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Design of Chilled Water Distribution Systems

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Abstract- A chilled water plant can be conceptually well designed but implemented in a manner that unnecessarily increase first costs. This paper evaluates different chilled water distribution systems configurations, for chilled water plant. These chilled water distribution systems configurationsincludePrimary-only-variable flow, and Primary-Secondary, Primary-distributed secondary, and Primary -coil secondary.Different analyses are performed in a model, and results are tabulated and plotted to compare energy costs. This paper offers recommendation to assist designers and engineers to select the chilled water distribution systems, without significant effort on designing.

Keywords- Chilled water distribution systems, VFD

I. INTRODUCTION

The analysis presented in this paper was done on an earlier chilled water plant design manual, and the prescriptive requirements of ASHRAE Standard 90.1. For any given application, it allows designer to select system that is best choice. All the schemes listed in this article uses multiple chillers in parallel for analysis. Note that chillers can alternatively be piped in series. First costs are higher with series piping due to larger pumps and piping. This configuration is avoided due to higher pump energy use, and larger piping.

These chilled water distribution systems configurations include Primary-only-variable flow, Primary-Secondary, Primary-distributed secondary, and Primary-coil secondary. All the system configurations listed above have pros and cons, discussed in detail.

1. Primary-only-variable flow:
For primary-only-variable flow scheme, primary pumps have Variable Frequency Drive (VFD) feeding to the coils. Chillers are piped in parallel for maximizing flow rate, and bypass valve is used to return some of the flow rate to chillers. Minimum flow rates are maintained through operating chillers, by using bypass valve. Differential pressure sensors across chillers are installed, corelated to flow. Bypass valve is controlled by flow (automatic). Bypass valve ensures to minimum chiller flow rate and these valves must be large handle the required flow rate capacity- this occurs via a low as the differential pressure setpoint used to control chilled water pump VFD's.

Primary-only systems always cost less and take up less space than primary-secondary systems, and with variable speed drives, primary-only systems also always use less pump energy than traditional primary-secondary systems. The analysis has been performed on few cases and is tabulated as below, to achieve 5psi pressure drop at each coil. Note that length of pipe associated for bypass valve is 30ft, and the bypass valve is set to 50gpm.

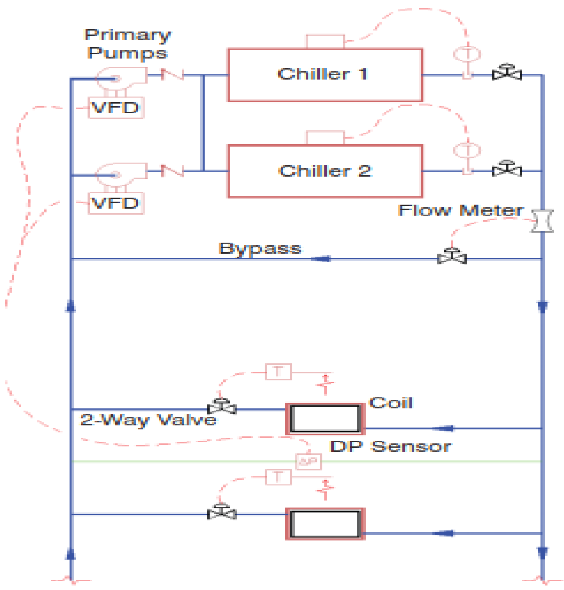

Fig 1. Primary –only variable flow with VFD arrangement schematic diagram.

Table 1. Analysis of both Primary pumps in operation with VFD (Primary-only variable flow with VFD pump arrangement).

	Flow Rate (gpm	Total Head(ft	Efficiency(%)	NPSHA (ft)	NPSHR (ft)	Main Pipe size (in)	Branch Size (in)
Primary pump 1	150	39.3	68.5	39.3	1.37	6	2.5
Primary pump 2	150	39.3	68.5	39.3	1.37	6	2.5

Above table shows analysis performed for both primary pumps are operating with Variable-Frequency drive (VFD) pumps.Two Pumps are operated simultaneously results in higher efficiency, and Net Positive Suction Head Available is lower than one pump is operated – see table 2 below.

Table 2. Analysis of one primary pump in operation with VFD (Primary-only variable flow with VFD pump arrangement).

	Flow Rate (gpm	Total Head(ft	Efficiency(%)	NPSHA (ft)	NPSHR (ft)	Main Pipe size (in)	Branch Size (in)
Primary pump 1	300	41.78	57.62	134	1.9	6	2.5
Primary pump 2	N/A					6	2.5

This arrangement resulted in the elimination of the extra set of pumps, and related appurtenances such as shut-off valves, strainers, suction diffusers, check valves, etc.). In addition to this, when compared to conventional primary-secondary systems these pumps are more efficient. As there are no secondary pumps in this scheme, less plant space is required. A lower first cost of system is achieved because of no secondary pumps, and lower energy costs.

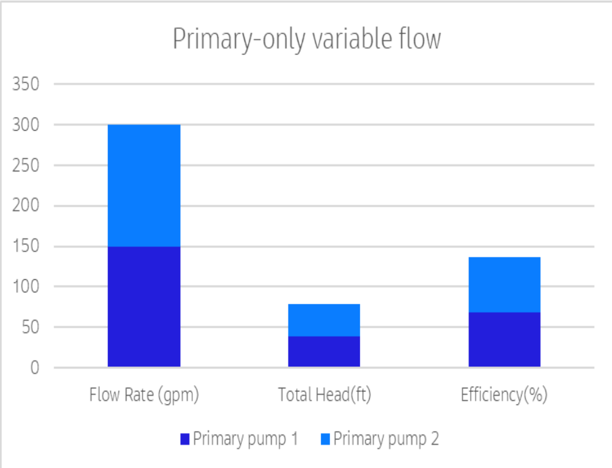

Fig 2. Results of primary-only variable flow arrangement.

2. Disadvantages of primary-only system:
Flow through operating chillers will suddenly decrease, if one of the chiller isolation valves is suddenly opened (during two chillers operation). By opening new chiller isolation valve slowly, the flow is slowly increased –using demand-based or by increasing setpoint. This step will result in staging chillers without; care must be taken to temporarily unload the active chiller. Finally, two chillers can be ramp up to the required load together.

A manual reset of the chiller is required if failure of bypass system occurs. If the loop is slow, it takes time to respond quickly when sudden changes happen in flow, especially during air handling units shut off at the same time- this translates to low/insufficient flow through the chillers, causing them to trip on low flow or low temperature.

3. Primary-Secondary Scheme:
In this scheme, variable flow through the evaporator, which allows flow to drop below design flow down to some minimum flow rate recommended by the chiller manufacturer? VFDs can be added to the primary pumps of a primary-secondary system and controlled to track secondary flow down to the chiller minimum rate, but at an increase in first costs and control complexity.

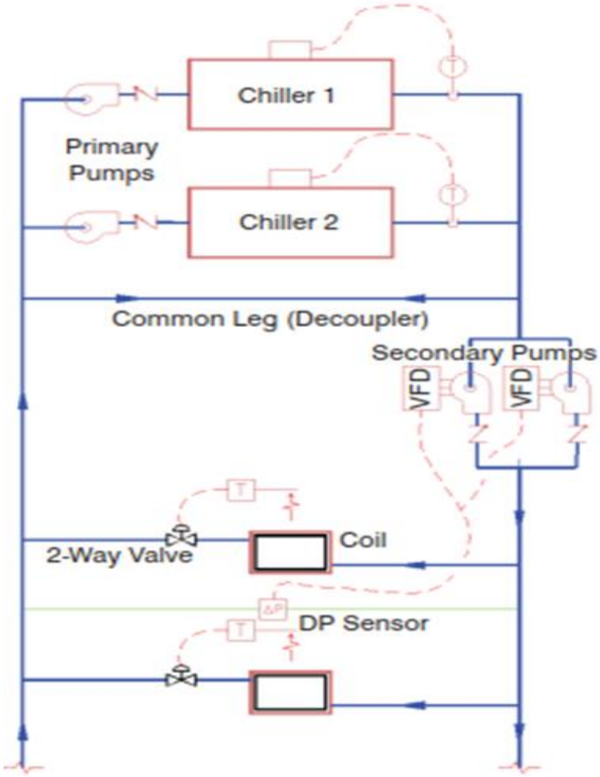

Fig 3. Primary –secondary VFD arrangement schematic diagram.

The primary pumps in the primary-secondary system will be inherently less efficient due to their high flow and low head. This can be partially mitigated by using larger pumps running at lower speed, but at an increase in first costs.

Table 3. Analysis of both Primary pumps and secondary pumps with VFDin operation (Primary-secondary VFD arrangement).

			Case 1: Delta P is 5psi		Set position: 100%		
	Flow Rate (gpm	Total Head(ft	Efficiency(%)	NPSHA (ft)	NPSHR (ft)	Main Pipe size (in)	Branch Size (in)
Primary pump 1	652	17.5	82.13	78.6	3.923	6	2.5
Primary pump 2	641	17.8	82.5	78.3	3.824	6	2.5
Secondary Pump-1	250	120.6	80.94	80.94	4.25	6	2.5
Secondary Pump-2	250	120.6	80.94	80.94	4.25	6	2.5

Table 4. Analysis of one Primary pump and secondary pumps with VFDin operation (Primary-secondary VFD arrangement).

			Case 2: Delta P is 5psi		Set position: 100%		
	Flow Rate (gpm	Total Head(ft	Efficiency(%)	NPSHA (ft)	NPSHR (ft)	Main Pipe size (in)	Branch Size (in)
Primary pump 1	670	16.9	80.9	78.9	4.083	6	2.5
Primary pump 2							
Secondary Pump-1	250	121.7		79.81		6	2.5
Secondary Pump-2	250	121.7		79.81		6	2.5

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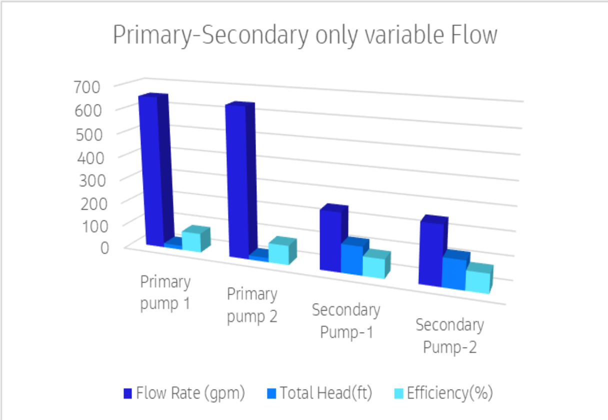

Fig 4. Primary –secondary variable flow arrangement results.

4. Primary-Distributed Secondary configuration:

The primary- distributed secondary scheme is best suited for plants serving groups of large loads, for example such as buildings in a college campus, etc.,The secondary pumps at the central plant are eliminated and variable speed pumps are added at each building.

Each secondary pump has VFD to achieve a set point differential pressure at the most remote coil in each building. Each secondary pump has a different head which meets load requirement for corresponding building. Building pump head are sized for this setpoint pressure drop (typically 4-5 psi) of the loop from plant to building, through building coils, via common leg back to the plant.See Figure 5, for illustration.

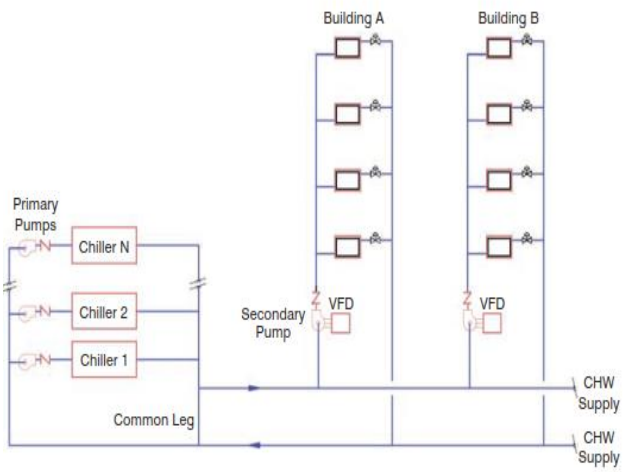

Fig 5. Primary –distributed secondary VFD arrangement schematic diagram.

The advantages of this design compared to conventional primary-secondary systems are listed below:

- Pump energy is reduced because of the custom pump heads and the more precise control of the variable speed drives. Over pressurization of control valves located near the central plant is eliminated.
- Secondary pump head must be sized for the most remote building (say 200ft) for conventional system, while the primary-distributed secondary building pumps close to the central plant can have much smaller heads (say 100 ft). Overall pump horsepower is reduced.
- The Secondary pumps has VFD capabilities (speed control), therefore system is self-balancing. Flow self-adjusts as shown in Table 5, and Table 6 as additional buildings are connected to the system. There is no need to throttle pressure at buildings.

Table 5 shows analysis performed for both primary pumps are operating at constant speed, and the secondary pumps with Variable-Frequency drive (VFD) pumps are operated.

Table 5. Analysis of both Primary and secondary pumps with VFD (Primary distributed secondary VFD pump arrangement).

	Flow Rate (gpm	Total Head(ft	Efficiency(%)	NPSHA (ft)	NPSHR (ft)	Main Pipe size (in	Branch Size (in
Primary pump 1	300	43.92	57.1	79.83	1.727	6	2.5
Primary pump 2	300	43.92	56.2	79.83	1.727	6	2.5
Secondary Pump 1	300	24.82	67.93	120.4	2.685	6	2.5
Secondary Pump 2	300	12.71	78	120.3	1.79	6	2.5

Table 6 shows analysis performed for one primary pump is operating at constant speed, and both secondary pumps with Variable-Frequency drive (VFD) pumps are operated. Primary pump-2 is analyzed as a standby option (i.e., it is not operating).

Table 6. Analysis of one Primary and secondary pumps with VFD (Primary distributed secondary VFD pump arrangement).

	Flow Rate (gpm	Total Head(ft	Efficiency(%)	NPSHA (ft)	NPSHR (ft)	Main Pipe size (i	Branch Size (in
Primary pump 1	600	39.5	81.18	113.8	3.838	6	2.5
Primary pump 2	N/A						
Secondary Pump 1	300	39.2	57.1	140.8	3.807	6	2.5
Secondary Pump 2	300	27.05	66.5	140.7	2.858	6	2.5

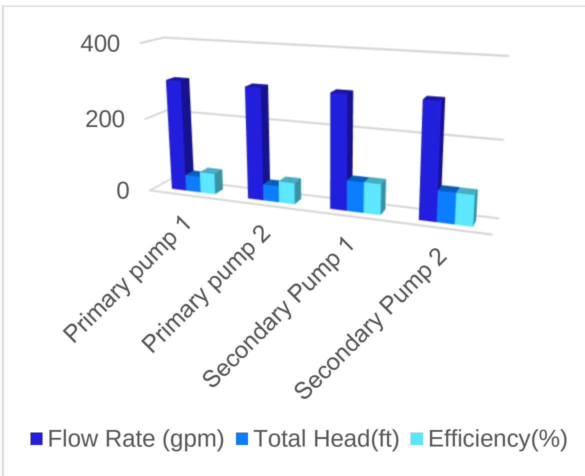

Fig 6. Primary – distributed secondary VFD arrangement: results

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With large, high head secondary systems (see Table 5 and 6), control valves must operate against excess differential pressure, reduces controllability. If there is not enough sufficient shut-off head, results in force flow through valve.

5. Disadvantages include:

Pressurization for expansion tank needs to be increased to maintain positive suction pressure at building pumps. This has only a minor cost impact to the expansion tank.Because there are more pumps for Primary-distributed secondary systems, usually cost more than conventional primary-secondary systems More space is required to house them.

6. Primary-coil secondary scheme:

Distributed variable speed driven coil secondary pumps is best suited for plants serving large individual air-handling systems. See Figure 6 below for primary circuit, and secondary circuit configuration.

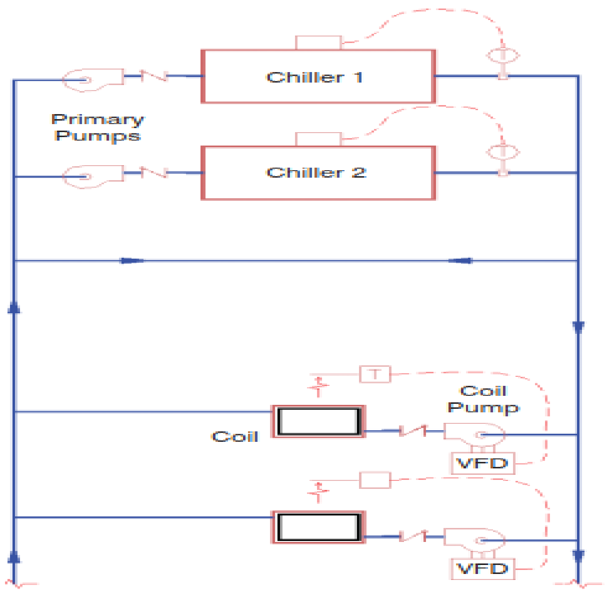

Fig 7. Primary- coil secondary arrangement schematic diagram.

Below are the advantages for this design scheme compared to a conventional primary-secondary system including:

- This is a reverse - return piping arrangement for chilled water systems – where first device supplied is the last returned. This scheme is intended, not only to keep low pressure drop across modulating two-way control valves but also to self-balance hydronic systems. In addition, this scheme provides equal pressure drop among all valves as they open and close with changing loads. It improves controllability of high pressure drop of large variable flow hydronic distribution systems. The system is self-balancing.
- With this design configuration, flow can be instantly controlled with VFD, and the control is precise. Because the control valves size is large, responsiveness of the valve is slow – designer does not worry about over pressurization of valve.
- In this design scheme, controls valve are eliminated due to reverse-return arrangements. Typically, these control valves are selected for 4psi to 5psi pressure drop, and there is a dedicated secondary pump for each coil. Both changes result in decrease of pump motor hp, and thus substantial savings.
- In this arrangement, it is not necessary to maintain a minimum differential pressure in the systems and pump head is reduced – resulted in lower pump energy. As there is no minimum DP, the pump efficiency is nearly constant.

See Table 7, for analysis of primary pumps and secondary pumps with VFD. This table shows analysis performed for both primary pumps are operating at constant speed, and the secondary pumps with Variable-Frequency drive (VFD) pumps are operated.

Table 7. Analysis of both Primary and secondary pumps with VFD (Primary – coil secondary pump arrangement).

	Flow Rate (gpm	Total Head(ft	Efficiency(%)	NPSHA (ft)	NPSHR (ft)	Main Pipe size (in)	Branch Size (in)
Primary pump 1	301	43.9	56.85	160.6	1.723	6	2.5
Primary pump 2	299	43.9	56.85	160.5	1.717	6	2.5
Secondary Pump 1	300	80.3	80.77	162.3	6.725	6	2.5
Secondary Pump 2	300	80.7	80.23	167	6.69	6	2.5

Table 8 shows analysis performed for oneprimary pump is operating at constant speed, and both secondary pumps with Variable-Frequency drive (VFD) pumps are operated. Primary pump-2 is analyzed as a standby option (i.e., it is not operating).

Table 8. Analysis of only one primary pump and secondary pumps with VFD (Primary – coil secondary pump arrangement).

	Flow Rate (gpm	Total Head(ft	Efficiency(%)	NPSHA (ft)	NPSHR (ft)	Main Pipe size (in	Branch Size (in)
Primary pump 1	600	39.5	81.2	160	3.836	6	2.5
Primary pump 2	N/ A					6	2.5
Secondary Pump 1	300	95.1	76.1	148	7.65	6	2.5
Secondary Pump 2	300	94.6	75.3	152.5	7.62	6	2.5

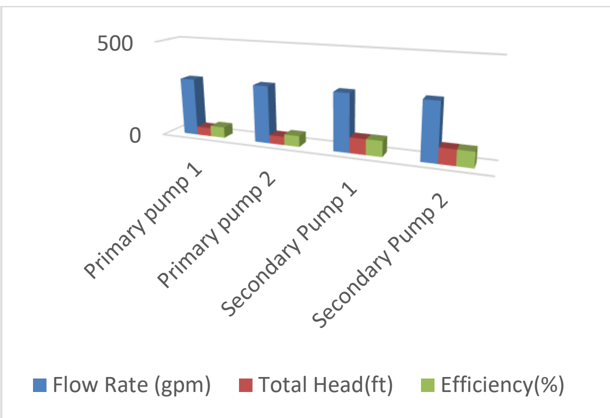

Fig 8. Results of both Primary and secondary pumps with VFD (Primary – coil secondary pump arrangement).

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7. Disadvantages:

There are few disadvantages for this arrangement. Flow through coil will be backwards from return to the supply, if a pump is not connected to the secondary circuit as shown in Figure 7. All coils need a pump. In this scheme, there is no redundancy for pumps is accounted in the schematic. Although table 7, and table 8 shows the analysis with redundancy for primary pumps only. For critical applications, redundant pumps are to be used so that the loads are met. This type of scheme is recommended if the coil flows greater than 100gpm.

II. CONCLUSION

First costs can varysubstantially depending on the chilled water distribution system configuration and details. It is easier to think that a chilled water plant has two chillers and pumps and provides one hundred tons of cooling capacity will cost about the same, regardless of designed chilled water distribution systemsandconfigurations. Furthermore, study providing chiller sequence of operations is performed to allow for more energy savings.

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