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ECONOMICAL ADVANTAGES IN USING CONVENTIONAL ENERGY SUPPLEMENTS IN THE DESIGN OF GEOTHERMAL DISTRICT HEATING SYSTEMS

James A. Batdorf and George M. Simmons

Department of Chemical Engineering
University of Idaho

ABSTRACT

Most geothermal heating systems are designed to handle the maximum load anticipated during a normal heating season. Typically, this load is associated with an ambient temperature of near 0°F. Since geothermal water usage increases exponentially as the load demand increases, designing to handle such a high peak load results in a very low usage factor (less than 20%) for the heating season. This means that less than 20% of the energy that could be supplied by a geothermal source is actually used. Designing for peak loads to occur at higher temperatures (eg. 20°F) and using natural gas as a supplement below that temperature, results in signifcant increases in geothermal utilization and overall natural gas savings. The economic tradeoffs in determining the optimum design temperature are discussed.

BACKGROUND

Many geothermal energy resources in the Western United States are low temperature (less than 200°F) hot water reserves. This quality of resource is best utilized in low temperature direct use applications such as space heating. Given the high cost of exploration and resource development it is more economical to develop resources that have a relatively large application. Since individual space heating demands are relatively small, it is usually necessary to develop a system for multiple users. These multiple user, or District Heating Systems are receiving considerable interest throughout the Western United States (1).

The retrofit of an existing space heating system for use with a geothermal water energy source generally utilizes the following strategy. A primary heat exchanger transfers energy from the geothermal water to a secondary working fluid (generally water). This fluid is then circulated to the building(s) to heat the room air. The primary heat exchanger may be located at or near the geothermal water production well or it may be located within the building. These differences are generally determined by such factors as the corrosion and precipitation properties of the particular geothermal fluid. After energy transfer from the secondary fluid to the building air the secondary fluid is recirculated back to the primary heat exchanger. Geothermal fluid leaving the primary heat exchanger is either surface discharged or reinjected into the substrata.

Depending on the particular design and installation of the existing heating system the extent of modifications required to convert to geothermal heating can vary over a wide range, from connecting into an existing hot water loop to modifying the air-handling equipment to accept larger heat exchangers and higher pressure drops. In most applications the original system is retained to provide emergency back-up and peak load requirements.

Changing the design point at which the back-up system is to be activated alters the geothermal system usage factor (ratio of actual use to system capacity). The system economics are primarily dependent on fixed costs and therefore the unit cost of geothermal energy is approximately equal to the annual fixed costs divided by the annual geothermal energy usage (usage factor times system capacity). This indicates that the geothermal energy unit cost is inversely related to the usage factor. In order to improve the economics of geothermal systems, it is generally desirable to increase the geothermal usage factor. Normally there is no control over the usage factor, however if the original system design includes back-up capability, this usage factor can be increased by relying more on back-up energy and expanding the system size to include more buildings. Obviously there is a trade-off between decreasing the cost of the geothermal energy and using more supplemental energy, which in turn requires additional capital for retrofitting additional buildings. This paper examines the economics of this trade-off and suggests that a switch over to back-up systems be done at ambient temperatures considerably higher than is normally done.

DISTRICT HEATING

A geothermal district heating system can be operated in a number of ways. A private investment group or municipal utility may develop the resource, construct the transmission system and sell the geothermal fluid. In other cases the developer and the consumer may be one in the same. For instance, in the Capitol Mall Heating Project in Boise, Idaho, the State of Idaho developed the resource and the energy will be used to heat state owned buildings (2).

The design of a geothermal district heating system requires careful planning and economic evaluation. Most of the system parameters are fixed by the resource location, the amount of production expected, the expected demand and the demand location. The areas available for greatest economic improvement are retrofit design and matching of the resource and demand. Several methods of improving the design and operation of a retrofitted heating system have been previously documented (3,4,5). In order to match the retrofit to the demand the number of buildings to be supplied should be adjusted along with the peak design load to be provided by the geothermal resource.

DISTRICT HEATING ECONOMICS

There are many ways to analyze the economics of a geothermal district heating system. In all cases the project economics are complicated by the variations in development and retrofit costs and by governmental incentives (tax credits, exploration and development grants, demonstration project grants, etc.). A good example of a recently completed district heating project is the Capitol Mall Geothermal Energy Project in Boise, Idaho. Over 95% of the $1,850,000 project cost was funded by the State of Idaho. The expected annual savings in natural gas expenditures is $150,000 (based on 1981 natural gas costs) (2). This would amount to a 7% return on the capital investment over a 30 year period. This simple analysis is based solely on the amortization of the capital investment and does not account for changes in operating costs, inflation, or escalation of natural gas costs.

Bloomster, et.al. (6) has published a comprehensive report on the costs associated with the development and operation of a geothermal district heating system. They discuss the sensitivity of the delivered energy cost to many factors including financing, well cost, usage factor, resource temperature and flow rate, well life, transmission and distribution costs, and geothermal fluid disposal costs. The energy cost is also dependent on the cost required to modify an existing heating system. This report indicates that the economics of a geothermal district heating system are determined primarily by the initial capital investment cost, the type of financing, and the usage factor. The variable costs (operation, maintenance, and pumping) are reported to be small when compared to the annual fixed costs (6). In order to more accurately determine and further improve the economics of a geothermal heating system it is necessary to determine the usage factor under different operating conditions.

USAGE FACTOR DETERMINATION

Usage factors can be calculated by integrating the geothermal flow requirements for a typical heating system over a typical heating season. This requires an accurate estimate of the heating requirements and the associated geothermal fluid flow requirements. Also it is necessary to know the distribution of heating requirements during a typical heating season. Figure 1 shows a distribution of average daily temperatures for the heating season in Boise, Idaho (these were compiled from 20 years of weather data). Various methods are available to estimate the heating requirements for a building with specified size, contruction, and ventilation requirements (7,8,9). Figure 2 shows the results of this type of analysis for a typical 100,000 sq. ft. office structure. Computer modeling techniques have also been developed to calculate the geothermal water requirements for a specific geothermal heating system (4,5). Figure 3 shows the results of this type of analysis for the office structure of Figure 2 and the geothermal heating system shown in Figure 4. Combining this information allows the prediction of the annual geothermal water requirements for a given building operating with a specific heating system under typical weather conditions. The annual amount of geothermal water required by the above mentioned office structure for a typical Boise, Idaho heating season would be 9,264,000 gallons. This estimate is based on a minimum design temperature of 0°F, at which the peak geothermal flow is 175 gpm. For a system designed specifically to meet this building's energy needs (peak flow of 175 gpm) the total system capacity would be 56,950,000 gallons for the total heating season, thus the usage factor would be 0.163. The usage factor for a district heating system of similarly designed buildings would be lower if the total system peak capacity was greater than the sum of the building peak requirements.

OPTIMIZATION OF DISTRICT HEATING SYSTEM ECONOMICS

The following analysis is for a hypothetical system of buildings, each having geothermal usage requirements similar to those shown in Figure 3. Assuming that this system has a maximum geothermal supply of 1000 gpm the annual usage factor can be calculated for various design temperatures. This design temperature is the point below which the back-up system is utilized to supplement heating requirements beyond the geothermal resource capabilities. As this temperature is increased more buildings can be added to the system since the peak demand for each building is then lower. Figure 5 shows the results of this analysis. Note that the usage factor starts at 0.163 which corresponds to 5.7 buildings on the system (1000 gpm/175 gpm peak load) and approaches 1.0 at a temperature of 68°F (1000 buildings using 1 gpm throughout the heating season).

For a given geothermal supply, the addition of another building to the system affects the economics in a number of ways. First, there is an increase in capital expense to retrofit the building and extend the distribution system to the building. Second, the peak amount of geothermal fluid available to each individual user is reduced. The third effect is an increase in the total amount of geothermal fluid supplied by the system for a given heating season. Fourth, the amount of supplemental energy required by each individual user will be increased as their peak geothermal capacity is reduced. The optimum number of buildings to place on a geothermal district heating system will depend primarily on the above economic impacts as well as the capabilities of the back-up system.

After a geothermal district heating project has been developed and is operational, it is obviously important to attempt to operate the system in such a manner as to maximize the economic return. The fixed costs involved in operating a district heating system include amitorization of the capital expenses for the resource exploration and development, distribution system construction, and heating system modification. The variable costs include supplemental energy costs, pumping costs, and operation and maintenance costs. The addition of a building to the geothermal heating system does not greatly affect the operation and maintenance costs and the pumping costs are at least an order of magnitude below the other costs. This indicates that the important costs to consider are the capital amortization costs and the supplemental energy costs. The "income" from a district heating system is the reduction in supplemental fuel expenditures. Therefore, the maximum economic return is a trade-off between increased savings in supplemental fuel expenses and increased expenses for distribution system expansion and heating system modifications.

The geothermal energy unit cost is calculated using life cycle costing and discounted cash flow analyses similar to that described by Bloomster, et. al. (6):

$$C = \frac{\sum_{n=1,n1} PW_n \times (CAP + \sum_{j=1,NBUILD} RETRO_j)_n}{\sum_{n=1,n1} PW_n \times (USAGE \times ENCAP)_n}$$

C = unit cost of geothermal energy
n1 = useful life, years
PW = present worth factor
CAP = capital cost of well and transmission system
RETRO = capital cost for each building
NBUILD = number of buildings on the system
USAGE = annual usage factor
ENCAP = energy capacity of the system

A cost analysis based on a municipal financed system with 8% financing and a 30 year project life was used to determine the effect of the usage factor on the geothermal unit energy cost. The basis for the cost analysis included an initial investment cost of $1,000,000, a cost of $100,000 for the addition of each building to the system, and a system energy capicity based on 1000 gpm and 50 °F temperature drop. The relation between the usage factor, number of buildings, and design temperature was determined as described for Figure 5, and resulted in the cost estimates as shown in Figure 6. Note that the minimum cost occurs at a design temperature of 40°F, this roughly corresponds to the location of the maximum in the average daily temperature distribution shown in Figure 1.

As economic analysis was also performed for a user owned system. In this case the incremental return from adding buildings to the system was estimated. As before, it is assumed that the geothermal resource has a maximum flow of 1000 gpm. The cost of adding a building to the system was estimated at $100,000. Natural gas savings were determined for operating the system with various design temperatures, these savings were based on a natural gas cost of $0.50/100,000 BTU. The results showed that increasing the number of hypothetical buildings heated by geothermal energy from 5.7 to 7.7 resulted in an incremental ROI of 10.7%; this corresponds to changing the design temperature (for peak load geothermal heating) from 0°F to 5°F. As this design temperature increased, the incremental ROI slowly decreased. Changing the design temperature from 25°F to 30°F (17.9 hypothetical buildings to 20) resulted in an incremental ROI of 9.2%. These results do not include any consideration for the escalation of natural gas costs or the variations in retrofit costs. As stated previously, the retrofit costs can vary greatly depending on the present building heating system ($100,000 was felt to represent an upper limit on these costs for the described building). The impact of natural gas cost escalation can also be significant. For this system, at 0°F design temperature, 142,000 therms of natural gas were displaced by the geothermal energy. At a design temperature of 30°F, 476,000 therms of natural gas were displaced by the geothermal energy (5.7 versus 20 buildings).

CONCLUSIONS

Large capital expenditures are required to develop a geothermal district heating project. Energy consumption for pumping and supplemental energy requirements for heating are the primary variable costs. Since the annual fixed costs for capital recovery are much larger than the variable costs, the geothermal energy cost is heavily dependent on the system usage factor. The design of a geothermal heating system should therefore include an accurate usage factor evaluation. This can only be accomplished by analyzing the combined effects of the heating season temperature distribution and the geothermal heating system performance. Future work by the authors will characterize various heating system/weather combinations with respect to usage factors.

The following considerations apply to the design of a geothermal district heating system where the users will own and operate the system. For heating systems with back-up or supplemental heating capabilities the unit cost of the geothermal energy can be minimized by correct selection of the system usage factor. This requires the addition of a sufficient number of buildings to the system so that the geothermal flow is at its maximum value when the ambient temperature drops to a predetermined level, below which the extra energy required is supplied by the back-up system. Our initial studies indicate that this point roughly coincides with the peak in the seasonal distribution of average daily temperatures, eg. 40°F for Boise, Idaho. Optimum economics for the heating system should also include an examination of the incremental return for the addition of each new building, these returns vary over a wide range depending on the specific retrofit costs for each building.

Utility owned systems will also benefit from increasing the usage factor. The system usage factor is determined by the end user and is therefore not directly controllable by the energy supplier. However, since the cost of supplying the geothermal energy is a direct function of the usage factor it may be advantageous for the supplier to attempt indirect control by providing cost incentives and/or penalties relating to individual use. More direct control might be achieved by usage agreements that limit the maximum flow to an individual user. This will also benefit the consumers, as higher usage factors will result in lower geothermal energy costs and therefore an improved return on consumer retrofit investment costs. This also provides utilities with an incentive to help consumers conserve geothermal energy by correct equipment selection and proper operation.

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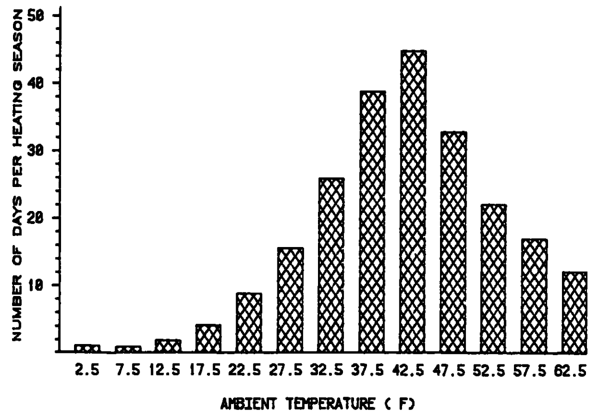

FIGURE 1: DISTRIBUTION OF AVERAGE DAILY TEMPERATURE

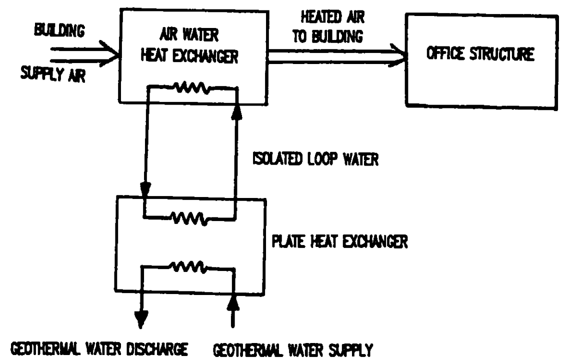

FIGURE 4: GEOTHERMAL HEATING RETROFIT CONFIGURATION FOR A TYPICAL OFFICE STRUCTURE

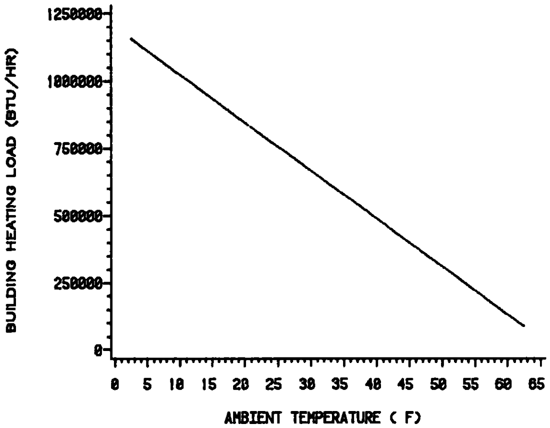

FIGURE 2: BUILDING HEATING LOAD VS. AMBIENT TEMPERATURE

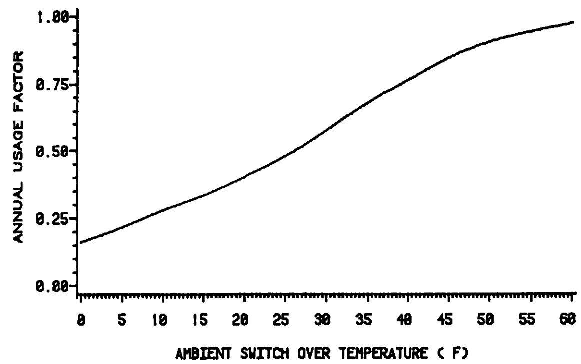

FIGURE 5: ANNUAL USAGE FACTOR VS. AMBIENT DESIGN TEMPERATURE

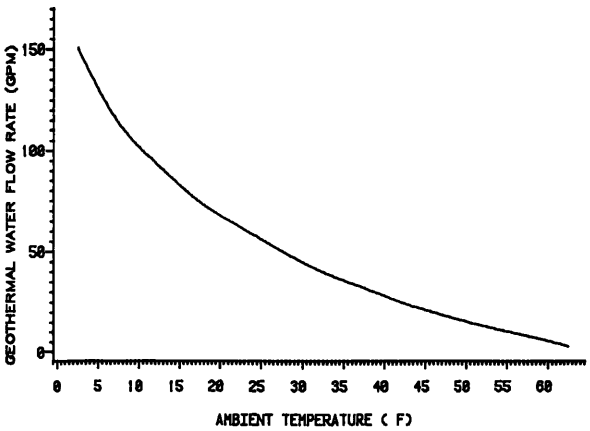

FIGURE 3: GEOTHERMAL FLOW RATE VS. AMBIENT TEMPERATURE

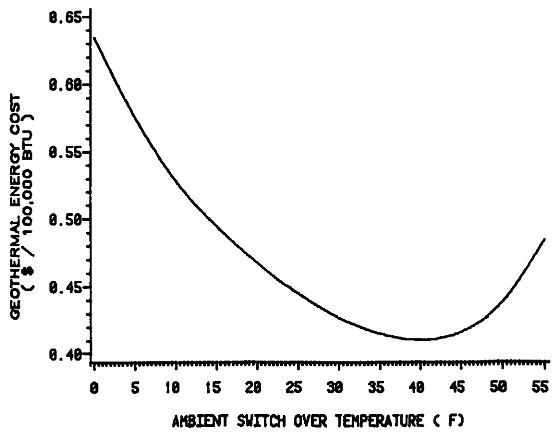

FIGURE 6: GEOTHERMAL UNIT ENERGY COST VS. AMBIENT DESIGN TEMPERATURE