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Maintenance and Service Costs of Commercial Building Ground-Source Heat Pump Systems

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ABSTRACT

It has been widely speculated, but as yet unsubstantiated, that commercial ground-source heat pump systems have significantly lower service and maintenance costs than alternative HVAC systems. This paper describes efforts recently undertaken to survey commercial buildings with ground-source systems. Data from 25 such systems are presented here including total maintenance costs in dollars per hundred square feet per year both for in-house and for contractor provided maintenance. The total maintenance costs for this sample were shown statistically to be significantly lower than those reported for conventional systems in the 1995 ASHRAE Handbook—Applications. *The mean annual total maintenance costs for the most recent year of the survey ranged from $7.32/100 ft^2 to $10.95/100 ft^2 for in-house labor and contractor provided maintenance, respectively.*

INTRODUCTION

Ground-source heat pump systems have been shown to significantly reduce energy bills in commercial buildings. In recent work for ASHRAE,[1] buildings with these systems had average annual total energy bills of 97 cents/ft^2 compared to 117 cents/ft^2 for the same buildings with conventional systems.

It has been widely speculated, but as yet unsubstantiated, that ground-source heat pump systems can significantly lower service and maintenance costs compared to alternative HVAC systems. A survey[2] undertaken for ASHRAE in 1983, and the current basis for chapter 33 of the *1995 ASHRAE Handbook—Applications*, established mean annual cost for HVAC maintenance of just over 32 cents/ft^2, based on data from 342 office buildings.

For example, if ground-source heat pump systems had annual service and maintenance costs 10 cents/ft^2 lower than traditional HVAC systems, combined with the 20 cents/ft^2 energy saving, simple payback periods would be reduced by one-third for a given incremental cost for the heat pump system. This would significantly improve the competitive position of these heat pump systems as well as build the confidence and acceptance of design teams and potential end users.

This paper reports the results of a survey and analysis of maintenance and service costs from 25 commercial and institutional buildings with ground-source heat pump systems throughout the United States and Canada.

THE SURVEY

Data Collection

The survey consisted of two approaches:

- A detailed two-part survey document was prepared. The first part consisted of a fax letter sent to buildings from a database of ground-source heat pump systems developed for ASHRAE[1] asking whether they were willing to participate in the survey. Where agreement was obtained by return fax, a second detailed questionnaire was forwarded for their completion. Considerable follow-up was required to encourage these sites to complete the package.
- A parallel activity was launched involving site visits to the headquarters of a school district in Ontario, Canada, and a similar visit to an engineering contracting company serving the northeastern United States. In this phase, detailed service and maintenance cost data were gathered on a total of six schools and another nine commercial/multi-unit residential ground-source systems.

Survey Questionnaire and Approach

The detailed survey questionnaire included a preamble explaining the importance of the survey to the ground-source

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heat pump industry, how the information would be ultimately published, and offering assistance to help with the data extraction, if needed. Financial support was also offered to offset reasonable costs incurred in assembling the data.

The survey questionnaire was designed to collect the following items of data:

- Contact information.
- Ground-source system and building information including type of system, type of building, location, building and system size, year installed, service provider(s).
- Scheduled and unscheduled maintenance activities, materials, and components.
- Labor, material, and equipment costs for the identified scheduled and unscheduled maintenance, service, and repair.

The survey questionnaire defined what was meant by ground-source heat pump system components and also provided definitions for the maintenance, service, and repair activities. These are defined as follows:

- Ground-source heat pump system components—heat pumps and their components, controls, zone thermostats, air filters, duct connections, ventilation units, electrical supply wiring and disconnects to the heat pumps, pressure temperature ports, hose kits, supply/return piping, antifreeze, valves and drain outs, manual or automatic air vents, central pumps and associated valves, air separator, blowdown drains, strainer, expansion tank, fill or make-up liquid line, supply and return headers, ground heat exchanger or water wells, pumps, plate frame heat exchanger, or pond-loop heat exchanger.
- Scheduled maintenance—preventative and corrective activities that are planned, budgeted, and scheduled.
- Unscheduled maintenance—maintenance activities that were not planned, budgeted, or scheduled but were undertaken to correct conditions of impending failure.
- Service—an action, not involving component repair or replacement, triggered by failure to restore operation.
- Repair—an action involving component or equipment repair or replacement, following failure, to restore operation.

Site Visits to School District/Mechanical Contracting Firm

The two multiple site data-gathering trips involved reviewing and gathering information from accounting files, work orders, invoices, and discussions with maintenance and service supervisors and staff. The data were entered into the detailed survey questionnaire database with the other data and analyzed.

ANALYSIS OF SURVEY DATA

Characteristics of the Sample

The locations, occupancy type, and building characteristics are summarized in Tables 1, 2, and 3. The sample consisted of 25 buildings located in the northeastern United States (12), Ontario, Canada (8), the South (3), the West Coast (1), and the North (1). Specific state locations are identified in Table 1.

The building type or occupancy (Table 2) was dominated by schools (15), followed by multi-residential (4), offices (3), warehouses (2), and a restaurant (1).

TABLE 1
Locations of Buildings

Region	State	Number
N.E. United States	New York	1
	New Jersey	2
	Pennsylvania	6
	Maryland	1
Midwest	Ohio	1
	Minnesota	1
	Indiana	1
Southern U.S.	Missouri	2
	Arkansas	1
West Coast	Oregon	1
Canada	Ontario	8

TABLE 2
Building Type

Type	Number
School	15
Office	3
Multi-Residential	4
Warehouse	2
Restaurant	1

Table 3 summarizes a number of important characteristics of the sample buildings. Floor area ranged from 6,500 ft^2 to 420,000 ft^2, with a median floor area of 39,000 ft^2 and an average floor area of 75,000 ft^2. The systems had been installed as many as 15 years earlier, with one system only completing its first year of operation at the other extreme. The average age of the buildings in the sample was five years. There were a total of 1644 individual heat pumps in the 25 buildings, ranging from only one unit (a large central water-to-water heat pump) to as many as 527 heat pumps in a large retirement community. Installed heat pump tonnage averaged 2.6 tons per 1000 ft^2 for a total of 4681 tons over the 25 projects. Table 4 provides details on the individual sites.

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TABLE 3
Building Characteristics

	Mean	Minimum	Median	Maximum
Floor Area	75,000	6,500	39,000	420,000
Age of System	1991 (5 years)	1995 (1 year)	1991 (5 years)	1981 (15 years)
Age of Reported Data	4 years	0 years (installation)	3 years	15 years
Heats Pumps per Building, Total Number - 1644	66	1	27	527
Tons per 1000 ft^2	2.6	1	2.5	5.5
Tonnage Total - 4681	187	33	90	1,118
Tons per Heat Pump	6	1.1	3.1	60

TABLE 4
Detailed Characteristics of Survey Sites

Building Type	Location	Tonnage	Size (ft^2)	# of H.P	Year Inst.
School	Ontario	93	52000	31	1991
School	Ontario	81	42000	27	1992
School	Ontario	69	37000	23	1991
School	Indiana	250	89000	74	1994
College	New York	101	21910	91	1995
School	Oregon	60	57915	1	1981
Office	Ohio	94	25620	19	1994
School	Minnesota	284	83000	94	1995
School	Arkansas	90	42585	34	1993
School	Ontario	105	40000	38	1992
School	Ontario	74	39000	24	1992
School	Ontario	81	32000	23	1991
School	Ontario	65	32000	20	1993
School	Ontario	41	34000	11	1992
School	New Jersey	412	110000	36	1990
Restaurant	Pennsylvania	36	6500	6	1987
Retirement Home	Pennsylvania	840	420000	316	1990
School	New Jersey	59	24000	21	1988
Office	Pennsylvania	252	104000	43	1990
Retirement Home	Pennsylvania	89	25000	76	1990
Retirement Home	Pennsylvania	1118	390000	527	1990
Multi-Residential	Pennsylvania	194	88000	74	1990
Office	Maryland	120	38410	23	1995
Warehouse	Missouri	33	13000	8	1989
Hangar	Missouri	40	18000	4	1987

Total Maintenance and Repair Costs—Averaged Over All Years

Of the 25 buildings reported here, only three used an outside contractor for service. In the remaining cases, inside service and maintenance staff were used. In the latter cases, the labor cost incurred was limited to the workers' wages. This is termed the "base cost" in Table 5. Table 5 summarizes the base-cost data, as gathered in the survey, averaged over all years by building type in dollars per 100 ft^2 (cents per ft^2). Most respondents with in-house labor indicated a labor-rate of approximately $26 per hour including fringe benefits. This was in good agreement with Means.[4]

A more appropriate labor rate to use for inside workers should include some measure of overhead and workers' compensation in addition to wages. Means[4] reports an average of 36% of base wages to cover overhead and workers' compensation for in-house labor. Table 6 presents the total maintenance costs averaged over all years by building type for the case of a 36% modifier to account for overhead and workers'

TABLE 5
Total Maintenance Costs Averaged Over All Years by Building Type
(Base Costs as given on Survey)*

	Number of Buildings	Mean Costs	Standard Deviation	Minimum Cost	Median Cost	Maximum Cost
All Buildings	25	6.50	5.22	0.44	5.28	17.20
Schools	15	4.69	3.81	0.82	3.34	14.47
Offices	3	10.81	6.89	3.51	11.74	17.20
Residence/Retirement Homes	4	10.51	3.60	5.59	11.11	14.23
Other	3	5.87	8.56	0.44	1.44	15.74

* Dollars per 100 ft^2 (cents per ft^2)

TABLE 6
Total Maintenance Costs Averaged Over All Years by Building Type
(In-house labor costs modified to account for benefits)*

	Number of Buildings	Mean Costs	Standard Deviation	Minimum Cost	Median Cost	Maximum Cost
All Buildings	25	8.17	6.55	0.52	7.08	20.79
Schools	15	5.94	5.09	0.89	4.13	18.94
Offices	3	12.27	6.67	4.68	14.94	17.20
Residence/Retirement Homes	4	13.83	4.72	7.31	14.70	18.59
Other	3	7.68	11.37	0.52	1.74	20.79

* Dollars per 100 ft^2 (cents per ft^2)

TABLE 7
Total Maintenance Costs Averaged Over All Years by Building Type
(Labor Costs Modified to Account for Contractor Overhead and Profit)*

	Number of Buildings	Mean Costs	Standard Deviation	Minimum Cost	Median Cost	Maximum Cost
All Buildings	25	9.56	7.75	0.58	8.37	24.99
Schools	15	6.97	6.18	0.94	4.13	22.66
Offices	3	13.49	6.78	5.66	17.20	17.60
Residence/Retirement Homes	4	16.59	5.66	8.74	17.70	22.22
Other	3	9.19	13.70	0.58	1.99	24.99

* Dollars per 100 ft^2 (cents per ft^2)

TABLE 8
Comparison of Total Maintenance Costs from the Most Recent Year of the Present Study and for Select Systems from ASHRAE*

Type of Equipment	No. of Buildings	Average Age of System	Mean Cost	Std. Dev.	Minimum Cost	Median Cost	Maximum Cost
Current Study							
Ground-Source Heat Pump - Base	25	5.0	7.32	6.92	0.44	5.63	23.50
In-House	25	5.0	9.30	9.11	0.52	7.35	31.45
Contractor O&P	25	5.0	10.95	10.99	0.58	8.37	38.08
ASHRAE*							
Water-Source Heat Pump	17	17.5	21.80	16.40	2.00	20.80	75.00
Packaged Air-to-Air Heat Pump	10	15.1	33.00	16.50	11.00	28.40	62.00
Split System Air-to-Air Heat Pump	6	23.7	26.40	15.30	9.60	25.70	49.30
Reciprocating Chiller	76	22.2	28.80	21.40	5.90	23.50	140.30
Centrifugal Chiller	207	20.7	36.30	35.30	1.60	26.10	266.00
Absorption Chiller	27	29.3	52.20	33.80	6.20	48.40	136.20

* ASHRAE 1985
Costs in dollars per 100 ft^2 (cents per ft^2)

compensation, in addition to the base wages in Table 5.

Where an outside contractor performs the service and maintenance, Means[4] suggests an average of 66% of base wages to cover overhead, benefits, and profit. Table 7 presents the total maintenance cost from the survey averaged over all years, by building type, for the case of a 66% modifier to account for contractor overhead, workers' compensation, benefits, and profit, in addition to the base wages in Table 5.

Total Maintenance and Repair Costs—Most Recent Year

One goal of the survey and analysis was to allow comparison between the total maintenance costs of the ground-source heat pump systems and data from other competing HVAC systems. ASHRAE[2] supported such an undertaking in 1983 and reported total cost for HVAC systems in a sample of 342 buildings. This is the basis for maintenance cost in chapter 33 of the *ASHRAE Handbook*. Table 8 presents a comparison of the total maintenance and service costs, from the current study, for the most recent year and the ASHRAE data[2] for various competing HVAC systems.

The base wages, base wages plus overhead, workers' compensation and benefits, contractor base wages, overhead, workers' compensation, benefits, and profit cases are all presented for the current study in Table 8. It is uncertain whether base (unloaded), base plus benefits, and overhead or contractor base wages plus benefits, overhead, and profit applied in ASHRAE.[2]

The ASHRAE sample is admittedly dated and it may be inappropriate to compare it with the current sample obtained 13 years later. The ASHRAE sample systems were much older, in fact, approaching the end of their useful lives. This may account for the much higher mean cost for total maintenance and service than for the ground-source heat pump, which are much newer systems. New HVAC equipment may also be more reliable. No attempt was made to inflation-correct the ASHRAE data.

However, one would expect that inflation over the past 13 years would have significantly increased service and maintenance labor, material, and equipment costs for all HVAC systems, including ground-source systems. This appears not to be the case as evidenced in Table 8. This will be discussed in more detail later in this paper.

Scheduled and Unscheduled Maintenance Cost Components and Nature of Maintenance and Repairs

Tables 9 and 10 present the scheduled cost components of the total maintenance and service costs reported earlier for both the averaged overall years and most recent year cases.

Similarly, in Tables 11 and 12, the unscheduled cost components of the total maintenance and service cost are presented.

The number of occurrences of the scheduled or preventive maintenance tasks reported by the sites is presented in Figure 1. Table 13 presents the unscheduled service, maintenance, and repair corrective actions reported by the sites. It becomes clear that a number of sites have experienced multiple corrective actions on specific components. For example, six sites reported all 39 pump motor replacements and the 30 pump shaft seal problems were experienced at only two sites.

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TABLE 9
Scheduled Maintenance Costs Averaged Over All Years*

	Mean Costs	Standard Deviation	Minimum Cost	Median Cost	Maximum Cost
Base Data	1.91	2.98	0.00	1.09	12.83
In-House Wage Multiplier (36%)	2.25	3.30	0.00	1.36	12.96
Contractor Wage Multiplier (66%)	2.53	3.61	0.00	1.61	15.30

* Costs in dollars per 100 ft^2 (cents per ft^2)

TABLE 10
Scheduled Maintenance Costs Reported for the Most Recent Year of the Survey (1996)*

	Mean Costs	Standard Deviation	Minimum Cost	Median Cost	Maximum Cost
Base Data	1.84	3.48	0.00	0.91	13.47
In-House Wage Multiplier (36%)	2.16	4.04	0.00	0.98	17.33
Contractor Wage Multiplier (66%)	2.42	4.56	0.00	1.06	20.55

* Costs in dollars per 100 ft^2 (cents per ft^2)

TABLE 11
Unscheduled Maintenance Costs Averaged over all Years*

	Mean Costs	Standard Deviation	Minimum Cost	Median Cost	Maximum Cost
Base Data	4.83	4.74	0.00	3.13	15.74
In-House Wage Multiplier (36%)	5.92	6.24	0.00	3.39	20.79
Contractor Wage Multiplier (66%)	7.03	7.53	0.00	3.80	24.99

* Costs in dollars per 100 ft^2 (cents per ft^2)

TABLE 12
Unscheduled Maintenance Costs Reported for the Most Recent Year of the Survey (1996)*

	Mean Costs	Standard Deviation	Minimum Cost	Median Cost	Maximum Cost
Base Data	5.47	7.06	0.00	2.03	23.49
In-House Wage Multiplier (36%)	7.14	9.33	0.00	2.77	31.45
Contractor Wage Multiplier (66%)	8.54	11.27	0.00	3.38	38.08

* Costs in dollars per 100 ft^2 (cents per ft^2)

COMPARISON WITH ASHRAE DATA

Test for Significant Difference in Mean Service and Maintenance Cost

Earlier in this paper, a comparison between the total maintenance costs of the ground-source heat pump systems reported here and the data from other competing HVAC systems from a study supported by ASHRAE[2] was presented. Table 8 summarizes the maintenance and service costs from this study and the data for different HVAC systems from the earlier work.

It was decided to test whether the mean service and maintenance cost found in the current study for ground-source systems was, in fact, significantly different from the mean service and maintenance cost reported by ASHRAE.[2] The mean service and maintenance cost for all 342 systems combined[2] was 32.2 cents/ft^2 with a standard error of the mean of 1.72 cents/ft^2.

The t- test is a statistical method for testing for differences in the mean value of a variable, such as the mean service and maintenance cost. It is used to determine the probability of a sample's mean differing from that of a population and indicat-

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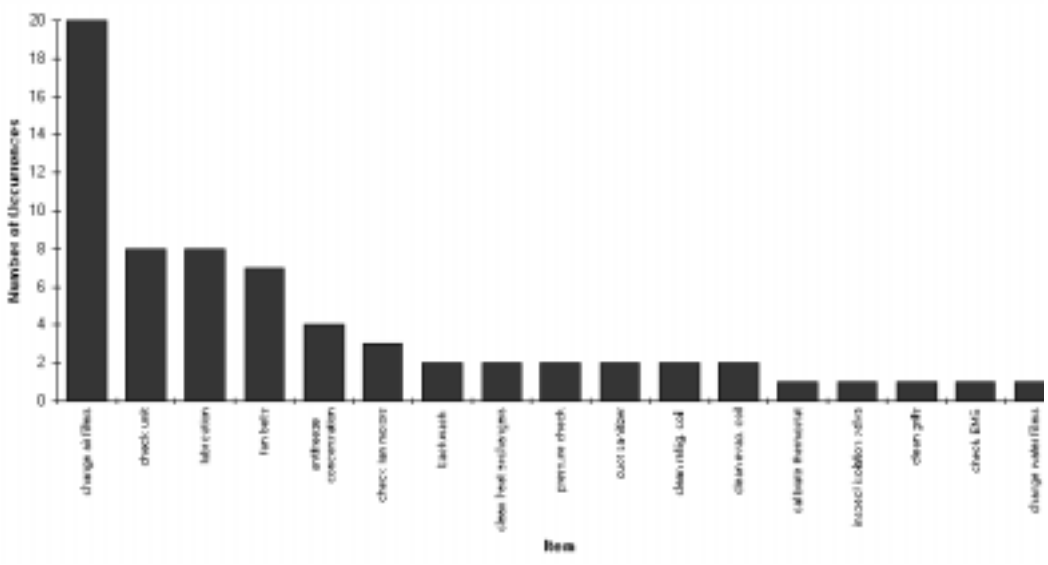

Figure 1 *Reported scheduled maintenance tasks.*

TABLE 13
Corrective Actions by Component

Component	Number of Sites with Problem	Number of Corrective Actions	Percent of Total	Component	Number of Sites with Problem	Number of Corrective Actions	Percent of Total
Compressor	13	84	15.6	Pressure Gauges	3	3	0.6
Refrigerant Leak	10	61	11.3	Repressurize Loop	3	3	0.6
Blower	9	49	9.1	Switches	3	3	0.6
Pump Motor	6	39	7.2	Coil (Clean)	1	2	0.4
Adjustments/misc.	9	35	6.5	Logic Board	2	2	0.4
Thermostat	10	34	6.3	Reversing Valve	1	2	0.4
Shaft Seals	2	30	5.6	Solenoid Valve	2	2	0.4
Insulation	8	22	4.1	Starter Coil	2	2	0.4
Expansion Valves	7	22	4.1	Timer	2	2	0.4
Relay	9	22	4.1	Circ. Pump Coupler	2	2	0.4
Piping/Pipe Material	3	18	3.3	Ductwork	1	1	0.2
Pumps	6	15	2.8	Electrical Wiring	2	2	0.4
Compressor Contactor	4	12	2.2	Ems	1	1	0.2
Controllers	3	12	2.2	Flush Loop	1	1	0.2
Fan Belts	6	10	1.9	Heat Exchanger	1	1	0.2
Fan Motor	5	9	1.7	Heater Motor	1	1	0.2
Hoses	4	9	1.7	High-Pressure Switch	1	1	0.2
Fan Contactor	2	8	1.5	Line Dryers	1	1	0.2
Antifreeze Leak	1	4	0.7	Solenoid Coils	1	1	0.2
Transformer	4	4	0.7	Temp. Controls	1	1	0.2
Automatic Air Vents	2	3	0.6	Total Corrective Actions		539	100
Condenser	2	3	0.6				

ing whether the sample mean differs for a reason or if it occurred by chance. The data were provided to an independent statistics consulting service at a local university,[3] which found that the cost advantage of the ground-source systems over the other HVAC systems[2] was 23.09 cents/ft^2 with a standard deviation of 2.51 cents/ft^2. They also stated that the cost advantage was statistically significant ($p < 0.01$). With 99% confidence, the cost advantage is no less than 15.56 cents/ft^2 and no greater than 30.62 cents/ft^2.

CONCLUSIONS AND RECOMMENDATIONS

Ground-source heat pump systems, in the sample of 25 presented here, have mean annual service and maintenance costs for the most recent year of the survey anywhere from 7.32 cents/ft^2 to as much as 10.95 cents/ft^2, depending on whether the work is done by in-house personnel or by an outside contracting organization. The mean age of the systems was five years.

The sample size, at present, is considered on the borderline of a representative sample of the population at large (minimum sample size should be over 30). Efforts are continuing to enlarge the sample with preference given to the approach of dealing with owners/contracting companies with multiple sites, as these were found to be most complete and our efforts more productive. A significantly larger sample would also allow for analysis of the mean service and maintenance cost for ground-source heat pump systems as a function of ownership/building type, system type, service and maintenance provider, system size, and other variables. The current sample is too small to allow for analysis of other variables.

ASHRAE is currently updating service and maintenance costs in chapter 33 of the *ASHRAE Handbook—Applications* entitled "Owning and Operating Costs." Data from the current study and the continuing efforts should be included in the updated chapter. The comparison with the 1983 results[2] presented here suggests that ground-source heat pump system service and maintenance costs are significantly lower than conventional HVAC systems. Comparisons with modern HVAC systems are essential to properly position ground-source heat pump systems in the mainstream of commercial/institutional building design. In the meantime, the data presented here should be useful to the design community.

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