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Harry J. Sauer
Missouri University of Science and Technology

Guruprasad Rao

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Harry J. Sauer, Jr. and Guruprasad Rao
University of Missouri-Rolla
Rolla, Missouri 65401

Abstract: The closed water loop heat pump (CWLHP) system has been shown to be an energy conserving building heating and cooling system. Such systems are most applicable where simultaneous heating and cooling needs occur. In these systems, internally generated space heat is used to meet heating needs before external heat is provided from a heating plant. The water loop is the transport system moving heat from where it is not wanted to where it is required. Addition of water storage gives an option to store thermal energy for later use. In the common arrangement for the closed water loop heat pump system, each perimeter zone is served by individual heat pumps while the cores zones are served by a central air handler. This paper reports the results of a study on the effect of component arrangement and system control strategy on the energy saving potential of the water loop heat pump used for heating and cooling of a commercial office building.

Introduction

There has been growing interest in the use and performance of Water Loop Heat Pump (WLHP) systems mainly due to the economic feasibility of the system. Research carried out by Howell (1985) revealed that climates that do not have extreme winters or summers are best suited for WLHP system.

The closed water loop heat pump systems are considered to be energy conserving building heating and air-conditioning systems. They are most applicable where simultaneous heating and cooling needs occur. In these systems internally generated heat is used before adding any external heat. The water loop is the transport system moving heat from where it is not required to where it is required. Addition of water storage gives an option to store energy for later usage. The water loop heat pump system design is similar to a four-pipe fan coil system in some ways. Each perimeter zone is served by individual heat pumps, while the core zones are served by a central air handler. The closed water loop heat pump system is referred to as a semi-central system. The non-central parts of the system are the heat pumps serving each zone separately. The central part is the water loop which carries energy from where it is not required to where it is required. Figure 1 shows a schematic of the Closed Water Loop Heat Pump system.

A typical winter day operation can be explained as follows. Perimeter zones will need heating, while core zones might need cooling because of human occupancy, lighting, equipment etc. Hence water is first passed through the core zones, where the heat pump rejects unwanted space heat from the zone to the water. The heated water is then passed into the perimeter zone heat pumps, where heat is extracted from the water and rejected into the zone. The closed water loop operation scheme shown in Figure 1 seems to work fine in winter. On performing the simulation, it was observed that the exhaust water temperatures from the core zones reached temperatures as high as 200°F (93°C) on some hot summer days. This hot water would be passed into the perimeter zones which require cooling and therefore the system would be inefficient. From this problem it was realized that water had to be cooled being supplied to the perimeter zones. There were two options to solve the problem.

The first option was inclusion of a cooling tower in the water circuit before allowing water into the perimeter zones, as shown in the Figure 2. The operation in winter will be similar to the old arrangement in that water will not pass through the new cooling tower. However in summer, when the water returning from the core zones is exceeding a preset temperature limit, the cooling tower will be used to cool the water before it is supplied to the perimeter zones. The second option involved allowing water in a parallel circuit to core and perimeter zones. This option is shown in Figure 3. With this option, operating modes for summer and winter are different. In winter, all the water will be passed into the core zones where heat will be picked up, and rejected to the perimeter zones. On a hot summer day, water will be distributed among the core and perimeter zones, thus allowing the perimeter zones to receive the same temperature water as that received by the core zones.

Building HVAC (heating, ventilation and air-conditioning) energy consumption represents a major part in a building's overall energy requirement. This HVAC energy consumption varies significantly with different air handling systems. The HVAC designers require software tools that aid in choosing the ideal system for a given building. The software tools in order to serve the purpose should be able to simulate a variety of HVAC systems, incorporating the state of the art demand and peak load reduction techniques. The simulations are performed every hour for an entire year and the energy meters keep track of the annual energy consumption. Several life cycle costing techniques are incorporated in the program. Based on the output of the simulation program, the designer will be able to select not only the most economical type of HVAC system but also which energy conserving measures will have a reasonable payback.

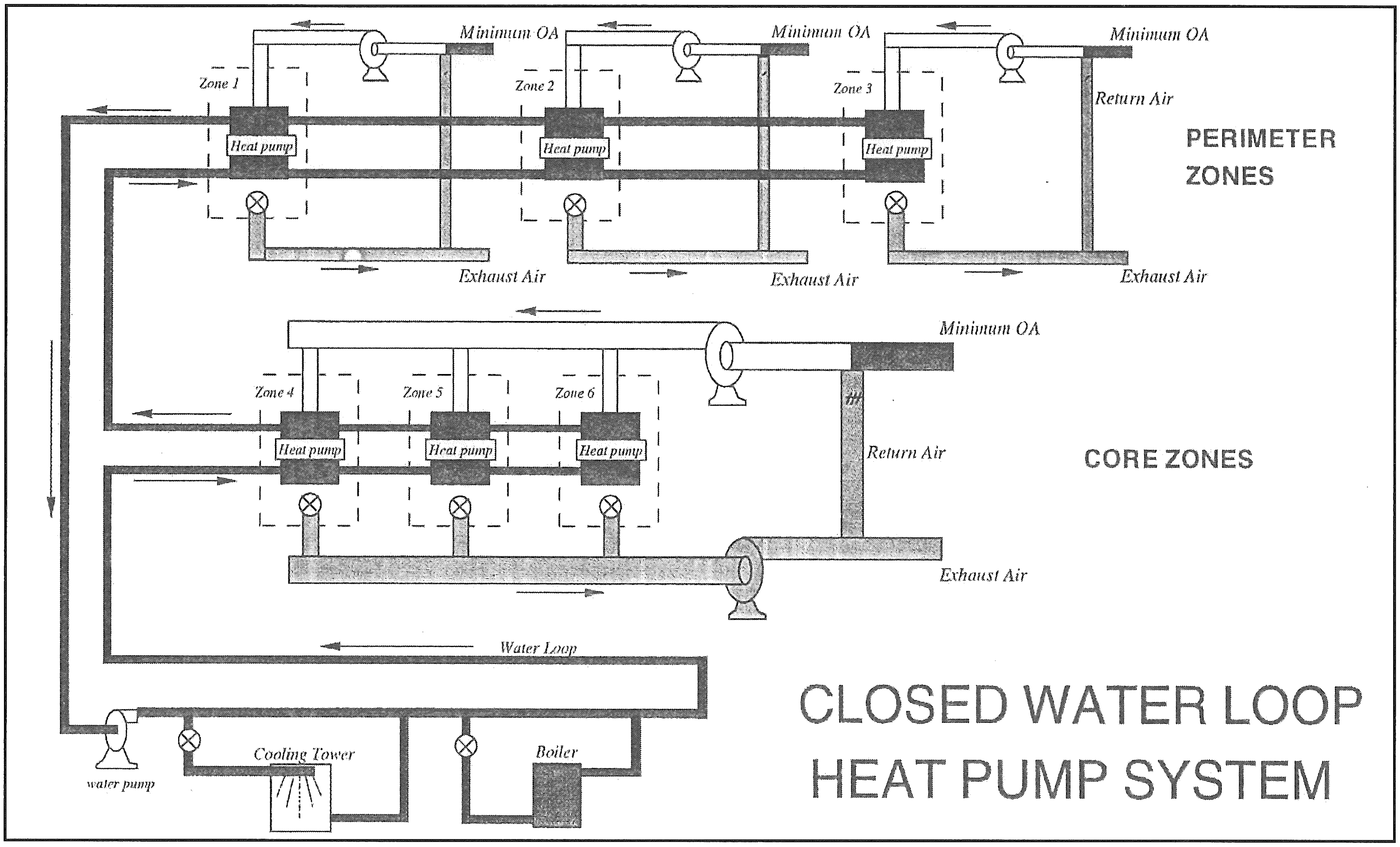

Figure 1. Schematic of Closed Water Loop Heat Pump (CWLHP) System.

Methodology

In the approach selected, the simulation of the building (mainly its physical aspects and internal loads) was separated from the simulation of different types of terminal and primary HVAC systems. The building loads program was made to simulate the building requirements as distinct from any HVAC systems that would provide the heating and cooling. This loads program was then incorporated into the various system programs. The main advantage of this approach was that comparison of different HVAC systems could be performed while being assured of a common basis in terms of building requirements. Only then could effects of the HVAC systems be properly observed. In addition, this approach allowed comparison between heat reclaim and economizer cycle priorities in systems that combined the energy-saving effects of both heat reclaim and economizer cycle operation.

To determine the requirements of the building in terms of sensible cooling, sensible heating, dehumidification and humidification for each hour, an energy balance was performed for each zone of the building on an hourly basis. It must be kept in mind that this analysis was aimed at developing a simplified, reasonably accurate procedure that would provide a common basis upon which different terminal and primary systems could be analyzed and the performance of those systems evaluated with the simultaneous operation of various energy conserving measures. The approach to calculate building cooling loads may be called an "Effective Temperature Difference (ETD)" Method with Time Averaging (TA). Anantapantula (1993) and Sauer et al (1996) provide details of the method.

Existing HVAC system simulation software from Anantapantula (1993) was expanded for this project by adding a module for the closed water loop heat pump. The program now has the capability for simulating the following secondary HVAC systems: Variable Air Volume, Multizone/Dual Duct, Four Pipe Fan Coil, and Closed Water Loop Heat Pump. The demand and peak load reduction techniques included in all the system simulations are economizers, heat reclaim, and thermal energy storage (TES). The software simulates the HVAC systems with combinations of the energy and/or load reducing techniques, and evaluates the energy consumption for each of the combinations. The software basically consists of four modules. Each module representing a type of HVAC system being simulated. All four modules are statically linked into a single executable. When the software is allowed to continue through the economic analysis, a detailed hour by hour simulation of the HVAC system is performed. Energy meters on the chiller and boiler keep track of the energy consumption. The total annual energy consumption is then the final count on the meters. Based on the detailed output, in terms of dollars and years of payback, the consultant should be able to make the optimal choice.

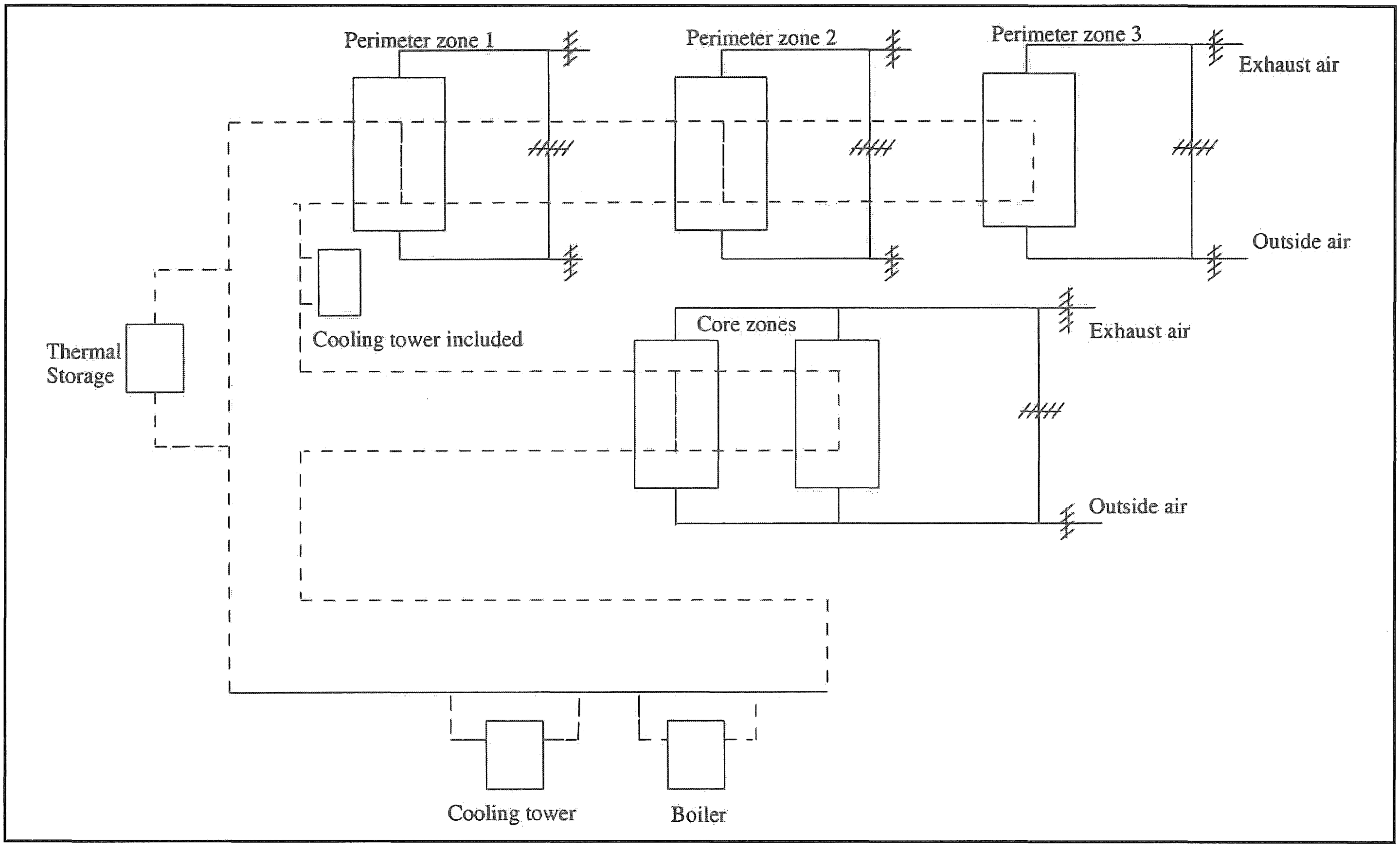

Figure 2. Closed Water Loop Heat Pump System Modification #1.

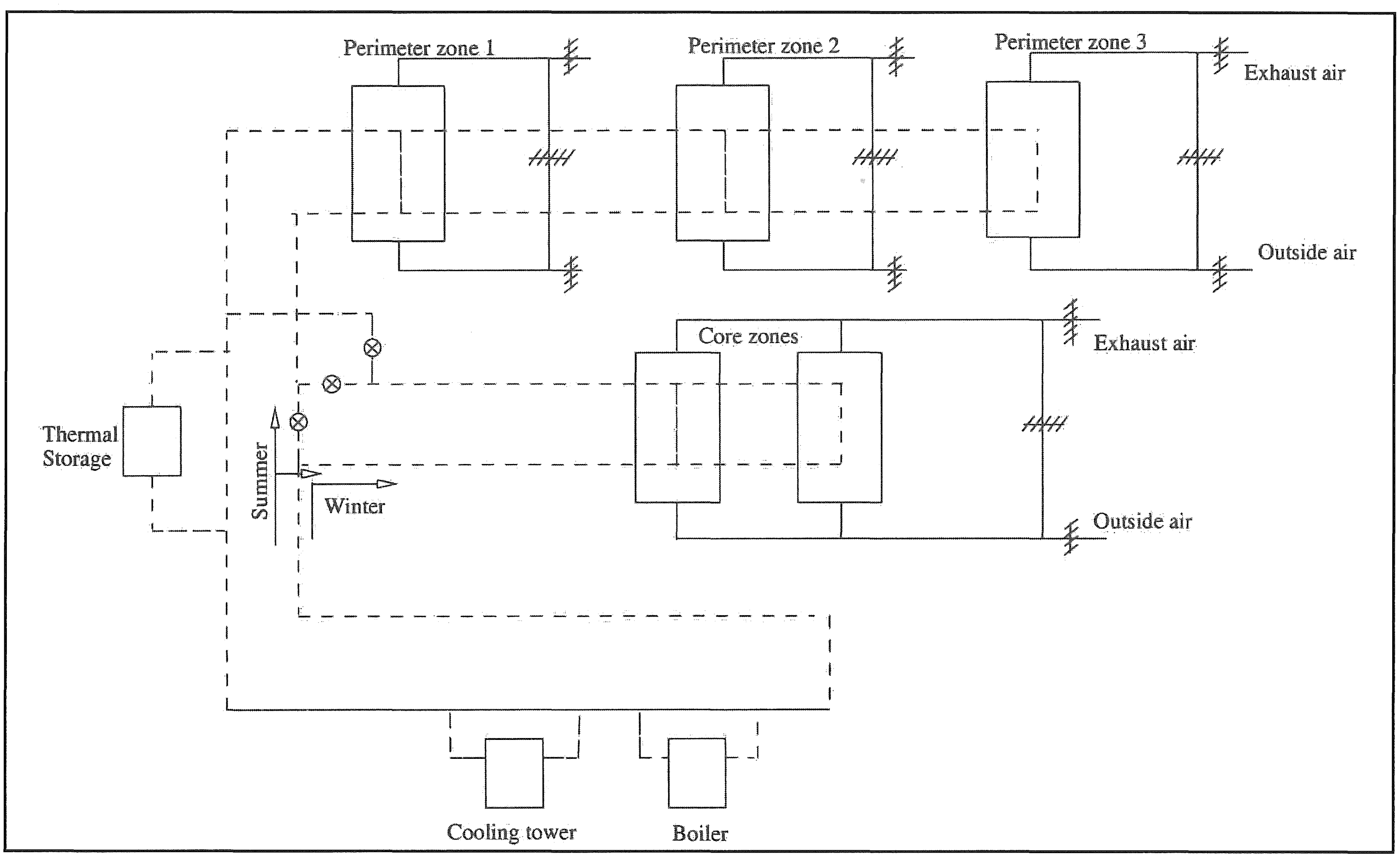

Figure 3. Closed Water Loop Heat Pump System Modification #2.

Input Data

The input data required by the program are mainly in the form of three types of data files, one containing data pertaining to the physical description and load schedule of the building, another providing details of the HVAC system operation, and three containing hourly weather data. To simulate the building in a particular location, the software requires three weather data files: cooling design day weather data, heating design day weather data, and hourly weather data for the entire year.

Building File. The program has the capability to calculate building loads for any number of zones. One line of data is input for each zone. In addition, the program can account for exterior walls facing any two directions and glass areas in each of those walls, in each zone of the building. Input data which must be specified for each zone are: roof, floor, wall, and glass areas and U-factors; ceiling height; building orientation; number of people during occupied period; and internal load level.

Weather Files. The weather data used for the programs came from U.S. Weather Bureau (now the National Weather Service) hourly data, provided on magnetic tape. The original data contained dry bulb temperature, relative humidity and cloud cover for every hour of the year (8760 hours). Subbarao (1990) has covered the calculational logic for determining the total normal intensities and solar heat gain factors for each orientation (North, South, East, West and Horizontal). The weather data available for each hour is comprised of: dry bulb temperature, humidity ratio, total normal intensities on walls facing North, East, South, West and on a horizontal surface, and solar heat gain factors for windows facing North, East, South, West and on a horizontal surface. Weather data files are been prepared for some 60 cities in the U.S. and can simply be copied to the user's hard drive.

HVAC Systems File. The modified HVAC Simulation Software is capable of simulating four types of HVAC systems: Variable Air Volume, Constant Volume Dual Duct, Four Pipe Fan Coil, and Closed Water Loop Heat Pump. For each system evaluated, a date file must be prepared prior to executing the program. The data for the life cycle cost estimation are included in this file. The systems file for the Closed Water Loop Heat Pump must include a rather complete description of the operating conditions and performance data for the CWLHP equipment and system. This file requires the following:

- Minimum OA Required
- Economizer Temperature Setpoint
- Preheat Coil Temperature Setpoint
- Supply Fan Static Pressure and Efficiency
- Cooling Coil Discharge Temperature and Humidity
- Hot Deck Maximum and Minimum Temperatures at corresponding OA Temperatures
- Chiller COP
- Boiler Efficiency
- Maximum storage capacity for heating, hours for reset
- Cost of energy
- Investment cost of installed energy conserving devices
- Years desired for payback
- Discount rate
- Escalation rate
- Expected life of equipment
- Circulating Water Pump Unit Size and Efficiency
- Water Side Pressure Drop
- Minimum and maximum piping loop water temperatures
- Cooling tower "approach"

Sample Results

The building that was simulated in this study was modeled after an existing two story, all electric office building located in St. Louis, Missouri. The building was divided into 16 zones. Physical description and building operation (base case) data were as given below.

Building roof area	: 22,810 ft^2 (2119 m^2)
Building floor area	: 45,620 ft^2 (4238 m^2)
Building exterior wall area	: 9,460 ft^2 (879 m^2)
Building glass area	: 7,536 ft^2 (700 m^2) (44% of Exterior Wall Area)

Each zone had an internal load density of 2.9 W/ft^2 (31 W/m^2). The building had 408 people for the base case and this number was prorated as per floor area for each zone. The zone ceiling height was 8.5 ft (2.59 m). The U-factors used were 0.25 Btu/hr ft^2 °F (0.79 W/m^2 °C) for the roof, 0.2 Btu/hr ft^2 °F (0.63 W/m^2 C) for the exterior walls and 1.0 Btu/hr ft^2 °F (3.15 W/m^2 °C) for the glass surfaces. A shading coefficient (SC) of 0.6 was used to account for interior and/or exterior shading). Other base case settings were as follow:

Inside setpoint: Temperature = 75 °F (23.9 °C)
Relative humidity = 50 %
Building thermal mass : M (Medium)
Building operation: 24 hours/day

Prior to conducting a detailed study on any particular HVAC system, such as the closed water loop heat pump, a more general analysis of potential energy conserving measures for the building in various locations was undertaken. The potential savings available with either heat reclaim alone or in conjunction with an economizer indicated that a more detailed study on the use of the closed water loop heat pump would be worthwhile. There is really no limit to the number of parametric or comparative studies than can be conducted. Thus, only a few examples are presented to demonstrate the unit energy requirements of the closed loop heat pump.

Figure 4 is a plot showing the components of the energy consumption at different locations when operated without storage. Heat pump heating energy and auxiliary boiler heating energy are less in Phoenix and Houston. Figure 5 is a similar plot, except that now water storage is included. As can be seen, there is very little effect on the auxiliary cooling energy but the auxiliary water heating energy change is significant. Auxiliary water heating energy dropped to zero in Houston and Phoenix, with a large drop also found for St. Louis and Minneapolis.

The results of this study demonstrate both the utilization of a simplified PC program for HVAC system selection as well as the potential of the closed water loop heat pump system as an energy efficient alternative to more conventional systems. The CWLHP offers considerable design flexibility and an inherent ability to recover heat in many commercial buildings.

If the result of this preliminary system selection indicates the water loop heat pump system, the designer can then find one or more sources of step-by-step technical design data for specific equipment selection, application, and specification, such as from EPRI (1994).

Conclusions

For more accurate energy estimating, there are a number of main frame and several PC hourly programs currently available. However, the manpower level and related costs required for developing and inputing the required data generally discourage the HVAC designer from utilizing such programs, except for major projects, for the initial selection of the "best" system. The methodology and associated PC program described in this paper offer an economical and easy to use tool for the design engineer during the initial selection process...and one that should properly promote the closed water loop heat pump system as one of the most energy efficient HVAC systems for buildings that have high internal loads and simultaneous heating needs. Although input data have been kept to a minimum, the various subroutines with the overall program have been shown to provide relatively accurate prediction of hourly building loads, energy requirements for the HVAC equipment, and life cycle costs which include investment costs, energy and demand costs, maintenance costs, and account for the time value of money.

References

Anantapantula, Surya, 1993, "Air Conditioning System Performance with Heat Reclaim and Economizer Operation", PhD Dissertation, University of Missouri-Rolla, Rolla, MO.

EPRI. 1994. "Water-Loop Heat Pump Systems. Volume 1: Engineering Design Guide (Revision 1)," EPRI TR-101134-V1R1, Electric Power Research Institute, Palo Alto, CA.

Howell, R.H., 1985, "Energy use in closed loop heat pump sys tems with variable storage, internal building loads for vari ous geographic locations." Proceedings of CLIMA 2000 World Congress on Heating Ventilation and Air-condition ing, Copenhagen, Denmark.

Sauer, Jr., H. J., S. Anantapantula, and R. H. Howell, 1996, "A Building Loads Program for HVAC System Simulation," ASME Paper 96-WA/HT-17, 1996 ASME International Mechanical Engineering Congress and Exposition, Atlanta, GA.

Subbarao, B., 1990, "Analysis of Flow Rates and Building Pressurization in a Variable Air Volume System," M. S. Thesis T6053, University of Missouri-Rolla, Rolla, MO.

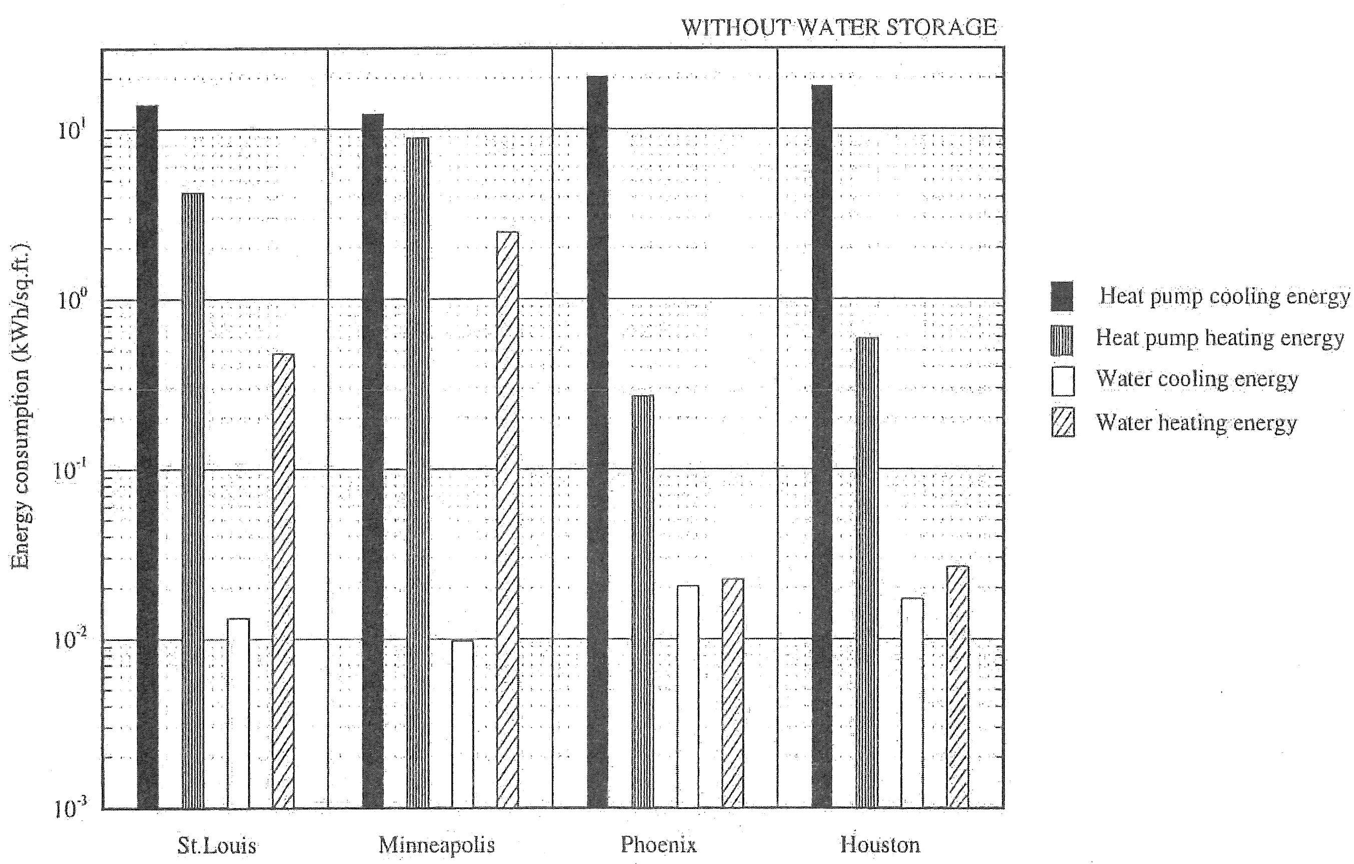

Figure 4. Energy Usage of Closed Water Loop Heat Pump (Without Storage).

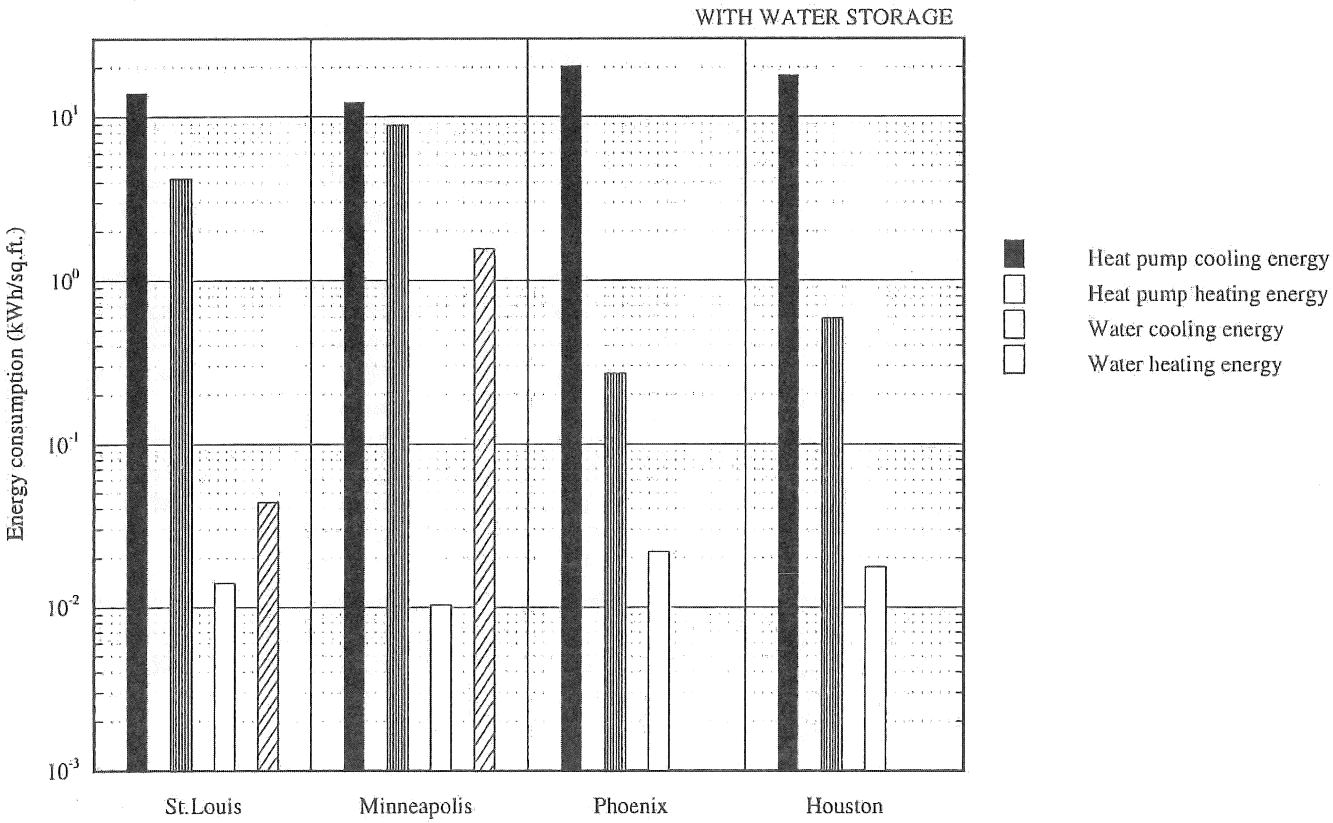

Figure 5. Energy Usage of Closed Water Loop Heat Pump (With Storage).