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Chilled water plant pumping schemes design & vfd chillers

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ABSTRACT

From the advent of central chilled water plants, the system for delivering chilled water to the end user has undergone significant changes as chilled water demands have increased, technology has improved, and energy efficiency has become an operational requirement. This paper reviews the history of chilled water pumping schemes and discusses the advantages of a direct-primary, variable flow system particularly on the impact to low ΔT syndrome.

***Keywords*— Low ΔT Syndrome, Chilled Water Pumping Scheme, Primary-Secondary, Direct-Primary, Variable Flow**

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I. Introduction

Chilled water has been a primary medium for the transfer of heat from building coils to the refrigeration system since the beginning of heating, ventilating, and air-conditioning design. Providing chilled water from a centrally located plant(s) has long been promoted as energy efficient and low maintenance means of rejecting heat from air-conditioning systems across a localized campus, whether that campus is a university setting, industrial complex, or large urban site. Initially, when energy costs were low, primary-secondary systems provided a stable and simple operation of the chillers and distribution systems. However, as energy costs increased, particularly in the late 1970s, the efficiency of the chillers and the costs associated with operating the distribution system became more important. As a result, the need for new schemes to improve chiller performance and reduce energy costs drove the HVAC industry to advance chilled water technology, particularly in the manner that chilled water is delivered. The pumping schemes for delivering chilled water can be separated into two categories, each with several off- shoots:

1. Direct-Primary (constant volume or variable volume)
2. Primary-Secondary (constant volume primary, variable volume secondary) refrigerant which is alternate refrigerant for HCFC R-22.

While chillers and cooling towers are large contributors to chilled water plant performance, a primary player in determining how well a plant performs is the efficiency of the chilled water distribution system. To understand the hydraulic considerations associated with delivering chilled water and how they influence system performance, it is important to understand how technology and design challenges over the years have influenced today's approach to chilled water pumping. This paper discusses the history of chilled water distribution systems and the development of a direct-primary system. Problems associated with the chilled water pumping schemes are defined and discussed and finally, this paper compares the advantages and disadvantages of primary-secondary and direct-primary pumping schemes..

With the advent of more sophisticated control systems and improvement in chiller technology over the last ten years, the direct-primary pumping scheme is being more widely used. It consists of a single variable volume chilled water loop (primary), which combines the chilled water plant and distribution systems. In order to vary chilled water flow to match the cooling load (position of two-way control valves), this pumping scheme allows the flow through the chillers to adapt to varying distribution conditions instead of having an independent secondary loop. The primary pumps perform double duty, circulating chilled water through the chillers as well as the distribution loop (see Figure 2). The pumps are equipped with variable frequency drives (VFD) to vary chilled water flow within the system to meet current operating conditions. This eliminates the need for chiller circulation pumps, but requires varying the flow through the chiller evaporator. This configuration was the long awaited answer to the problems presented by primary-secondary pumping. However, it is not without its own limitations. While chiller manufacturers have been allowing adjustable flow through the chillers, upper and lower limits have been placed on the flow rates. These manufacturers are typically limiting tube velocities from 5.0 feet per second to 10.0 feet per second. In addition, careful attention must be given to the allowable rate of change in evaporator flow. Typically, manufacturers limit this rate of change to 1,000 gpm per 15 minute period.

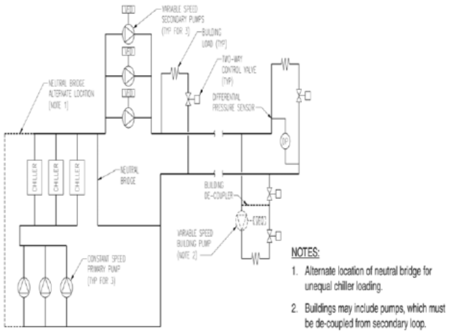

Figure 1 –Primary-Secondary Pumping Scheme

Fig 1

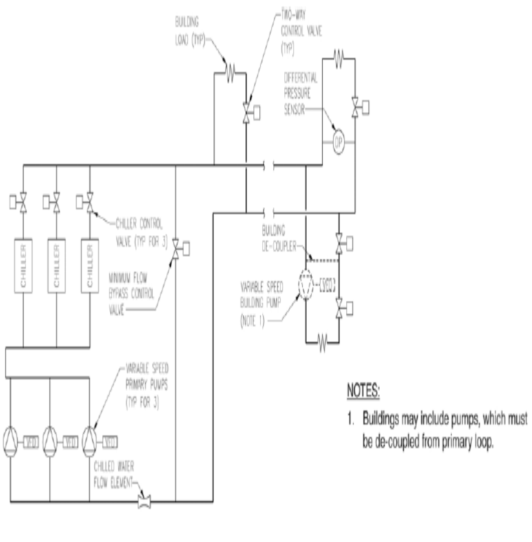

Figure 2 –Direct-Primary Pumping Scheme

Fig 2

II.EXPERIMENTAL SET-UP AND PROCEDURE

Because of these constraints additional design features are required with a direct-primary pumping scheme. The most significant of these features is the installation of a minimum flow bypass line and control valve as shown in Figure 2. Should the system load drop to the point where the flow rate needed to satisfy the buildings is less than the minimum flow required for the chillers, the minimum flow bypass control valve opens allowing some flow to re-circulate back to the chillers.[24] In order for this to work properly, the control of the system is dependent upon the accurate measurement of chilled water flow and proper selection of the bypass control valve.[25] The inability of the bypass valve to properly open and close may result in the chillers tripping due to low flow. As with primary-secondary systems, the designer of this pumping scheme must consider what influences the buildings may have on the operation of the plant. Any building pumps that remain in operation must also be hydraulically decoupled from the primary loop otherwise there is a risk of negative differential pressure and its inherent control problems. Furthermore, the single set of pumps used in this configuration will develop a higher system total dynamic head. In selecting the system design pressure, the designer must pay careful attention to the design of existing building systems.

The following is a list of the advantages to implementing a direct-primary system:

Neutral Bridge: The direct-primary system does not include two hydraulically independent loops that are separated by a neutral bridge. As a result, the pump flow rate is better matched to the cooling load within the distribution system and the absence of a neutral bridge prevents mixing of supply and return water **Adjustable Chiller Flow**: Allowing the flow through the chiller to vary above normal design flow lets the operator increase flow to the chiller and match the system ΔT. This maximizes the output of a given chiller and eliminates the need to start additional chillers and pumps prior to reaching nameplate capacity.

Capital Investment: The smaller quantity of pumps and the more efficient piping runs associated with this pumping scheme can yield a lower capital investment when compared to the primary-secondary system.

Lower Operating and Energy Costs: Since the direct-primary system uses fewer pumps and is better equipped to match system load; it will generally yield lower energy and operating costs per annum as compared to the primary-secondary system

Requires Less Plant Space: Constant flow pumps serving a production loop are not needed because the primary pumps circulate the water through the chillers as well as the distribution system. This requires less floor space, fewer spare parts, and can result in lower capital costs and pump maintenance costs.

III.RESULT & DISCUSSION

One of the primary benefits listed above is the energy savings a chilled water plant can realize per annum just from operating the chillers to their full nameplate capacity. To demonstrate this, consider the 9,000-ton chilled water plant previously discussed operating over a cooling season, which lasts from April through November. Due to the low return water temperature, the plant operators are required to operate more chillers than are needed during part load conditions due to the constant flow through the evaporators.

Consequently, the chillers cannot be fully loaded during these periods. The price tag associated with this operating scenario can be significant. For purposes of this example, assume the campus experiences a load profile as defined by Figure 3.

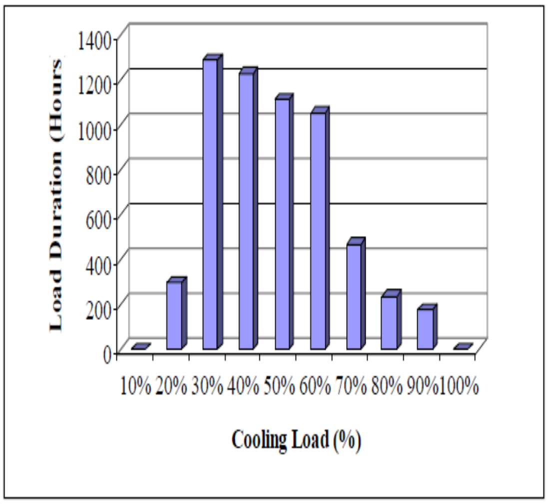

Figure 3 – Example Chilled Water Plant Load Profile

Assuming the chilled water plant sees a return water temperature of 50°F at part load conditions below 70 percent load, the chiller energy usage can be calculated. The particular chillers in this example are guaranteed to operate at the following efficiencies:

1. Full Load: 0.595 kilowatts per ton

2. 75 Percent Load: 0.559 kilowatts per ton

3. 50 Percent Load: 0.612 kilowatts per ton

4. 25 Percent Load: 1.019 kilowatts per ton

The results of this energy analysis can be seen in Table 2. The direct-primary pumping scheme with variable flow through the chillers will use 4 percent less energy over a single cooling season than a primary-secondary system with constant flow through the chillers. So simply operating the chillers to their full potential saves a significant amount of energy over the life of a plant

In addition, to the savings in chiller operation, a single loop with variable flow will inherently result in a net energy savings in pumping power. Because the chilled water flow rate follows the cooling load, the flow rate being pumped is matched to what is actually needed in the buildings. Again, the limit to this savings is the minimum flow required through the chillers, which in the case of this example is 4,500 gpm.

Table 2 – Example Chilled Water Plant Energy Usage from Chillers

Cooling Load (%)	Load Duration (Hours)	Primary-Secondary Electrical Demand (kW)	Primary-Secondary Energy Usage (kWh)	Direct-Primary Electrical Demand (kW)	Direct-Primary Energy Usage (kWh)
10	0	917	0	917	0
20	293	1,037	303,575	1,037	303,575
30	1,288	1,871	2,410,576	1,871	2,020,988
40	1,230	2,074	2,550,030	2,074	2,550,030
50	1,113	2,754	3,064,211	2,754	2,798,846
60	1,054	3,110	3,278,610	3,110	3,307,071
70	468	3,522	1,649,846	3,522	1,649,846
80	234	4,075	954,575	4,075	954,575
90	176	4,706	826,768	4,706	826,768
100	0	5,355	0	5,355	0
Total			**15,038,190**		**14,411,698**

IV.CONCLUSION

Chilled water delivery has undergone significant changes since the advent of central chilled water generation. Responding to the various demands of operations, equipment, and the drive for more efficient plants has led to a multitude of variations on two basic concepts, namely primary-secondary and direct-primary pumping schemes. Because the pumping scheme is the heart of a chilled water system, important lessons can be learned from our past as we look to the future of district energy.

The arch nemesis, as it were, of the central chilled water plant comes not from the plant itself, but ironically, from the buildings those plants serve. While solutions to low ΔT syndrome can and should be addressed with building HVAC improvements, the effects this phenomenon can have on chilled water production can be tempered with proper design of the chilled water pumping. We have reviewed the basics of these pumping schemes comparing them with one another. Table 3 summarizes their advantages.

Table 3 – Pumping Scheme Comparison Summary

Primary-Secondary Pumping Benefits	Direct-Primary Pumping Benefits
Constant flow through chiller evaporator.	Mitigates effects of Low ΔT Syndrome.
Simplified controls and operation.	Potential reduction in plant capital and operating costs.
Wide spread experience among plant operators.	Reduction in number of pumps, i.e., less plant space required.
Smaller motors and less impact to building system design pressure.	

Clearly, the benefits of the direct-primary system allow much greater flexibility for the operators in providing chilled water where it is needed in the most efficient manner possible. However, this system is more complex and requires training and understanding of how it is to operate. Even though primary-secondary systems remain the “comfortable choice,” direct-primary, variable flow systems are picking up momentum as the preferred operational scheme.

NOMENCLATURE

dc Capillary tube internal diameter, m

L Capillary tube length, m

m· Mass flow rate, kg/sec

Pd	Discharge pressure, Pa
Ps	Suction pressure, Pa
Vg	Specific volume of vapor, m3/kg
Vf	Specific volume of liquid, m3/kg
μg	Dynamic viscosity of vapor, pa-s
μf	Dynamic viscosity of liquid, pa-s
g	Gravitational acceleration, m/sec2
ΔP	pressure difference across capillary, pa
μ	Dimensionless parameter group

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