# Analysis of Modeling the Effect of different Multi Phase Properties

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**Abstract**

As we all of us are aware that Heat Transfer has great impact in today life. It has been observed that in the last many years there has been a large enhancement in the use of Heat Transfer. Due to wide use of these phenomena of Heat Transfer there is a requirement of Study of pore-scale modeling to study multiphase flow in porous media. Different properties of pore like fluid arrangements, computations of relative permeability, interfacial area, dissolution rate and many other physical properties have been made. Combined with a realistic description of the pore space, predictive modeling of a variety of processes, Due to above reasons the study about modeling the Effect of Phase Properties is urgently required. In this Paper we have described the Model of the Effect of Multi Phase Properties.

**Keywords:** Effective thermal conductivity (ETC); Binder conformability, Parameter modeling, GSHP; Pipe size; Grout, Capital Cost by HVAC System Type.

**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 and a number of reports for and 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 (Fig. 1A & 1B). 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 attributed to the degree of difficulty in drilling (rock or soil type), and especially due to availability and experience of drilling contractors 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.

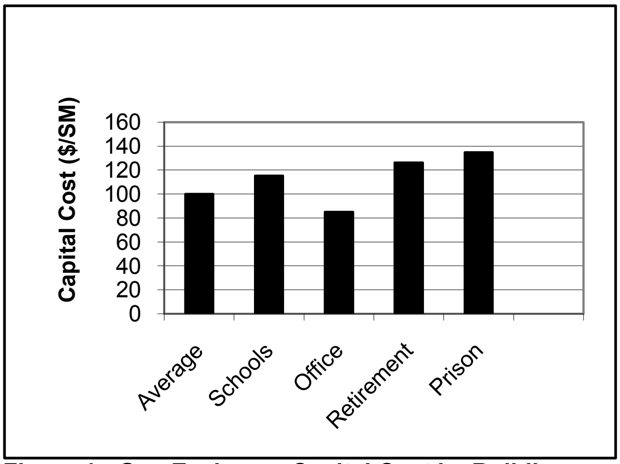


**Figure 1: Geo Exchange Capital Cost by Building Type**

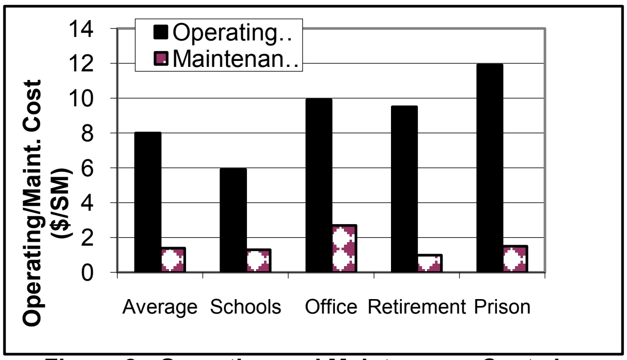


**Figure 2: Operating and Maintenance Costs by Building Type**

**Table 1**

**GHP System Capital Costs by Building and Ground Loop Type**

| Average of: | GHP HVAC Capital Cost, $/m$^2$ (# of data points) | GHP HVAC Capital Cost, $/m$^2$/kW (# of data points) |
|---|---|---|
| All Case Studies and References | $100.10 (72) | $1,026.6 (55) |
| **Building Type** | | |
| Schools | $115.40 (32) | $1,020.6 (24) |
| Office Buildings | $85.00 (13) | $1,005.1 (11) |
| Retail | $35.90 (5) | $1,097.4 (3) |
| Medical Centers | $84.10 (2) | $811.1 (2) |
| Retirement | $126.20 (3) | $1,119.1 (2) |
| Apartment/Multi-Residential | $100.00 (2) | $1,059.1 (2) |
| Prisons (correctional acility) | $134.90 (3) | $1,320.6 (2) |
| Gas Station/Convenience Store | $232.40 (1) | $1,952.3 (1) |
| **Ground Loop Type** | | |
| Vertical Closed Loop | $117.90 (50) | $1,106.9 (39) |
| Horizontal Closed Loop | $55.10 (8) | $717.7 (6) |
| Vertical Open/Groundwater | $55.00 (7) | $853.4 (5) |
| Hybrid (Vertical closed loop and coolingtower) | $112.70 (1) | $1,472.0 (1) |

**Figure: Operating and Maintenance Costs by Building Type**

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 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/m2. Robert Dooley of R. J. Dooley and Associates found that GHP systems for schools ran about $120/m2 (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 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.

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 the system efficiently and temperatures in the loop reached a summer high of 126ºF and a winter low of 18ºF (Bloomquist, 1999).

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 easily adapted to the needs of the particular installation. Among the major oil companies, 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 and Figure 2 (Moore, 1999). With an average cost of only $52/m2, rooftop units with electric resistance heating and electric cooling have the lowest capital costs.

**Table 2**
**Capital Costs of Conventional HVAC Systems**

| HVAC System Type | Capital Cost, $/m$^2$ (# 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/m2 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/m2, and a two-pipe or four-pipe system with a chiller, cooling tower, and central boiler cost from $150 - $180/m2.

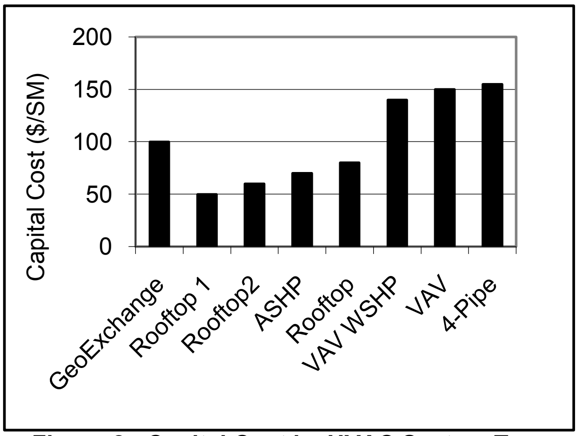


**Figure 2: Capital Cost by HVAC System Type**

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

**Operating Costs**

Operating costs summarized in Table 4 and Figure 3 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.

**Table 3**
**Capital Costs of Rooftop Units from RS Means**

| Rooftop Unit and Building Type | Capacity Range (tons) | kW | Small Capacity ($/m$^2$) | Large Capacity ($/m$^2$) |
|---|---|---|---|---|
| **SINGLE ZONE** | | | | |
| Offices | 1.58 to 31.67 | 5.53 to 110.85 | $113.60 | $72.90 |
| Schools and Colleges | 1.92 to 38.33 | 6.72 to 134.16 | $137.90 | $87.50 |
| Medical Centers | 1.17 to 23.33 | 4.10 to 81.66 | $83.70 | $55.40 |
| Department Stores | 1.46 to 29.17 | 5.11 to 102.10 | $104.60 | $67.20 |
| **MULTIZONE** | | | | |
| Offices | 9.5 to 79.16 | 33.25 to 277.061 | $185.50 | $118.50 |
| Schools and Colleges | 11.5 to 95.83 | 40.25 to 335.41 | $198.00 | $144.00 |
| Medical Centers | 7 to 58.33 | 24.50 to 204.16 | $136.60 | $87.30 |
| Department Stores | 8.75 to 72.9 | 30.63 to 255.15 | $170.50 | $109.00 |

For all GHP systems evaluated, energy operating costs averaged 8.0/m2/year, while the mixture of conventional HVAC system types averaged $11.20/m2/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).

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

| | Building Energy Costs, $/m$^2$/YR (# of data points) | | |
|---|---|---|---|
| **Weighted Average of:** | **Geo Exchange** | **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.

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

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

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**

| | Building Energy Costs, $/m^2$/YR (# of data points) | | |
|---|---|---|---|
| **Conventional HVACSystem Type** | **Geo Exchange** | **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 and Fig. 4). However, since completion of his research, a major effort to gather such information was initiated by the Geothermal Heat Pump Consortium and by the United States Department of Energy. A great

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,

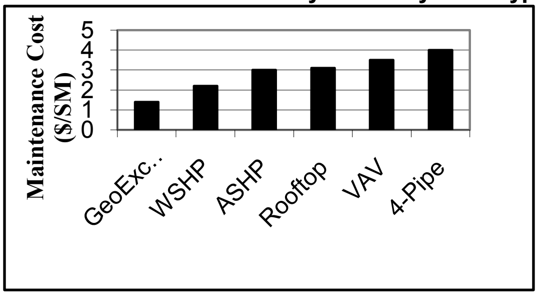
**Table 6**
**Comparison of Total Maintenance Costs by System Type**

| Equipment Type | No. of Bldgs. | Avg.Age | MeanMaint. Cost ($/SM/YR) | Maint. Cost Range ($/SM/YR) | MeanMaint.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– .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 System Air-to-Air Heat Pump[b] | 6 | 23.7 | 2.64[d] | .96– .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**

1. 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.
2. 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.
3. 1997 dollars
4. 1983 dollars

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




Maintenance costs would still be 39 percent less than for a water source (California system) heat pump system according to the ASHRAE data. This author found that even systems or 20 or more years old had maintenance costs that average ca $1.3/m^2$ (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).

**Conclusions**

For the methodology part of this work, both a dimension method and a model for computation of effective thermal conductivity were introduced and discussed. The transient method for the measurement of thermal diffusivity was exposed to be accurate enough to permit analysis of different pigment/binder tablet materials and structures. The pigment/binder tablet material used for the measurements was shown to relate well to the structures as found in heavy weight paper coatings. This method was therefore adopted to measure and discuss thermal diffusivity in the succeeding studies.

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