SELECTED COST CONSIDERATIONS FOR GEOTHERMAL DISTRICT HEATING IN EXISTING SINGLE-FAMILY RESIDENTIAL AREAS

Kevin Rafferty
Geo-Heat Center

INTRODUCTION

District heating in existing single-family residential areas has long been considered to be uneconomical due to the low heating load density. In comparison to the typical downtown business districts load density is low; however, there are some characteristics of residential areas which could serve to enhance the economics of district heating.

Among these are:

- Wide variety of heating fuels (and costs) which can result in a range of conventional heating costs of 3 or more to 1 for the same heating load density,
- Availability of unpaved areas for installation of the distribution system,
- Fewer utilities in the pipeline corridor,
- Less traffic control requirements during construction,
- Potential for the use of uninsulated piping, and
- Older, poorly insulated structures with high energy use.

In addition to these considerations, the Geo-Heat Center has recently completed work which identified 271 western U.S. population centers which are collocated with geothermal resources of greater than 50°C. In many of these sites, due to the absence of industrial facilities, district heating would be the most useful application of the resource.

With these factors in mind, this report explores some of the issues related to costs involved in the installation of geothermal district heating (GDH) in existing single-family residential areas.

Using an actual residential area as an example, individual sections of the report examine:

- Distribution piping costs and potential savings areas,
- Central plant vs. individual-home heat exchangers,
- Customer branch lines costs, and
- Current conventional heating costs vs. district system debt service revenue requirements.

DISTRIBUTION PIPING

In order to evaluate the opportunities for cost reductions in distribution piping, it is first necessary to determine the costs associated with conventional construction. To accomplish this, costs from the most recent GDH construction (Klamath Falls city district system line extensions) were used as the basis for conventional construction.

Recent line extensions on this system and others have been of the 6" size and employed preinsulated ductile iron material. Previous work (Rafferty, 1990b) has identified this material as being the least expensive alternative among the preinsulated options for this type of application.

Bids on the recent Klamath Falls work are not broken down by task. As a result, costs for similar installation were calculated using vendor quotes and standard industry estimating handbooks (Means, 1995, 1996). The results of this comparison were quite close (calculated cost $94.51 per foot, actual construction $100 per foot) with the calculated cost slightly less than the actual construction costs. This difference may be attributable to the relatively short length of the extensions compared to the size of a complete system. As a result of the close agreement, the same calculation method was used to develop costs for other line sizes in the 3" to 12" range. These calculations were then compared to the actual bid figures.

Costs for installation of preinsulated distribution piping were broken down into 11 categories: saw cutting of existing pavement, removal of pavement and trench spoils, hauling of pipe (local), trenching and backfill, pipe material, bedding, installation and connection of piping, valves, fittings, traffic control, and paving. Table 1 provides a summary of the current base case costs for installation of preinsulated ductile iron piping.

Figure 1 presents this data in the form of percentages for 6-inch pipe size. The distribution of the costs is fairly stable over the range of pipe sizes. Costs for the pipe and installation constitute a somewhat higher percentage at the upper end of the size range; but, the difference is not significant (50.2% @ 3", 56.9% @ 12").

Table 1. Base Case Cost Summary - Ductile Iron Distribution Piping

	Line Size (Supply and Return)					
	3"	4"	6"	8"	10"	12"
Cut	4.12	4.12	4.12	4.12	4.12	4.12
Remove	2.20	2.20	2.57	2.57	2.90	2.90
Haul	0.71	0.71	0.83	1.14	1.37	1.71
Trench and Backfill	8.83	8.83	10.01	10.01	16.31	16.31
Bed	2.57	2.65	3.84	3.87	3.98	4.06
Pipe (pre-insulated)	27.18	30.75	34.23	45.48	57.63	64.41
Install	10.68	12.53	14.38	22.31	26.45	33.00
Fittings	3.00	3.00	4.17	6.02	8.60	11.15
Valves	1.95	1.95	2.73	4.07	6.13	9.23
Thrust Blocks	0.37	0.37	1.22	2.81	4.44	6.22
Traffic	3.09	3.43	3.93	4.58	5.50	6.87
Repave	10.66	10.66	12.48	12.48	14.08	14.08
Total	75.36	81.20	94.51	119.46	151.51	174.06

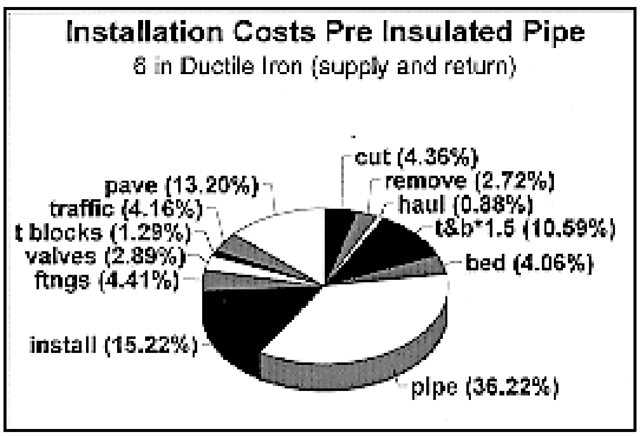

Figure 1.

Potential Cost Reduction

Figure 2 presents a simplified representation of installation costs (6") using only five cost categories. The three largest cost categories, and hence, largest potential areas for cost reduction are: pipe and installation, trenching and backfilling, and pavement related costs.

It is clear that installation in unpaved areas holds the potential of substantial (20%) cost reduction. In downtown business areas, the prospects for installation in unpaved areas is small. In residential areas, however, particularly areas developed prior to the 1960s, it is not uncommon to find unpaved alley ways between each block. Installation of distribution lines in these areas could, depending upon the line size, reduce per foot costs by 12% (12") to 22% (3"). In addition to these savings, it is possible that unpaved areas may not require the level of traffic control assumed for the downtown area in the basic cost calculations. If traffic control can be completely eliminated (such as closing the area during construction), a savings of approximately 4% could be realized.

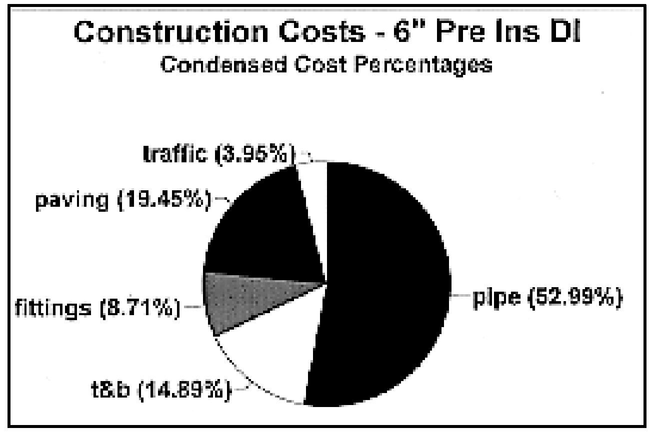

Figure 2.

In the area of trenching and backfilling, there is a small opportunity for cost reduction if the pipeline corridor is free of existing utilities. The costs shown in Table 1 for trenching and backfilling, incorporate a 50% cost penalty for working around existing utilities. It is unlikely, even in residential areas to find a pipeline corridor completely free of obstruction; however, the potential exists for savings, in the 6" size, of up to 3.5% of per foot costs. The savings ranges from 3.9% @ 3" pipe size to 3.1% at the 12" size.

The largest portion of the installed cost is related to the piping itself. The costs for pipe material, hauling, and installation amount to approximately 50% of total costs over the range of piping size (3" through 12") considered in this study. As a result, this area should offer the potential for savings.

Previous work (Rafferty, 1990a; Rafferty, 1989a) has identified preinsulated ductile iron as the lowest cost alternative to the previously used asbestos cement material. As a result, the opportunity to reduce costs through the use of an alternate preinsulated product is unlikely. In some cases, however, it may be possible to reduce costs by using uninsulated piping for distribution.

Due to corrosion considerations, any uninsulated piping would have to be of non-metallic construction. Uninsulated metallic piping operating at temperatures in the 120^{o}F range can experience excessive exterior corrosion due to exposure to soil moisture.

Commercially available non-metallic materials suitable for the application include: fiberglass and CPVC piping. Cross-linked polyethylene (PEX) is a product which is suitable for the temperature and pressures employed in district heating. It is a European product and its availability in this country is limited to preinsulated products in the 4" and smaller nominal size range.

Table 2 presents cost data on uninsulated epoxy adhesive fiberglass piping compared to preinsulated ductile iron.

Table 2. Savings - Uninsulated Fiberglass Return Line

Size	FG Pipe Material	Labor & Joining Materials	Total	Preinsulated DI	$/ft Savings	% Savings
3	9.21	2.39	11.60	18.93	7.33	9.7
4	11.28	3.14	14.42	21.64	7.22	8.9
6	16.56	5.00	21.56	24.30	2.74	2.9
8	27.60	7.05	34.65	33.89	- 0.76	- 0.6
10	40.98	9.89	50.87	42.04	-8.83	- 5.8
12	52.61	12.17	64.78	48.71	-16.07	- 9.2

Notes: Fiberglass piping as per vendor quote +25% O&P. Labor and material for joining epoxy adhesive type fiberglass, includes savings of $0.335/ft (3") and $0.035/ft (4") for elimination of thrust blocks and lower cost fiberglass fittings. Savings percentage indexed to base cost per foot (return line only) in Table 1.

The table assumes the use of only an uninsulated return line. It is also possible to use uninsulated supply; however, the savings of this approach are reduced due to the requirement for installation of temperature-maintenance control valves at strategic points on the system to assure adequate supply temperature to customers. When the control valve costs are deducted from the piping cost savings, the results are marginal to negative. A similar comparison for CPVC piping was made but cost for this material actually exceeded the preinsulated ductile iron costs.

Figure 3 presents a summary of distribution piping costs on a per foot basis for sizes 3" through 12" assuming the optimistic case where all of the potential cost reductions identified in this section could be implemented. These would include: unpaved area for installation, no existing utilities in the pipe line corridor, uninsulated return lines (3" and 4" sizes), and no active traffic control requirement.

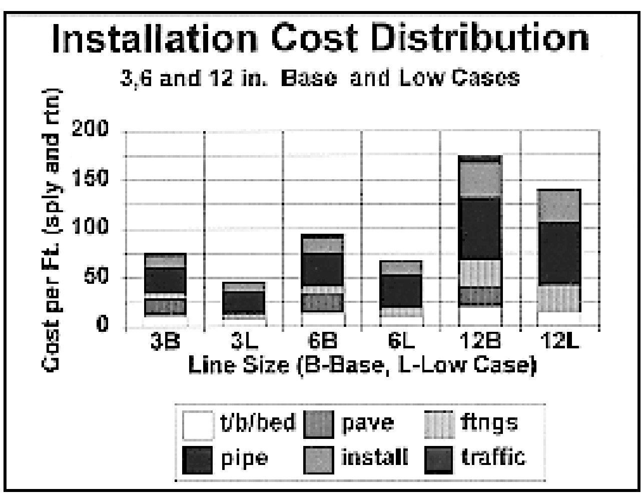

Figure 3.

This figure combines the individual cost areas into six basic groups. It is apparent that the largest savings potential occurs in the smallest piping sizes (3" and 4"), This occurrence benefits the residential distribution case since a majority of the distribution systems piping would be in the smaller pipe sizes.

INDIVIDUAL VS. CENTRAL HEAT EXCHANGER

It is advisable in all geothermal direct use systems to isolate the geothermal fluid from the building heating system it serves. This strategy greatly reduces the extent of geothermal fluid chemistry induced corrosion and scaling in the user's system. In district heating systems, there are two approaches to this isolation:

- Indirect system - central heat exchanger facility with a treated water loop serving the customers, and
- Direct system - geothermal fluid is delivered directly to the customer and an individual heat exchanger (or exchangers) is located at each user.

Due to the economics of scale in large heat exchangers and pumps, it is reasonable to assume that there will be a point when the cost of a large number of individual heat exchangers will exceed that of larger central equipment. This cross-over point is influenced by the loads served along with water temperature.

Space heating in residences is rarely accomplished with hot water heating in the western states. Most homes use some form of forced-air system (heat pump, propane, gas or electric furnace or electric baseboards units).

To accommodate the use of geothermal district heating, heat is transferred from the district system fluid, through the heat exchanger to the house loop. On the building side, a circulating pump provides flow to the terminal unit (or units) after which it is returned to the heat exchanger for reheating. To maintain pressurization, an expansion tank and domestic water pressure reducing valve are included on the loop. A room thermostat controls the circulating pump and heating water control valve on a call for heat.

The space heating equipment required can be reduced substantially if an indirect district system is employed. In this approach, the heat exchanger, expansion tank, pressure reducing valve, city water cross connection and circulating pump along with their associated fittings can be eliminated. For a typical home with a heating system designed for a load of 75,000 Btu/hr, a total of $1250 in mechanical components can be eliminated by using an indirect system design.

In order to eliminate these items, a central heat exchanger plant would be required to provide the same function (isolation of the building system from the geothermal fluid). The central plant would contain the same type of equipment (circulating pumps, heat exchangers, expansion tanks, controls and pressurization equipment), but on a larger, more economical scale.

Figure 4 compares the cost of the individual customer heat exchanger to the cost of the central plant. The plot is based on the assumption of a 75,000 Btu/hr load at each customer. It is apparent that a lower cost results for the use of a central plant under all conditions of 5,000,000 Btu/hr system capacity and above. This would correspond to a customer count of approximately 66 homes. Extrapolating these curves slightly suggests that the break-even point would occur at approximately 3,000,000 Btu/hr system capacity or about 40 homes at 75,000 Btu/hr each.

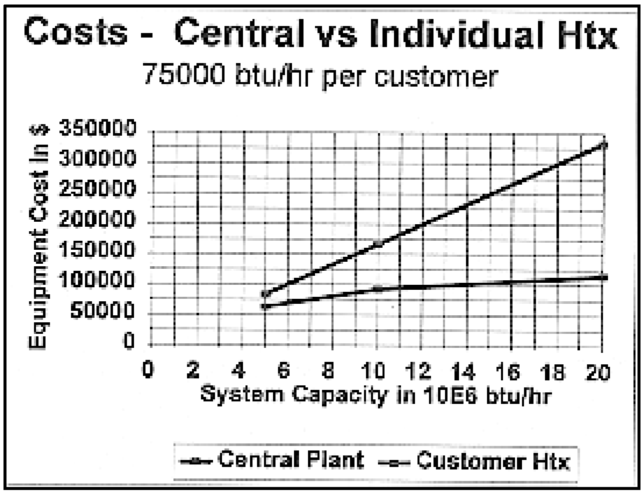

Figure 4.

CUSTOMER BRANCH LINES

One of the major cost items for small customers of a district heating system is branch lines. These lines connect the customer building with a curb valve box (and ultimately the distribution lines in the street).

In a single-family setting, these lines are likely to be a minimum of 60 feet in length (5,000 ft^2 lot with the home placed in center of lot) and due to their size (typically 3/4" to 1 1/2": nominal diameter) varying flow and potential damage to overlying vegetation, insulation is unavoidable.

Assuming a central plant design for the distribution system (treated water to customers), there are three realistic choices for the piping material: preinsulated copper, field insulated copper and preinsulated flexible polyethylene (cross-linked polyethylene or "PEX").

Table 3 provides a summary of the costs for the three materials.

It is apparent that the field insulated copper enjoys a cost advantage over the remaining materials, particularly preinsulated PEX.

Based on the use of the field-insulated copper branch piping, and a distance of 60 ft from the curb box to the house wall, a figure of approximately $1400 per house results.

Table 3. Cost Summary Branch Lines - 1"

	Field Insulated Copper (Type K)	Preinsulated (Type K)	Preinsulated Flexible PEX
Trench	1.30	1.30	1.30
Backfill	2.32	2.32	2.32
Material (pipe)	5.37	16.04	16.85
Insulation (incl. labor)	1.38	--	--
Fittings	--	--	3.45
Installation	9.04	3.35	2.04
Subtotal	19.41	23.01	25.96
20% contingency	3.88	4.60	5.19
Total	23.29	27.61	31.15

Economics of System Development

In order to evaluate the overall economics of district heating in moderate density residential areas, a specific section of Klamath Falls, known as the Mills Addition, provides a convenient example. This area is characterized by relatively small lot sizes (5000 ft^2) and includes unpaved alleyways between each block which could potentially be used for piping installation. This area is representative of similar single-family residential subdivisions in small-to-moderate sized western U.S. cities.

The example area contains 256 homes which average 1100 ft^2> in size. Using a value of 40 Btu/hr per ft^2 (uninsulated walls, single glass, R-19 attic insulation, 1 air change per hour (ACH) and allowing 30,000 Btu/hr for domestic hot water heating, results in a value of 74,000 Btu/hr per home. Using a 70% load diversity factor, the required plant capacity for 256 homes would amount to 13.3 x 106 Btu/hr. From Figure 4, the plant cost for this capacity would be approximately $225,000.

Tables 4 and 5 present a cost breakdown for the distribution system using the base case and low-case costs discussed earlier.

Table 4. Base Case Capital Cost - Mills Addition Distribution

Size	Length	Unit Cost	Total
3"	5,520'	$ 75.36	$ 415,987
4"	1,840'	81.20	149,408
6"	960'	94.51	90,730
8"	160'	119.46	19,114
			675,239
	Branch lines (street to curb box)		128,000
		Total	$ 803,239

Table 5. Low-Case Distribution Capital Cost - Mills Addition

Size	Length	Unit Cost(1)	Totals
3"	5,520'	$45.85	$ 253,092
4"	1,840'	51.63	94,999
6"	960'	67.46	64,762
8"	160'	90.96	14,554
			427,407
	Branch lines (street to curb box)		128,000
		Total	$ 555,407

(1) Assumes unpaved area, no existing utilities, uninsulated return line (3" and 4"only), no traffic control requirements.

Resource development costs can vary widely. To evaluate these costs a spreadsheet previously developed by the Geo-Heat Center (Rafferty, 1995) was used to evaluate several alternatives.

Table 6 presents the alternative cases considered for resource development.

Table 7 summarizes the range of costs for the three major portions of the district system. The low case assumes minimum resource development costs and distribution system installation costs. The high case incorporates the maximum value (used in this report) for resource development and distribution.

Table 7. Expected Cost Range for 256 Homes GDH System

	Low	High
Resource	$ 140,000	$ 540,000
Central plant	225,000	225,000
Distribution	555,000	803,000
Total	$ 920,000	$ 1,568,000

Given the range in potential capital costs to implement the system, it is possible to calculate the required revenue to support the financing of this cost. At prevailing interest rates (8%), the revenue required to cover the debt service only would amount to between $86,800 and $148,000. Assuming 75% subscribership, the necessary revenue per home would amount to a range of $452 to $771 (the low and high cases respectively).

In order to evaluate the feasibility of district heating, it is necessary to determine the current conventional heating costs in the service area. Previous work by the Geo-Heat Center (Rafferty, 1992) has identified an energy consumption for all gas homes in this area of approximately 0.80 therms per square foot for space and domestic hot water heating. Table 8 presents the current cost data for meeting the same loads based on the use of different fuels and fuel combinations.

Table 6. Variations in Geothermal Resource Development Costs

Well depth (ft)	1500	1000	1000	2000	2000	500	500
Water temperature (F)	170	170	170	170	170	170	170
Delta T (F)	40	50	40	50	40	50	40
Injection	Y	N	Y	N	Y	N	Y
Pumping required	Y	Y	Y	Y	Y	Y	Y
No. production wells	2	1	1	1	2	1	2
No. injection wells	1	0	1	0	1	0	1
Static level (ft)	200	200	200	300	300	100	100
Cost ($)	$406,000	230,000	390,000	330,000	540,000	140,000	310,000

Table 8. Annual Conventional Heating Costs

Fuel	$/yr
All gas	484
Gas with electric hot water	638
50% gas/50% wood/gas hot water	439
Fuel oil with electric hot water	716
50% fuel oil/50% wood/electric hot water	632
All propane	977
50% propane/50% wood/electric hot water	763
All electric	1,053
50% electric/50% wood/electric hot water	801

Notes:
Fuel oil @ $0.95/gal
Natural gas @ $0.55/therm
Propane @ $1.00/gal
Electricity @ $0.06/kWh
DHW @ 55° / 130°, 65% efficiency (fuels),
48 therms (840 kWh) standby tank loss
Fossil fuels @ 70% efficiency, wood @ 50% efficiency

For systems serving more than about 40 homes (@ 75,000 Btu/hr per home), an indirect distribution design (incorporating central heat exchangers) results in a lower total cost than a direct design (in which the geothermal fluid is delivered to the customer).

Branch service lines on the customer's property, are a significant cost item. Of the three principal piping installation methods available, preinsulated copper, field insulated copper and preinsulated flexible polyethylene (PEX), the field insulated copper has the lowest installed cost at approximately $23.00 per lineal foot (for supply and return).

Based on the example residential area evaluated in this paper, it appears that geothermal district heating in existing single-family residential areas could be feasible in situations where:

- Propane, fuel oil and electricity (or combination of these fuels with wood) dominate the conventional heating used,
- Small lot sizes (<5,000 ft^2),
- Subdivisions where unpaved areas are available for installation of some or all of the distribution system, and
- Customer penetration rate is high (>=75%).

REFERENCES

Lienau, P. and H. P. Ross, 1995. "Low-Temperature Resource Assessment Program," Geothermal Resources Council Transactions, Vol. 19, Geothermal Resources Council, Davis, CA.

Means, R. S., Co., 1996. Means Mechanical Cost Data-1996, 19th ed., R. S. Means Co., Inc. Kingston, MA.

Means, R. S., Co., 1995. Means Site Work and Landscape Cost Data-1995, R. S. Means Co., Inc., Kingston, MA.

Rafferty, K., 1995. "A Spreadsheet for Geothermal Direct Use Cost Evaluation." Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.

Rafferty, K., 1992. Unpublished report to city of Klamath Falls regarding billing options for Michigan Street residences. Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.

Rafferty, K., 1990a. "An Overview of U.S. Geothermal District Heating Systems," ASHRAE Transactions, Vol. 98, Part 2, American Society of Heating, Refrigerating and Air Conditioning Engineers.

Rafferty, K., 1990b. "Should You Go Bare - The Feasibility of Uninsulated Piping - A Spreadsheet," Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.

Rafferty, K., 1989a. "Geothermal District Piping - A Primer," Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.

Rafferty, K., 1989b. "A Material and Equipment Review of Selected U.S. Geothermal District Heating Systems, " Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.