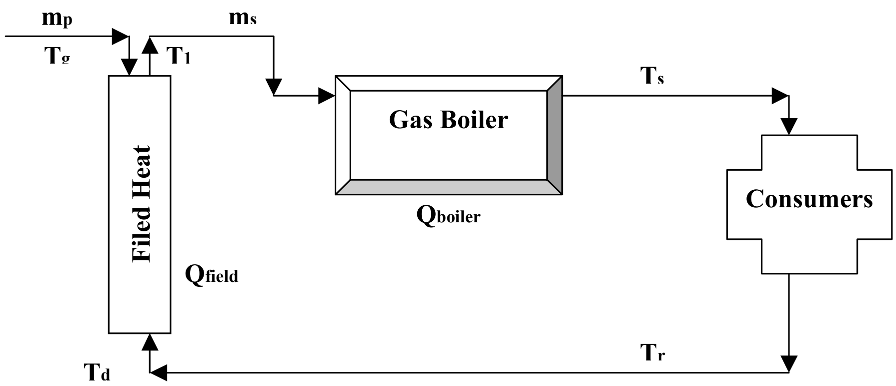

FIGURE 16: Additional heat provided by a gas boiler

The following presented values are the results of the calculations:

T_g = 80°C - geothermal water temperature;
T_d = 8°C - discharge (reinjected) water temperature;
T_1 = 64°C - temperature of water from heat exchanger;
$T_r = T_2$ = 45°C - temperature of water to heat exchanger;
T_S = 85°C - supply temperature;
m_p = 40 l/s - preliminary flow, geothermal water;
m_s = 149 l/s - secondary flow, water to town;
Q_{boiler} = 13 MW;
Q_{field} = 12 MW;
Consumers, Q = 25 MW.

6.3 Engine driven vapour compression heat pump

The great majority of heat pumps work on the principle of a vapour compression cycle. The main components in such a heat pump system are the compressor, the expansion valve and two heat exchangers referred to as the evaporator and the condenser. The components are connected to form a closed circuit.

A volatile liquid, known as the working fluid or refrigerant, circulates through the four components. This kind of heat pump can be used in the design of the system.

In the evaporator the temperature of the liquid working fluid is kept lower than the temperature of the heat source, causing heat to flow from the heat source to the liquid, and the working fluid evaporates. Vapour from the evaporator is compressed to a higher pressure and temperature. The hot vapour then enters the condenser, where it condenses and gives off useful heat. Finally, the high-pressure working fluid is expanded to the evaporator pressure and temperature in the expansion valve. The working fluid is returned to its original state and once again enters the evaporator. The compressor is usually driven by an electric motor and sometimes by a combustion engine.

An electric motor drives the compressor with very low energy losses. The overall energy efficiency of the heat pump strongly depends on the efficiency by which the electricity is generated. When the compressor is driven by a gas or diesel engine (Figure 17), heat from the cooling water and exhaust gas is used in addition to the condenser heat (Heat Pump Centre, 1998).

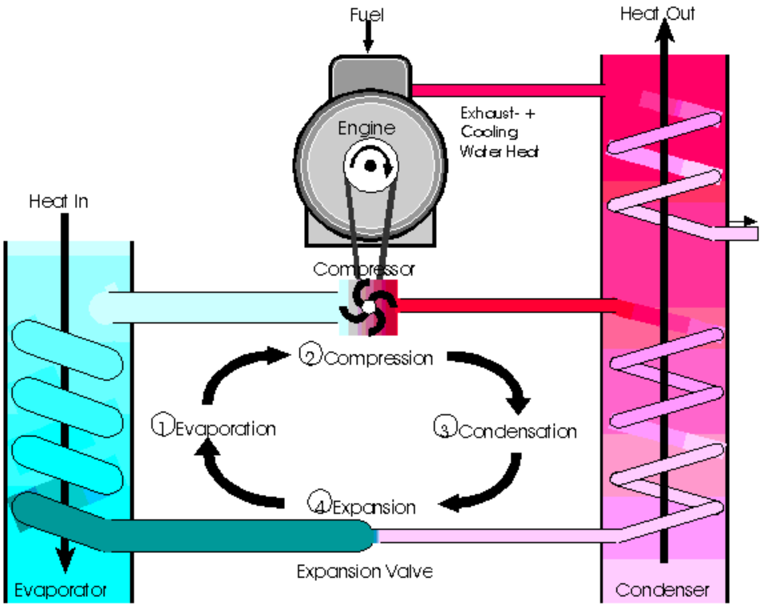

FIGURE 17: Closed cycle, engine driven heat pump

7. GEOTHERMAL INVESTMENT - ECONOMIC STUDY

After discussing some of the technical problems associated with building and operating a geothermal heat plant and district heating system, it is necessary to focus on the economics of geothermal investments. For the real case, however, the costs are offcourse "monitored" continuously (Figure 18).

The major feasibility test of any energy system is how economically it can compete with its alternatives. Determination costs of a geothermal district heating system should be made for comparison with conventional fossil fuel alternatives. The heat demand study for the town could be made as a preliminary study with an approximate estimate of the heat production and transmission costs. It is noteworthy, that cost data for any city are highly dependent on its unique circumstances, and data that are specifically derived for local applications should be substituted for guide values when possible.

Capital costs are estimated for the geothermal production field development, the peaking station, the transmission system, and the local distribution system and in building retrofit equipment. Estimates of the geothermal production field costs include costs incurred in exploring and developing the field. The number of production wells required to supply the selected market area are determined by dividing the total peak-heating load by the thermal power per well. The number of injection wells is usually 50% of the number of production wells. Drilling costs are site-specific and mainly depend on the depth and temperature which determine the type of drill rig that is necessary. Generally, wells up to 1 km of depth and with temperatures beolow 120˚C can be drilled with drill rigs intended for domestic water wells. Since drilling costs vary greatly depending on local conditions, they should be obtained from local drillers.

The capital cost of the conventional fuelled peaking station capital cost is dependent on the size of the

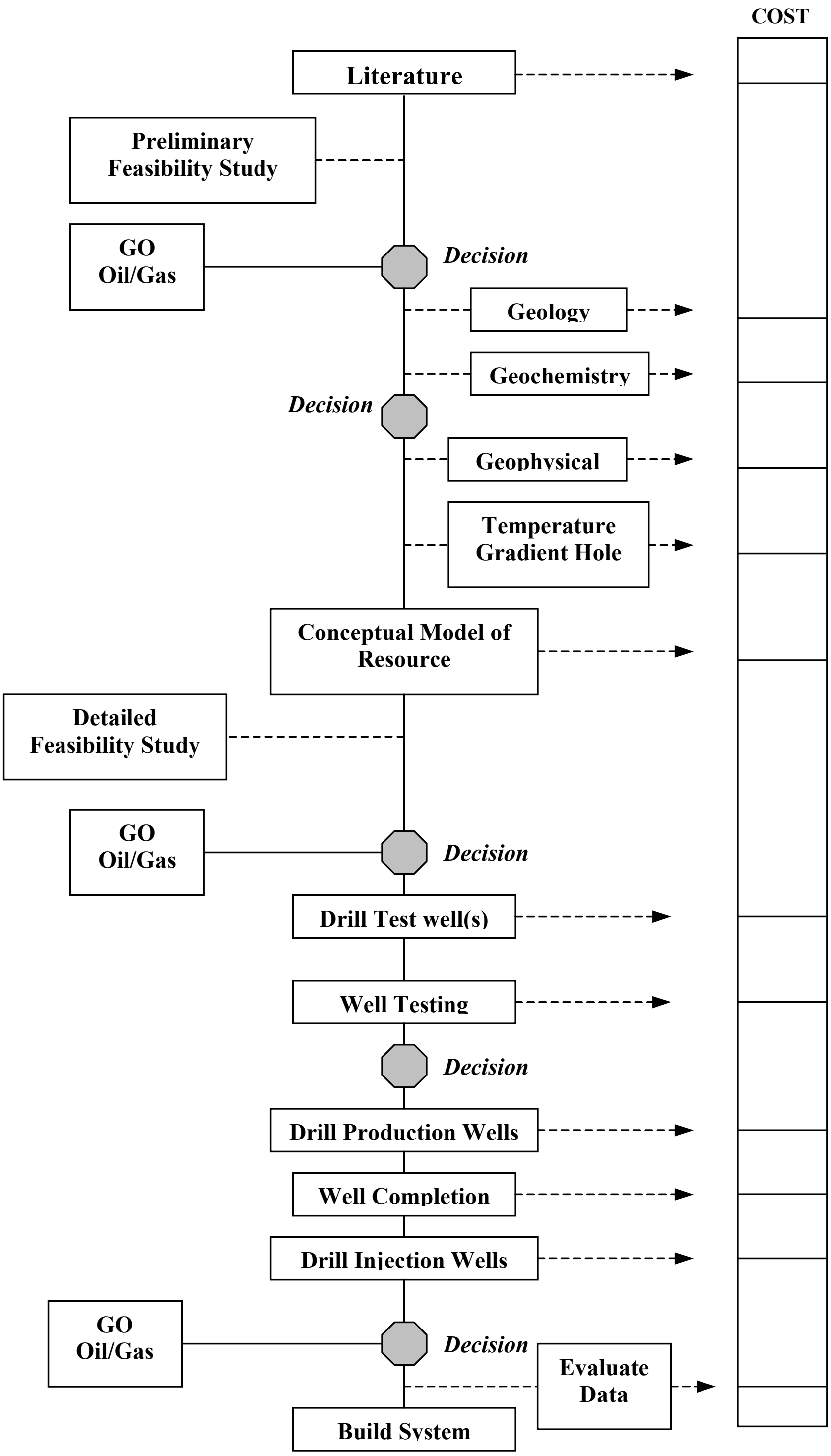

FIGURE 18: Geothermal production field development cost schedule

boiler. The size is determined from the heat load duration curve, which gives the contribution of the buildings' heat loss in the district that is to be supplied by the peaking station.

Local distribution costs include the pipes and accompanying equipment needed to convey hot water from the transmission pipes to street hook-ups of individual buildings. Because the distribution piping must be sized to service maximum energy demands, the cost of the distribution system is dependent on the peak heating load, size of the market area, and a factor that takes into account the thermal density and type of piping. Transmission costs depend mainly on

- Thermal demand density within the market area;
- Distance between market perimeter or central pumping station and geothermal production field.

An alternative is to express transmission costs as a proportion of local distribution costs.

The profitability of building a geothermal heat plant is not always clear. The investors really want to know when they get their money back, and how much the net profit could be. They are also interested in how the operation of geothermal heat plant will affect local economies and what benefits are provided to the consumers.

Investment costs of building a geothermal plant depend

- on some components that are depend on the size of the geothermal heat plant;
- but also on components that only partly are dependent on the geothermal heat plant size.

Components included in investment costs of building a geothermal heat plant are:

- Drilling and reinforcement of wells – half and linear dependence on depth, total dependence on number of wells;
- Geothermal pipes – half and non-linear dependence on number of wells;
- Buildings, roads, infrastructure – partly dependent on plant size;
- Technical infrastructure – partly dependent on plant size;
- Heat pumps + reinforcement – linear dependence on number of pumps;
- Peak gas boilers – depend on total peak heat requirements, not covered by geothermal.

Drilling depth is linearly dependent on the temperature of the aquifer. So investment costs of the plant are dependent on well depths and water temperature. Geological work and drill work (survey, drilling, wells reinforcement) are also an important part of the total plant cost (Figure 19). In general, it is more than 60% of the total plant value (Maliszewski,1996).

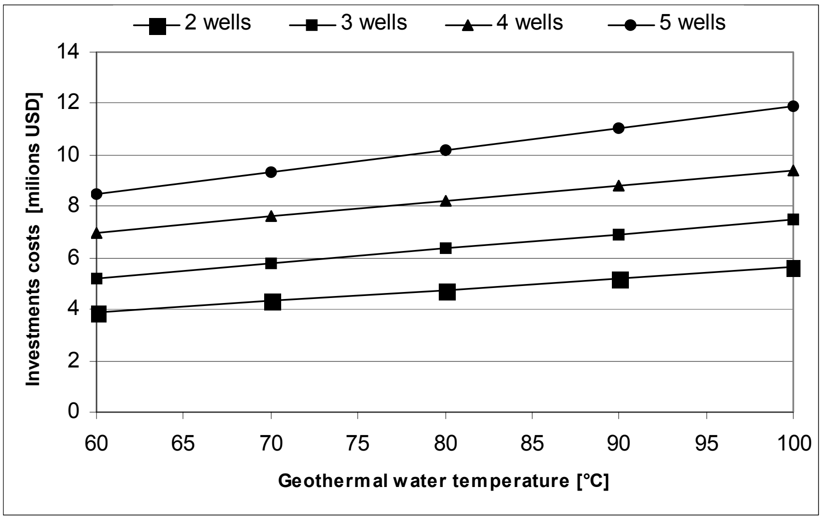

FIGURE 19: Investment costs depend on number of wells and geothermal water temperature

Analysing Figure 19 shows that in the 5 well case, an additional 30˚C of geothermal water costs additional 2.5 million USD. Often it is more economical to install heat pumps or peak gas boilers instead of drilling deeper.

7.2 Cost of alternative systems

Heat provision for a district heating system could be realised with many other systems than geothermal. There are solar energy systems, biomass systems, and fossil fuel systems. Specific energy provision costs were calculated on the basis of monetary value for the year 1999 (Germany) with no inflation taken into consideration. The results for each district heating system are shown in Table 10. According to the table the heat provision costs of different options vary significantly. The provision of heat with a system based on the use of fossil energy is the cheapest option. Notable is the heat provision from biomass and geothermal energy extracted from deep underground. The system using geothermal energy has high investment costs.

TABLE 10: Comparison of costs in €/GJ

	Dwelling house	**Small district heating system**	**Large district heating system**
Solar energy	21.0	28	
Biomass	14.4	18.2	17.8
Geothermal energy			
Soil & groundwater	11.9-13.1		
Deep wells		17.6-18.6	
Hydroth. resources			16.0-20.7
Fossil energy	12-12.5	13.6-14.3	12.1-12.8

For a biomass based heat provision system in this capacity range, a highly sophisticated combustion technology is used in most cases to meet the legal environmental standards. Additionally, a person is needed to run the plant. Fairly high costs are the result. Costs could only be reduced if the biomass feedstock was available at very low costs. Compared to such a system, heat provision from solar energy (solar thermal energy and a seasonal heat storage system) is much more expensive.

Compared to fossil fuels, proucing heat from geothermal is still much more expensive. But if only systems for heat provision based on renewable energies are compared to each other, the use of geothermal energy can easily compete.

Costs for heat provision with deep wells are shown in Table 11. It shows two possibilities, one based on a new well, and the other assumes that there is a well already available due to exploration of oil or gas.

TABLE 11: Costs if heat is provided with deep wells (in 1,000 €), the share of geothermal energy is assumed to be 71%

	New well	**Existing well**
Investment costs		
Heat source	1800	1.250
Heat pump	200	200
Peak load system	220	220
Building, others	220	200
District Heating System	450	450
Sum	**2.890**	**2.320**
Operation & mainten. costs		
Energy costs	80	80
Maintenance	90	90
Sum	**170**	**170**
Heat provision costs (at plant gate /at consumer)		
In €/GJ	16.0/18.6	15.5/17.6
In €-cent/kWh	5.8/6.7	5.4/6.4

To sum up, the use of geothermal energy for covering a given heat demand can easily compete with other renewable energy sources and under certain circumstances also with the use of fossil energy. But in most cases, use of geothermal energy for the provision of heat in Poland and in most places in Europe is more expensive than the use of oil and gas. If, therefore, such options should be used due to environmental or other reasons, administrative and/or legal measures must be applied to make these options economically feasible (Kaltschmitt, 2000).

7.2 Legal requirements

At present in Poland some thermal waters, specified by law, are considered minerals. This means that an applicant intending to explore and exploit them must follow all the rules of the *Geological and mining act* of February 4, 1994 (to get exploration concessions, confirmation of geological documentation, and exploitation concessions). An applicant's mining activity will be considered as an operation of a mining plant. Other thermal waters are not considered minerals and may be exploited according to the rules of the *Water act* of October 24, 1974. Exploitation of heat pumps should follow the rules of the *Construction act* of 9 July and, in only some cases, of the *Water act*. This situation may result in large and unjustified differences for particular investors, depending on the kind of thermal water available (Lipinski, 1996).

Note: There already exist new changed laws about the utilisation of geothermal water, concessions and permissions in Poland. The author of this study unfortunately has had no access to those acts.

8. CONCLUSIONS

- After analysing the thermal power demand for Nowogard town and the geothermal resources in the area, one can say that with an additional heat source such as a gas boiler or heat pump, sufficient geothermal energy can be provided for the town.
- With no existing district heating system in Nowogard, the bad conditions of all pipes, the majority of coal and coke boilers working at low efficiency, and the huge air pollution – the one and only right conclusion is that Nowogard needs a new clean heat source and a district heating system.
- Analysing simulation results of a modelled geothermal district heating system, and taking into consideration system costs, and alternative system costs, one can say that the utilisation of geothermal energy in Nowogard is economically justified.
- The successful operation of the Pyrzyce geothermal heat plant, located near Nowogard with similar conditions, is one more convincing reason for starting the utilisation of geothermal energy in Nowogard.

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APPENDIX I: Simulation input files

Input files

File 1

Node	Node nr	X coordinate	Y coordinate	Z coordinate
node	1	0	0	0
node	2	-1111	111	0
node	3	-1056	389	0
node	4	-1333	278	0
node	5	-944	111	0
....				
node	154	6389	-3444	0

File 2

Pipe	from node	to node	length [m]	diameter[m]	roughness	heat loss
pipe	1	2	1116.653	0.416057	0.00004600	16.8000
pipe	2	3	283.279	0.197210	0.00004600	16.8000
pipe	2	7	392.837	0.392584	0.00004600	16.8000
pipe	3	4	299.176	0.121556	0.00004600	16.8000
pipe	3	5	299.176	0.078444	0.00004600	16.8000
....						
pipe	29	32	351.364	0.007953	0.00004600	16.8000

Flow	node	discharge[kg/s]	head [m]
flow	58	-7.350000	80.000000
flow	61	-4.220000	80.000000
flow	55	-0.090000	80.000000
flow	57	-0.070000	80.000000
flow	53	-0.250000	80.000000
....			
flow	72	-1.890000	80.000000

Head	node	head[m]	head[m]
Head	1	80	80

APPENDIX II: Pipes specifications

Pipe	from node	to node	length[m]	diameter[m]
pipe	1	2	1116.653	0.416057
pipe	2	3	283.279	0.197210
pipe	2	7	392.837	0.392584
pipe	3	4	299.176	0.121556
pipe	3	5	299.176	0.078444
pipe	7	63	314.270	0.341416
pipe	3	6	527.046	0.165871
pipe	7	8	1947.616	0.221258
pipe	63	43	235.702	0.194191
pipe	8	10	512.197	0.146510
pipe	63	64	600.925	0.322705
pipe	8	48	1024.394	0.190023
pipe	10	11	124.226	0.042127
pipe	43	44	166.667	0.082245
pipe	10	12	175.682	0.054865
pipe	43	45	200.308	0.093576
pipe	10	19	248.452	0.142933
pipe	48	50	283.279	0.185150
pipe	10	9	388.889	0.045579
pipe	48	49	392.837	0.068132
pipe	64	65	512.197	0.117934
pipe	41	43	675.863	0.183998
pipe	64	73	678.142	0.313817
pipe	12	13	124.226	0.038125
pipe	12	14	124.226	0.026758
pipe	65	66	124.226	0.051745
pipe	45	46	157.135	0.090925
pipe	19	22	166.667	0.079744
pipe	73	74	200.308	0.185716
pipe	41	42	248.452	0.061103
pipe	45	47	277.778	0.035217
pipe	12	15	283.279	0.041661
pipe	19	20	447.903	0.052394
pipe	50	51	590.564	0.185150
pipe	65	67	633.431	0.112771
pipe	73	95	724.356	0.280943
pipe	38	41	959.038	0.181575
pipe	19	27	984.447	0.114022
pipe	22	23	55.556	0.075204
pipe	67	68	78.567	0.076937
pipe	95	96	111.111	0.119023
pipe	74	75	157.135	0.060094
pipe	27	28	166.667	0.023461
pipe	15	16	175.682	0.027717
pipe	20	21	229.061	0.052394
pipe	22	24	277.778	0.038664
pipe	51	52	333.333	0.136420
pipe	15	17	404.451	0.035830
pipe	95	97	447.903	0.269425
pipe	27	29	527.046	0.115260
pipe	51	59	555.556	0.147924

pipe	74	76	668.977	0.182116
pipe	38	39	724.356	0.162926
pipe	38	40	724.356	0.058792
pipe	67	69	724.356	0.095156
pipe	32	38	773.799	0.104063
pipe	76	77	55.556	0.066651
pipe	69	70	78.567	0.065336
pipe	69	71	157.135	0.080064
pipe	97	98	157.135	0.090275
pipe	17	18	175.682	0.035830
pipe	52	53	175.682	0.037573
pipe	29	30	229.061	0.022168
pipe	32	33	248.452	0.070161
pipe	32	34	248.452	0.091183
pipe	24	25	283.279	0.033259
pipe	52	54	351.364	0.134740
pipe	24	26	355.729	0.025738
pipe	76	78	392.837	0.177186
pipe	29	31	423.099	0.110837
pipe	97	101	942.809	0.263595
pipe	59	60	982.878	0.147924
pipe	34	35	166.667	0.082700
pipe	34	36	175.682	0.052394
pipe	54	55	175.682	0.025738
pipe	54	56	229.061	0.134126
pipe	98	99	235.702	0.084335
pipe	101	102	277.778	0.128314
pipe	78	79	323.942	0.147573
pipe	98	100	333.333	0.045981
pipe	101	103	458.123	0.189440
pipe	101	104	524.110	0.191296
pipe	78	81	647.884	0.123145
pipe	60	62	702.728	0.118856
pipe	60	61	1199.280	0.108363
pipe	71	72	1648.980	0.080064
pipe	56	57	124.226	0.023461
pipe	79	80	124.226	0.147573
pipe	36	37	175.682	0.052394
pipe	104	105	248.452	0.187156
pipe	81	82	299.176	0.065336
pipe	56	58	400.617	0.133646
pipe	104	147	820.268	0.064435
pipe	81	85	993.808	0.113942
pipe	82	83	157.135	0.061351
pipe	147	148	229.061	0.046377
pipe	82	84	277.778	0.032562
pipe	105	106	404.451	0.177229
pipe	85	86	650.261	0.113942
pipe	105	113	747.424	0.087457
pipe	147	152	1470.911	0.052713
pipe	106	107	175.682	0.060854
pipe	86	88	222.222	0.095753
pipe	106	108	229.061	0.092706
pipe	106	109	248.452	0.159788

pipe	148	149	283.279	0.042584
pipe	148	150	299.176	0.025738
pipe	86	87	477.907	0.078279
pipe	113	114	503.077	0.025738
pipe	113	116	512.197	0.056603
pipe	113	115	671.280	0.074312
pipe	152	153	2786.652	0.052713
pipe	88	89	111.111	0.091568
pipe	150	151	175.682	0.025738
pipe	88	90	283.279	0.042127
pipe	109	117	423.099	0.158024
pipe	153	154	671.280	0.052713
pipe	109	110	1809.611	0.042127
pipe	117	121	124.226	0.154124
pipe	117	118	166.667	0.056034
pipe	90	91	337.931	0.042127
pipe	90	92	337.931	NaN
pipe	110	112	355.729	NaN
pipe	110	111	668.977	0.042127
pipe	118	119	124.226	0.045171
pipe	118	120	124.226	0.041187
pipe	121	122	166.667	0.083598
pipe	121	123	175.682	0.141770
pipe	92	94	229.061	NaN
pipe	92	93	277.778	NaN
pipe	123	125	248.452	0.137675
pipe	123	124	283.279	0.053343
pipe	125	127	111.111	0.135011
pipe	125	126	283.279	0.044757
pipe	127	128	124.226	0.081477
pipe	127	134	248.452	0.120341
pipe	128	129	124.226	NaN
pipe	134	135	283.279	0.071525
pipe	128	130	351.364	0.081477
pipe	134	136	351.364	0.107877
pipe	130	131	124.226	0.061842
pipe	136	137	283.279	0.107877
pipe	130	132	337.931	0.063745
pipe	132	133	175.682	0.063745
pipe	137	138	423.099	0.043910
pipe	137	139	474.667	0.104056
pipe	139	141	404.451	0.083151
pipe	139	140	650.261	0.076937
pipe	141	142	229.061	0.064662
pipe	141	146	248.452	0.063512
pipe	142	143	229.061	0.052071
pipe	142	144	283.279	0.047532
pipe	144	145	200.308	0.047532
pipe	29	32	351.364	0.007953

NaN – NO FLOW, diameter 0