Chapter 2.8

THE ECONOMICS OF GEOTHERMAL HEAT PUMP SYSTEMS FOR COMMERCIAL AND INSTITUCIONAL BUILDINGS

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Introduction

Geothermal heat pump (GHP) systems first became popular in the 1950s after the initial introduction of the technology at the Commonwealth Building in Portland, Oregon, in the U.S. Numerous replications of that system, dating from about the same time, can be found throughout the western United States, serving a number of commercial and institutional buildings and complexes. Another resurgence in the development of GHP systems came following the oil crises of the 1970s when fears over rising costs and the availability of energy drove developers to look to systems that used indigenous resources. First cost, although still important, took a back seat in comparison to many other factors. However, after nearly 50 years of use, geothermal heat pumps still make up only a small percentage of heating, ventilation, and air conditioning (HVAC) installations. A lack of information and understanding relative to capital, operating, and maintenance costs, appear to stand in the way of more universal acceptance of the technology. A number of recent analyses and research studies as well as a number of case studies have now begun to shed light on the economics of geothermal heat pump systems versus various other HVAC system alternatives. This paper draws heavily from work prepared for Lockheed Martin Idaho Technologies Company (Moore, 1999), case studies completed by the author (Bloomquist, 1999), and a number of reports by the U.S. Department of Energy.

Cost Factors

In order to compare the economics of geothermal heat pump systems to other HVAC alternatives, a direct comparison must be made between capital costs, operating costs, and maintenance costs. Once a clear understanding of the relative costs associated with the various alternatives is established, it is then possible to use the information to conduct a simplified life cycle cost analysis in order to compare the relative costs of the alternatives.

Capital Costs

Capital costs for geothermal heat pump systems are normally thought to exceed the cost of most, if not all, of the alternative HVAC systems. However, as can be seen from Table 1 (Moore, 1999), there is considerable variability in the capital costs associated with installation in various building types and as much variability in capital cost dependent upon ground loop type. Other variations in capital cost can be attri-

buted to the degree of difficulty in drilling (rock or soil type), and especially due to availability and experience of drilling con--tractors in drilling bores and installing downhole loops. Another major factor is ground or water temperature. In the case of the use of vertical loops, the thermal conductivity of grouting material can also play a major role as significant reductions in bore length may be achievable through the use of high-conductivity grouts.

Table 1
GHP System Capital Costs by Building and Ground Loop Type

Average of:	GHP HVAC Capital Cost, $/ft^2 (# of data points)	GHP HVAC Capital Cost, $/cooling ton (# of data points)
All Case Studies and References	$100.10 (72)	$3,593 (55)
Building Type		
Schools	$115.40 (32)	$3,572 (24)
Office Buildings	$85.00 (13)	$3,518 (11)
Retail	$35.90 (5)	$3,841 (3)
Medical Centers	$84.10 (2)	$2,839 (2)
Retirement	$126.20 (3)	$3,917 (2)
Apartment/Multi-Residential	$100.00 (2)	$3,707 (2)
Prisons	$134.90 (3)	$4,622 (2)
Gas Station/Convenience Store	$232.40 (1)	$6,833 (1)
Ground Loop Type		
Vertical Closed Loop	$117.90 (50)	$3,874 (39)
Horizontal Closed Loop	$55.10 (8)	$2,512 (6)
Vertical Open/Groundwater	$55.00 (7)	$2,987 (5)
Hybrid (Vertical closed loop and cooling tower)	$112.70 (1)	$5,152 (1)

On a US$ per square meter basis, GHP capital costs average $100+/m^2, ranging from a low of 35.9/m^2 for commercial space to as much as $134.90/m^2 for correctional facilities (Moore, 1999). The low and high GHP costs represent fairly atypical applications (Moore, 1999) found that the capital cost for retail space was skewed by several buildings that also included relatively large areas of warehouse or service spaces that were either unconditioned or under-conditioned. This, of course, tended to result in a very low capital cost per square meter. At the other end of the spectrum, correctional

facilities and gas station/convenience stores have capital costs higher than average; with correctional facilities, this is attributable to the complexity brought about by security concerns and with gas stations/convenience stores, the floor area is small compared to the load. This load can include car wash, refrigeration, etc. (Moore, 1999). The GHP capital cost information found in Table 1 was somewhat tempered by information providing designs of GHP as well as conventional HVAC systems. Phil Schoen of Geo-Enterprises found that in the Oklahoma City School District, an area with

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a well-developed infrastructure of drillers and system installers that installed, costs ranged from $120 to $150 per square meter, including full direct digital control (DDC). However, by controlling the GHC system with simple, programmable thermostats instead of full DDC, that the cost could be lowered to about $100/m^2. Robert Dooley of R. J. Dooley and Associates found that GHP systems for schools ran about $120/m^2 (Dooley, 1998).

Vertical, closed-loop, ground loop systems are the most expensive (Table 1) due to the high cost of drilling. However, if the total number of vertical feet can be reduced through the use of enhanced thermal conductivity grouts, then the cost of drilling can

Figure 1A: GeoExchange Capital Cost by Building Type

be significantly reduced (Allen and Kavanaugh, 1999). Hybrid systems consisting of a vertical closed-loop combined with a conventional cooling tower were also found to be on the high end of the capital cost scale.

Capital costs for horizontal, closed-loop systems averaged less than 50 percent of the cost of the vertical, closed-loop systems. However, for large installations, it may be impossible to find adequate areas for the installation of a horizontal closed-loop system, and for retrofit applications, this is

nearly always the case. One exception to this may be schools whose sport or play fields may provide the required open areas for horizontal systems.

An example of a system built without adequate area for a horizontal loop can be found in Walla Walla, Washington. The local Public Utility District decided to go with GHP and a horizontal loop layout for the heat exchanger. However, due to space limitations, the loop was installed in layers with approximately one vertical meter separating each of the loops. Unfortunately, due to soil conditions and the inadequate loop separation, the system did not achieve the heat exchange capacity necessary to operate t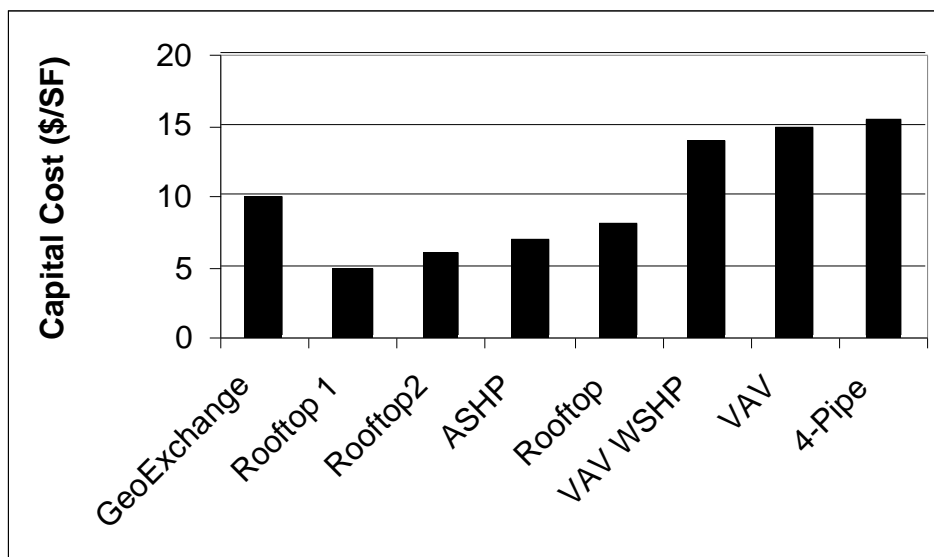he system efficiently and temperatures in the loop reached a summer high of 126°F and a winter low of 18°F. As was noted above, the capital cost per meter associated with gas stations/convenience stores is significantly above the average for GHP systems. However, such installations are a very promising and rapidly growing segment of the industry. These facilities integrated not only heating and cooling, but ice making, refrigeration, snow melting, and often the heating of water for an associated car wash. While the installed costs per square meter were relatively high due to the need for an extensive ground-loop system to handle the various loads. GHP systems have been found to be both cost effective and

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easily adapted to the needs of the particular installation. Among the major oil compani-
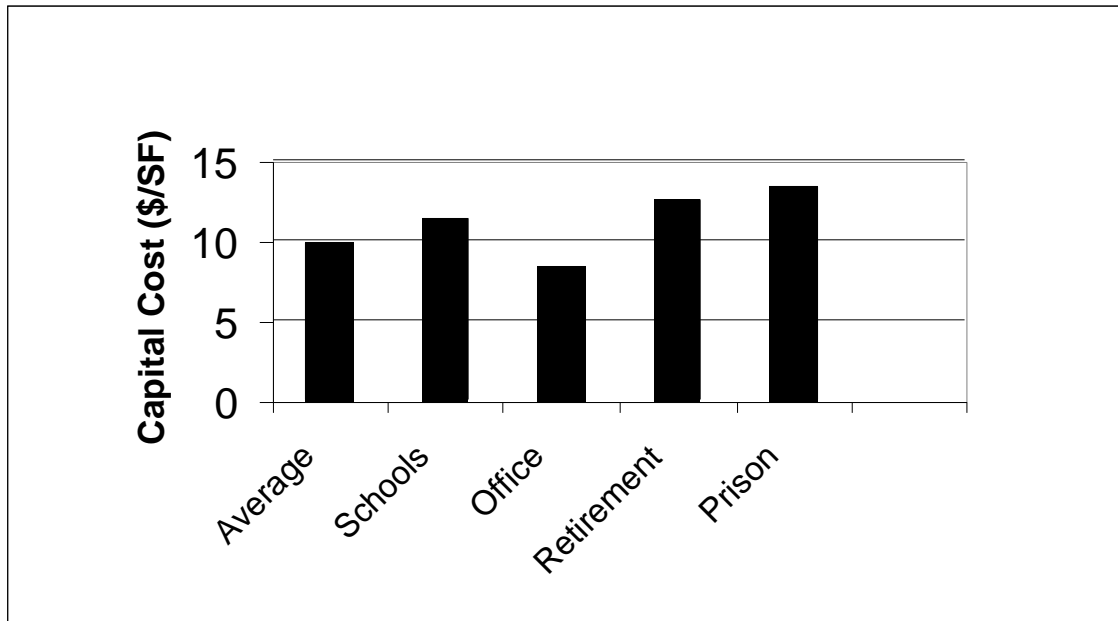

Figure 1B: Operating and Maintenance Costs by Building Type

es, Phillips 66, Texaco, and Conoco have led the way by installing GHP systems at multiple facilities.

For comparison purposes, the capital cost of conventional HVAC systems are provided in Table 2 (Moore, 1999). With an average cost of only $52/m^2, rooftop units with electric resistance heating and electric cooling have the lowest capital costs. When the electric resistance heating unit is repla-

ced with gas heating, the cost increases to $61/m^2. The four-pipe fan coil system was found to be the most expensive at 170.70 $/m^2. Variable air volume (VAV) systems with electric chiller, cooling tower, and gas boiler come in at $161.60/m^2, and water-source (often referred to as a California heat pump system) with a gas boiler and cooling tower to temper the circulating loop come in at 133.40 $/m^2.

Table 2
Capital Costs of Conventional HVA Systems

HVAC System Type	Capital Cost, $/SF (# of data pts)
Rooftop DX (direct expansion) with electric heating	$52.00 (2)
Rooftop DX with gas heating	$61.00 (5)
Air-source heat pump	$74.70 (3)
Rooftop variable air volume (VAV)	$86.10 (4)
Water-source heat pump with gas boiler & cooling tower	$133.40 (11)
Central VAV with chiller, cooling tower, & gas perimeter heat	$161.60 (8)
Four-pipe fan coil unit with electric chiller & gas boiler	$170.70 (8)

The capital cost for conventional HVAC systems, as seen in Table 2, was found by Moore (1999) to agree with the experience of HVAC designers he interviewed. For example, a rooftop unit systems with electric cooling and gas heating runs about 70.00 $/m^2 in Oklahoma City, Oklahoma, depending upon complexity of the installation and

controls selected. A standard air-source heat pump system was found to run approximately $80 - $90/m^2, and a two-pipe or four-pipe system with a chiller, cooling tower, and central boiler cost from $150 - $180/m^2.

Figure 2: **Capital Cost by HVAC System Type**

NOTE: Rooftop1 = Rooftop DX with electric heat VAV = Variable air volume
Rooftop 2 = Rooftop DX with gas heat WSHP = Water-source heat pump
ASHP = Air-source heat pump

Another source of data on equipment cost is the *Mechanical Cost Data* published by the R. S. Means Company, Inc., of Kingston, Massachusetts. The Means data is regionalized and published yearly, and is the accepted standard for cost estimating. Table 3 presents typical means data for simple rooftop systems and includes material, labor and

Table 3
Capital Costs of Rooftop Units from RS Means

Rooftop Unit and Building Type	Capacity Range (tons)	Refriger. (tons)	kW	Refriger. (tons)	kW	Small Capacity ($/SF)	Large Capacity ($/SF)
SINGLE ZONE							
Offices	1.58 to 31.67	1.58	5.56	31.67	111.38	$113.60	$72.90
Schools and Colleges	1.92 to 38.33	1.92	6.75	38.33	134.81	$137.90	$87.50
Medical Centers	1.17 to 23.33	1.17	4.11	23.33	82.05	$83.70	$55.40
Department Stores	1.46 to 29.17	1.46	5.13	29.17	102.59	$104.60	$67.20
MULTIZONE							
Offices	9.5 to 79.16	9.5	33.41	79.16	278.41	$185.50	$118.50
Schools and Colleges	11.5 to 95.83	11.5	40.45	95.83	337.03	$198.00	$144.00
Medical Centers	7 to 58.33	7	24.62	58.33	205.15	$136.60	$87.30
Department Stores	8.75 to 72.9	8.75	30.77	72.9	256.39	$170.50	$109.00

contractor overhead, and profit. The costs as shown are for single-zone rooftop
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systems in the larger capacity ranges and correlates well with the costs in Table 2

Operating Costs

Operating costs summarized in Table 4 are a mixture of actual utility bills and engineering estimates. Most of the GHP operating cost data gathered by Moore (1999) was gathered from case studies and represents actual costs. Most of the operating costs for conventional HVAC systems, on the other hand, are engineering estimates developed during the analysis prior to selection of the GHP alternative. Some of the case studies, however, were based on retrofits of existing

systems, thus providing the opportunity to compare the GHP system to the system that was replaced.

Unfortunately, Moore (1999) was unable to obtain operating cost data for each and every building type for which capital cost data was available.

For all GHP systems evaluated, energy operating costs averaged 8.0/m^2/year, while the mixture of conventional HVAC system types averaged $11.20/m^2/year. This is an

average across the board savings in operating costs of 29 percent. GHP applications in schools and retail space were found to have the lowest energy operating cost on average ($5.90 and $5.80/m²/year, respectively).
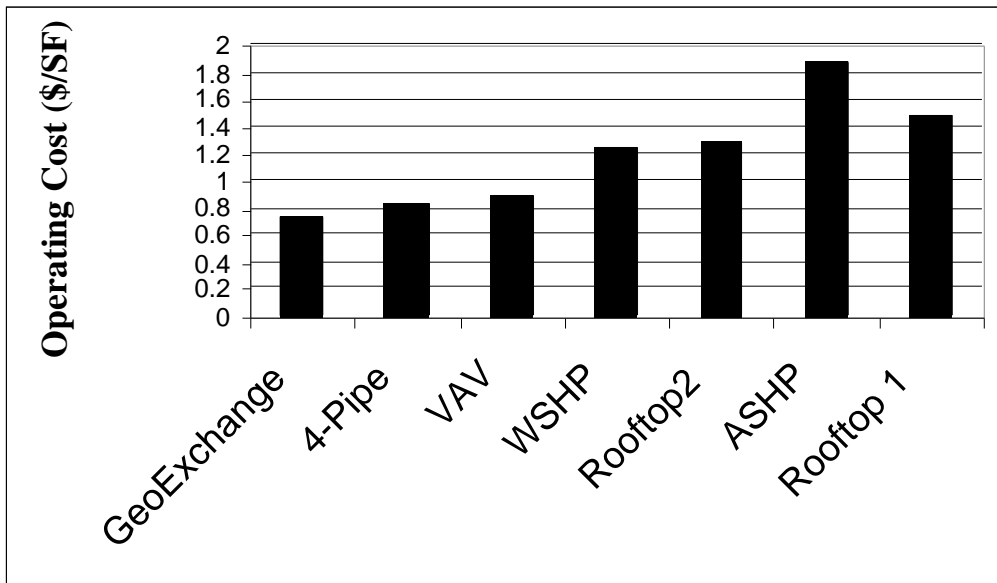

Figure 3: **Operating Costs by HVAC System Type**

NOTE: Rooftop1 = Rooftop DX with electric heat   VAV = Variable air volume
Rooftop 2 = Rooftop DX with gas heat   WSHP = Water-source heat pump
ASHP = Air-source heat pump

Table 4
**GeoExchange and Conventional HVAC System Energy Costs by Building
And Ground-Loop Type**

Weighted Average of:	Building Energy Costs, $/SF/YR (# of data points)		
	GeoExchange	Conventional HVAC	Savings
Building Type			
All Sites and References	$8.00 (52)	$11.20 (42)	29%
Schools	$5.90 (22)	$9.20 (19)	36%
Office Buildings	$9.90 (10)	$13.90 (8)	29%
Retail	$5.80 (4)	$9.50 (3)	39%
Retirement	$9.50 (2)	$13.30 (3)	26%
Prisons	$11.90 (2)	$12.20 (1)	2%
Gas Station/Conv. Store	$89.90 (1)	$122.30 (1)	26%
Ground Loop Type			
Horizontal Sites	$4.70 (6)	$8.90 (3)	47%
Vertical Sites	$8.20 (34)	$11.30 (33)	27%
Groundwater Sites	$8.10 (6)	$10.50 (3)	23%

GHP technology saved schools 36 percent in energy operating costs. Since most schools are unused or underutilized during the summer months, both GHP and conventional HVAC energy costs are on the low end of the spectrum, largely because of the lack of summer air conditioning requirements.

As was the case with capital costs for retail space, GHP operating costs are also skewed by buildings that include warehouse and service areas that are either not cooled or under conditioned. This drives down the operating cost per square meter. However, even in these atypical situations, GHP systems were found to provide a cost savings of 39 percent.

Moore (1999) found that in correctional facilities, GHP systems resulted in only a 2 percent cost savings as compared to the conventional HVAC systems.

Unfortunately, the comparison involved only three systems and may not be representative.

As was the case with capital costs, operating costs per square meter for integrated CHP applications in gas stations/convenience stores is very high compared to systems that provided only heating, cooling, and domestic hot water. The high operating cost is attributed to additional loads for ice making, refrigeration, snow melting, and provision of hot water for car washes.

Table 5 compares the energy operating cost developed by Moore (1999) for GHP systems to conventional HVAC system types. He included only data for those applications for which energy costs were available for both GHP and conventional HVAC system.

Table 5
**GeoExchange and Conventional HVAC System Energy Costs by
Conventional HVAC System Type**

Conventional HVAC System Type	Building Energy Costs, \$/SF/YR (# of data points)		
	GeoExchange	Conventional HVAC	Savings
Rooftop DX with gas heating	\$9.70 (4)	\$12.50 (4)	22%
Rooftop DX with electric heating	\$12.10 (2)	\$17.50 (2)	31%
Air-source heat pump	\$8.70 (3)	\$14.80 (3)	41%
Water-source heat pump	\$7.30 (3)	\$9.00 (3)	30%
Four-pipe fan coil unit	\$6.30 (6)	\$8.60 (6)	27%
Two-pipe fan coil unit	\$4.90 (4)	\$6.00 (4)	18%

1) DX = direct expansion
2) The water-source heat pump system includes a cooling tower and gas boiler
3) The central VAV system includes an electric chiller, cooling tower, and gas-fired perimeter heating or hot water reheat
4) Four-pipe and two-pipe systems have an electric chiller and gas boiler

Maintenance Costs

Maintenance cost data has been the most difficult to obtain and was available to Moore (1999) for only a limited number of systems (Table 6). However, since completion of his research, a major effort to gather such information was initiated by the Geo-

thermal Heat Pump Consortium and by the United States Department of Energy. A great deal of this work was undertaken on behalf of both organizations by the author (Bloomquist, 1999) (Table 7). In addition, ASHRAE is currently sponsoring a project to update the maintenance data presented in the 1991 and 1995 editions of the ASHRAE

Application Handbook. That information was originally gathered during the 1985-86 study by Dohrmann and Alereza of ADM Associates, Inc. A new publication on GHP maintenance requirements and cost is expected to be released by ASHRAE in 2001 or early in 2002.

Moore (1999) relied primarily on maintenance costs for GHP systems developed during a 1997 Caneta Research study sponsored by the Geothermal Heat Pump Consortium. For comparison to conventional HVAC systems, the Caneta Research study relied on maintenance costs from the 1985-86 study by Dohrmann and Alereza.

The Caneta study concluded that the ASHRAE data from Dohrmann and Alereza are dated and reflected the maintenance costs for older equipment approaching the end of its useful life. As would be expected, equipment nearing the end of its useful life would require much more maintenance and repair than, for example, the average five-year-old equipment that made up the bulk of the GHP system evaluated by Caneta. However, even if the mean GHP maintenance cost of $1.01/m^2 were doubled in a crude attempt to account for equipment age, maintenance costs would still be 39% less than
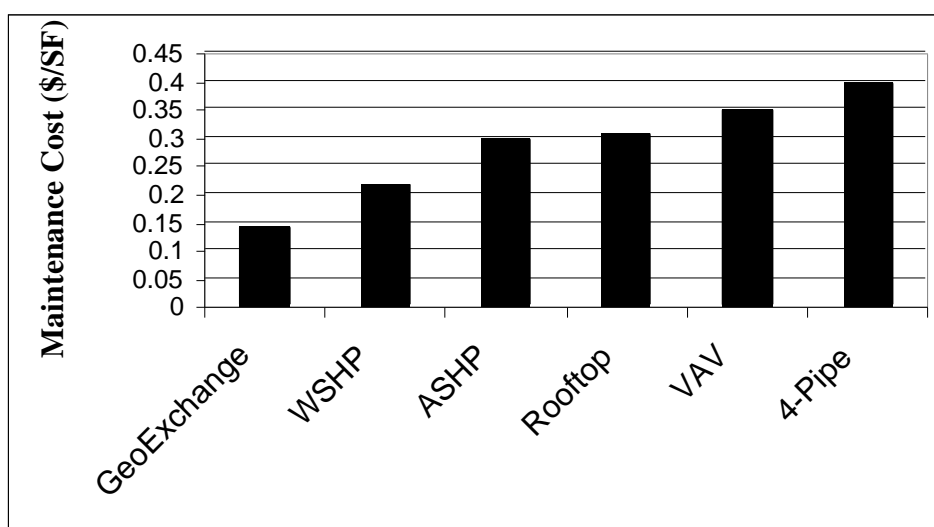

Figure 4: **Maintenance Costs by HVAC System Type**

NOTE: Rooftop = Rooftop DX with gas heat   VAV = Variable air volume
        ASHP = Air-source heat pump   WSHP = Water-source heat pump

Table 6
Comparison of Total Maintenance Costs by System Type

Equipment Type	No. of Bldgs.	Avg. Age	Mean Maint. Cost (¢/SM/YR)	Maint. Cost Range (¢/SM/YR)	Mean Maint. Cost, 97$ (¢/SM/YR)
Geothermal Heat Pump[a]	25	5.0	1.00[c]	.05-3.47[C]	1.00
Water-Source Heat Pump[b]	17	17.5	2.18[d]	.20-7.50[d]	3.33
Packaged Air-to-Air Heat Pump[b]	10	1.51	3.30[d]	1.10-6.20[d]	5.03
Split Syst Air-to-Air Heat Pump[b]	6	23.7	2.64[d]	.96-4.93[d]	4.02
Reciprocating Chiller[b]	76	22.2	2.88[d]	.59-14.03[d]	4.39
Centrifugal Chiller[b]	207	20.7	3.63[d]	.16-26.60[d]	5.53

Absorption Chiller[b]	27	29.3	5.22[d]	.62-12.62[d]	7.96

Notes:
a)   Average of in-house (incl. overhead and benefits) and contractor (incl. overhead and profit) total maintenance costs for most recent year of Caneta Research study.
b)   Data for conventional HVAC systems in Caneta Research Study come from Analysis of Survey Data on HVC Maintenance Costs, ADM Associates, Inc., prepared for ASHRAE Technical Committee 1.8, December 1985.
c)   1997 dollars
d)   1983 dollars

Source: *Survey and Analysis of Maintenance and Service Costs in Commercial Building Geothermal Systems*, D. Cane, A. Morrison, B. Clemes, C. Ireland, Caneta Research Inc., for the Geothermal Heat Pump Consortium, RP-024, Revised October 1997.

for a water source (California system) heat pump system according to the ASHRAE data. This author found that even systems over 30 years old had maintenance costs that average __/m^2 (Table 7). The GHP maintenance costs could be tripled and still save 45 percent compared to ASHRAE's data for a centrifugal chiller system (Moore, 1999).

Table 7
Geothermal Heat Pump System Maintenance

Site	Date GSHP Installed	Square Footage	Heat Pump Capacity	kW	Tons/ 1,000 Square Foot	Maintenance Cost $0.00/Square Foot/Y
Beaver Lake Middle School	1994	109,000	250 tons	879	2.29	0.23 – 0.35
Bryant College	1996	41,390	80 tons	281	1.94	0.01
Clark County PUD Administration	1957 1989****	32,000	100 tons	352	3.13	0.50
Exchange Building	1971	265,000	1,094 t.	3,848	3.98	0.16
Grant County Courthouse	1982	52,000	300 tons	1,055	5.77***	0.11
Haverhill Public Library	1994	44,000	107.5 tons	378	2.43	0.09 – 0.14
Heritage College Library	1991	17,400	48.5 tons	171	2.66	0.64[1]
Inn of the Seventh Mountain	1992	228,800	500 tons	1,759	1.79	0.16
Kittitas Middle School	1991	39,000	84 tons	295	2.15	0.20
LDS Office Tower	1972	683,000	2,250 tons	7,913	3.30	0.13 – 0.15
Lane Community College	1981	58,000	110 tons	387	1.55	0.12[2]
North Bonneville City Hall	1995	46,000	10 tons	35	2.17	0.05
Parkview Apartments	1965	207,400	400 tons	1,407	1.93	0.12 – 0.15
Squaw Valley Day Care	1993	23,000	40,000	141	1.66	0.02 –

						0.03
Sundown M Ranch	1985	61,800	199	700	3.22	0.12 –
	1990	20,650	56	197	3.71	0.15
	1992	39,736	149	524	3.75	total
	1995	7,500	29	102	3.87	square
						footage
Tacoma City Light	1954	130,000	350 tons	1,231	2.69	0.51
Tower Building	1980	133,000	300 tons	1,055	2.25	0.11
Walla Walla Community College	1974	100,000	600 tons	2,110	6.00****	0.10 - 0.15
Walla Walla Corps of Engineers	1995	91,432	600 tons	2,110	3.13	0.57*
Whitman College Science Building	1964	88,000	120 tons	422	1.36	0.05
Whitman College Administration Building	1988	30,000	100 tons	352	3.33	>0.10
Yakima County Correctional Facility	1983	180,000	300 tons	1,055	1.66	0.06 – 0.08

* Maintenance contract.

** Includes $0.025/square foot/year for chemical treatment.

*** System was designed to provide for a law and justice center that was never connected to the system. 150 tons or 2.88 tons per square foot meets the requirements of the buildings connected to the system.

**** System designed to meet future expansion of the college campus that did not occur.

***** Original configuration was 100 ton centrifugal chiller rented in 1989 with two 30-ton and two 20-ton reciprocating compressors.

Economic Analysis

Moore (1999) collected capital and operating and maintenance costs for GHP systems and various types of conventional HVAC systems. From this data, he was able to conduct simplified life-cycle cost analyses for SN HVAC system types. These systems were:

1. Geothermal heat pump,
2. Rooftop DX with gas heating,
3. Air-source heat pump,
4. Water-source (California type) heat pump
5. Central variable air volume, and
6. Four pipe

Table 8
GeoExchange and Conventional HVAC System Maintenance Costs by Building and System Type

Weighted Average of:	Maintenance Costs, $/SF/Yr (# of data points)		
	GeoExchange	**Conventional HVAC**	**Savings**
All Sites and References	$1.40 (13)	$3.60 (15)	61%
Building Type			
Schools	$1.30 (10)	$3.70 (11)	65%
Office Buildings	$2.70 (1)	$3.40 (1)	21%
Retirement	$1.00 (1)	$2.50 (2)	60%

Prisons	$1.50 (1)	$4.80 (1)	69%
Conventional HVAC System			
Rooftop DX with gas heating	$1.10 (1)	$3.30 (1)	67%
Air-source heat pump	$1.10 (1)	$3.00 (1)	63%
Water-source heat pump	$1.50 (4)	$2.30 (4)	35%
Central variable air volume (VAV)	$1.10 (1)	$3.50 (1)	69%
Four-pipe fan coil unit	$1.70 (5)	$4.00 (5)	58%
Two-pipe fan coil unit	$.80 (1)	$3.10 (1)	74%

Table 9
GeoExchange and Conventional HVAC System Maintenance Costs Estimated by GeoSchool Software

HVAC System Type	Maintenance Costs, $/SF/YR	Savings with GeoExchange
GeoExchange	$1.10	n/a
Water-source heat pump	$2.50	56%
Air-source heat pump	$3.00	63%
Rooftop DX with gas heating	$3.30	67%
Central variable air volume (VAV)	$3.50	69%
Four-pipe fan coil unit	$3.60	69%

Source: GeoSchool software was provided by R.J. Dooley & Associates. Software development was sponsored by the Geothermal Heat Pump Consortium.
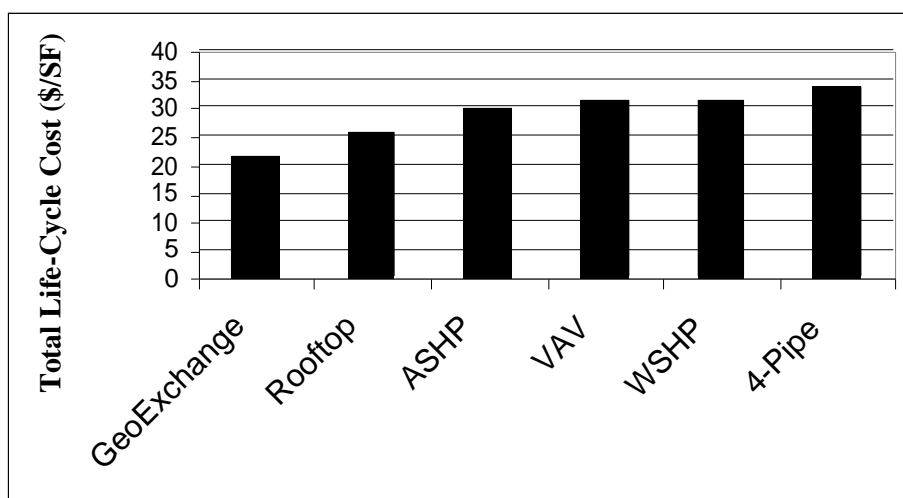

Figure 5: **Total Life-Cycle Costs**

NOTE: Rooftop = Rooftop DX with gas heat   VAV = Variable air volume
ASHP = Air-source heat pump   WSHP = Water-source heat pump

The results of the life-cycle cost analyses are shown in Table 10. Two different discount rates (4.5% and 6%) were chosen for the analyses. In selecting the discount rate, Moore (1999) originally considered two standard rules of thumb: (1) the prime rate plus 1 percent, and (2) the 30-year treasury bond rate plus 1 1/2 percent. However,

both seemed to be excessive, 7.75 and 6.81 percent, respectively, while the 30-year mortgage rate was at 6 1/2 percent. Since he believed that developers of commercial buil- dings could borrow money at rates below conventional mortgage rates, he finally decided on the low and high cases represen- ted by the 4.5 and 6 percent direct rates.

Table 10
Life-Cycle Cost Analysis

System Type	Capital Cost ($/SF)	Operating Cost ($/SF/YR)	Maintenance Cost ($/SF/YR)	Simple Pay back (years)	20-Year Present Value of Operating Costs ($/SF)	20-Year Present Value of Maint. Costs ($/SF)	Total 20-Year Life-Cycle Cost, or LCC ($/SF)	Savings
4.5% Discount Rate, No Operating or Maintenance Cost Escalation								
GeoExchange	$100.10	$8.00	$1.40	n/a	$104.10	$18.20	$222.40	n/a
Rooftop DX w/ gas	$61.00	$12.50	$3.30	6.11	$162.60	$42.90	$266.50	22%
ASHP	$74.70	$14.80	$3.00	3.02	$192.50	$39.00	$306.20	32%
WSHP	$133.40	$12.40	$2.30	immed.	$161.30	$29.90	$324.60	36%
VAV	$161.60	$9.00	$3.50	immed.	$117.10	$45.50	$324.20	36%
Four-Pipe	$170.70	$8.60	$4.00	immed.	$111.90	$52.00	$334.60	38%
6.0% Discount Rate, No Operating or Maintenance Cost Escalation								
GeoExchange	$100.10	$8.00	$1.40	n/a	$91/8	$16.1	$207.90	n/a
Rooftop DX w/gas	$61.00	$12.50	$3.30	6.11	$143.40	$37.90	$242.20	14%
ASHP	$74.70	$14.80	$3.00	3.02	$16.98	$34.40	$278.90	14%
WSHP	$133.40	$12.40	$2.30	immed.	$142.20	$26.40	$302.00	31%
VAV	$161.60	$9.00	$3.50	immed.	$103.20	$30.10	$305.00	32%
Four-Pipe	$170.70	$8.60	$4.00	immed.	$98.60	$45.90	$315.20	34%
4.5% Discount Rate, 2.0% Operating and Maintenance Cost Escalation								
GeoExchange	$100.10	$8.00	$1.40	n/a	$125.30	$21.9	$247.30	n/a
Rooftop DX x/ gas	$61.00	$12.50	$3.30	6.11	$195.80	$51.70	$308.50	33%
ASHP	$74.70	$14.80	$3.00	3.02	$231.80	$47.00	$353.50	41%
WSHP	$133.40	$12.40	$2.30	immed.	$194.20	$36.00	$363.60	43%
VAV	$161.60	$9.00	$3.50	immed.	$141.00	$54.80	$357.40	42%
Four-Pipe	$170.70	$8.6	$4.00	immed	$134.70	$62.60	$368.00	44%
6.0% Discount Rate, 2.0% Operating and Maintenance Cost Escalation								
GeoExchange	$100.10	$8,00	$1.40	n/a	$109.50	$1.92	$22.87	n/a
Rooftop DX w/ gas	$61.00	$12.50	$3.30	6.11	$171.10	$45.20	$277..20	25%
ASHP	$74.70	$14.80	$3.00	3.02	$202.50	$41.10	$318.30	35%
WSHP	$133.40	$12.40	$2.30	immed.	$169.70	$31.50	$334.60	38%
VAV	$161.60	$9.00	$3.50	immed.	$123.20	$47.90	$332.70	37%

| Four-Pipe | $170.70 | $8.60 | $4.00 | immed. | $117.70 | $54.70 | $343.10 | 39% |

Moore (1999) made the decision to not escalate energy prices based on information from the Energy Information Administration (EIA, 1998). Although now we realize that these projections were far from correct, it did avoid a difficult problem of separating electricity and natural gas for the operating costs completed.
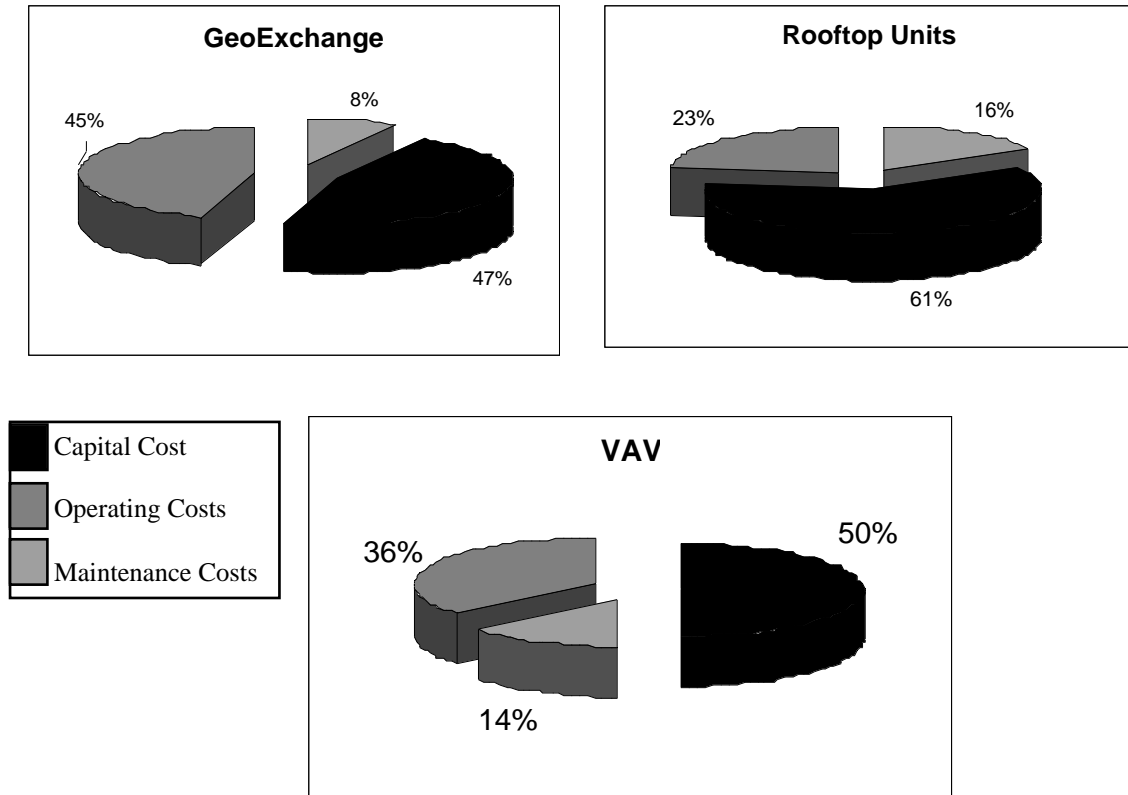

Figure 6: **Total Life-Cycle Cost Components**

HVAC equipment degrades over time resulting in a loss of efficiency, an increase in maintenance cost and made frequent and costly repairs. ASHRAE (1995) estimates that maintenance cost increases by about 1/2 percent per year due to equipment age. Moore (1999), however, in conducting a linear regressive on the maintenance cost versus date of construction borrowed the information from Dohrmann and Alereza (1986) and came up with about 3 percent per year. Moore (1987) decided to rank this number down to 2 percent and believes that the actual impact of escalating operating and maintenance costs or life-cycle cost lies somewhere between 0 percent and 2 percent (Table 10). The author (Bloomquist, 1999) found that operating and maintenance costs are not directly correlatable with age of equipment, but much more dependent upon whether or not routine maintenance was carried out, whether the maintenance is done in-house or contracted out, etc. In fact, the highest maintenance costs were for new systems where the maintenance was being done via a maintenance contract at what appeared to be exorbitant rates.

From Table 10, it is clear that GHP systems offer the lowest life-cycle cost of all HVAC system types evaluated. Based on the discount rate of 4.5 percent, the life-cycle cost of GHP systems average from 22 to 38 percent lower for basic rooftop and four-pipe fan coil systems, respectively. In fact,

the capital cost premium of GHP systems versus air-source heat pumps and rooftop units is recovered with the savings in operating and maintenance costs, from three to a little over six years, respectively.

From the data compiled by Moore (1999), GHP systems averaged lower in first costs than water-source (California type) heat pumps, central variable air-volume and four-pipe systems, thus making GHP cheaper to install, own, and to operate.

However, there are a number of factors to consider. First, in areas without a well-established infrastructure of CHP drillers and installers, GHP can substantially exceed the $100/m^2 average found in Moore's (1999) research. Second, soil and rock type can have a significant impact on drilling cost. Third, although open loop systems based on two or multiple wells are often less costly than closed loop systems to construct, but many have significant maintenance problems associated with wells and pumps if not maintained properly.

Despite the cautions, well-conceived, large projects will attract regional and even national contracts with the expertise and experience necessary to develop a cost-effective, well-designed system. And it must be noted that even if capital cost should be as high as $120 to $150/m^2, that GHP systems almost invariably win out on a life-cycle cost basis due to the cost benefits derived from operating and maintenance savings.

As would be expected, increasing the discount rate reduces the preset value of future GHP operation and maintenance cost benefits while increasing the escalation in operating and maintenance cost increases the present value of those future savings.

Figure 6 illustrates the life-cycle cost components of a typical GHP, rooftop, and variable air-volume systems. The three pie charts (taken from Moore, 1999) clearly show the characteristic differences of the three systems. Capital and operating costs share in roughly equal parts 90 percent of the total life-cycle cost of a GHP system, while maintenance represents only 8 percent of the total. Rooftop units, on the other hand, are relatively inexpensive to install,

but 60 percent of the life-cycle cost is operating cost. The VAV system is attractive from an operating standpoint, but cannot compete on first cost or on maintenance costs.

Conclusion

Based on the relatively little research that has been conducted to date on GHP systems, it appears that GHP systems can offer a significant savings in both operating and maintenance costs over conventional HVAC systems. While GHP systems continue to have a substantially higher first cost than some alternatives, such as rooftop units, they actually have lower installed costs than some of the more complex systems such as variable air-volume, water-source (California type) heat pumps, and four-pipe systems.

The GHP industry is still plagued with a lack of detailed information on the installed cost of various HVAC alternatives and long-term operation and maintenance cost for GHP as well as alternatives. Without this information, it is difficult to make a convincing argument in favor of GHP to a developer unfamiliar with the technology or the long-term cost implication of GHP systems.

It is critical that organizations such as the Geothermal Heat Pump Consortium, the International Ground Source Heat Pump Association, BOMA (Building Owner and Manager Association), ASHRAE, as well as state and federal energy agencies pursue the development of a comprehensive data base of all relevant HVAC costs so that systems can be evaluated on a realistic life-cycle basis. Without this information, decisions relative to HVAC systems will continue to be based on past experience or, more commonly, on cheapest first cost.

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