INTERNATIONAL SUMMER SCHOOL
on Direct Application of Geothermal Energy
POLISH GEOTHERMAL ASSOCIATION
International Geothermal Days
POLAND 2004
EUROPEAN BRANCH
Under the auspice of Division of Earth Sciences

2.

Improving the Operations and Economic Performance of the Zakopane, Poland Geothermal District Heating System through Modeling

Dr. Gordon Bloomquist, Washington State Univ. Energy Program, Olympia, WA
Robert G. O'Brien, P.E, Washington State Univ. Energy Program, Olympia, WA
Mr. Svend Strunge, Seven Technologies A/S, Birkerød, Denmark

KEY WORDS: Zakopane, Computer modeling, Heatmap, Term

ABSTRACT

A project supported by the World Bank has been under development during recent years to reduce air pollution from local coal-fired boilers through increased utilization of geothermal heat (resources are transmitted 14 km from production wells to the City of Zakopane) and natural gas (for peaking) in the Podhale region of Southern Poland.

The project objectives include eventual connection of over 4200 individual households and 172 commercial/industrial loads supporting up to 80,000 people in the Region. HEATMAP was used to develop a hydraulic and economic model for the Zakopane district energy system. The model identified hydraulic deficiencies in the distribution system as well as economic factors needed to support the viability for the project. The model initially developed in HEATMAP was transferred into TERMIS for extensive operational analysis and evaluation.

1. INTRODUCTION

Zakopane is a small mountain town (about 30,000 residents) that is often referred to as Poland's winter capital. It is situated in the Podhale Valley at the foot of the Tatra Mountains-part of the Carpathian range - along the Slovak border. The town attracts about two million visitors a year to its recreation facilities - the numerous ski lifts and ski jumps in the winter and superb rock climbing in the summer.

In recent years the Podhale Valley has been plagued by air pollution resulting from particulate and sulfur oxide emissions from old coal fired boilers used by thousands of households and other facilities. As a result of the emissions and atmospheric inversions, Zakopane and the adjacent Podhale Valley area were often covered with a visible lingering and unpleasant smog condition.

2. BACKGROUND

During the late 1980's, efforts were initiated to develop geothermal resources as a means for abating air pollution in Zakopane and the Podhale Valley. Initially, funding was obtained from World Bank and local Polish sources to drill geothermal wells and provide the beginning elements of a district energy system. Further support from the World Bank beginning with a $38.2 loan in June 2000, coupled with a $5.4 million grant has enabled the scope of the geothermal district energy system to be greatly expanded. Currently, about $96.7 million has been invested in developing geothermal resources and constructing the extensive district energy support network (plants and pipe lines) that exists today. Table 1 shows the current financial structure for the Podhale District energy project (Project Appraisal Document, March 23, 2000, World Bank)

The Geothermal District Energy Project Podhale is currently operated as a joint stock company, Geotermia Podhalanska S.A., consisting of 15 groups of shareholders.

The Geothermal District Energy system consists of two doublets (production and re-injection wells) at Banska Nizna and Bialy Dunajec (about 2 kilometers from each other), a geothermal base load plant (30 MWt) in Banska Nizna (located between the doublets about 14 km from Zakopane), a gas peak load plant in Zakopane (35 MWt from gas or 15 MWt from oil), 14 km of pre-insulated transmission pipe (both supply and return—DIN 400 to DIN 500) between the geothermal base load plant and the gas peak plant, three pumping plants (about 260 meters of elevation head between the plants), and about 76 km of district heating network connecting 100 customers (as of 2004--supporting in excess of 10,000 people) mostly in Zakopane. The project is planned for future expansion into the areas of Koscielisko to the West of Zakopane and Nowy Targ to the North of the Geothermal Base Load Plant. Drilling for additional geothermal resources is also anticipated. The total potential customer support pro-jection for the Podhale basin project is about 80,000 people. A layout diagram of the existing Geothermal District Energy system for the Podhale Valley is shown in Figure 1, below:

Table 1. Funding Scheme for Podhale District Energy Project

Fund Source	Million US Dollars
World Bank (Loan)	$38.2
World Bank (Grant)	$5.4
European Union	$18.2
National Fund for Environment (Poland)	$12.7
Polish Eco Fund	$1.3
Other Polish Sources	$20.9
Total Funding	$96.7

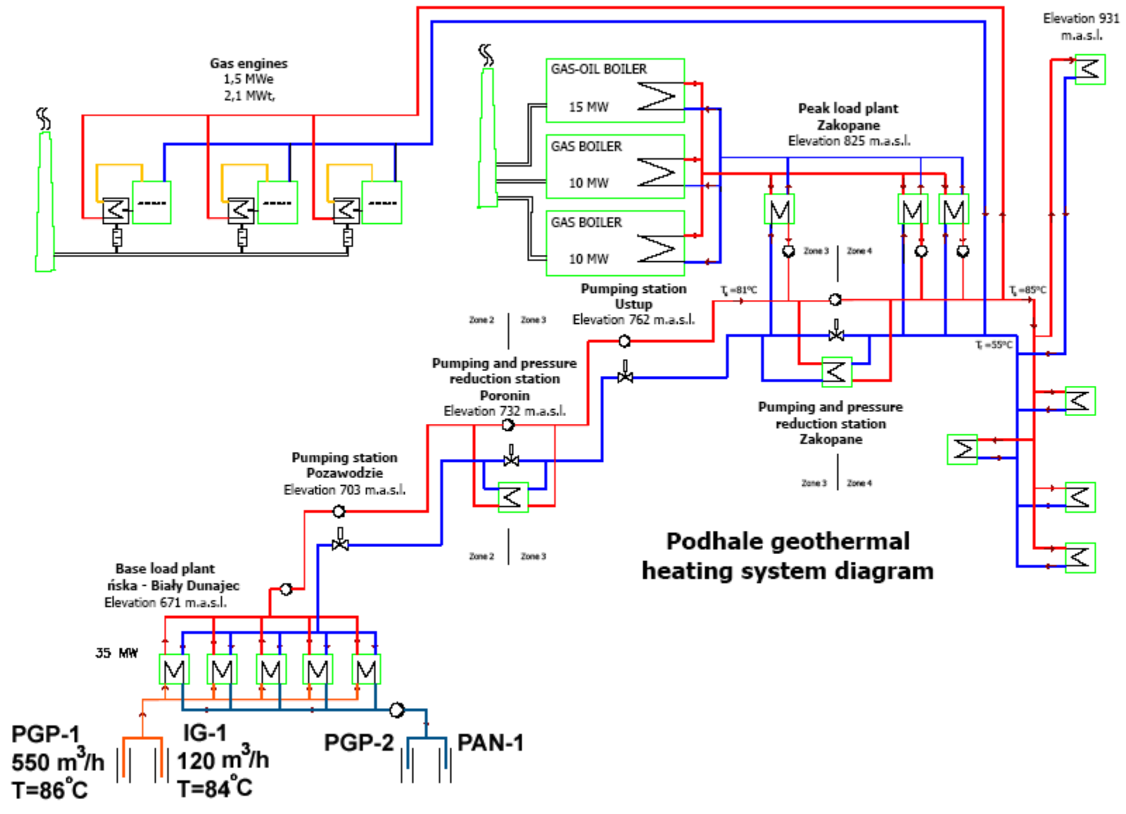

Fig. 1 General Layout of Podhale Geothermal District Heating System

Implementation of the geothermal project resulted in about a 50% decrease in both particulates and sulfur dioxide emissions in Zakopane in 2002 compared to mean annual concentrations during the 1994-1998 periods.

3. HEATMAP Analysis

In 2003 Washington State University—Energy Program was asked by the World Bank to model the Zakopane system. The initial interest was in evalua-ting the economics of the system as it was continuing to lose money despite receipt of numerous grants that covered a substantial portion of the capital expendi-tures as well as international loans with different pay-ment schedules. Secondly, the World Bank was inte-rested in the overall capability of HEATMAP as a tool to be used to evaluate other potential projects in Central and Eastern Europe/Eurasia (total thirty-eight countries) that were to become eligible for project assistance including loan guarantees under the newly established $25,000,000 Geo Fund. It is anticipated that a majority of the projects would include geo-thermal district heating.

HEATMAP was used to model the existing Zakopane district heating system during mid-2003 to determine potential problem areas (extreme veloci-ties, pressure drops, difficulty in supporting custo-mers, etc.) in the extensive distribution network and required revenues to support the economic requirements for the Zakopane portion of the project.

For example, the HEATMAP analysis revealed that severe velocities and pressure gradients would occur in parts of the distribution network, such as pipes 090-091-092-093-094-095, where velocities exceeded 5 meters per second. See Fig. 2, Zakopane problem velocity and pressure gradient area.

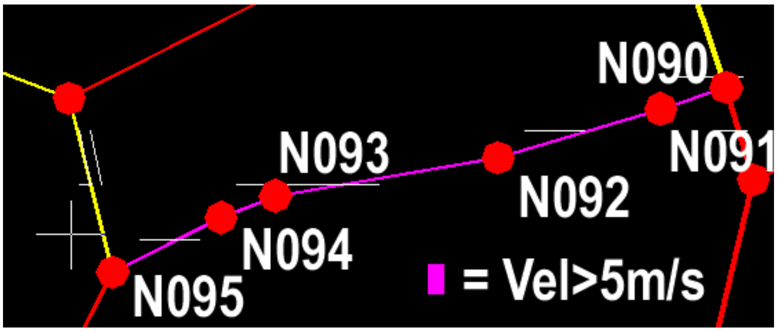

Fig. 2 Zakopane Problem Velocity and Pressure Areas.

A life cycle revenue requirement analysis was also performed by HEATMAP over the project life. Table 2, shows that to meet a return on equity of 5%, it would be necessary to charge consumers 62.96 Polish Plz/Gj in 2004 and decreased amounts as additional customers are connected and the revenue increases. The 2003 price was at approximately 52 Plz per Gj—considerably below what would be required to meet revenue requirements until the additional load comes on line.

Table 2. Sample of HEATMAP Economic Results

Revenue Requirement Summary Page

HEATMAP Economic Analysis -

Scenario name: All consumers
Return on equity: 5.0%
Analysis life: 11 Years

Year			2004	2005	2006	2010	2011
Plant Send Out (Gj/Yr)			297,727	386,151	390,167	390,167	390,167
Sales Price (PLZ/Gj)			62.96	50.34	51.66	59.74	61.96

After carefully analyzing the economic situa-tion and realizing the seriousness of the problem, it was determined that in order to get a better under-standing of the reasons behind the imbalance between capital investment and revenue generation, it would be beneficial to evaluate the heat load density of the area. Since such analysis was beyond the capability of HEATMAP Seven Technologies of Birkerød, Denmark was brought into assist with the analyses. Seven Technologies has developed an extremely powerful quasi steady state tool, TERMIS, which includes online, offline, and real time analysis capabilities. For purposes of the analysis, the Zako-pane HEATMAP model was brought into TERMIS to allow for a calculation of heat load density versus the installed kilometers of distribution piping.

In order to have a better understanding of the relationship between thermal sales and installed dis-tribution piping a detailed analysis of such infor-mation from over 280 Danish district heating systems was first undertaken. These 280 systems supply a total customer load of over 24,500 MW_{th} and involve over 11,400 km of distribution piping. Based on the analysis it was found that the average heat load den-sity per km of pipe is 2.15 MW_{th}. And in fact several of the systems have a ratio exceeding 5.0 MW/km and less than 40% have ratios below 1.0 MW/km.

Once the Zakopane system had been loaded into TERMIS (Fig. 3) it was easy to evaluate the en-tire system or any portion thereof. Based on an ins-talled customer capacity of 21 MW_{th} and with a total pipeline network length, exclusive of service pipes, of 76 km, the heat load density was calculated to be only 0.28 MW/km. This is well below comparably sized communities in, for example, Denmark. To determine if this was a system-wide problem or whether or not there were only isolated portions of the system with extremely low heat load densities, each sub part of the system was looked at in detail (Fig. 4, for example). The heat load density of this sub part of the distribution network consists of 5.7 km of distri-bution pipe and supplies a customer load of 1.21 MW_{th}. This gives a heat load density of only 0.21 MW/km. Once again, in comparing this to a similar sized network in a small Danish community with 6 km of pipe, the heat load density was found to be 0.9 MW/km—again much higher than in Zakopane. Ba-sed on this information, several recommendations were proposed to improve the economic performance of the system.

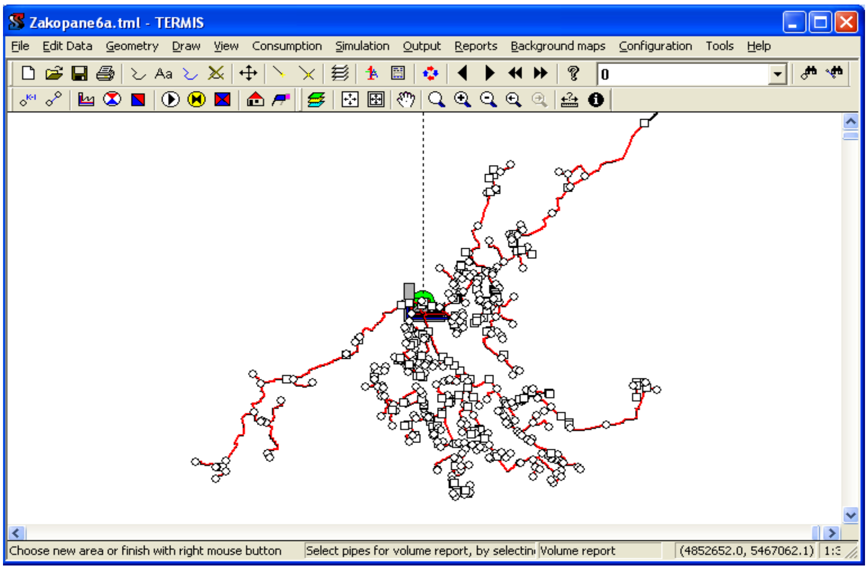

Fig. 3 Heat density for the distribution part of Zakopane (Red shows 0.28 MW/km load density)

These include:

- Focus should be placed on in-fill within the geo-graphic boundaries of the existing distribution net-work to increase load dramatically, e.g. industrial or large commercial users.
- Extension of the existing network should only be considered to connect areas with high heat load densities, e.g. > 1.0-1.5 MW/km pipe.
- Every effort should be made to minimize energy losses in the network that are a result of overcapacity until the load on the network reaches full capacity.
- The **_t** at each consumer should be optimized to reduce thermal losses and pumping requirements and maximize revenue.

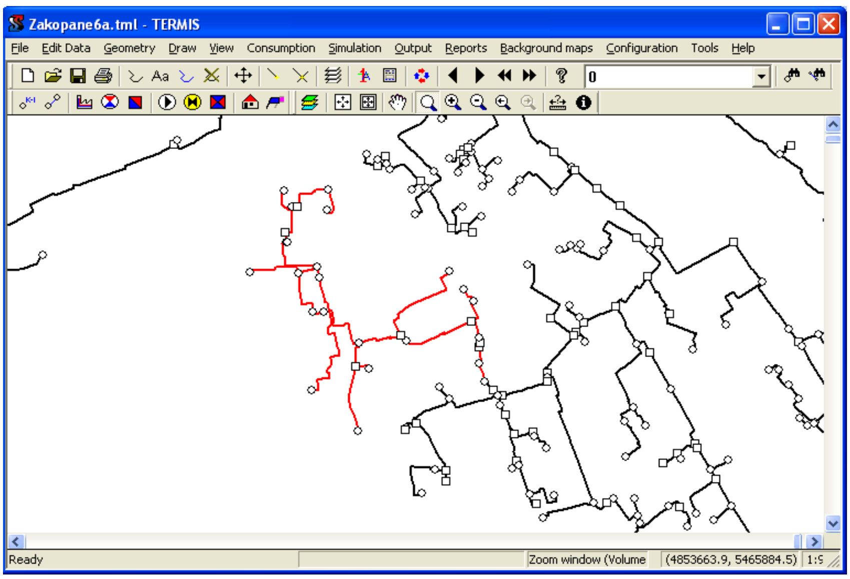

Fig. 4 Heatload Density of a sub area of Zakopane (Red shows 0.21 MW/km load density)

It is clear from the above that if such an analysis had been conducted prior to design and construction of the system, that a number of things could have been done differently. Fortunately for the residents of Zakopane, the decision to construct a geothermal district heating system was driven as much by environmental considerations as it was economics. And although the economic performance of the system will continue to improve over time based on the very positive steps management has now taken, the citizens of the area are already reaping the environmental benefits, and as more and more customers go on line, those benefits will continue to grow.

Since the completion of the original analysis, Geotermia Podhala_ska has moved forward on the implementation of TERMIS in Zakopane. The real time TERMIS model will interface directly with their SCADA system. The real-time system will include the pump and production optimization module. In addition, the installation will include model manager for model building, demand manager for demand management and determination of temperature drop profiles by consumer type. Geotermia Podhala_ska has also ordered multiple copies of the off-line version of TERMIS for further design analysis plus the 7T-Grabber for presentation of SCADA and TERMIS data across software platforms.

There are two purposes for implementing the above described software tools.

a. Operational assistance and optimization. For example, a major objective is to eliminate the heat exchanger in the middle of the pipeline from the geothermal plant to the city of Zakopane – this design feature causes considerable energy loss because it requires system operators to run the fossil fuel peaking plant during times when all heat could be supplied from the geothermal resource.

b. Determine system locations where additional load can be added without effecting existing customers. Geotermia Podhala_ska desires to significantly increase the system load at minimum cost (i.e. install as little new pipeline as possible). Potential customer connections will be evaluated in terms of individual heat demand (i.e., high demand customers will be targeted) and each potential users impact on overall network performance will be evaluated. Marketing of new consumers and system changes (modifications) will be optimally synchronize so that a maximum rate of return on investment can be realized.

In addition TERMIS is being adopted to assist the staff in four critical areas:

- Operation
- Expansion
- Marketing
- Accounting

For improved Operation, the SCADA system provides production information every second of system operation. TERMIS will allow real time analysis of the information to achieve optimum system operation and consequently reduce cost.

For system Expansion planning, TERMIS will be used to determine potential impacts upon system operation as well as a design tool for the proper sizing of heat exchangers to achieve optimum **_t** at the customer.

For Marketing, TERMIS can draw upon historical data to demonstrate benefits to future customers.

For Accounting, TERMIS can be used to calculate the actual costs of all system components (e.g. fuel used, pumping energy, etc.) so that the true operating costs can be defined and allocated equitably to system customers. The system can also be used for billing purposes.

A good example of the benefits of the use of the model is in the area of temperature **_t.**

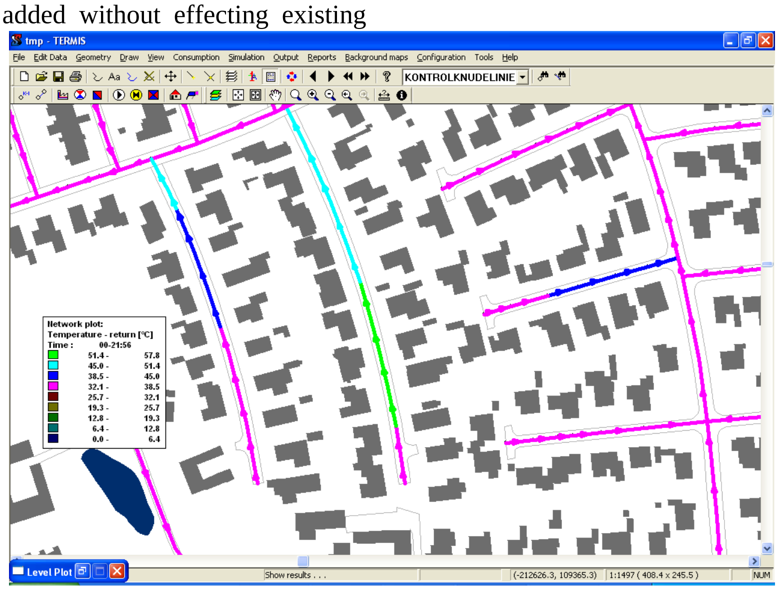

Fig. 5 Temperature distribution on return side

Customers which do not have a sufficient temperature drop (_t) have an adverse effect on the operational performance of the system. In Figure 5 it can be seen that most customers have a satisfactory temperature drop (PINK) while a few (where pink goes to green or blue) do not. The model allows for easy identification of such customers so that their systems can be upgraded.

Another impact area where the adoption of a real time model can provide significant benefit is in customer relations.

Various operational problems that may cause a system to shut down may occur from time to time in any district heating system. When this happens the initial goals include bringing the system up to normal operation and to inform customers when they can expect proper service. In a complex network with multiple plants this will not be a trivial task, but using a simulation model the process can be greatly simplified.

In the example below, Figure 6, a "cold plug" has been progressing into the system for some time, coming from the plant in the NE corner. It can also be seen that the plant is producing heat again, and in fact, is pushing the cold plug into the rest of the system.

The plot below (Fig.7) is a zoom around the plant in the SW corner of the network where the cold plug is about to arrive. The second plant is supplying hot water at normal temperature level, but the cold source water is being mixed with the hot water from the plant.

In order for the operator to inform customers when operation is back to normal, he/she will make use of a time series plot showing the temperature development at individual nodes over time. The plot below (Figure 8) has 3 nodes before mixing water with second plant and 3 nodes being part of the distribution network in the SE corner.

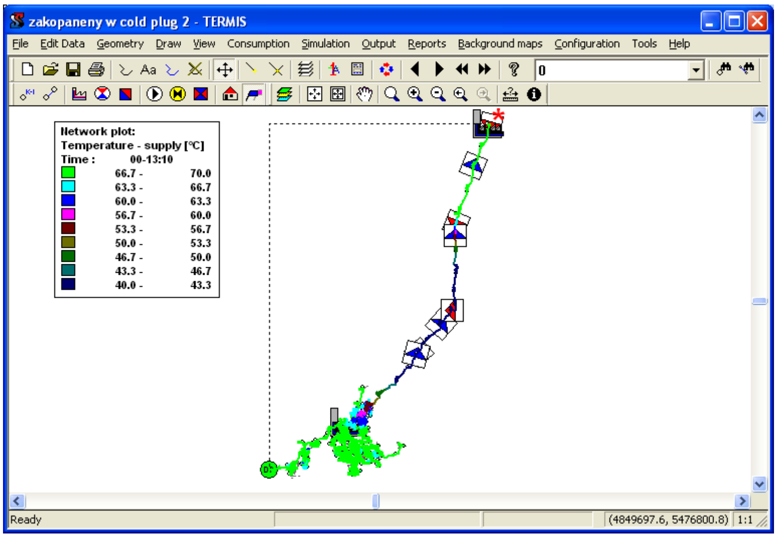

Fig. 6 Temperature propagation through the network as a result of a cold plug

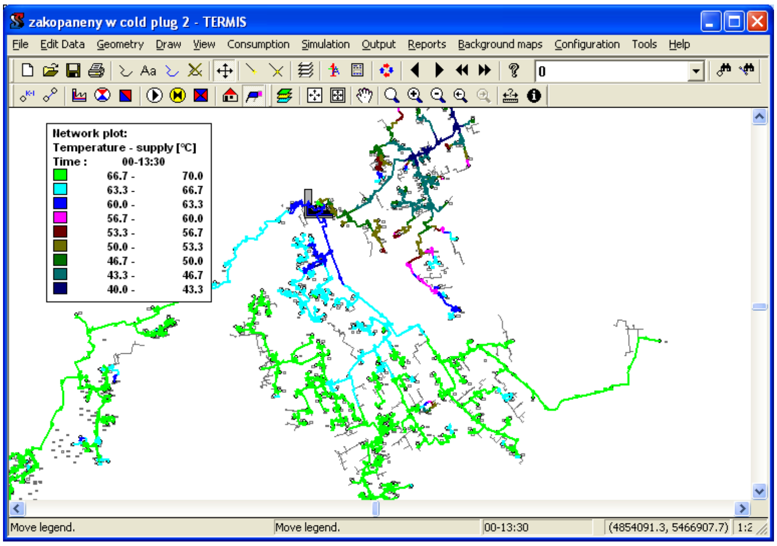

Fig. 7 Mixing of hot and cold water on the network - notice (colors) dark green water becomes blue after mixing)

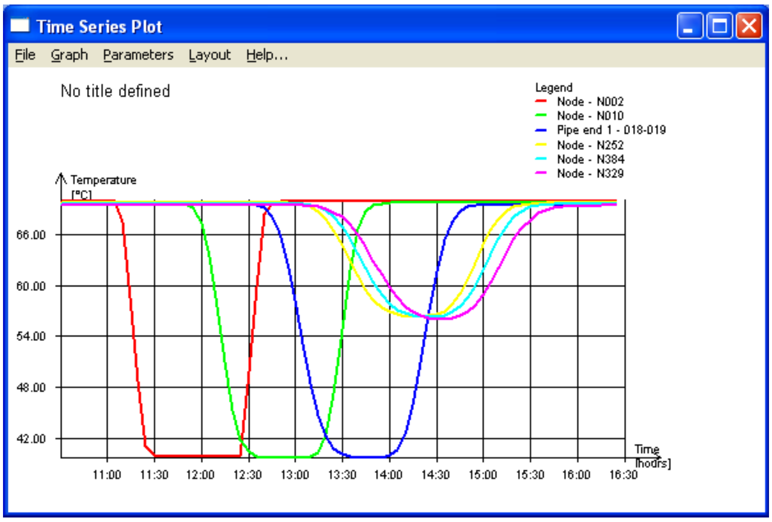

Fig. 8. Temperature development at different nodes

From the plot above one can conclude that the problems at plant one (NE corner) lasted for about one hour, that the travel time down to the second plant (SE corner) is about 2 hours and the customer at node N329 will experience a problem between 13:30 and 16:00 after which the system becomes normal. In other words, with a model of the network the operator will be able to warn customers of what is about to happen and inform them when things can be expected to return to normal again. If possibilities exist to increase temperature and flow at plant (SE corner), the effect of the cold plug in the SW/SE part of the distribution network may be abated. Again the operator could use the model to determine the most effective ratio between higher temperature fluid and increasing flow.

4. SUMMARY

The Zakopane system provides a prime example of the challenge facing developers and operators of new geothermal district energy systems. Because of the very substantial upfront investment that is required, it is often extremely difficult to meet revenue requirements within the first few years of start up.

Through the use of two models, HEATMAP and TERMIS, it has been possible to determine not only when revenue expectations will be realized but to also determine what steps should be taken to maximize the use of existing assets, improve efficiency of operation, reduce costs, improve customer services and relations, and ultimately increase market penetration.

By integrating all operations under a common model platform, it is also possible to greatly improve internal communication, provide for better planning, facilitate marketing, and finally, provide for better system administration.

REFERENCES

Project Appraisal Document, March 23, 2000, World Bank.