SURVEY OF WATER-SOURCE HEAT PUMP SYSTEM CONFIGURATIONS IN CURRENT PRACTICE

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ABSTRACT

Water-source heat pumps (WSHP) are achieving ever greater market acceptance in commercial applications. A variety of system configurations have contributed to this success. A survey of WSHP system configurations currently utilized in commercial applications has been performed. This paper summarizes the results of the survey.

The survey identified four basic WSHP system configurations. Nomenclature for the configurations was established based on the nature of the liquid flow path serving each WSHP and on the energy source/sink that maintains the liquid within acceptable temperature limits for efficient and reliable WSHP operation. The survey identified two liquid flow path types. In the "open-loop" flow path, liquid from the environment is discharged back to the environment through operating WSHP. In the "closed-loop" flow path, liquid is contained in a closed system and recirculated through the WSHP. The survey found only one generally accepted open-loop source/sink for commercial applications, namely, groundwater. The three generally accepted closed-loop source/sinks identified were the heater/rejecter, ground-coupling, and environmental water sources (surface water or groundwater). Each basic WSHP system configuration has several variations. The paper describes each of the four basic WSHP system configurations and their major variations.

A survey of WSHP system application characteristics was also performed. The paper presents the results of this survey in the form of a series of generalizations intended to assist designers in selecting the most beneficial WSHP system configuration for a given application. It is believed that WSHP are suitable for many more commercial applications than common knowledge would indicate, partly because application evaluations are not always performed based on the most beneficial WSHP system configuration.

INTRODUCTION

WSHP have been manufactured as a commercial product in the United States for 30 years (Hughes 1987). The original markets for WSHP were primarily residential. The first market was in southern Florida, and these early systems used groundwater or canal water as the energy source/sink. Water was pumped from the source and discharged directly through the heat pump to the surface (canal, ditch, etc.). Some multifamily residential and commercial applications used open-circuit cooling towers to condition recirculated water but, in any event, the water loop was open to the atmosphere at some point in the system.

About 25 years ago, systems using closed loops with an indirect closed-circuit water cooler for heat rejection and a boiler for heat addition emerged in commercial applications on the West Coast (Hughes 1987). Referred to as the California heat pump system, this concept quickly spread to the East Coast and elsewhere. Today this system configuration is commonly referred to as the water-loop heat pump (WLHP) system (Pietsch 1988), and the market is primarily commercial (office buildings, etc.), but includes institutional buildings such as schools, nursing homes, and hospitals.

Since these early beginnings, several additional industry trends have occurred. The open-loop groundwater systems have moved north and west, necessitating the development of unitary WSHP capable of operating efficiently with lower temperature groundwater. Although this market is primarily residential, wherever the industry becomes well established, a light commercial market follows.

The introduction of European plate-and-frame heat exchanger technology, with its low temperature drop characteristic, has led to the emergence of closed-loop groundwater and surface water systems for a variety of nonresidential applications.

The development of reliable underground plastic piping technology with a long life has led to the emergence of closed-loop ground-coupled systems. This system configuration has necessitated the development of unitary WSHP, which operate efficiently over an even wider range of entering liquid temperatures than needed for groundwater. Although this system configuration was pioneered for residential applications, wherever the ground-loop installation infrastructure becomes well established, a light commercial market follows.

As a result of these historic developments, there now exists a family of commercial WSHP system configurations. These system configurations are described in the next section and application characteristics are reviewed in the subsequent section to assist designers in selecting

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the most beneficial WSHP system configuration for their application.

SYSTEM CONFIGURATIONS

The common characteristic of all four basic WSHP system configurations is the use of WSHP as terminal units serving space-conditioning and/or water-heating loads. Each space-conditioning WSHP is controlled by its own thermostat, and is allowed to provide heating or cooling as required. WSHP units that provide hot water may do so as a byproduct (while heating or cooling) or on demand. Applications vary in number of units from several to thousands of WSHP units. A liquid is circulated to each WSHP to serve as the energy source or sink. The same circulation system can also serve liquid-cooled process equipment, such as ice makers or refrigerated display cases.

The family of commercial WSHP system configurations includes one open-loop member and three closed-loop members. The three closed-loop system configurations are distinguished by the method used to condition the closed loop so that heat pump entering liquid temperatures remain within the allowable range of the WSHP.

Water-Loop Heat Pump System (WLHP)

The basic water-loop heat pump system configuration is represented schematically in Figure 1. The system utilizes a closed loop that recirculates water through heat pumps that are plumbed in parallel. In most applications, water recirculates continuously. Heat storage with water tanks to enhance the heat recovery capability of the system or to keep heater operation off-peak is optional. The central pumping station includes two full-sized pumps in parallel to protect against WSHP flow loss. The closed-loop water is conditioned with a heat adder (usually an electric or fossil fuel boiler) and a heat rejecter (usually a closed-circuit evaporative water cooler or an open cooling tower with isolation plate-and-frame heat exchanger).

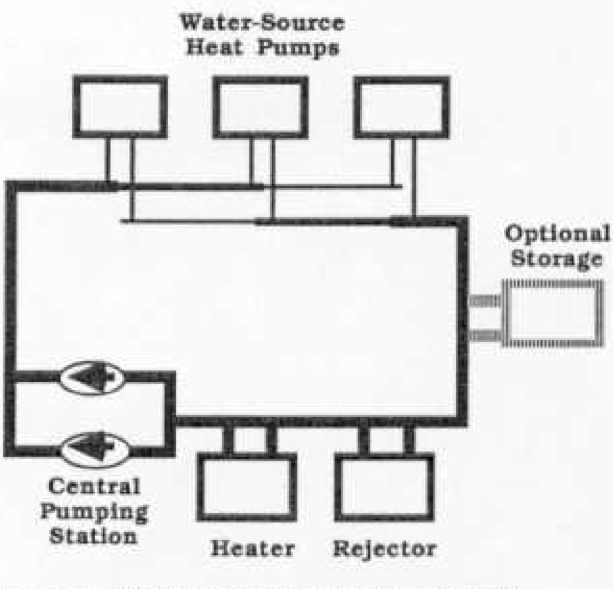

Figure 1 Water-loop heat pump system (WLHP)

Following conventional practice, the water loop is maintained between 60°F and 90°F (*Climate Master Handbook* 1977). As the water loop temperature approaches 90°F, various stages of the heat rejecter are turned on to maintain the temperature below 90°F. As the loop temperature approaches 60°F, various stages of the heat adder are turned on to maintain the loop above 60°F. Between 60°F and 90°F, the loop is allowed to float with no heat addition or rejection required.

The basic system has several variations. Boilerless systems, where perimeter heat pumps have resistance heat backup, are sometimes used in warm climates (*McQuay Manual* 1987). Self-contained VAV packaged air conditioners (similar to WSHP but cooling only, 20 to 80 tons, and VAV on the air side) are sometimes used on a floor-by-floor basis in high-rise buildings (Linford and Taylor 1989). Some floor-by-floor self-contained packages have optional direct-cooling coils to pre-cool return air with the closed-loop liquid at outdoor temperatures below 50°F. This water-side economizer variation is used in applications where the resulting cooling savings in the core exceed the benefit of the core-to-perimeter heat recovery that would otherwise occur in systems with WSHP on the perimeter. The water-side economizer option requires heater/rejecter control resets at outdoor temperatures below 50°F so that the heater is off and the rejecter maintains the closed-loop temperature within a range suitable for direct cooling. Floor-by-floor self-contained packages can serve the core teamed with WSHP on the perimeter or, in warmer climates, they may serve the entire floor with an alternate heat source for morning warm-up and perimeter heating. Perimeter WSHP in water-side economizer systems should be designed for the lower entering water temperatures that they will encounter.

Closed-Loop Ground-Coupled System (CLGC)

The basic closed-loop ground-coupled system configuration is represented schematically in Figure 2a. As with the water-loop heat pump system, a closed loop is used to recirculate liquid continuously through heat pumps plumbed in parallel. Heat storage with liquid tanks to enhance heat recovery capability is not necessary because the ground coupling provides a massive storage effect. In warmer climates, water is the closed-loop working fluid but, in cooler climates, an antifreeze solution is required. The closed-loop central pumping station includes two full-sized pumps in parallel to protect against WSHP flow loss.

The ground coupling provides both conditioning of the closed-loop liquid and energy storage (*WaterFurnace Manual* 1989). The ground coupling consists of polyethylene or polybutylene heat-fusible pipe and can be configured as either horizontal or vertical earth loops or as pipe spools in a body of surface water (commonly called surface water or pond loops). Each earth loop or pipe spool is a separate circuit. They are plumbed to the indoor closed loop via multiple parallel runouts, each with multiple parallel circuits. This enables the runout and circuit pipe to be of small, standard diameters, which are less expensive and more easily handled during installation than larger diameter pipe. Also, since each runout can be

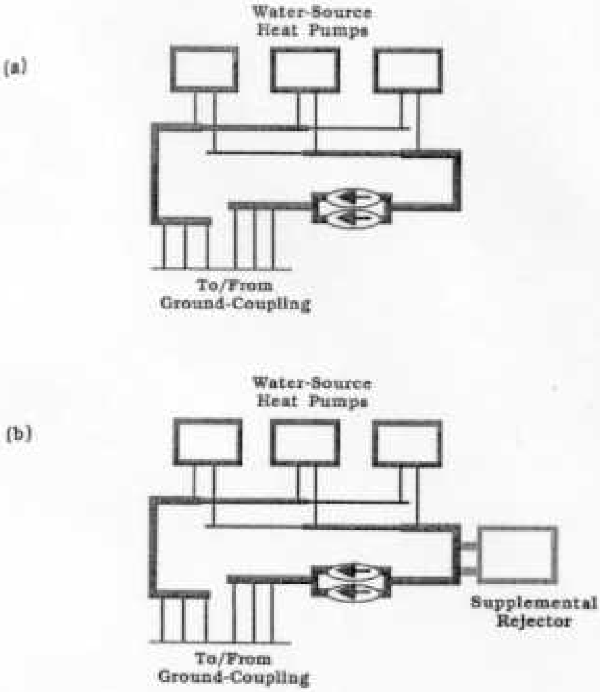

Figure 2 Closed-loop ground-coupled system (CLGC)

isolated, the closed-loop central pumping station can generate sufficient velocity to flush the air out of the system initially. Unlike other WSHP system configurations, the ground-coupled system has multiple parallel circuits at lower elevations than the closed-loop fill line and pumping station. Consequently, design provisions for flushing and filling are relatively more important.

Following conventional practice, the earth loop or surface water loop subsystem is sized to maintain WSHP entering liquid temperatures between approximately 25°F and 105°F (*WaterFurnace Manual* 1989). As a result, WSHP utilized in ground-coupled systems must be designed for operation over this extended temperature range.

The basic system has one major variation. In applications where the required size of the earth loop or surface water loop subsystem is much larger at the cooling design condition than at the heating design condition, it is sometimes more economical to add a heat rejecter (usually a closed-circuit evaporative liquid cooler or an open cooling tower with isolation plate-and-frame heat exchanger) to the system, as in Figure 2b. This allows the ground-coupling subsystem to be sized for heating.

Closed-Loop Water-Source System (CLWS)

The basic closed-loop water-source system configuration is represented schematically in Figure 3a. As with the previous system configurations, a closed loop is used to recirculate liquid continuously through heat pumps plumbed in parallel. Heat storage with liquid tanks to enhance heat recovery capability and lower source water consumption is optional. In warmer climates, water is the closed-loop working fluid but, in cooler climates, an antifreeze solution is required. The closed-loop central pumping station includes two full-sized pumps in parallel to protect against WSHP flow loss.

The closed loop is conditioned via a plate-and-frame heat exchanger using groundwater or surface water as the energy source/sink. If groundwater is used, the primary equipment consists of at least two wells with submersible well pumps for system protection against pump failure. Ideally, each well can provide the maximum required groundwater flow. The thermal capacitance of the closed loop prevents short-cycling of well pumps. If surface water is used, the primary equipment consists of dual pumps and auxiliary gear, usually located in a pump house at water's edge, with screened and strained inflow/outflow to the body of water.

Several variations to the basic system configuration exist (Shymko 1988). In the North, a boiler may be added to the system (Figure 3b) in order to maintain minimum allowable heat pump source temperatures when source water is at its coldest or to limit the required size of the source water system. Also in the North, a central liquid-to-liquid WSHP may be added in addition to the boiler, and the terminal heat pumps converted to two-pipe fan coil units (Figure 3c). This has the same advantages as Figure 3b but, in addition, may save capital cost and/or operating cost. Capital cost may be lower if the savings from fan coils rather than heat pumps are greater than the cost of the central heat pump. Operating cost may be lower because the presence of both the boiler and central heat pump enables dual fuel operation to minimize demand charges. A disadvantage is the loss of heat recovery capability and comfort, since all zones on a runout must be either heating or cooling. These problems can be minimized by putting core and perimeter zones on separate runouts, each with its own boiler (or converter) and central heat pump.

Open-Loop Groundwater System (OLGW)

The open-loop groundwater system configuration is represented schematically in Figure 4. When a heat pump operates, groundwater is discharged through the unit to waste (surface discharge or aquifer re-injection). All heat pumps are plumbed in parallel. The use of surface water (from canals, lakes, streams, etc.) is no longer recommended by most WSHP manufacturers due to heat exchanger fouling. The primary equipment consists of two wells with submersible well pumps and diaphragm-type expansion tank(s) with sufficient volume to prevent well pump short-cycling. Multiple wells are recommended for system protection against pump failure. None, some, or all of the units may be discharging groundwater at any given time. Ideally, each well can provide the maximum required groundwater flow.

APPLICATION CHARACTERISTICS

There are a number of different application characteristics that determine which of the four basic WSHP system configurations is most appropriate for a given application. These include availability of groundwater, availability and size of surface water, site land area, heat recovery potential, building height and size, mechanical room space availability, acceptability of outdoor equip-

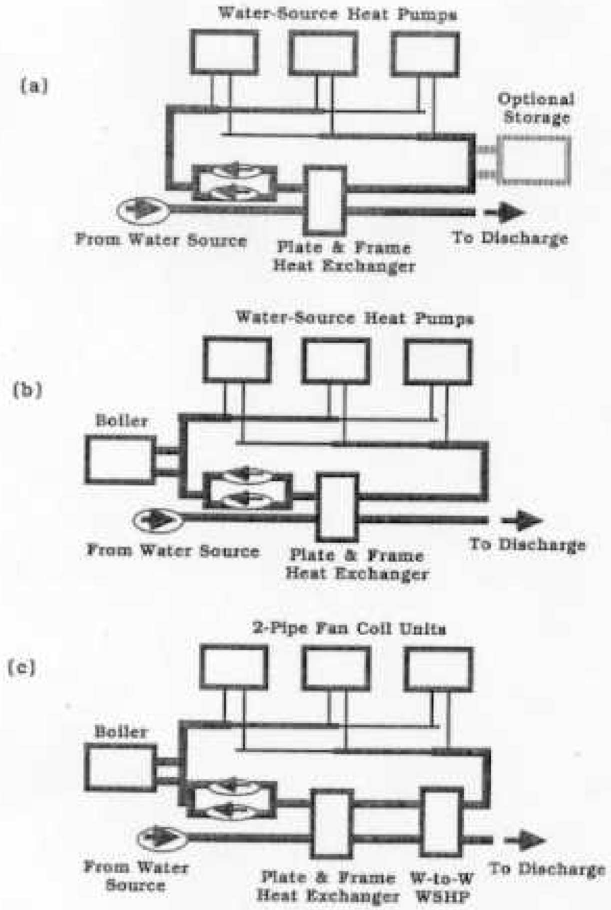

Figure 3 Closed-loop water-source system (CLWS)

ment, and anticipated heat pump entering liquid temperature range.

Availability of Groundwater

WSHP system configurations utilizing groundwater are not possible unless suitable groundwater resources (quantity and quality) are available. Use and disposal of groundwater are increasingly regulated, so the designer must be aware of all regulations that apply. The next step is to review well logs and other hydrogeological records available for the vicinity of the proposed site. If the approach seems feasible, gravity surveying can be used to spot the wells on the site (Shymko 1988). If there is any remaining question, a test well can be drilled for capacity and quality tests before committing to the system configuration. Many commercial applications have a need for water (sprinkler systems, etc.) even if they are on municipal water systems, so the test well is not necessarily a wasted investment if not used for a heat pump system.

Availability and Size of Surface Water

WSHP system configurations utilizing surface water require access to a body of surface water of adequate size. The use of public bodies of water is increasingly regulated, so the designer must be aware of all regulations that apply. Certain commercial, institutional, and multifamily developments include the creation of bodies

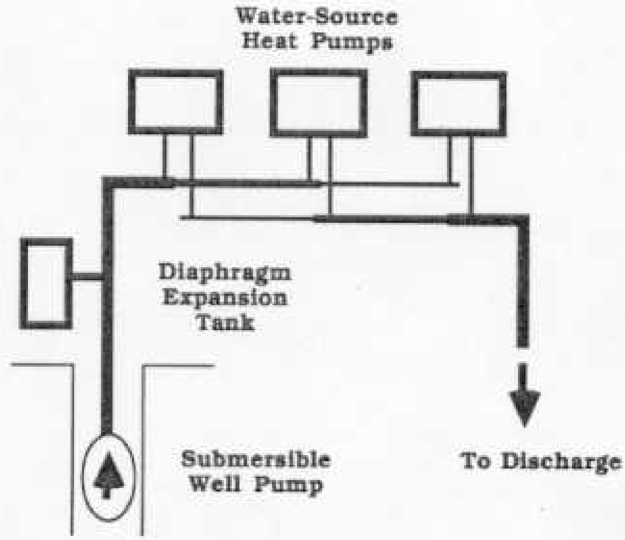

Figure 4 Open-loop groundwater system (OLGW)

of water to solve hydrological problems at the site (e.g., man-made ponds and lakes to help drain a site), for aesthetics (e.g., reflecting pools), or for compliance with regulations (e.g., runoff retention basins). The way the body of water is used depends on the WSHP system configuration. Either water is drawn from and discharged back into the body of water or spools of pipe are submerged in the body of water. In either case, the critical closed-loop conditioning design load (heat rejection or heat extraction) must be accommodated by the body of water. General rules for determining the capacity of a body of water were not found, although several rules-of-thumb with caveats exist (Kavanaugh 1989; *WaterFurnace Manual* 1989).

Available Land Area

Available land area is of concern for closed-loop ground-coupled systems. Typical horizontal earth-loop area requirements are as follows (*WaterFurnace Manual* 1989):

	North (ft^2/ton)	South (ft^2/ton)
2 pipes per trench	2000	3500
4 pipes per trench	1500	2400
6 pipes per trench	1500	2400

Vertical earth loop requirements are about 275 ft^2 per ton, assuming that the subsurface structure allows each bore to be deep enough to serve one ton. In the North, the required depth is about 150 ft/ton; in the South, it is about 250 ft/ton. If drilling conditions make these depths impractical, the required surface area in ft^2/ton can be estimated as 275 times the ratio of the required depth over the achievable depth.

As a general rule, applications that require parking have enough space for horizontal earth loops under the parking lot up to about 20 to 30 tons. Beyond that, vertical earth loops may be required. Concerns have been raised that the heat rejection capacity of horizontal earth loops under hot black asphalt surfaces may be significantly reduced. No evidence was found concerning this issue. It is believed that asphalt helps the soil retain moisture and may improve performance.

Heat Recovery Potential

In general, to have a high heat recovery potential, a building must have both a significant year-round core cooling load and a perimeter heating load during some seasons, or cooling loads and a significant need for hot water year-round.

The open-loop groundwater system configuration has no capability to perform heat recovery, but the three closed-loop systems do (to varying extents) depending on the nature of the heat recovery potential of the application. Figure 5 shows three cases for application heat recovery potential.

Heat recovery potential is greatest in applications that experience a significant number of hours per year where some heat pumps are adding heat to the liquid and some are extracting heat from the liquid (Figure 5a). If the hourly additions and extractions balance, the closed loop performs heat recovery at constant temperature with no central loop conditioning required. Slight imbalances cause slow temperature excursions in the closed loop. Large imbalances cause more rapid excursions.

If all heat pumps are extracting or adding heat simultaneously, no heat recovery occurs and the most rapid loop temperature excursions are experienced. However, heat recovery can still occur on days where some hours have net heat extractions and some have net heat additions to the closed loop (Figure 5b). A common example is heat recovery between occupied hours with net heat additions and unoccupied hours with net heat extractions. Diurnal heat recovery requires that the closed loop have some type of storage beyond the thermal capacitance of the liquid in the loop, if central loop conditioning is to be minimized. Ground-coupled systems have this storage built in, in the form of an earth loop coupled to the ground or a surface water loop coupled to a body of water. Other closed-loop configurations require a liquid storage tank subsystem to achieve this diurnal heat recovery.

During periods where the time between hours with net heat extractions and net heat additions exceeds approximately a day (Figure 5c), closed loops with water tank storage subsystems will achieve only modest heat recovery, and central loop conditioning is required to keep the loop temperature within the allowable range. In water-loop heat pump systems, this means running the heater to maintain the low limit or running the heat rejecter to maintain the high limit. In closed-loop water-source systems, this means running the water source through the plate-and-frame heat exchanger to either add or reject heat to/from the closed loop. Only the ground-coupled system can span such periods without using primary energy for loop conditioning.

Although earth and surface water loops can be sized so that ground-coupled systems never use primary energy for loop conditioning, it is sometimes more economical to add a heat rejecter (*WaterFurnace Manual* 1989). If full sized, the earth or surface water loop must

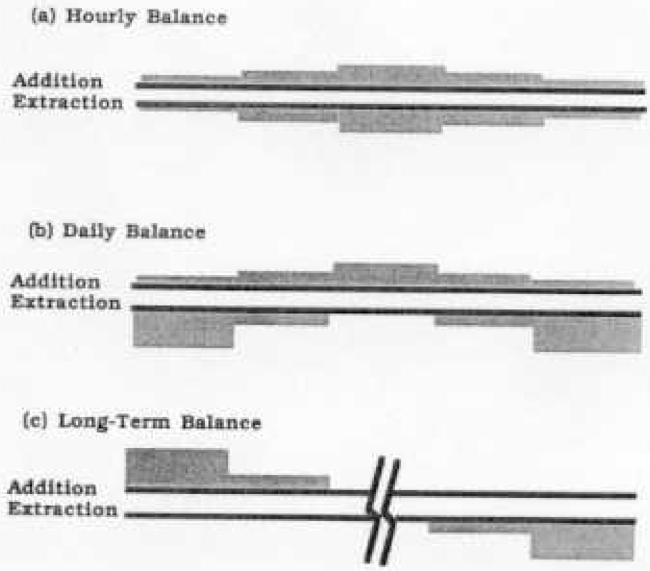

Figure 5 Three levels of heat recovery potential

retain the heat pump entering liquid temperature within the allowable range (25°F to 105°F for extended range units). But since getting rid of the heat is the major problem in many applications, this can lead to systems that never see heat pumps entering temperatures below 40°F to 60°F. By sizing the earth or surface water loop for heating and adding a heat rejecter, less expensive systems can be designed because they use the entire extended range capability of the heat pumps. Concerns have been raised that extended range applications reduce WSHP reliability and service life. No data addressing this issue were found; however, the application is still less extreme than that encountered by the highly reliable air-source heat pump.

Building Height and Size

Open-loop groundwater systems are limited to small, low-rise applications in areas where groundwater is legal to use, plentiful, of high quality, and has a high static water level. The building must be low-rise and the static water level shallow because well pump power consumption increases dramatically with vertical lift (i.e., from the static water level to the highest WSHP).

In general, the larger the application, the more likely that the system of choice is the water-loop heat pump system because standard-range WSHP are less expensive than extended-range units. Also, multistory buildings typically have year-round core cooling loads, and floor-by-floor self-contained VAV packages can be used with water-side economizers or heat recovery to WSHP on the perimeter. Water-side economizers on many WSHP are not as economical as on one self-contained package per floor. Twenty-five thousand square feet is often quoted as the practical lower limit on building size for the water-loop heat pump system, but this depends on a number of factors, including building shape, internal loads, and climate. There is no limit on height, although designers must take care to ensure that the closed-loop piping material used at any given elevation can withstand the static pressure head.

Closed-loop water-source systems require groundwater or surface water. If groundwater is used, they are limited to small- and medium-sized applications (up to about 40,000 ft^2) in areas where groundwater is legal to use, plentiful, of high quality, and has a high static water level. There is no limitation on building height because the high point in the open loop is usually in the first-level mechanical room. The static water level must be shallow because well pump power consumption increases dramatically with vertical lift. Groundwater consumption is relatively low per ton-hour since heat recovery is possible; however, sites that can produce enough groundwater for more than 40,000 ft^2 are rare unless a dual fuel boiler is added to the basic system configuration. If surface water is used, there is no limit on the height of the building, but size is limited by the thermal load that the body of water can support.

Closed-loop ground-coupled systems with vertical earth loops are limited to use in buildings with about six stories or less because of the static pressure head ratings of the earth loop pipe. Higher rated pipe could be used, but it would be more expensive and more difficult to handle during installation. For all practical purposes, building height is not a factor in horizontal earth loop or surface water loop applications. Theoretically, there is no building size limit on ground-coupled applications if land area is not an issue. However, above about 20 to 30 tons, the parking lot may not be large enough for a horizontal loop, and above about 100 to 200 tons it may not be large enough for a vertical earth loop either. An earth loop supplemented with a heat rejecter can physically accommodate applications from 0% to 25% larger, depending upon the relative heating and cooling loads of the application. However, there is a point beyond which ground-coupled systems are more expensive than other WSHP system configurations. For earth-loop and surface water-loop systems, it appears that the water-loop heat pump system is more economical beyond about 100 tons (Duffy 1989). For surface water-loop systems, it appears that the closed-loop water-source system is more economical beyond about 30 tons.

Mechanical Room Space Availability

All WSHP system configurations use minimal mechanical room space since the heat pumps are scattered throughout the building, located near the point where their heating, cooling, or hot water output is required. The open-loop groundwater system requires room for little more than the diaphragm pressure tanks. The water-loop heat pump system only requires room for the central pumping station, boiler and, when used, the water storage subsystem. The rejecter is typically on the roof or at the side of the building. In high-rise applications, the mechanical rooms for the floor-by-floor, self-contained, packaged VAV units are typically smaller than the duct shafts required for central VAV systems. The closed-loop water-source system only requires room for the central pumping station, plate-and-frame heat exchanger and, when used, the water storage subsystem. If the water source is groundwater, the pumps are submerged in the wells. If the water source is surface water, there is typically a pump house at water's edge. The closed-loop ground-coupled system only requires room for the central pumping station. If a supplemental rejecter is used, it is located on the roof or at the side of the building.

Acceptability of Outdoor Equipment

If outdoor equipment is not acceptable to the architect or building owner, the only WSHP system configurations meeting this requirement are open-loop groundwater systems, closed-loop water-source systems (groundwater, or surface water with pumping station in mechanical room), and closed-loop ground-coupled systems (without a supplemental rejecter).

Heat Pump Entering Liquid Temperature Range

The entering liquid temperatures to be experienced by zone heat pumps in a particular application depend on both the WSHP system configuration selected and the geographic location. The ARI has two test standards for WSHP in existence and a third in the making. ARI 320 is for WSHP as applied in water-loop heat pump systems. ARI 325 is for WSHP as applied in open-loop groundwater systems or water-loop heat pump systems with water-side economizers. A draft ARI test standard (ARI 330) is in circulation for WSHP as applied in closed-loop ground-coupled and water-source systems where units are exposed to extended range conditions. The major difference between test standards is the liquid-side entering temperature at the test conditions. ARI 320 tests performance at 70°F and 85°F; ARI 325 tests performance at 50°F and 70°F; and ARI 330 tests performance at 32°F and 77°F. When selecting and sizing heat pumps, it is important that the unit have the appropriate ARI certification and be operable and efficient over the entire range of entering liquid temperatures to be encountered in the application. In the case of low-temperature applications where a final standard is not yet in place, the manufacturers can supply performance data at 30°F.

The high and low temperatures listed in Table 1 are typical of those encountered in various WSHP system configurations in North America (*WaterFurnace Manual* 1989). In Table 1, "perimeter-dominated" applications are those with little heating/cooling heat recovery potential because the loads in all zones are climate driven. "Core-perimeter" applications are those where the core is cooling year-round due to internal loads, and the perimeter is climate driven.

Note that only the water-loop heat pump system can do without closed-loop insulation and an antifreeze working fluid no matter where it is applied. Even in this system, antifreeze is a common measure to prevent freezing in the outdoor rejecter in the North or to prevent sweating in water-side economizer designs. The open-loop groundwater system does not have a closed loop, so antifreeze is not an issue; however, insulation on the piping is required to prevent sweating. Closed-loop ground-coupled and closed-loop water-source systems typically require both pipe insulation and antifreeze in the closed loop.

CONCLUSIONS AND RECOMMENDATIONS

Four basic WSHP system configurations were found in current practice, one open-loop and three

TABLE 1
Typical Application Temperature Extremes (°F)

	Area in North America					
	North		Middle		South	
	Htg	Clg	Htg	Clg	Htg	Clg
Closed-Loop Ground-Coupled:						
• Earth loop						
Perimeter-Dominated	30	75	40	105	55	105
Core-Perimeter	35	105	50	105	70	105
• Surface Water Loop						
Perimeter-Dominated	30	70	35	105	45	105
Core-Perimeter	35	105	45	105	55	105
Closed-Loop Water-Source:						
• Groundwater						
Perimeter-Dominated	40	85	45	85	50	85
Core-Perimeter	40	85	45	85	50	85
• Surface Water						
Perimeter-Dominated	30	85	37.5	90	45	95
Core-Perimeter	30	85	37.5	90	45	95
Water-Loop Heat Pump:						
Perimeter-Dominated	65	85	65	85	65	85
Core-Perimeter	65	85	65	85	65	85
Open-Loop Groundwater:						
Perimeter-Dominated	50	55	55	60	60	65
Core-Perimeter	50	55	55	60	60	65

closed-loop. The closed-loop system configurations are distinguished by the method used to condition the closed-loop liquid to maintain WSHP entering liquid temperatures within acceptable limits. The four basic system configurations are water-loop heat pump systems (WLHP), closed-loop ground-coupled systems (CLGC), closed-loop water-source systems (CLWS), and open-loop groundwater systems (OLGW). The primary attributes of these system configurations are summarized in Table 2.

The survey uncovered some information useful for deciding between WSHP system configurations for applications. The use of engineering systems analytical techniques would be required to be more specific on a building type and regional basis. After the most beneficial configuration is selected, more specific information would also be useful for comparing the selected WSHP configuration to competitive systems. If this information were generated and summarized in a usable form, designers would consider WSHP for more applications.

The survey also uncovered some information gaps. Design-development work is needed to generate more accurate and practical methods of determining the thermal capacity of natural and man-made bodies of surface water and of sizing earth loops and surface water loops (with and without supplemental rejecters) for nonresidential applications.

Finally, one of the major perceived problems with all four basic WSHP system configurations is the means to provide fresh ventilation air. It would be useful to survey current practice and establish acceptable practice for the general benefit of the WSHP industry.

TABLE 2
Summary Attributes of WSHP System Configurations

System	Source/Sink	Loop Conditioning	Applications
WLHP	Conditioned loop	Heater/rejecter	Commercial/institutional 100 tons and more
CLGC	Conditioned loop	Earth loop or surface water loop (rejecter optional)	Residential and commercial/institutional 100 tons and less
CLWS	Conditioned loop	Plate-and-frame heat exchanger to groundwater or surface water	Commercial/institutional 100 tons and less with groundwater, larger possible with surface water.
OLGW	Groundwater	N/A	Residential and low-rise commercial/ institutional 40 tons and less

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DISCUSSION

T. Irwin, Marketing Technical Services Representative, United Cities Gas Co., Brentwood, TN: Could you provide more information regarding heat rejectors and the correlation to sizing ground-source heat pumps? Also, what is the electric demand of a water-loop heat pump and how does it compare to a ground-coupled system?

P.J. Hughes: In the conventional GCHP system, the earth loop is sized to maintain acceptable inlet temperatures to the WSHPs at all times. The lowest acceptable temperature is about 25°F and the highest is about 110°F. In many applications, getting rid of the heat (e.g., maintaining 110°F at cooling design conditions) requires a larger earth loop than extracting heat from the ground (e.g., maintaining 25°F at heating design conditions). In these cases it may be more economical to add a supplemental heat rejector and size the earth loop for the design heating condition. The heat rejector is sized to meet the earth loop heat rejection capacity shortfall at the cooling design condition. This answers how supplemental heat rejectors relate to earth loop sizing. Sizing of the WSHPs themselves are unchanged by the use of a supplemental heat rejector because zone loads and design entering liquid temperatures are the same either way.

Concerning the difference in electric demand between WLHP and GCHP systems, several qualifications must be made. A standard WLHP system at the design cooling load will have about 75% to 80% of the WSHP capacity operating, and the heat rejector operating at maximum capacity. A standard GCHP system at the design cooling load will have the same WSHP capacity operating, but the system has no heat rejector. A GCHP system with a supplemental rejector will have the smaller-than-full-capacity supplemental rejector operating at the cooling design condition.

At first look it seems obvious that the GCHP system will always have lower electric demand because the heat rejector is either smaller or non-existent. In actuality, the WSHPs in the GCHP system are operating less efficiently with higher inlet temperatures at cooling design conditions (105-110°F rather than 85-90°F for WLHP), so the difference between GCHP and WLHP is partially offset. For GCHP systems with supplemental rejectors it may be possible to "glide through" electric utility system peak periods without using the rejector by running the rejector continuously during the off-peak hours of those days and relying on the storage effect of the earth loop. In my opinion, some research in this area to develop better design and control guidelines would be useful.

M. Dizenfeld, P.E., Marriott Corp., Washington, DC: Your diagrams show double risers for the core and perimeter. Are they necessary?

Hughes: Separate risers for core and perimeter are not necessary. Some designers choose to use them for first-cost, control, or operating reasons. As a first-cost example, separate risers of one piping material may be less expensive than a single riser of another. As a control example, in variable-speed closed-loop pumping applications isolation of the core during unoccupied periods is possible with one control valve with separate risers but requires valves on each floor with a single riser. As an operating example, separate risers enable change-out of piping expansion joints without shutting down the entire closed-loop system. Separate risers do not retard heat recovery because full mixing occurs at the pumping station.

C.S. Trueman, P.E., B.C. Buildings Corp., Victoria, BC, Canada: How extensively is thermal storage used in water-loop heat pump systems? When thermal storage is used, what is the typical range of storage volumes, say, relative to floor area?

Hughes: Thermal storage is not widely used in WLHP systems. There is evidence to suggest that diurnal heat recovery potential exists in many applications and that, if properly managed with storage, this potential could either eliminate the boiler altogether or limit its size and operation.

At this point the most common forms of thermal storage are water tanks and earth loops. For good diurnal heat recovery, water tanks are sized at 50 to 100 gallons per total installed ton of WSHP. Evidence suggests that earth loops required for the diurnal storage function can be much smaller than those for loop-conditioning and long-term storage.

Clearly the earth loop duty is much easier in an application where enough heat is rejected during occupied hours to cover unoccupied period requirements even on the heating design day than, say, the duty in a residential application. Clearly the earth loop in this circumstance is used more for storage than for loop-conditioning with heat extracted from the ground. How much smaller the earth loop can be in this circumstance is not well known. In my opinion, some research in this area to develop better design and control guidelines would be useful.