SOFTWARE TO DESIGN AND ANALYZE GEOTHERMAL DISTRICT HEATING AND COOLING SYSTEMS, AND RELATED AIR QUALITY IMPROVEMENTS

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ABSTRACT

HEATMAP® is a computerized tool intended to provide a fast, reliable, and economic means of describing and analyzing geothermal district heating and cooling (DHC) systems. Use of the program furnishes owners, developers, designers, planners, engineers. and operators with extensive technical and economic information that may be used to model potential alternative system development and operational strategies and to compare such systems with existing heating and cooling supplier. The software can also be a valuable tool for community planners in defining all aspects of developing, evaluating, and justifying a new geothermal DHC project. The program consists of four major components: a central controller. a geographic orientation and layout program. a geothermal system production program, and a distribution network analysis program.

The geothermal production program will allow the user to draw and describe a geothermal well field production system with multiple production and injection wells connected to a single plant, or multiple doublets serving as a single production plant. Both production and injection wells can be modeled and costs calculated.

The use of the program should significantly enhance the user's ability to cost-effectively determine the technical and economic feasibility of developing a geothermal DHC system as well as the environmentill benefits to he derived from the reduction in air emissions that can result from the replacement of existing fossil fuel-fired systems.

1. INTRODUCTION

Geothermal district energy is the use of geothermal resources tu supply thermal energy to a group of buildings or industries. It is a technology dating back to antiquity when Roman cities, e.g., Pompeii, circulated geothermal waters through trenches beneath buildings to supply heating and thermal water for baths. Modern geothermal district energy dates back to 1892 when the Artesian Hot and Cold Water Company, now the Boise Warm Spring Water District, began service in Boise. Idaho (Rafferty, 1992). In the United States, there are now over 20 geothermal district systems in California. Colorado, Idaho, Nevada, New Mexico, Oregon, Washington, and Wyoming producing over 750 x 10^9 KJ of energy per year. 'These systems have a present production capacity of over 17,000 l/sec of 50-100°+C water that is supplied through aver 80 km of piping (Lund, et al.. 1990: Rafferty, 1992; Rafferty. 1994b). The largest of these systems is in San Bernardino, California, where 37 buildings are served hy a 24-km district system fed by two 300 (meter deep geothermal wells that can produce over 600 liters per minute of approximately 50°C water (Rafferty, 1994a).

In the Aquitaine and Paris basins of France. a large number of geothermal district energy systems have hren developed since the early 1970s. The 60+ systems. most of which consist of production and injection doublcts. each serve 1.000 to 5.000 housing units or the equivalent load in hospitals. schools, etc. (Coudert, 1984: Jaudin. 1990).

Tainjin, China's third largest city. with a population of 9.2 million inhabitants, has the largest geothermal district energy system in the world. Over 850,000 sq. meters of floor space are heated and as early as 1980. 100,000 people in the industrial area of Tanggu were provided with geothermal district heat from 16 geothermal wells (Jinrong, 1992) (District Heating and Cooling. 1994).

In Iceland. over Y0 percent of the heating requirements of the capitol city of Reykjavik are provided through a geothermal district energy system Icelanders, in fact, enjoy the highest per capita availability of geothermal district energy from systems that supply over 80 percent of the country's total apace heating requirement (Lund. 1988). Other countries that have developed geothermal district energy systems include Sweden, Denmark. Japan. Turkey. Hungary. Italy. and Great Britain (Karul, 1988).

Services available from a geothermal district energy system can include space heating and/or cooling, domestic water hrating, and industrial and agricultural process heating. In addition to geothermal resources, many geothermal district energy systems incorporale the use of thermal storage and fossil-fueled peaking and backup boilers or cogeneration equipment. Where geothermal waters are not warm enough to use directly (<ca 50°C), water source heat pumps can he used to boost the temperature to required levels such as in Lund. Sweden; Chateauroux, France: and Ephrata, Washingtun, USA (Bloomquist and Schuster. 1994) (Bjelm & Scharnell, 1983) (Jaudin, 1990).

However, despite the recent worldwide activity in developing geothermal district energy systems. the role that geothermal can play in providing environmentally attractive. stable. economic energy is far from being fully appreciated. This is reflected in the limited attention that geothermal district energy receives in the development of community energy plans. the design of new energy facilities. and the renovation of existing systems.

2. PLANNING FOR GEOTHERMAL DISTRICT ENERGY SYSTEMS

Geothermal resources for a district energy system must be located. defined, and proven within measurable limits. While district energy technology is far from new. utilization of geothermal energy to operate such systems is unfamiliar in most areas to local residents. community leaders. and the financial community. and is thus considered to be a new and somewhat risky undertaking. Required assessment activities will normally be concerned with reservoirs location. aquifer depth, and resource temperature. chemistry, and production capacity. In addition, consideration must he given to legal determination of resource ownership, potential conflicts with competing resource or groundwater users. environmental impacts. expected longevity or reliability of the geothermal reservoir to support the needs of the system. and disposal alternatives.

However. all too often a disproportionate level of effort is directed to the location and assessment of the geothermal resource, and little attention is given to the technical and economic feasibility of meeting a communities thermal energy requirements with a geothermal district energy system.

The technical and economic feasibility of geothermal district energy systems can only he made through a thorough analysis of potential district customers: The location, size. density, and time haaed demand of the thermal energy load for space heating and cooling, water heating. and process heating will largely determine the feasibility of a district energy system. The availability and prices of competing fuels must be evaluated. and an estimate made of the potential for market penetration. Only after a thorough market analysis, the results of the geothermal resource assessment program. and the capital and operating cost estimates generated through the development of a conceptual system design. can a preliminary determination of the project's feasibility be made. The cost and complexity of completing such studies has, however. been a major barrier to the inclusion of geothermal district energy as a major element of community energy planning and ultimately design. A software program, HEATMAP". has been designed to significantly reduce the cost of completing these studies, and is intended for the use of planners. architects. engineers, designers, and developers.

3. HEATMAP™

HEATMAP® approaches geothermal district energy from the premise that a community's thermal energy supplies and demands are important determinations in the community development process. Community thermal loads are a direct function of land uses. The types, location, density, and mixes of land uses in a community will determine its suitability for district energy: moreover, land-use relationships to local energy sources such as geothermal resources will, to a large extent. determine the technical and economic feasibility of using such local resources fur a district energy system.

HEATMAP" is a computerized tool that provides a fast and reliable means of planning. designing, describing, and analyzing proposed and existing geothermal district heating and cooling (DHC) systems. It will evaluate the feasibility of using geothermal resources directly if moderate tu high temperature resources (50-150°C) are availahle, or in conjunction with water source heat pumps (or other fossil fuel or renewable energy-fueled boilers) if only low temperatures (< ca 50°C) resources are present. The program also provides a quantitative estimate of improvements in air emissions that result from DHC implementation or expansion. thus providing developers with a powerful argument to use in influencing local community energy policy. Owners and operators of existing geothermal DHC systems can use the program to evaluate their system performance and model the effect of various potential system scenarios, such as. adding new customers, extending service to areas outside of the existing service territory. or determining the adequacy and robustness of the existing distribution network. The software can also he used to determine the best mix between geothermal and the use of "conventional" heating and cooling equipment.

The program allows for the evaluation of the thermal demands of a community's land uses. Thermal load density. far example. is a function of a community's land uses: the thermal loads per unit of building floor space for heating. cooling. and domestic hut water. and any local industrial or agricultural process loads. Thermal load density is usually expressed as Joules or Megajoules per hour per hectare (MJ/h/ha). Thr program can he used to provide an estimate of the minimum district heating/cooling sales price per unit of land area. i.e., thermal load density, necessary for economically operating a community-wide system. The program generated reports can be used to compare each neighborhood's thermal demands per unit of land area to the community-wide minimum necessary for district energy service. The resulting thermal density ratios will constitute a favorability rating for each neighborhood, indicating either its suitability for district heating/cooling service, or the need for appropriate land-use changes, e.g., increased densities or greater mix of land uses. such as mixed residential and commercial development.

One important feature of the program is the ability to develop a complete data file fur each building or facility in the proposed district energy service area. This information can he effectively used to perform detailed sensitivity analyses of various scenarios. For example, scenarios can he run that concentrate on only specific types of buildings or uses. or only on buildings with internal thermal distribution systems that are easily retrofitted to use district energy

The program functions through the integration of tour separate software programs: HM. a central controlling program: AutoCAD, a computer aided design program: HMOPS, a HEATMAP? AutoCAD Interface program; and LICHEAT. a distribution network analysis program. AutoCAD is used to establish a graphical

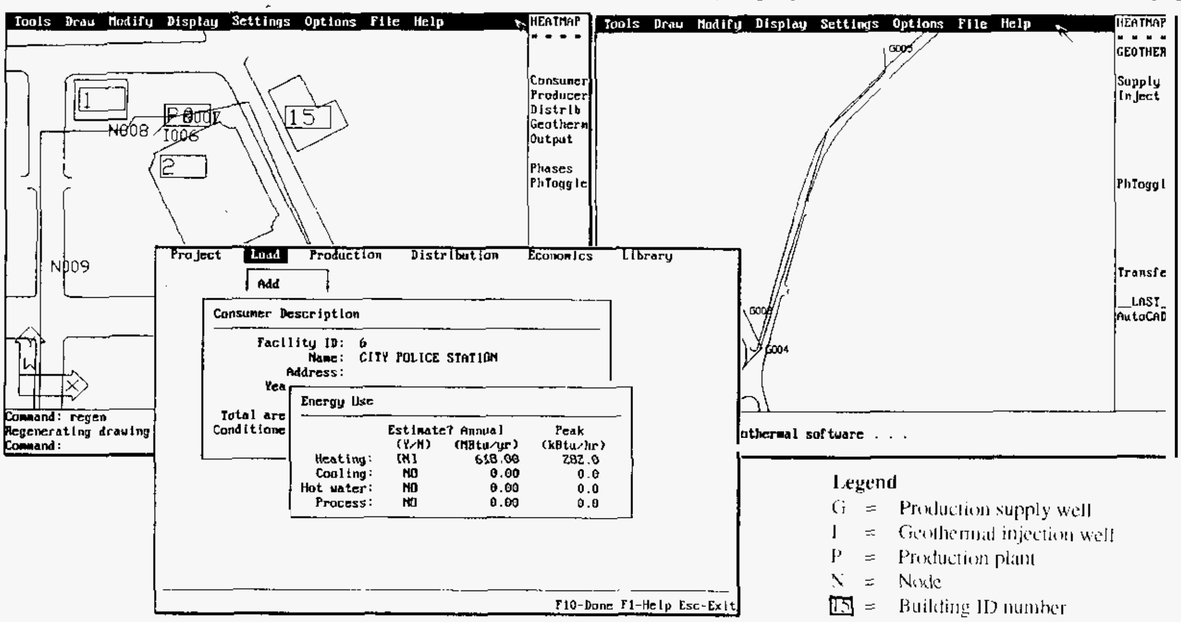

Figure 1
Sample Screens

database that contains the map of the community under study. routing of pipelines. and the location of pumps, production plants (including the geothermal well field). and heating and cooling loads (Figure 1). Where applicable, the graphical system may include the location of other infrastructure systems including streets and sidewalks, and other utilities. e.g., gas. electricity.

The HM program binds the four components of the program into a single. coordinated system. It provide.; a hierarchical system of menus to control program execution. maintain the project database. and govern the exchange of data with AutoCAD *and* LICHEAT. HM also controls the printing of reports. and performs the analyses required for estimating heating and cooling loads. selecting and assessing production and injection fields and associated piping, and evaluating financing options and economics.

The database and the HEATMAP' software are organized to correspond to seven categories of information and function: general project description; geothermal wells and collection system consumer hearing and cooling loads: geothermal central production plant: DHC distribution system; financing and economics: and library (support data).

4. SOFTWARE PROGRAM STRUCTURE

4.1 Project Description

The user defines a new project by providing general information about the target geothermal DHC system. Among the data items requested by the program are: location: name and description: type of system: distribution medium (i.e., hot water or steam and chilled water): cost for specific geothermal components; and weather data. Based upon the values entered by the user, the program will provide certain user-changeable default values (e.g .distribution system pressure and temperatures).

4.2 Consumer Heating and Cooling Loads

For each consumer in the project database. the program will estimate or permit user input lor energy consumption of space heating. space cooling. and domestic hot water. Process loads must be entered by the user. The program will also calculate air emissions of SO, NO,. CO_2, and particulates for each existing boiler in all buildings included in the proposed DHC service area, based on existing equipment. fuel. and operational efficiency.

The methodology used to estimate consumer loads is patterned directly after COMPACT. a software tool developed by Lawrence Berkeley Laboratory under the sponsorship of the Electric Power Research Institute (EPKI). The COMPACT computer program calculates an energy utilization index (EUI), expressed in terms of kWh/unit of area/year. Separate EUIs are established for space heating, space cooling. and domestic hot water. The EUI calculation is based upon statistical data gathered for over 6,000 buildings, and an algorithm that adjusts estimated consumption values according to weather conditions at the location of the DHC project.

4.3 Geothermal Well Field

The geothermal system production program will allow the user to draw and describe a geothermal well field production system (Figure 1) that will consist of one or multiple production and injection wells connected to a single production plant. or multiple doublers, i.e.. pairs of production and injection wells, serving as a single production plant. Both production and injection wells can be modeled and costs and related energy requirements calculated.

4.4 Production Plants

The central production plant will accommodate hot water heating and chilled water cooling (if coaling is provided) for a district heating and/or cooling network (DHC) connected to various consumers. The geothermal hot water will be used as a heat source for directly heating (i.e., through a heat exchanger in the central production plant) the DHC network or indirectly heating the system (e.g., as a thermal input source to equipment in the plant. such as, a heat pump or supporting boiler(s)). The geothermal water may also he distributed from a producrion header directly to each building, where a heat exchanger will he located, before being collected at an injection header for return to injection wells. The user must specify a feu system parameters for the geothermal system. including: temperature(s) and mass flaw rates (i.e., liters per seconds) of geothermal water from each production well lo the central production plant, temperature of the geothermal water leaving the heat exchanger (if present) in the central production plant. and return temperature of the hot water for the DHC system Geothermal water can also be used as the heat source for absorption cooling equipment. Geothermal fluid effluent can either be disposed of back into the reservoir by injection or used in a secondary application such as agriculture or aquaculture. If multiple injection wells are specified, the software will assume that the mass flow of the geothermal effluent will be distributed equally among the established wells.

The user can specify hoth heating and cooling production equipment to operate in either base load or peak mode. Production equipment fuel sources include coal. natural gas. electricity, fuel oil, and biomass. Both steam and hot water heating systems can he selected. The cost of energy purchased to operate the production equipment is calculated by the program or may he specified by the user.

4.5 Distribution System

The user designs a complete DHC distribution network on the project map using an AutoCAD system (Figure 1). The HEATMAP* program "reads" the CAD drawing of the map. and creates a record in the database for each section of pipe, pump. valve, and node (consumer or production plant) in the system. Initially. thew records contain little more than locational data expressed in x. y, z coordinates. The program correlates this information with heating/cooling load data and passes it to the LICHEAT program which analyzes the distribution system to determine pressures, temperatures, end flows at each pipe and node. From the results of this analysis, the program constructs an inventory of technical specifications and sizes and costs for all pipcs. pumps. and valves required by the system.

The LICHEAT software system was developed and provided to WSEO for inclusion in HEATMAP" by LICconsult of Birkerød, Denmark. The LICHEAT program is used to model and analyze the physical characteristics and behavior of distribution networks in over 200 operating DHC systems worldwide.

4.6 Economics

Specific user provided cost information can be furnished for exploration, drilling, well-head equipment, testing. pumps, land, buildings, hear production and exchanging equipment, operation and maintenance. permits, and royalties.

Rased upon the project conditions specified by the user the program will calculate the total cost far hearing production and distribution (hot water or steam) and cooling production and distribution (chilled water). There costs are calculated on hoth a levelized basis throughout the project life. and separately for each year of the project (Tahle 1). Both public and private ownership can be considered. Based upon the total cost of the system and total customer load, the program will calculate the required sales price for each unit of delivered energy

Special features included in the economic analysis include: income stream from thermal sales; electrical sales (cogeneration); debt financing from bonds or bank loans; annual cost escalation for major expense categories: separate construction and long-term debt financing; tax calculations including various lax depreciation methods; tax credits; and a sensitivity analysis of sales price versus key production plant operating expenses.

Table 1
Summary Page

04/06/94 HEATMAP Economic Analysis - HEATMAP DHC Study
Summary Page

Case name: Geothermal case 1
Discount rate: 4.50
Analysis life: 30

	1'193	1995	1997
Plant Send Out (MBtu/yr)	121214	123214	123214
Investments (Escalated $)	2559235	0	0
Carrying costs (Escalated $/yr)			
(+) Debt P&I	217810	217810	217810
(+) Equity P&I	102369	95332	88294
(+) Insurance	7678	8980	10504
(+) Property taxes	0	0	0
Total	327857	**322122**	316607
Variable expenses (Escalated $/yr)			
(+) Purchased Fuel	319991	374278	437772
(+) Operating Labor	495091	579079	677316
(+) Eq. Service/Repl	97550	114099	133455
(+) Distrib system maint	20770	242'13	28415
(+) Geother distrib maint	6171	**7218**	8442
(+) Income Taxes	0	0	0
(+) Other	0	11	0
(+) Revenue	0	0	0
(+) Sales Tax/Fees	124049	138958	156515
Total	1036684	12116414	1405057
Required Rev. (Escalated $/MBtu)			
(+) Carrying costs	2.66	2.61	2.57
(+) Variable expense	8.41	9.79	11.40
Total	11.07	12.41	13 97
Average Sales Price	21 67		
Required Rev. (Present Val. $/MBtu)			
(+) Carrying costs	2.66	2.39	2.15
(+) Variable expense	8.41	R97	9.56
Total	1 107	11.36	1172
Average Sales Price	13.38		
Project Present Value ($)	32971350		

4.7 Library

The library contains a wide **variety** of information from which default **values** and assumptions are obtained for use throughout the program (note: default values are **user** changeable). Data tables are maintained for six categories of information: Weather, Fuel: Statistical energy use **indexes;** Production units; Consumer heating and cooling equipment: and Piping. Library default **values** are included in the software to simplify **user** input and permit **a quick** analysis of potential geothermal district **energy** applications. For very specific **analysis** of system features, the software allows users to **change** (i.e., customize) various default data information.

5. UNITS SYSTEMS

The program has been designed to support both English and Metric units. There are separate executable versions **of** the program for each units system, hut both are generated from the **same** set **of** source code. **A** compile-time option determines which version of the program will he produced by the compiler.

6. SOFTWARE HARDWARE REQUIREMENTS

HEATMAP® 1.0, which was released in the spring of 1994, will run on any IBM compatible (80386 or later) computer meeting the following specifications: DOS 3.3 or later, math coprocessor, 4 **MB** or greater **RAM,** *60* MB or greater hard disk, AutoCAD release 10 or later, and **a** mouse. A WINDOWS version of the program was released in the fall of 1994. The WIN-DOWS platform requires Microsoft WINDOWS version 3.x or later, AutoCAD release 12 for WINDOWS with 8 MB or more RAM. and a 200 MB or greater hard disk.

7. FUTURE PLANS

Several important enhancements to the program are now under development or are planned for the near future. These include (1) the ability to input hourly load and production data, greatly facilitating the ability to accurately size and optimally operate thermal storage and peaking equipment; (2) a new cogeneration and thermal storage production module: (3) a number of new analysis routines that will allow the user to quickly determine operational problems and distribution system reinforcement opportunities; and (4) an enhanced graphics package that will allow the user to easily analyze system conditions and develop presentation materials.

8. CONCLUSION

A major harrier to the inclusion of geothermal district energy as a major clement of community energy planning and ultimately design is the cost of completing the required feasibility and design studies. A computer software program, HEATMAP", has been designed to significantly reduce the cost of completing such studies, and is intended for use hy planners, architects. designers, engineers, and operators for the purposes of:

- Establishing a basis for thermal supplies and demands as determinants in the community development process which allows land-use planning to he used to optimize geothermal district **energy** development.
- Identifying areas where detailed engineering and economic assessments of geothermal district energy opportunities may he warranted
- Performing detailed feasibility studies in high potential areas.
- Designing a geothermal district energy system that optimizes the use of geothermal resources while minimizing the cost of the distribution net and thermal losses through the year.
- identifying areas where land-use changes should he focused to improve long-term conditions for geothermal district energy.
- Providing an educational tool that will allow puhlic officials to develop a better understanding of the role of geothermal district energy in community energ) planning and system design and construction

9. ACKNOWLEDGMENT

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