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MODELS - CAN THEY REALLY BE TRUSTED IN DETERMINING THE FEASIBILITY OF A GEOTHERMAL DISTRICT ENERGY SYSTEM?

R. Gordon Bloomquist, Ph.D.
Washington State University Energy Program
P.O. Box 43165
Olympia, Washington 98504-3165
USA

Toni Boyd
Oregon Institute of Technology
Geo-Heat Center
Klamath Falls, Oregon 97601
USA

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ABSTRACT
Over the past two decades, a number of computer models have been developed in order to reduce both the cost and time required to evaluate the technical and economic feasibility of implementing geothermal district energy systems. Among the first of these was Geo City, developed in the late 1970s. Over the years, Geo City was followed by a number of other models developed by colleges and universities, national labs, and private consulting companies. Some were little more than spreadsheets while others took the power of a mainframe computer. One of the more recent entries into the field is HEATMAP©, developed by the Washington State University Energy Program.

A thorough testing of the HEATMAP© program against as-built and operating experience is presented together with a discussion of what capabilities the "ideal model" should provide.

1. INTRODUCTION

The use of geothermal district heating systems dates back to Roman times when geothermal waters were sometimes circulated beneath buildings for heating, often in association with the supply of Roman baths. As early as the 14th century, the French city of Chaudes-Aigues Cantal installed a geothermal district heating system and that system still exists today. In the United States, the first geothermal district heating system was built in Boise, Idaho, in 1892. This system, known originally as the Artesian Hot and Cold Water Company and later as the Boise Warm Springs Water District, still serves the Warm Springs district ot the city of Boise, Idaho, and has served as the catalyst for the development of the Boise, Idaho, capitol campus system and a municipally-owned district energy (heat and/or cooling) system serving the downtown business district (Rafferty 1992), as well as systems in Nevada, California, Oregon, and New Mexico, while in Europe and Scandinavia, systems in Iceland and France represent some of the most extensive geothermal district energy systems in the world.

Growth of the geothermal district energy sector in the United States, however, has slowed dramatically since the mid to late 1980s, and although there has been some interest in areas such as Reno, Nevada, and Mammoth Lakes, California, in the 1990s, no new geothermal district energy systems have been developed since the late 1980s, despite extensive studies of the resource potential in the western states. However, few studies of technical and/or economic feasibility have been completed during the same time period.

In fact, establishing a methodology by which technical and economic feasibility and revenue generation potential can be estimated often appears to be the quintessential question and a prerequisite to any serious consideration of the development of geothermal district energy systems. Numerous attempts to develop a system capable of accurately estimating the technical and economic feasibility of a geothermal district energy system have been made. The first serious attempt was probably a computer model developed by the Pacific Northwest Laboratory in Richland, Washington, known as Geo City. However, work by Eliot Allen of Eliot Allen and Associates, "Preliminary Inventory of Western U.S. Cities with Proximate Hydrothermal Potential," (Allen and Shreve, 1980) and the development by the Washington State Energy Office of HEATPLAN must also be included. These systems were, unfortunately, extremely simple in either their assumptions or applications, and none proved to be capable of generating numbers creditable enough to be given serious consideration by the development or financial community. All were, however, capable of, at a minimum, identifying sites that showed promise and that warranted additional analyses.

2. MODELING PROGRAMS: A REVIEW

The primary premise of most models is that district energy feasibility is a direct function of thermal load density. This builds upon information developed in Sweden where numerous existing district heating systems had been evaluated in an attempt to establish the relationship between district heating viability and heat load density (Whalman 1978). Based on the geography, proposed service area, and heat load, favorability for district heating was based on the following scale.

$$\text{Study Area Favorability Ratio} = \frac{\text{Study Area Net Density of Annual Heat Use (KJ/ha/year)}}{\text{Minimum Heat Sales Needed for System-wide Operation (KJ/ha/year)}}$$

Favorability Ratios	
>5.16	Very Favorable
3.75 – 5.16	Favorable
1.49 – 3.74	Possible
0.89 – 1.48	Questionable
<0.89	Unfavorable

However, the development of district energy requires more sophisticated and comprehensive simulation and optimization models to handle increasingly more complex data systems or requirement for the analysis of technical and economic data. Modern district energy systems may include multiple production units to meet base as well as peak demand, geographically distributed customers with varying service requirements, and multiple pipelines to connect them.

The models must be able to handle complex system and building load calculations, varying climatic conditions, changes in fuel and labor costs, taxation policies, environmental impacts, and multiple financing options.

2.1 New System

In determining the technical and economic feasibility of a new district energy (heating and/or cooling) system, the key questions are:

- What are the actual building loads; when do these loads occur; and what is the thermal load density of a given area?
- What are the best technical solutions for providing thermal production, e.g., should the system be based on cogeneration or trigeneration (electrical generation, heating, and cooling) with cascaded hot water used in absorption equipment?
- Will the system require multiple central heat exchanger plants or can all of the equipment be located in a central facility?
- What is the planned maximum extent of the system; will it be constructed in phases; what is the likely penetration rate based on marketing surveys?
- What are the economic trade offs in terms of production cost and varying delivery temperatures vs cost of the distribution network?
- How should the distribution system be laid out to provide maximum operational security and customer assurance?
- How are economics affected by using various piping materials, flow rates, and/or send-out and return temperature?
- Are there tax incentives or utility programs that can improve the economics of a system that accomplish certain environmental policy or operational goals?
- What financing options are available and how can multiple financing options be packaged to obtain the most cost-effective package?

System Expansion Planning

In planning the expansion of an existing district energy system, another set of issues must be considered that are dependent upon whether such expansion is being considered to increase the reliability of an already over extended system, or to meet the needs of planned new construction.

If the goal is increased reliably, the questions are:

- Should distribution constraints be dealt with by making changes in the production equipment to increase or decrease send-out temperature; should new mains be constructed where capacity is constrained; or should new production plants be located so as to avoid the distribution constraints?
- Should production constraints be alleviated through adding production equipment to existing plants; by adding storage; or should additional satellite or peaking plants be built?

If the issue is how to serve new construction, the questions most often asked are:

- Could the area be served from a stand-alone system constructed to meet the new load?
- Can the existing production plant and/or distribution system be expanded and/or extended to serve the new load economically?
- Can the new load be served by the existing system with peaking demand being met locally?

System Operation

In operating a district energy system, the goals are to minimize operational cost, maximize equipment and personnel productivity, and maintain system reliability and security. In order to achieve these goals, the model must be able to determine:

- What effect various operational changes will have on system costs and system security?
- What options are available for providing service in the case of a forced or planned outage?
- Does the system provide a reasonable margin of over capacity in both production and distribution to meet unexpected load conditions?

Model Concept

The basic concept of a model is to provide a hierarchy to the decision making process. Ideally, the district energy model should be capable of a range of functions from preliminary technical and economic feasibility through system design, operational planning, and system expansion or renovation. The model should be able to handle multiple design or operational scenarios with a minimum amount of user input (manipulation). Finally, the model should be able to be easily adapted to various ownership structures and financing options while maintaining extensive amounts of capital and variable cost data in a library system that is easily user-defined for each scenario alternative.

Because district energy systems are by nature geographical dependent, the model should provide or be easily interfaced with a CAD or GIS program that allows for precise location of all consumer loads, production equipment, and distribution systems components, including, for example, pipes, valves, and pumps.

The model must provide both financing and economic analysis capability. It is necessary in any economic analysis to include all capital investment costs associated with both the production plant(s) and the distribution system, as well as operation and maintenance costs. All cost categories must provide for escalation over time. This is especially true of fuel cost. The economic submodel must also allow the user to consider the impacts of tax incentives as well as energy and environmental taxes imposed. Where cogeneration or trigeneration is considered, income from electrical sales must be included in the analysis together with sales of heating and/or cooling. Where both heating and cooling services are provided by the same supplier, the model must be able to account for the costs and revenues separately. Also, the model must be capable of evaluating various economic parameters, such as cash flow, internal rate of return, and life cycle cost analysis.

Finally, financing the project must be considered. Because certain financing options are available dependent upon ownership structure, the model must be able to treat financing by public and private entities differently. Public financing will almost always be done through the sale of some sort of government-backed bond that usually carries a more attractive interest rate than would be available to the private sector. On the other hand, public entities normally do not pay taxes except in the case of energy and environmental taxes, and rarely can take advantage of any tax incentives. Private entities, on the other hand, can raise capital through stock sales or private placement (equity), may borrow from a commercial bank or may have the ability to sell bonds. Rates of interest can vary considerably as can expectations for rate of return on equity. Private entities do, however, have the ability to take advantage of tax incentives but must also pay local and federal taxes on income earned. Once again, the ability of the model to allow for iterative runs based on various inflation rates, interest rates, rates of return, and taxes and tax benefits that may apply to various equipment and fuel types, will allow the user to determine the optional system both technically and economically.

In the late 1980s and early 1990s, a number of models were developed in an attempt to better predict the impact of various governmental programs directed toward development of district energy systems (DERIM); estimate the feasibility of district energy implementation (DETECT); or actually establish the cost of providing district energy service (HEATMAP©). DERIM and HEATMAP© were both developed by the Washington State Energy Office, now the Washington State University Cooperative Extension Energy Program (WSU), while DETECT was developed by the District Energy Committee of the International Energy Agency. Prime contractor for the development of DETECT was the Danish firm of RH and H Consult (Rambøll, Hannemann and Højland AS), now Rambøll, (Bloomquist, et al, 1999). The Oregon Institute of Technology Geo-Heat Center has also developed a spreadsheet model that allows for an initial assessment of geothermal district energy potential based on a limited number of input variables (Lineau and Ross 1996).

2.2 HEATMAP©

HEATMAP© was developed in response to the need to improve analytical modeling capabilities for district energy distribution systems. The model provides a fast and reliable method of modeling district heating and cooling (DHC) systems and attempts to incorporate many of the features of an "ideal" model.

The program has been developed by WSU on behalf of the New York State Energy Research and Development Authority, the Swedish Council for Building Research, the Swedish Trade Office, the United States Navy and Army, the United States Department of Defense, United States Department of Energy, and Public Works and Government Services Canada (Science Directorate).

The model provides ease of data manipulation and simplified procedures for performing comparative analyses of multiple scenario alternatives.

Features include: a graphical analysis package covering analytical procedures; metric (SI) capability; CAD compatibility; international currency units; use of ASHRAE-compatible temperature bin data; insertion of specific pump and valve curve operating data; extensive report generation options; graphical diagnostics; and color plots of distribution system parameters.

The program allows the user to establish and maintain a project database that stores a structured, detailed description of the target or existing DHC system. The database and the HEATMAP© software are organized to correspond to the six general categories of information and function that are required to complete a DHC project:

- General project description
- Consumer heating and cooling loads
- Production plants
- Distribution system
- Economics
- Reports
- Library (support data)

The database is linked to a three dimensional project map that is constructed using CAD software. The location of each DHC consumer and production plant in the database is identified on the map. For geothermal systems, this includes production and injection wells and transmission piping as well as the heat exchanger plant and back-up or peaking boilers. The map also contains a representation of the distribution network. Each node and pipe depicted on the map is linked to a corresponding record in the project database.

An additional important feature of the program is its capability to analyze air emissions from existing in-building equipment and compare levels of emissions to those that will be present after DHC implementation.

For each consumer added to the project database, the program requests annual energy consumption data for space heating, space cooling, and domestic hot water. If the user is unable to provide actual data (e.g., from utility bills), the program estimates the annual load based on the conditioned square footage of the facility and its end use, e.g., offices, school, or residential, etc. The methodology used for estimating consumer load uses an energy utilization index (EUI), expressed in terms of kWh/square foot/year or kWh/square meter/year (in SI units). Separate EUIs are established for space heating, space cooling, and domestic hot water. If industrial process loads are present in a facility, the user must specify the actual load for each.

Based on annual loads for each consumer, the program calculates peak loads. The aggregated annual and peak load totals for all DHC consumers serve as inputs to the procedure that calculates the load duration curve. This procedure relies upon a variety of other input data, including weather (temperature bin table) and distribution system losses.

The user can specify heating and/or cooling production equipment to operate in either base load or peak mode. Peak equipment is assumed to be capable of operating over a wide load range, and can be brought on line rapidly. Base load equipment, e.g., a geothermal plant consisting of fluid production equipment, heat exchangers, and pumps, is assumed to operate with higher turn down ratios and requires additional time to be brought on line. Cooling equipment includes absorption units, heat pumps, and steam or electric-driven centrifugal chillers. For a geothermal system, absorption cooling or binary-driven centrifugal or screw chillers, would be the most logical choices.

The cost of energy purchased to operate the production equipment is calculated on a seasonal basis. Seasonal calculations allow the effects of varying energy costs and equipment performance to be considered. The seasonal purchased energy costs and the duration of each season may be specified by the user.

The user designs a complete DHC distribution network on the project map using CAD software. The program "reads" the CAD drawing of the map, and creates a record in the database for each section of pipe and node (consumer or production plant) in the system. The program correlates the input geographical information with heating or cooling load data and passes an output file to the distribution analysis module. This model analyzes the entire distribution system (both supply and return) to determine: pressures, temperatures, flow and thermal energy characteristics for each pipe and node; and pipe sizes if unspecified by input data (e.g., in new systems or expansions). From the results, an inventory of technical specifications and costs for all system components is constructed.

The program library contains a wide variety of information from which default values and assumptions are obtained for use throughout the program.

In most cases, the data in the support library is stored and manipulated in the form of tables. Data tables are maintained for six categories of information:

- Weather Data
- Fuel Data
- Statistical EUI Data
- Production Unit Data
- Consumer Heating and Cooling Equipment Data
- Pipe Data

On the basis of the project conditions specified by the user, the program will calculate the necessary break-even unit sales price for each consumer by mode of operation, i.e., heating production (hot water or steam) and cooling production (chilled water).

Prices are calculated for ***each year*** of the project ***and on a levelized basis*** throughout the project life. Both public and private ownership can be considered.

The sales price of either heating or cooling service is calculated based on the "minimum acceptable revenue requirement" financial model. The general calculation approach involves determining the required revenue stream associated with each production plant's operating expenses (e.g., purchased energy, operating labor, equipment maintenance and repair, debt, taxes, and others). Required return on investment is treated as an expense item. The gross revenue that must be present for the system to operate profitably is determined from the sum of all revenue streams generated by the system operation. By calculating the required gross revenue for each year of the project life, and knowing the annual heating and cooling production send out, the program will determine the average sales price.

Special features of the economic analysis module include: debt financing from bonds or bank loans; equity financing; ability to annually escalate cost factors including capital equipment, fuels, operating labor, and maintenance costs; separate construction and long-term debt financing; income tax calculations including various tax depreciation methods; tax credits; income stream from thermal sales and electrical; consequences or impacts of environmental taxes applied to different fuels or production methods; and a sensitivity analysis of sales price versus key production plant operating expenses.

3. MODEL VALIDATION

After carefully establishing the capability of HEATMAP©, the next step was to test the validity of the use of the model and determine applicability to estimate customer loads, system components, technical requirements, costs of system components, ultimately economic feasibility based on revenue generation potential.

Based on data available from the Final Report: Low-Temperature Resource Assessment Program (Lienau and Ross 1996), a number of favorable cities were identified and a decision was made to apply HEATMAP© to Klamath Falls, Oregon. Klamath Falls was selected because data was extremely accessible, and because HEATMAP© runs could be validated against actual as-built system parameters.

In the fall of 1998, data was obtained relative to the Klamath Falls municipally-owned and operated geothermal district heating system needed for inclusion in HEATMAP© and upon which comparisons would be made between model outputs and actual operating parameters. Information collected included climatological data, resource data, production and injection well information, information on the plate and frame heat exchangers and pumps, consumer heat load requirements, distribution system layout and pipe sizes, as well as system operating parameters, e.g., sendout and return temperature and flows.

This information allowed for two independent run modes of the HEATMAP© model. The first was based upon the as-built and operated system and established the baseline for evaluating the model. The second and subsequent runs were made based on model-generated estimates of various data including consumer loads and dimensioning of the distribution piping network.

From an evaluation of the data (Table 1), it can clearly be seen that although individual building loads calculated by the model vary somewhat from those derived from utility bills and/or engineering analysis, the overall system peak load calculated by the program 3,118 (kW_t) is quite close to the actual of 2,885 (kW_t). Total annual load calculated by HEATMAP© was 3,432 MWh_t/yr. vs 2,929 MWh_t/yr. actual (see Table 1). This is very similar to results encountered in other similar tests of the HEATMAP© program in, for example, Albany, New York, where the aggregate load of 10 major commercial buildings as calculated by HEATMAP© was within 2 percent of the actual total load of the buildings based on historical utility data.

It must be remembered, however, that two identical buildings will generally have somewhat different energy load profiles as a result of variations in occupancy levels and patterns, individual comfort preferences, etc. And although model-generated data closely approximated actual usage in the test, actual data should be used whenever possible.

A more important test of the model’s capabilities was in the sizing of the entire distribution piping system, including both production and return lines. The cost of the distribution system will generally comprise between 60 and 75 percent of the entire capital cost of a new district energy system. Any major error in this portion of the analysis would be unacceptable and could lead to either the abandonment of what could be a viable project if the model overestimates system requirement and costs or significant cost overruns if the model underestimates system requirements and costs or, possibly even worse, a system that cannot meet the peak demands of customers.

4. CONCLUSION

Based on a comparison of an existing distribution system and the HEATMAP© output (Table 2), it can be clearly seen that the model estimates pipe sizes somewhat smaller than those installed; however, the system, as built, was designed for built out beyond the present service area. The HEATMAP© runs indicate that the program can satisfactorily estimate pipe sizes consistent with present system requirements.

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TABLE 1 - HEATMAP© CONSUMER LOAD SUMMARY, KLAMATH FALLS, OREGON

			HEATMAP© Estimated Loads		Design Loads	
ID	**Consumer Name**	**Square Meters**	**Heating Annual (MWh_t/yr.)**	**Heating Peak (kW_t)**	**Heating Annual (MWh_t/yr.)**	**Heating Peak (kW_t)**
U18	Presbyterian	6,096	59	114	143	131
U17	Ross Ragland	10,973	146	182	257	202
U16	First Baptist	21,946	407	293	407	352
U15	Sacred Heart	21,946	439	3,339	513	346
U13	Snowmelt	91	2	146	2	8
U14	SVS Bank	3,200	68	143	68	93
U12	US Bank	1,850	40	88	40	64
U11	Pacific Linen	11,521	269	439	269	209
U10	Eagles	1,524	36	59	36	52
U09	Balsinger	21,946	469	293	469	372
U08	County Annex	4,206	90	53	90	107
U07	Library	21,946	469	176	469	504
U06	Courthouse	10,973	0	0	235	216
U04	City Hall	3,200	68	94	33	58
U03	City Annex	1,737	33	35	70	89
U02	Post Office	11,521	246	158	246	224
U01	Fire Station	3,712	87	126	87	92
	TOTAL	158,389	2,929	2,885	3,432	3,118

TABLE 2 - HEATING DISTRIBUTION PIPE CHARACTERISTICS

	Klamath Falls Current Operation					HEATMAP© Estimated		
Pipe #		Length (m)	Dia. (cm)	Flow (L/s)		Length (m)	Dia. (cm)	Flow (L/s)
1	002-001	48.2	25	-53.6		48.2	25	-33.5
2	002-003	71.1	25	52.0		71.1	25	32.5
3	004-003	480.9	25	-45.6		480.9	20	-28.5
4	005-004	81.4	25	-44.7		81.4	20	-28.0
5	005-006	115.4	20	20.5		115.4	15	12.8
6	005-013	193.0	20	20.3		193.0	15	12.7
7	005-020	91.1	15	3.9		91.1	8	2.4
8	006-007	32.2	20	19.4		32.2	15	12.2
9	007-008	21.6	20	19.3		21.6	15	12.1
10	008-009	58.3	20	17.7		58.3	13	11.1
11	009-010	110.8	15	12.0		110.8	13	7.5
12	009-011	145.1	15	5.7		145.1	8	3.6
13	013-014	135.2	10	3.6		135.2	8	2.2
14	013-021	41.7	20	16.7		41.7	13	10.5
15	015-016	59.5	15	15.7		59.5	13	9.8
16	016-017	225.1	15	14.2		225.1	13	8.9
17	017-018	22.6	10	5.6		22.6	8	3.5
18	018-019	93.8	8	1.8		93.8	5	1.2
19	020-012	47.5	10	3.9		47.5	8	2.4
20	021-015	37.6	15	16.7		37.6	13	10.5

Distribution System Parameters

Max. temperature (ºC)	82.2 at node N001	Max. temperature (ºC)	82.2 at N001
Max. pressure (kPa)	552 at node N001	Max. pressure (kPa)	634at N001
Min. temperature (ºC)	67.8 at node N019	Min. temperature (ºC)	59.3at N019
Total energy produced	3,192 kWh_t	Total energy produced	3,192 kWh_t
Total energy consumed	3,104 kWh_t	Total energy consumed	3,104 kWh_t
Thermal distribution losses	88 kWh_t	Thermal distribution losses	88 kWh_t
Losses at % of production	1.6%	Losses as % of production	1.4%