GEOTHERMAL HEAT PUMPS
CONCERNS OVER OPERATION, MAINTENANCE, AND RELIABILITY UNFOUNDED

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ABSTRACT

The first geothermal heat pump system in the United States was installed in the Commonwealth Building in downtown Portland, Oregon, in 1946. This extremely successful and highly publicized project led to the installation of numerous installations throughout the Northwest and eventually the entire United States. Now, after 50 plus years of operating experience, it is time to take a close look at how well these systems have performed, their operating and maintenance histories, cost competitive, and long-term customer satisfaction. Case histories of over 20 systems have been developed representing a range of system designs, end-use applications, and geographic areas. Despite some problems related almost exclusively to poor maintenance or, in some instances, to wells, an overwhelming majority of owners and operators are highly satisfied with their system, often citing cost savings and a lack of operation and maintenance problems as significant advantages over other systems.

1. INTRODUCTION

Despite the fact that commercial geothermal heat pump (often called ground source heat pump or geoexchange) systems first gained moderate popularity in the U.S. as early as the late 1940s and early 1950s, widespread acceptance of the technology by architectural and engineering firms, mechanical design teams, developers, and building owner/operators has been extremely slow. And although there was a momentary increase in the installation of geothermal heat pump systems following the oil crises of the 1970s, it has not been until the past few years that interest in commercial geothermal heat pump systems has once again been on the rise. However, uncertainty over first cost, life cycle cost, operation and maintenance questions, and system long-term reliability have continued to plague the industry and prevent greater adoption of the technology.

In order to meet this need, a number of studies have been completed to document maintenance and operation histories, equipment replacement requirements, actual cost of service, and long-term system reliability. The number of such studies has, however, been fairly limited and good data has not always been readily available as few building owners maintain good records and often ownership has changed, some times several times, since the system was first installed. In order to improve and strengthen the operation and maintenance data base Washington State University (WSU) has completed a series of case studies of commercial geothermal heat pump systems.

The United States, and especially the state of Washington, has long been a leader in geothermal heat pump installation and use following the first successful demonstration of the technology at the Commonwealth Building in Portland, Oregon, in 1946. Most of these early systems are still providing a high level of service to building owners, and include systems in Tacoma (Tacoma City Light Building, 1954), Vancouver (Clark County PUD, 1956) Walla Walla (Whitman College 1964), Ephrata (Grant County PUD, 1955).

Data obtained through the course of the current study indicates that geothermal heat pump technology is energy efficient with total building electrical energy use for those buildings where data was available ranging from 0.87 to 2.27 kWh/m^2/year while HVAC-related energy use ranged from 0.78 to 0.94 kWh/m^2/year. Maintenance costs were also found to be very attractive and averaged \$0.016/m^2/year (Table 1). The most interesting findings of this work, however, were the high level of reliability that most systems had provided over periods exceeding 25 to 30 years if routine maintenance procedures were followed and the very high level of owner satisfaction that was witnessed during the course of the interviews that were conducted.

2. PRESENT STUDY

The present study was conducted in two phases. The first began with a look at a number of installations in Washington State with an emphasis on obtaining information on building size and use, type and size of geothermal heat pump system, reasons for selecting geothermal heat pump technology, and owner/operator satisfaction with the system. The second phase of the study expanded the geographic area to include systems in several additional parts of the country and the scope to include much more concentration on operational, maintenance, and reliability issues.

Systems were first identified through conversations with equipment sales representatives, architectural and engineering firms, well drillers, ground loop installers, HVAC contractors, and utilities. Once a substantial number of systems had been identified, the owner/operator of each system was contacted by phone and an interview conducted to determine whether or not the system should or could be further considered. The prime criteria for selection was willingness on the part of the owner/operator to participate in the study, availability of data, and age of the system. Every effort was made to include as many systems as possible with 20+ years of operating history, and as few as possible with five years or less of operating history.

Once the systems had been selected, detailed interviews were conducted with the owner/operator, maintenance staff, and, when possible, the system designer. The interviews were conducted by phone and often required discussions with several individuals. Once the interviews were completed, all of the systems were visited, additional interviews conducted, and each system gone through in as much detail as possible. Table 1 summarizes the important building and ground source heat pump (GSHP) system characteristics of the 22 buildings that serve as the basis for this paper.

As a baseline for a comparison of the results of this study, ASHRAE operation and maintenance estimates were reviewed. The ASHRAE Handbook (ASHRAE, 1995) provides a standard method for calculating maintenance cost for commercial-size HVAC systems. Based on calculations using the ASHRAE method, geothermal heat pump system maintenance can cost from 0.010 to \$0.020/m^2/year in 1996 dollars U.S. compared to \$0.035 (medium) to \$0.046/m^2/year (mean) for an average conventional HVAC system. As a comparison, the Fort Polk, Louisiana, (Pratsch, 1999) project is budgeted at \$0.017/m^2/year while the 14,070 kW$_t$ Galt House East Hotel in Louisville, Kentucky, has a cost of \$0.011/m^2/year. (Geothermal Heat Pump Consortium, 1996).

3. GEOTHERMAL HEAT PUMP INSTALLATIONS

3.1 Selection Criteria

A number of the GSHP systems that date back to the 1950s were installed as a result of the building owners' wish to adopt a unique, quality design that would create a positive impression in the community. This was also at a time when air conditioning was becoming more and more of an issue, and a driving force in selection of many of the geothermal systems. In the mid to late 1970s and early 1980s, a number of systems were built as a direct result of the oil crises of the early 1970s. Many of those interviewed who had had responsibility for the construction of these systems indicated that the availability of a secure, locally available, indigenous resource was extremely important in the decision-making process, especially in a time of rapidly escalating energy costs and concerns over fossil fuel availability. Many owners of the more recently-developed systems contributed their decisions to go with geothermal heat pumps to past experience with such systems, very high quality of the installation, energy efficiency, and cost savings. Other reasons given included:

- environmental considerations
- compatibility with building design or retrofit requirements
- utility incentives
- reputation of engineering design firm
- need for individual temperature control
- reduced space for mechanical equipment
- life cycle cost savings.

In truth, the publicity that many of the early systems received played a major role in replication of the technology in nearby areas. This can be clearly seen with the success of the Commonwealth Building in Portland, and the press that is was afforded. To a large extent, many of the systems that were built in that era were a desire on the part of building developers to capitalize on the positive publicity that the Commonwealth Building generated.

4. DEVELOPMENT TRENDS

Development trends can be divided into several distinct designs, including pumped wells with central or distributed heat pumps and loop systems, horizontal or vertical, relying primarily on a distributed heat pump system layout. Fortunately for the industry, all of the above seem to offer unique solutions to meet building design or retrofit requirements. Unfortunately, the industry has not yet matured to the point where all engineering design teams feel comfortable with all available technical alternatives, and thus design is often as much a factor of prior experience as it is a conscious decision to select the most appropriate technology for a given application.

Most early systems were based on pumped wells with either injection or disposal to nearby surface water. Other systems used surface water sources such as lakes, but were of essentially the same design. The heat pumps were water-to-water and two- or four-pipe systems were used to circulate water to fan coil units situated throughout the building. By the early 1970s, pumped systems were still dominating the geothermal heat pump scene, but distributed systems were becoming a major player. With the availability of polybutelene pipe in the late 1970s, the trend seems to be moving more and more toward horizontal or vertical closed loop systems, although for many large commercial applications, the open loop water source system does seem to provide some economic advantage and continues to capture a significant market share where constraints on ground or surface water use have not been adopted.

On the building side, decentralized or distributed heat pump systems seem to increasingly dominate the field primarily because of the ease of operation and localized temperature control that they provide. This seems to be an extremely attractive configuration in schools where the individual needs of each classroom can be easily met, and each teacher has total control over the system. Large, centralized systems, however, continue to play a major role and are ideally suited to many retrofit situations, especially where, because of the historical nature of buildings, major changes are very difficult or impossible. Centralized systems are also an extremely attractive choice for office parks or where low-temperature hydronic heating can be provided.

Because of the wide range of water sources and ground loop configurations that can now be used and the number of in-building systems that are possible, geothermal heat pump systems can now be tailored to fit almost any possible need. The only challenge for the design engineer is to determine the best combination of water or ground source and in-building configuration to best serve the client's needs in the most efficient, reliable, and cost-effective manner possible.

5. BUILDING AND GSHP SYSTEM CHARACTERISTICS

Table 1 presents information on in-building system design and energy performance. Unfortunately, because of the age of many of the installations, no actual capital cost data was available for most systems and, therefore, no attempt has been made to cover capital cost information in any detail. For the 22 systems that are covered in this paper, the installed heat pump capacity varies from a low of 15.69 kW_t/km^2 to a high of 69.23 kW_t/km^2 (the system was designed to meet future growth at the college). For the water source systems, flows range from 0.023 mL/J of installed capacity to 0.134 mL/J of installed capacity with an average of 0.061 mL/J. Required flow is, of course, very dependent upon water temperature and heating and cooling requirements. For closed loop systems, the heat exchanger circuit pipe length ranged from 20.5 m/kW_t to 52.0 m/kW_t, with an average of 39.3 m/kW_t. Of those with vertical bores, the range is 14.4 m to 17.7 m of bore per kW_t.

Building electrical energy use ranges from 0.87 kWh per square meter per year to 2.27 kWh per square meter per year, with an average of 1.74 kWh per square meter per year. For those systems where it was possible to determine electrical load for the mechanical system, the range was 0.78 kWh per square meter per year to 0.94 kWh per square meter per year. Electrical rates and demand charges are so utility-specific that no meaningful trend could be discerned from an analysis of available data.

6. EQUIPMENT AND DESIGN PROBLEMS

Due to the fairly unique differences between open and closed geothermal heat pump systems, the equipment and design problems will be treated separately as will maintenance issues and costs.

6.1 Open-Loop System

As was mentioned earlier, open systems dominated the geothermal heat pump market from 1946 until approximately 1980 when horizontal and vertical closed loop systems became readily available. A majority of open loop systems rely on one or more wells.

Water is withdrawn from the well or other source and disposed of through the use of injection wells, through surface discharge, or, in the case of standing column wells, the water is returned to the outer annulus of the production well.

There is little doubt that well problems dominate when it comes to open loop systems. The two most often encountered problems are inadequate flow in the production well and plugging that causes pressure build-up in the injection well. Production problems are most often a result of excessive draw down of the acquifer due to over use or severe drought. It can also be a result of sedimentation in the bottom of the well. In many cases, the wells are simply not drilled deep enough or completed correctly. Many such problems can be corrected by deepening the production well or by reworking. In those cases where sedimentation is a problem, correct screening can provide a relative straightforward solution. However, the vast majority of problems associated with open loop systems are caused by the injection well. The principal cause appears to be iron bacteria and, where a mature colony is established, extremely difficult to eliminate. The problem can, however, be minimized by regular maintenance including chlorination (once every 3-6 months) and back pumping of the well. In some cases, the pressure build up problem is caused by scaling (often calcium carbonate, $CaCO_3$). Again, the problem can be minimized through the use of chemical treatment, although in some severe cases, some reworking of the well on a regular basis may be required. Of course, excessive injection pressure may also be the result of poor well completion or an inadequate injection horizon.

The next most common problem associated with open loop systems is pump failure. Both open shaft, vertical down-hole pumps; and submersible pumps are regularly employed and, at least for those cases where high volume is desired, the down-hole shaft system appears to dominate. Principal problems seem to be with bearings and seals, often resulting in the need for major maintenance and, in a worse case scenario, resulting in a broken shaft. Major pump problems seem to be avoided through proper sand screening and by ensuring adequate lubrication.

Finally, the lack of a heat exchanger (shell and tube or plate and frame) to isolate the production flow from the in-building equipment can result in major system problems including excessive corrosion in the heat pump tube bundle. Most systems are now moving from shell and tube to plate and frame exchangers due to the closer approach temperature, the ease of maintenance and the flexibility they offer in terms of ease of expansion.

6.2 Closed-Loop System

Closed-loop systems began to challenge the dominance of the open-loop systems in the late 1970s/early 1980s. However, unlike open-loop systems where required flow can easily be determined based on load, source temperature, and equipment performance, loop length is much more difficult to calculate and is highly dependent upon soil characteristics including temperature, moisture content, particle size and shape, and heat transfer coefficients. Correct sizing of the ground loop continues to be a cause for continued design problems and special attention should be placed on minimizing inference between loops, whether they be horizontal or vertical.

Other problems associated with loop design and installation include improper header design, inadequate system purging, leaks associated with corrosion of fittings, or poor workmanship. All of the above problems can be minimized through proper system analysis and design, and the use of well-trained and experienced installation personnel. One of the most often encountered problems is related to the circulated heat transfer fluid. Methanol and Environol seem to be the least problematic and best heat transfer fluid choices.

6.3 Central vs Distributed Heat Pump Systems

There seems to be very few problems associated with either the choice to employ a centralized or decentralized heat pump arrangement. Both afford the capability to provide supplemental heating or cooling through the use of boilers or cooling towers. The only major design problems that seem to be somewhat common in many centralized heat pump systems is the use of a two-pipe system to circulate hot or chilled water. Because the two-pipe system does not allow for the simultaneous supply of both heating and cooling, the building owner/system operator must choose which service will be provided at any given time. Because most such systems are difficult to reverse once the decision is made to go from, for example, heating to cooling, the system can not readily be changed back should a late spring cold spell come unexpectedly. Because the provision of heating is almost always more critical than cooling, operators most often chooses to error on the side of having heat available.

7. OPERATION AND MAINTENANCE

7.1 Open-Loop System

Most maintenance problems associated with open-loop systems are well related and concern problems with pumps, including bearings and seals. Other maintenance issues include the need to clean or even rework production and injection wells and the need for chemical treatment of injected water to control scaling or bacterial growth that plugs the injection wells. Another potentially major maintenance issue is removal of sand from the heat exchanger(s) if adequate filters and/or sand traps are not used.

7.2 Closed-Loop System

Maintenance of closed-loop systems appears to be extremely minimal and restricted to circulating pumps unless the heat transfer fluid results in corrosion of fittings and other system components.

7.3 Central and Decentralised Heat Pump Systems

Central heat pump systems seem to require very limited maintenance, and because all major pieces of equipment are located in a central location, most maintenance chores can be carried out easily. Decentralized systems, on the other hand, do require considerably more routine maintenance including changing filters every three to six months. For example, when the Tower Building in Yakima, Washington, was purchased by the present owner, approximately one compressor per week required replacement; however, once a routine preventative maintenance program was put into place, only one compressor failure occurred over the entire following year. Care should be taken when installing a decentralized system to ensure that maintenance personnel have adequate access to each unit for routine maintenance and also for repairs when they become necessary.

Despite the maintenance issues mentioned, maintenance costs are relatively low in all but a few cases, averaging $0.016 per square meter per year (see Table 1). In only three of the cases evaluated was maintenance considered a major concern. In one of these, the equipment was in definite need of replacement after nearly 35 years of service, and with the others, problems with the heat transfer fluid had resulted in serious corrosion problem and leaks as well as control problems due to the leaks. Anonymously high maintenance costs were a result of, in one case, a poorly structured maintenance contract; in another, lack of local maintenance providers; and in two cases, to relatively high in-house personnel costs assigned to the HVAC system.

8. CONCLUSION

Geothermal heat pump systems are an increasingly attractive option for commercial buildings. Based on over 50 years of operating experience, it is safe to say that earlier concerns over long-term reliability, operation, and maintenance costs were, to a large extent, unfounded. Although some systems have had to be replaced due to problems related to production and/or injection well problems, a majority of the systems have proven to be extremely reliable, with many having been in service over 25 years, and maintenance problems and costs have been acceptably low.

Advancements in equipment, installation techniques, and control systems as well as knowledge of heat transfer continues to reduce equipment and design problems. Increasing knowledge and use of a wide variety of water sources as well as ground loop designs and configurations, together with the number of in-building systems that are now possible allow that geothermal heat pump technology can be tailored to fit almost any possible building need.

REFERENCES

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TABLE 1. BUILDING AND GSHP DESCRIPTIONS

Site	LOCATION	Building Type	Square Meters	System Type	Number of HP Units	Heat Pump Capacity, kW_t	kW_t per km^2	kWh/Square Meter/Year	Maintenance Cost $0.00US/Square Meter/Year
Beaver Lake Middle School	Issaquah, WA 1994 - New	Middle School	10,126	Ground loop - loop under athletic field - 45,062 meters in loop - 840 kW_e electric boiler	52	879	26.42	1.02	0.021– 0.033
Bryant College	Smithfield, RI 1996 - Retrofit	2 College Dormitories	3,530	Ground loop – 36 @ 138 meters deep vertical bores - 9,963 meters total	16	281	24.35	(a)	0.001
Clark County PUD Admin.	Vancouver, WA 1957(a)- New	Administration Offices	2,973	Open loop – heat exchanger well - 116 meters deep – 12 ºC, 19 L/s possible	4	352	36.12	(a)	0.046
Exchange Building	Farmington, CT 1971 - New	Office & Commercial Complex	25,548	Open loop – four wells - 84 meters deep – 13 ºC total flow 32 L/s	495	3,848 kW_t plus an 879 kW_t chiller to provide heat to loop	45.92	1.60	0.015
Grant County Courthouse	Ephrata, WA 1982 - Retrofit	Courthouse & Courthouse Annex	4,831	Open loop – connected to 31 ºC municipal water supply system	1 x 2	1,055	66.58 (c)	(a)	0.010
Haverhill Public Library	Haverhill, MA 1994 - Retrofit	Library	4,088 including 2,508 1994 addition	Open loop – four wells - standing column – 14 ºC 4-5 L/s per well isolated with heat exchanger	19	378	28.04	1.50	0.008– 0.013
Heritage College Library	Wapato, WA 1991 - New	College Library	1,672	Open loop 10+ºC isolated with plate and frame heat exchanger	13	169	30.69	(a)	0.059 (g)
Inn of the Seventh Mountain	Bend, OR 1992 - Retrofit	Condominium, Hotel Complex, Convention Center, Spa, and Pools	26,012+ 350 units and convention center	Open loop – 1 well - 73 L/s	2	1,759	20.65	2.27 (e)	0.015
Kittitas Middle School	Kittitas, WA 1992 - New	Middle School	3,623	Ground loop – vertical bores 70 bores, 61 meters deep Total 8,534 meters	30 (18 H_2O-to-air) (12 H_2O -to- H_2O)	295	24.81	(a)	0.019
Lane Community College	Eugene, OR 1981 - Retrofit	Downtown Comm.College - Converted Montgomery Ward Store	5,388	Open loop – 3 wells – 16 ºC Total flow 16 L/s	1 3 compressors	317	17.89	1.86	0.012– 0.014
LDS Office Tower	Salt Lake City, UT 1972 - New	Offices & Public Rooms - 30-story Tower plus 2 Wings	63,172	Open loop – 4 wells - total flow 513 L/s. two wells at 119 meters deep. two wells at 192 meters deep, 19-24ºC	3	7,913	38.08	(a)	0.011 (h)
North Bonneville City Hall	North Bonneville, WA 1995 - Retrofit	City Hall Administration and Offices	427	Ground loop – horizontal 1,829 linear meters	2	35	25.04	0.87	0.005
Parkview Apartments	Winchester, MA 1965 - New 318 apts.	Condominium Complex	19,267	Open loop – 2 wells 11 to 15 ºC 95 L/s total flow	2 Compressors/ units	1,407	22.27	1.43 (f)	0.011– 0.014

Site	LOCATION	Building Type	Square Meters	System Type	Number of HP Units	Heat Pump Capacity, kW_t	kW_t per km^2	kWh/Square Meter/Year	Maintenance Cost $0.00US/Square Meter/Year
Squaw Valley Day Care	Squaw Valley, CA 1993 - New	Day Care Center with Snow Melt	1,394 sqm bld. – 836 sqm snow melt	Closed loop – horizontal ground loop 2,880 meters	4	141	19.15	0.001 (d)	0.002- 0.003
Sundown M Ranch	Yakima, WA 1985 - New 1990 - New 1992 - New 1995 - New	Drug & Alcohol Rehab Complex	 5,741 1,918 3,691 697	Open loop – 2 wells -61 meters deep total flow 35 L/s 10+ºC	 139 50 89 19	 700 197 524 102	 37.15 31.27 43.27 44.65	1.92	0.011- 0.014 total square meters
Tacoma City Light	Tacoma, WA 1954(b)- New	Administration & Office Building	12,077	Open loop – 2 wells - 14ºC– 27 meters deep – 50 L/s 12ºC – 65 meters deep – 79 L/s - shallo[w] well winter; deep well summer - separate by heat exchanger	2	1,231	31.04	2.23	0.047
Tower Building	Yakima, WA 1980 - Retrofit	Offices with first floor Commercial	12,356	Open loop – connected to two wells vi[a] heat exchanger 37 meters and 74 meters deep 16-18ºC	152	1,055	25.96	(a)	0.010
Walla Walla Community College	Walla Walla, WA 1995 - New	Administration office, classrooms, student lounge, and cafeteria	9,290	Open loop – one production well - 11 12ºC, - 366 meters. – 63 L/s - wate rejected to city water system prior t treatment	2	2,110	69.23 (b)	(a)	0.009- 0.014
Walla Walla Corps of Engineers	Walla Walla, WA 1995 - New	Administration Office and Printing Shop	8,494	Open loop – connected to municipal wate system via heat exchanger - 4-16ºC	120	943	36.12	2.00	0.053 (a)
Whitman College Science Building	Walla Walla, WA 1955 - New	Science Building	8,175	Open loop – pumped well 23ºC with intermediate heat exchanger 47 L/s		422	15.69	(a)	>0.005
Whitman College Administra-tion Building	Walla Walla, WA 1989 - Retrofit	Administration Building	2,787	Open loop – pumped well 23ºF with intermediate heat exchanger 47 L/s	39	352	38.42	(a)	0.009
Yakima County Correctional Facility	Yakima, WA 1983 - New	Correction Facility	11,148 (1983) 5,574 (1991) Total 16,722	Open loop – 274 meters well 21ºC connection via heat exchanger	2	1,055	19.15	1.84	0.006- 0.007

a) Not separately metered.
(b) Originally 2 centrifugal chillers were used; however, in 1988 one was replaced with a twin screen Dunham Bush chiller.
(c) Sized to provide conditioning to Law and Justice Center but never connected.
(d) Average daily winter HCAC system usage, facility not occupied or used year round.
(e) 1.43 *kWh/m²/yr. equals total consumption. HVAC consumption equals* 0.78 *kWh/m²/yr.*
(f) 2.27 *kWh/m²/yr equals total consumption; however, HVAC consumption equals* 0.94 *kWh/m²/yr.*
(g) Maintenance contract.
*(h) Includes $*0.0023*/square meter/year for chemical treatment.*

TABLE 2 - GEOTHERMAL HEAT PUMP SYSTEMS

Site	Date GSHP Installed	Square Footage	Heat Pump Capacity	Tons/1,000 Square Feet	Ground Loop Feet/Tons	Bore Hole Feet/Ton	kWh/Square Foot/Year	Maintenance Cost $0.00/Square Foot/Year
Beaver Lake Middle School	1994	109,000	250 tons	2.29	591.36	NA	11.00	0.23 – 0.35
8.1 Bryant College	1996	38,000	80 tons	2.11	408.6	204.3	*	0.01
Clark County PUD	1957*****	32,000	100 tons	3.13	NA	NA	*	0.50
Exchange Building	1972	265,000	1,094 tons	3.98	NA	NA	17.18	0.16
Grant County Courthouse	1982	52,000	300 tons	5.77***	NA	NA	*	0.11
8.2 Haverhill Public Library	1994	44,000	107.5 tons	2.43	NA	NA	16.13	0.09 – 0.14
Heritage College Library	1991	17,400	48.5 tons	2.66	NA	NA	9. *	0.64†
Inn of the Seventh Mountain	1992	248,800	500 tons	1.79	NA	NA	10. 24.47******	0.16
Kittitas Middle School	1991	39,000	84 tons	2.15	333.00	166.0	*	0.20
Lane Community College	1981	58,000	110 tons	1.55	NA	NA	19.97	0.13 – 0.15
LDS Office Tower	1972	683,000	2,250 tons	3.30	NA	NA	*	0.12†
North Bonneville City Hall	1995	46,000	10 tons	2.17	600.00	NA	9.40	0.05
Parkview Apartments	1965	207,400	400 tons	1.93	NA	NA	15.35*******	0.12 – 0.15
Squaw Valley Day Care	1993	23,000	40 tons	1.66	236.00	NA	0.013****	0.02 – 0.03
10.1 Sundown M Ranch	1985 1990 1992 1995	61,800 20,650 39,736 7,500	199 tons 56 tons 149 tons 29 tons	3.22 2.71 3.75 3.87	NA NA NA NA	NA NA NA NA	20.66	0.12 – 0.15 total square footage
10.2 Tacoma City Light	1954	130,000	350 tons	2.69	NA	NA	24	0.51
Tower Building	1980	133,000	300 tons	2.25	NA	NA	*	0.11
Walla Walla Community College	1974	100,000	600 tons	6.00**	NA	NA	*	0.10 - 0.15
Walla Walla Corps of Engineers	1995	91,432	286 tons	3.13	NA	NA	21.50	0.57†
Whitman College Science Building	1964	88,000	120 tons	1.36	NA	NA	*	0.05
Whitman College Administration Building	1988	30,000	100 tons	3.33	NA	NA	*	>0.10
Yakima County Correctional Facility	1983	180,000	300 tons	1.66	NA	NA	19.81	0.06 – 0.08

** Not separately metered.*
*** Sized for expansion of college that did not occur.*
**** Sized to provide conditioning to Law and Justice Center but never connected.*
***** Average daily winter HCAC system usage, facility not occupied or used year round.*
****** Original configuration was 100 ton centrifugal chiller replaced in 1989 with two 30-ton and two 20-ton reciprocating compressors.*
******* 15.35 kWh/sq.ft/yr. equals total consumption. HVAC consumption equals 8.43 kWh/sq.ft./yr.*
******** 24.47 kWh/sq.ft/yr equals total consumption; however, HVAC consumption equals 10.14 kWh/sq.ft./yr.*
†Maintenance contract.
† Includes $0.025/square foot/year for chemical treatment.