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Comparing Maintenance Costs of Geothermal Heat Pump Systems with Other HVAC Systems in Lincoln Public Schools: Repair, Service, and Corrective Actions

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ABSTRACT

The Lincoln Public School District, in Lincoln, Nebraska, recently installed vertical-bore geothermal heat pump systems in four new elementary schools. Because the district has consistent maintenance records and procedures, it was possible to study repair, service, and corrective maintenance requests for 20 schools in the district. Each school studied provides cooling to over 70% of its total floor area and uses one of the following heating and cooling systems: vertical-bore geothermal heat pumps (GHPs), air-cooled chiller with gas-fired hot water boiler (ACC/GHWB), water-cooled chiller with gas-fired hot water boiler (WCC/GHWB), or water-cooled chiller with gas-fired steam boiler (WCC/GSB). Preventative maintenance and capital renewal activities were not included in the available database. GHP schools reported average total costs at 2.13 ¢/ft²-yr, followed by ACC/GHWB schools at 2.884 ¢/ft²-yr, WCC/GSB schools at 3.73 ¢/ft²-yr, and WCC/GHWB schools at 6.07 ¢/ft²-yr. Because of tax exemptions on material purchases, a reliance on in-house labor, and the absence of preventative maintenance records in the database, these costs are lower than those reported in previous studies. A strong relationship ($R^2 = 0.52$) was found between costs examined and cooling system age: the newer the cooling equipment, the less it costs to maintain.

INTRODUCTION

Geothermal (ground-coupled) heat pump (GHP) systems installed in four new (1995) elementary schools in Lincoln, Nebraska have been found to be among the lowest consumers of total energy of over fifty schools located within the district. Specifically, the average annual source energy consumed by the GHP schools is 93.7 kBtu/ft² (Martin 1999) whereas the only other schools to provide cooling for 100% of their floor area consume an average of 132.5 kBtu/ft². In conjunction with a study of the energy consumption of all of Lincoln's schools, a review of their maintenance request database was performed in an effort to learn more about actual maintenance costs for GHPs, and to compare these with more conventional HVAC systems found in the district.

Recently, a study of the annual maintenance costs for 25 buildings with GHP systems was conducted (Cane et al. 1998). This study focused on maintenance activities considered to be either responses to failures (repair or service) or those that were part of a planned maintenance program (preventative and corrective). The sample included 15 schools, three offices, four multi-family homes, two warehouses, and one restaurant. Average annual costs ranged from 9.3 ¢/ft² for in-house labor, to 10.95 ¢/ft² for contracted work. More specifically, average annual maintenance costs for schools ranged from 4.69 ¢/ft² for in-house work, to 6.97 ¢/ft² for contracted labor. The age of these schools ranged from three to 17 years, with an average age of 6.2 years.

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TABLE 1
Data Collected to Establish School Characteristics Database

Building Data	Original Floor Area	ft^2
	Original Age	Year
	Number of Additions	#
	Additional Floor Area	ft^2
	Number of Portables	#
	Portable Floor Area	ft^2
	Total Floor Area	ft^2
Primary Cooling	Primary Cooling Equipment	Type
	Age of Primary Cooling Plant	Year
	Portion of Floor Area Served	%
	Rated Output Capacity	Tons
Secondary Cooling	Secondary Cooling Equipment	Type
	Age of Secondary Cooling Plant	Year
	Portion of Floor Area Served	%
	Rated Output Capacity	Tons
Primary Heating	Primary Heating Equipment	Type
	Age of Primary Heating Plant	Year
	Portion of Floor Area Served	%
	Rated Output Capacity	MMBtuh, BHP, kW
Secondary Heating	Secondary Heating Equipment	Type
	Age of Secondary Heating Plant	Year
	Portion of Floor Area Served	%
	Rated Output Capacity	MMBtuh, BHP, kW
Primary Distribution	Primary Distribution Equipment	Type
	Age of Primary Distribution Plant	Year
	Portion of Floor Area Served	%
Secondary Distribution	Secondary Distribution Equipment	Type
	Age of Secondary Distribution Plant	Year
	Portion of Floor Area Served	%

An older study of conventional HVAC systems was commissioned by ASHRAE (Dohrmann et al. 1986) and is the basis for the maintenance costs listed in the 1995 *HVAC Applications Handbook* (ASHRAE 1995). This early study contained a sample of 342 commercial buildings, located across the U.S., of ages ranging from two to over 25 years old. Multiple system types were included, but not GHPs, which were not commonly available at the time. Average annual maintenance costs for the entire sample were 32 ¢/ft^2, with a median cost of 24 ¢/ft^2.

In consideration of the approaches used, and results obtained from these two previous studies, a review of the maintenance effort at Lincoln Public Schools (LPS) is underway. The first component of this review is the analysis of a two-year database of maintenance requests for all schools within the district. Following a preliminary review of the database, it was clear that not all maintenance activities are included. Specifically, planned preventative actions are often scheduled by less formal methods and not always found in the database. Therefore, the majority of the data contained in this database covers mainly actions that are repair and service responses to equipment failures, or are considered to be corrective maintenance (ASHRAE 1987). This study summarizes the maintenance data from 20 schools, with a focus on the unplanned actions required at the schools utilizing GHPs. Each school studied provides cooling to over 70% of its total floor area, and uses one of the following heating and cooling systems: vertical-bore geothermal heat pumps (GHPs), air-cooled chiller with gas-fired hot water boiler (ACC/GHWB), water-cooled chiller with gas-fired hot water boiler (WCC/GHWB), or water-cooled chiller with gas-fired steam boiler (WCC/GSB).

BACKGROUND ON AVAILABLE DATA

In order to compare HVAC system maintenance costs for all schools in the Lincoln District, an understanding of the physical characteristics and equipment installed at each school was necessary. Characteristics, such as floor area, facility age and number of additions, and HVAC system types, capacities, and commissioning dates were provided by the district. Table 1 lists the categories of data collected for the building characteristics database. Table 2 provides a basic summary of building and system data for schools with the four systems studied. Characteristics records indicate a range of total floor areas from 22,150 ft^2 to 367,826 ft^2, school ages from three to 75 years, cooling plant ages from two to 32 years, and heating plant ages from three to 70 years.

The school district maintains a database of maintenance requests that were submitted within the past 2–3 years for all facilities within the district. Maintenance records include the date of request, date of completion, request category (or work codes), craft(s) requested, labor rates, hours and costs, material costs, and a brief description of the problem. The database contains over 300 work codes that identify the category of request. Examples of work codes include heating, cooling, Energy Management System (EMS), plumbing, and telephone repair. Based on a query performed by the school district, over 7,600 maintenance requests using HVAC-related work codes were identified.

Of the original 7,600 maintenance records categorized under HVAC work codes, 2,934 were verified as legitimate HVAC-related activities. A record-by-record review of the HVAC-related requests provided by the district found that many labeled as HVAC work codes were actually concerned with water fountain or restroom repairs. This verification process also determined that the database requests for maintenance actions were mainly repair and service responses to equipment failures, or corrective maintenance. Planned actions, such as preventative maintenance, are not included in the database, nor were any capital renewal projects for complete replacement of older HVAC equipment. Following verification, the data were then subdivided by school and examined.

The majority of the database requests indicate that most work was performed by in-house LPS labor. Lincoln relies heavily on its in-house work force to handle most maintenance jobs and rarely uses contractors. Additionally, because their first-year system warranties had expired, all GHP requests were completed by in-house staff. The average in-house base wage (including fringes) reported for HVAC requests is $14 per hour. Maintenance requests may be handled by a variety of skill levels, depending on the requirements of the task. On-site custodians, mechanical equipment technicians (based at all high schools), and mobile craft specialists have base labor rates, including fringes, that range from $13.50 to $18.75 per hour. The corresponding national averages for in-house base labor rates (Means 1998), including fringes, are slightly higher at $15.50 for common maintenance laborers and $27.30 for skilled workers. Including workers compensation and overhead, the national common and skilled labor rates are $21.14 and $36.85, respectively. Labor costs presented here are normalized to a national basis and include fringes, workers compensation, and overhead.

In addition to labor rates, hours, and costs, the database provides information on material costs. Because the school district enjoys tax-exempt status, the material costs provided do not include any form of sales tax.

SUMMARY OF RESULTS

Tables 3 and 4 summarize labor hours, labor costs, material costs, and total costs for schools utilizing the four groups of HVAC systems studied. Table 3 specifically presents this information on a per request basis, while the data in Table 4 are presented on an annual basis. These results represent a two to three year snapshot of repair, service, and corrective maintenance actions taken during the lifetime of the installed equipment.

Database records indicate that, by their third year of operation, individual repair, service, and corrective maintenance requests by the GHP systems are less costly than those reported for the conventional systems of various ages (Table 3). The average labor effort required per GHP request was 2 hours, with a labor cost of $47. While GHP labor costs per request are only slightly lower than the average reported for WCC/GHWB systems ($53), material costs per GHP request at $29 are well below those for ACC/GHWB systems at $79. Average per request material costs are highest for WCC/GSB systems at $122. As a result, GHP schools reported lower average total costs per request at $77, followed by ACC/GHWB schools at $153, WCC/GHWB schools at $157, and WCC/GSB schools at $253.

On an annual cost basis, combined labor and material costs for repair, service, and corrective actions are lower, on average, for GHP systems than for the three other systems studied (Table 4). Average annual labor effort and labor costs reported for the GHP systems, at 43 hours and $937, are competitive with the average for WCC/GHWB systems, at 52 hours and $1,142. Average total labor effort and costs are highest for the WCC/GSB schools at 121 hours and $2,703 per year. Similar to the per request comparison, average total annual costs are lowest for GHP schools as a result of lower material costs. GHP schools reported lower average total annual costs at $1,508, followed by ACC/GHWB schools at $2,870, WCC/GHWB schools at $3,250, and WCC/GSB schools at $6,487.

The commonly recognized method to compare costs from one case to the next uses an area-normalized basis. Annual reported average total costs per square foot of floor area are lowest for GHP systems. GHP schools reported total average repair, service, and corrective maintenance costs at 2.13 ¢/ft^2-yr, followed by ACC/GHWB schools at 2.88 ¢/ft^2-yr, WCC/GSB schools at 3.73 ¢/ft^2-yr, and WCC/GHWB schools at 6.07 ¢/ft^2-yr. A review of the

TABLE 2
Building and Heating and Cooling System Characteristics for 20 Schools in Lincoln, Nebraska

Group A: Geothermal Heat Pumps (Vertical Bore)						
School	School Type	Total Floor Area (ft^2)	Age of School (yrs)	Age of Primary Cooling System	% of Floor Area Cooled	Age of Primary Heating System
Campbell	Elem.	69,670	3	3	100%	3
Cavett	Elem.	72,550	3	3	100%	3
Maxey	Elem.	69,670	3	3	100%	3
Roper	Elem.	72,550	3	3	100%	3
minimum		***69,670***	***3***	***3***	***100%***	***3***
maximum		***72,550***	***3***	***3***	***100%***	***3***
average		***71,110***	***3***	***3***	***100%***	***3***
std. deviation		***1,663***	***0***	***0***	***0%***	***0***
Group B: Air-Cooled Chiller and Gas-Fired Hot Water Boiler						
School	School Type	Total Floor Area (ft^2)	Age of School (yrs)	Age of Primary Cooling System (yrs)	Fraction of Total Floor Area Cooled (%)	Age of Primary Heating System (yrs)
Belmont	Elem.	104,724	75	5	87%	5
Humann	Elem.	89,523	8	8	79%	8
minimum		***89,523***	***8***	***5***	***79%***	***5***
maximum		***104,724***	***75***	***8***	***87%***	***8***
average		***97,124***	***42***	***7***	***83%***	***7***
std. deviation		***10,749***	***47***	***2***	***5.66%***	***2***
Group C: Water-Cooled Chiller and Gas-Fired Steam Boiler						
School	School Type	Total Floor Area (ft^2)	Age of School (yrs)	Age of Primary Cooling System (yrs)	Fraction of Total Floor Area Cooled (%)	Age of Primary Heating System (yrs)
East	H.S.	367,826	31	2	85%	31
West Lincoln	Elem.	66,963	42	21	69%	42
minimum		***66,963***	***31***	***2***	***69%***	***31***
maximum		***367,826***	***42***	***21***	***85%***	***42***
average		***217,395***	***37***	***12***	***77%***	***37***
std. deviation		***212,742***	***8***	***13***	***11.31%***	***8***
Group D: Water-Cooled Chiller and Gas-Fired Hot Water Boiler						
School	School Type	Total Floor Area (ft^2)	Age of School (yrs)	Age of Primary Cooling System (yrs)	Fraction of Total Floor Area Cooled (%)	Age of Primary Heating System (yrs)
Zeman	Elem.	52,640	24	24	96%	24
Everett	Elem.	91,163	70	6	83%	70
Fredstrom	Elem.	60,732	15	15	73%	15
Goodrich	M.S.	118,632	29	8	90%	29
Hill	Elem.	56,016	22	22	86%	22
Kahoa	Elem.	54,282	26	26	89%	26
McPhee	Elem.	47,784	33	3	100%	33
Morley	Elem.	56,391	37	23	78%	37
Park	M.S.	191,081	72	8	92%	8
Pyrtle	Elem.	44,276	34	32	100%	3
Rousseau	Elem.	73,065	34	2	91%	34
Bryan	H.S.	22,150	42	26	100%	42
minimum		***22,150***	***15***	***2***	***73%***	***3***
maximum		***191,081***	***72***	***32***	***100%***	***70***
average		***72,351***	***37***	***16***	***89.83%***	***29***
std. deviation		***44,596***	***18***	***10***	***8.74%***	***17***

TABLE 3

Typical Labor Hours, Labor Costs, Material Costs, and Total Costs Spent Per Call for Repair, Service, and Corrective Maintenance. Labor Costs Include Base Wages, Workers Compensation, and Overhead and Are Normalized Using National Averages. Costs Do Not Include Preventative Maintenance or Capital Renewal Actions

Group A: Geothermal Heat Pumps (Vertical-Bore)				
School	Labor Effort per Request (hours)	Labor Costs per Request ($)	Material Costs per Request ($)	Total Costs per Request ($)
Campbell	2	43	47	89
Cavett	2	45	39	84
Maxey	3	58	17	75
Roper	2	45	15	59
minimum	***2***	***43***	***15***	***59***
maximum	***3***	***58***	***47***	***89***
average	***2***	***47***	***29***	***77***
std. deviation	***0***	***7***	***16***	***13***
Group B: Air-Cooled Chiller and Gas-Fired Hot Water Boiler				
School	Labor Effort per Request (hours)	Labor Costs per Request ($)	Material Costs per Request ($)	Total Costs per Request ($)
Belmont	4	88	80	168
Humann	3	62	77	139
minimum	***3***	***62***	***77***	***139***
maximum	***4***	***88***	***80***	***168***
average	***3***	***75***	***79***	***153***
std. deviation	***1***	***19***	***2***	***21***
Group C: Water-Cooled Chiller and Gas-Fired Steam Boiler				
School	Labor Effort per Request (hours)	Labor Costs per Request ($)	Material Costs per Request ($)	Total Costs per Request ($)
East	3	76	150	226
West Lincoln	8	185	95	280
minimum	***3***	***76***	***95***	***226***
maximum	***8***	***185***	***150***	***280***
average	***6***	***131***	***122***	***253***
std. deviation	***3***	***78***	***39***	***39***
Group D: Water-Cooled Chiller and Gas-Fired Hot Water Boiler				
School	Labor Effort per Request (hours)	Labor Costs per Request ($)	Material Costs per Request ($)	Total Costs per Request ($)
Zeman	2	52	40	92
Everett	2	42	39	81
Fredstrom	2	39	41	80
Goodrich	2	54	48	101
Hill	3	61	45	105
Kahoa	2	50	41	92
McPhee	1	26	36	62
Morley	4	84	305	389
Park	3	69	73	142
Pyrtle	3	74	392	466
Rousseau	2	34	24	58
Bryan	2	48	168	217
minimum	***1***	***26***	***24***	***58***
maximum	***4***	***84***	***392***	***466***
average	***2***	***53***	***104***	***157***
std. deviation	***1***	***17***	***122***	***134***

TABLE 4

Typical Number of Requests, Labor Effort and Costs, Material Costs, Total Costs, and Total Costs Per Square Foot, Per Year for Repair, Service, and Corrective Maintenance. Labor Costs Include Base Wages, Workers Compensation, and Overhead and Are Normalized Using National Averages. Costs Do Not Include Preventative Maintenance or Capital Renewal Actions

Group A: Geothermal Heat Pumps (Vertical-Bore)						
School	Requests per Year	Labor Effort per Year (hours)	Labor Costs per Year ($)	Material Costs per Year ($)	Total Costs per Year ($)	Total Costs per ft^2-Year (¢/ft^2-yr)
Campbell	19	36	793	865	1,658	2.38
Cavett	20	42	919	786	1,705	2.35
Maxey	23	61	1,315	393	1,708	2.45
Roper	16	33	724	238	962	1.33
minimum	***16***	***33***	***724***	***238***	***962***	***1.33***
maximum	***23***	***61***	***1,315***	***865***	***1,708***	***2.45***
average	***20***	***43***	***937***	***571***	***1,508***	***2.13***
std. deviation	***3***	***13***	***264***	***303***	***365***	***0.54***
Group B: Air-Cooled Chiller and Gas-Fired Hot Water Boiler						
School	Requests per Year	Labor Effort per Year (hours)	Labor Costs per Year ($)	Material Costs per Year ($)	Total Costs per Year ($)	Total Costs per ft^2-Year (¢/ft^2-yr)
Belmont	24	93	2,072	1,894	3,966	3.79
Humann	13	36	786	988	1,774	1.98
minimum	***13***	***36***	***786***	***988***	***1,774***	***1.98***
maximum	***24***	***93***	***2,072***	***1,894***	***3,966***	***3.79***
average	***18***	***65***	***1,429***	***1,441***	***2,870***	***2.88***
std. deviation	***8***	***40***	***909***	***641***	***1,550***	***1.28***
Group C: Water-Cooled Chiller and Gas-Fired Steam Boiler						
School	Requests per Year	Labor Effort per Year (hours)	Labor Costs per Year ($)	Material Costs per Year ($)	Total Costs per Year ($)	Total Costs per ft^2-Year (¢/ft^2-yr)
East	43	148	3,277	6,481	9,758	2.65
West Lincoln	11	94	2,128	1,088	3,216	4.80
minimum	***11***	***94***	***2,128***	***1,088***	***3,216***	***2.65***
maximum	***43***	***148***	***3,277***	***6,481***	***9,758***	***4.80***
average	***27***	***121***	***2,703***	***3,784***	***6,487***	***3.73***
std. deviation	***22***	***38***	***812***	***3,813***	***4,626***	***1.52***
Group D: Water-Cooled Chiller and Gas-Fired Hot Water Boiler						
School	Requests per Year	Labor Effort per Year (hours)	Labor Costs per Year ($)	Material Costs per Year ($)	Total Costs per Year ($)	Total Costs per ft^2-Year (¢/ft^2-yr)
Zeman	35	82	1,810	1,397	3,207	6.09
Everett	8	16	347	324	671	0.74
Fredstrom	7	12	274	290	563	0.93
Goodrich	36	88	1,947	1,721	3,668	3.09
Hill	26	70	1,548	1,138	2,686	4.79
Kahoa	27	63	1,372	1,125	2,497	4.6
McPhee	18	21	469	640	1,110	2.32
Morley	24	87	1,971	7,205	9,176	16.27
Park	14	44	958	1,014	1,972	1.03
Pyrtle	21	70	1,578	8,332	9,910	22.38
Rousseau	30	46	1,020	711	1,731	2.37
Bryan	8	18	405	1,409	1,814	8.19
minimum	***7***	***12***	***274***	***290***	***563***	***0.74***
maximum	***36***	***88***	***1,971***	***8,332***	***9,910***	***22.8***
average	***21***	***52***	***1,142***	***2,109***	***3,250***	***6.07***
std. deviation	***10***	***29***	***648***	***2,689***	***3,089***	***6.71***

building characteristics data seems to indicate that a linear relationship exists between these aggregated costs and cooling system age. While no relationship exists between the heating system age and these aggregated costs ($R^2 \rightarrow 0$), a statistically significant linear relationship does exist between cooling system age and costs ($R^2 = 0.52$, $p < 0.05$). Figure 1 illustrates the linear dependence of aggregated repair, service, and corrective maintenance costs on cooling system age.

Compared with the aforementioned ASHRAE-sponsored maintenance studies, the maintenance costs reported by Lincoln seem low. There are several reasons for this, including Lincoln's dependence on in-house labor instead of contracted labor, a sales tax exemption on material purchases, and the inclusion of other building types in the original ASHRAE maintenance study. Additionally, because these costs do not include preventative maintenance actions, a complete maintenance picture is not presented. An effort is presently underway to collect data from the school district regarding typical preventative maintenance efforts and costs required by each system type. Further, this interim analysis based on the maintenance request database does not recognize the fact that the school district payroll includes all maintenance staff as full-time employees whether or not their time is fully accounted for in the database. An effort is presently underway to fully account for all of Lincoln's actual maintenance costs, and when completed the values are expected to be comparable to the previous work.

The top five work codes listed for each system type are presented in Table 5. Clearly there exists some overlap between work codes as well as definitions that are extremely general in nature, however there is some value in the generalizations. Selection of appropriate work codes is dependent on the requestor, and thus gray areas exist between codes. Requests listed under heating and air conditioning generally pertain to problems with the plant and air-handling equipment, but also include complaints of ''room too cold'' or ''room too hot.'' EMS and control requests are similar in that both list issues with thermostats or comfort complaints. Many requests under EMS, however, specifically mention reprogramming, replacement batteries, and communication problems. The other major work codes, pump repair, boiler repair, and ventilation repair, are more clearly defined.

A closer look at the details of GHP requests indicate several common, recurring equipment, design and installation problems. The most common problem, which is actually an application flaw, is leakage found in the packing of motorized two-way ball valves located at each heat pump. The two-way valves isolate the unit when not in operation and are part of the variable flow design of the water loop. Ball valves with external actuators were selected over solenoids as a cost saving measure. It is hypothesized that either the external

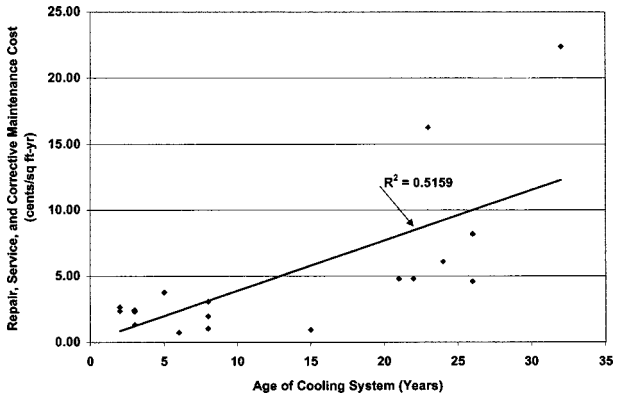

Figure 1 *Relationship between aggregated repair, service, and corrective maintenance costs and cooling system age.*

TABLE 5
Top Five Work Codes Cited for Repair, Service, and Corrective Maintenance Actions. Data Do Not Include Preventative Maintenance or Capital Renewal Actions

Group A: Geothermal Heat Pumps (Vertical-Bore)		
Work Code	Total Calls Per Year (4 schools)	Calls per Year per School
Heating	20	5
Air Conditioning	10	2.5
Pump Repair	9	2.25
Controls	9	2.25
EMS Equipment	6	1.5
Group B: Air-Cooled Chiller and Gas-Fired Hot Water Boiler		
Work Code	Total Calls Per Year (2 schools)	Calls per Year per School
Air Conditioning	6	3
EMS Equipment	6	3
Controls	4	4
Boiler Repair	5	2.5
Group C: Water-Cooled Chiller and Gas-Fired Steam Boiler		
Work Code	Total Calls Per Year (2 schools)	Calls per Year per School
Controls	9	4.5
Air Conditioning	8	4
Ventilation	5	2.5
Heating	4	2
Boiler Repair	4	2
Group D: Water-Cooled Chiller and Gas-Fired Hot Water Boiler		
Work Code	Total Calls Per Year (12 schools)	Calls per Year per School
Controls	60	5
Heating	29	2.4
Boiler Repair	27	2.25
Air Conditioning	22	1.8
Ventilation	16	1.3

actuators torque the valve stems such that the packing leaks, or that the valves were intended for manual operation and limited cycles. Most of the actuators have been disengaged and the valves left in the open position. Another source of leakage from the GHP units themselves reportedly came from the condensate lines or drip pans. Condensate leaks may be caused by problems such as unlevel mounting of units, failure to flush lines with biocide to prevent clogs, unit damage during shipping or at the site, poor mounting of the condensate drip pan, or pinched hoses. Several occurrences of water leakage at the loop central pumping station were also reported. Like the schools with conventional systems, all GHP schools reported common thermostat, freezestat, or other control-related issues, in addition to EMS alarms for GHP unit shutdowns. Filter racks and/or access doors were added to many of the heat pumps to make filter changes and servicing easier for personnel. Finally, a handful of requests were received to repair heat pump vibration or noise.

Many of the requests listed for the GHP systems identify concerns that have been commonly expressed by designers, contractors, and those considering GHPs as an alternative to more conventional heating and cooling equipment. While the existence of these issues in this database supports such concerns, it is obvious that many of the problems could have been avoided with improvements in application and/or installation. Additionally, as is evident in the cost summary data, resolution of these problems proved to be inexpensive as maintenance actions were completed quickly with low-cost materials by less-skilled laborers.

CONCLUSIONS

Based on a two to three year snapshot of maintenance requests recorded in the Lincoln Schools maintenance database, four schools heated and cooled with vertical-bore geothermal heat pumps were found to have the lowest average annual repair, service, and corrective maintenance costs, per square foot, when compared to sixteen other schools utilizing three other types of conventional HVAC systems. GHP schools had average costs of 2.13 ¢/ft^2-yr, in comparison to ACC/GHWB schools at 2.88 ¢/ft^2-yr, WCC/GSB schools at 3.73 ¢/ft^2-yr, and WCC/GHWB schools at 6.07 ¢/ft^2-yr. A relationship does exist between these costs and the age of the cooling system, and at an average age of three years, the four GHP systems studied are among the youngest in the district. These costs are low in comparison with those found in other studies, as most of the work was completed by in-house labor (as opposed to contracted labor), material costs were tax-exempt, and preventative maintenance actions were not included in the database (the district handles these less formally). The next phase of this study will attempt to develop total maintenance costs by quantifying preventative maintenance activities and associated costs and capital renewal requirements for older HVAC systems throughout the district.

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