COMMISSIONING THE DOMESTIC HOT WATER SYSTEM ON A LARGE UNIVERSITY CAMPUS: A CASE STUDY

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ABSTRACT

The Texas A&M University (TAMU) main campus in College Station consists of 110 buildings with 12.5 million square feet of gross building space. Seventy-one of these buildings are connected to the main campus domestic hot water (DHW) distribution system. The DHW loop is more than 50 years old and has had continuing distribution problems. The main problems reported from several buildings were low hot water temperature and long delays in obtaining hot water at fixtures. The objective of this study was to investigate the causes of these problems and help determine how to best operate the system.

It was found that reported problems of low flows, low temperatures and long hot water lag time resulted from reverse flows and no hot water circulation caused by:

- Unadjusted return pumps with heads too high.
- Pumps not installed or not running where needed.
- Pumps with heads too low.
- Check valves not installed where needed.
- Insufficient piping capacity in two locations.

This paper presents possible control strategies to alleviate these problems identified during the field investigation.

INTRODUCTION

Domestic hot water (DHW) is an important component of building occupant comfort. It should be supplied promptly and at acceptable temperatures to end-users. At the same time, energy loss from the distribution system should be kept as low as possible.

Circulating systems that continually circulate DHW throughout the campus distribution loops and each building have been the conventional design for commercial, industrial and large residential projects such as the Texas A&M University campus.

Unless the DHW maintenance system is adequate, sizing criteria of the entire system become inaccurate, and its operation falls below design standards (ASPE, 2003). End-users then start to experience low hot water temperatures and long delays in obtaining hot water at fixtures. The American Society of Plumbing Engineers (ASPE) (2003) considers time delays longer than 31 seconds to be unacceptable. In addition to inconveniencing end-users, time delays can also cause significant amounts of potable water to be wasted as the water warms up at fixtures. Negative loop differential pressures in a system can result in buildings with no DHW flow or even backflow where no check valves are installed.

To minimize or avoid such problems, ASPE (2003) recommends system balance, properly designed and controlled circulating pumps, check valves on each return line where it joins other return lines, shutoff valves to isolate sub-loops if necessary, and a balancing valve with each shutoff valve in order to re-balance the loop after isolation. Alternatively, a balancing valve with memory stops should be installed if the balancing valve is also used as a shutoff valve.

Many studies have reported efforts to balance circulated domestic hot water distribution systems (Penny 1990; Cirillo et al. 1990; Goldner 1994; Szantho 1998; Killmeier 1998 and Stewart et al 1999). The objective is to provide the correct flow distribution through the network and therefore the correct temperature at each draw-off point.

Thermostatic aquastats, time clocks, or a combination of both may be used to control the circulating pumps in an energy-efficient manner. The use of aquastats will be considered in this investigation.

This paper will detail the findings of the field investigations conducted, with particular emphasis on the problems identified, and will suggest control strategies to overcome these problems.

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SITE INFORMATION

Texas A&M University campus

The Texas A&M University campus in College Station consists of a main campus and a West campus separated by a railroad. The main campus consists of 110 buildings with 12.5 million ft^2 of gross building space, and is served by the main campus DHW loop investigated in this paper. No DHW distribution system is present on West campus.

Utilities plants

Potable water is produced from 8 wells located near the Riverside Campus (another campus independent of the main and West campuses and located at a distance of several miles from either). It is aerated to cool and remove dissolved gases at the TAMU Wellfield water treatment facility. Water is then chlorinated and pumped approximately 7 miles to campus.

DHW is made in the central utilities plant by condensing 20 psig steam using two heat exchangers, and in the south satellite plant using two gas-fired boilers. Both plants are interconnected.

In 2002, the total DHW production was approximately 43 billion BTUs, 25 billion BTUs at the central plant and 18 billion BTUs at the south satellite plant.

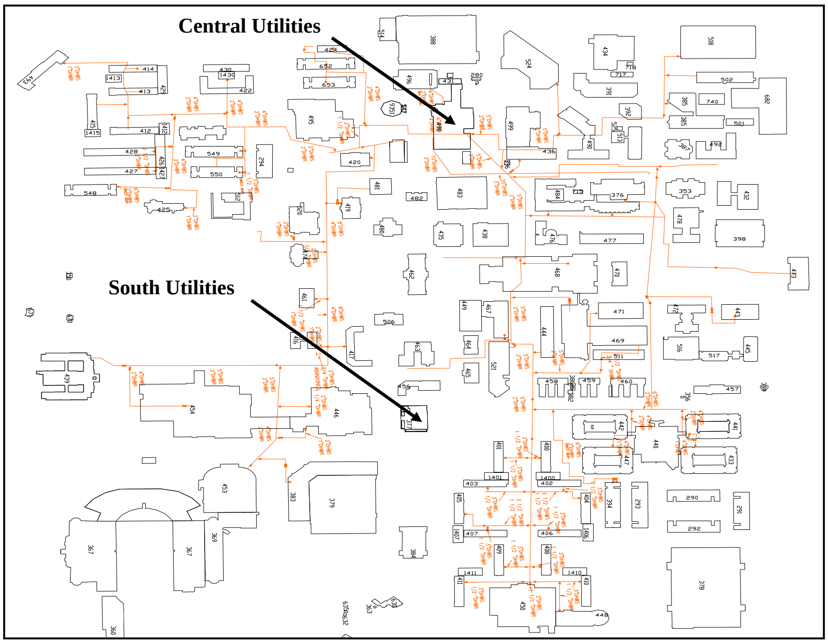


Figure 1. Domestic Hot Water distribution system

DHW loop

The main campus DHW loop has a total piping length in excess of 13 miles and serves seventy-one main campus buildings. DHW is produced locally at some of the other buildings. Figure 1 shows the main campus DHW distribution system, and gives a general picture of the number of buildings served and the complexity of the distribution loops. The central utilities plant serves a portion of the main campus, while the south utilities plant serves the rest as shown.

Investigated buildings

The seventy-one buildings on the DHW loop are investigated in this paper. They consist of 42 dormitories, 26 classroom/office buildings and 3 dining halls, and are divided into eight sub-loops in order to simplify the analysis.

FIELD INVESTIGATION FINDINGS

The buildings were investigated for check valves and supply and return pumps. The investigation revealed that:

- Check valves were not installed in 21 buildings.
- Pumps were not running in 11 buildings.
- Pumps were not installed in 23 buildings.

The investigation also showed that the head was too high in some return pumps, which caused the pressure in the return line to become higher than that in the supply line. This was confirmed by pressure measurements and flow rate readings that revealed that reverse flow was occurring through some buildings, and no DHW circulation through others. Pumps with insufficient head were also found, such as the Corps of Cadets return pump, which is rated at 1/25 hp and should have at least ½ hp for the 14 dormitories served.

CAPACITY VERIFICATION

Central utilities plant

Figure 2 is a diagram of the DHW systems in the Central Utilities Plant. Domestic hot water is produced at 140 °F by condensing 20 psig steam in two shell-and-tube heat exchangers. Each heat exchanger has a design flow rate of 330 gpm and a design capacity of 23 MMBtu/hr. The capacities of the heat exchangers and the pumps were found to be sufficient. The DHW is circulated to campus in three interconnected loops.

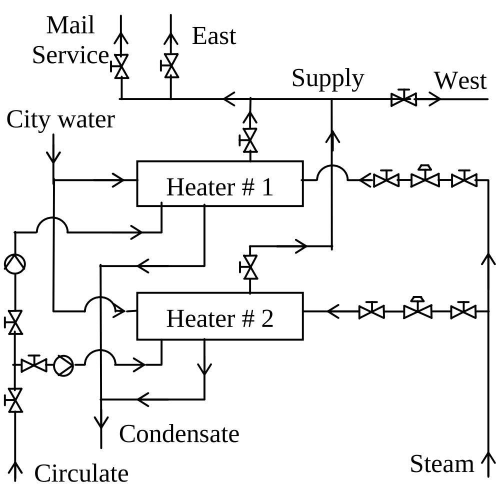


Figure 2. Central Utilities Plant

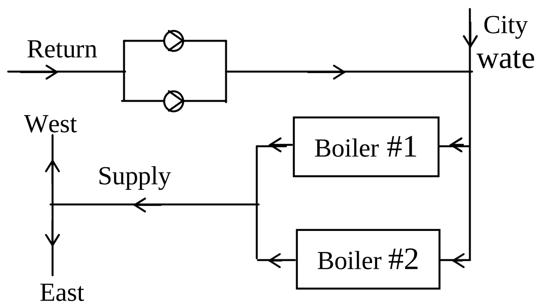


Figure 3. South satellite plant

South satellite plant

Figure 3 is a diagram of the south satellite plant. Domestic Hot Water is produced at the south satellite plant at 140 °F in two gas-fired boilers. The design flow rate is 175 gpm for each boiler and 90 gpm for each pump. The design input capacity of each boiler is 8.4 MMBtu/hr. The capacity of the boilers was found to be sufficient as was the design capacity of the return pumps Because of some irregular pressure measurements, the two return pumps need to be investigated further.

Piping system

In order to verify the capacity of the piping system, maximum hourly DHW consumption was estimated for each building based on ASHRAE DHW consumption standards. Piping size requirements were then determined for supply and return pipes. Return flow rate was estimated at 5 gpm. Calculated and existing pipe sizes were compared for supply and return pipes.

The capacity of existing supply and return pipes was found to be sufficient, except in two locations:

- Section 1: A return pipe section served by the south utilities plant. The existing pipe size is 2" and the calculated size is at least 2½". This is shown in Figure 4.

- Section 2: A return pipe section served by the central utilities plant. The existing pipe size is 2” and the calculated size is at least 3”.

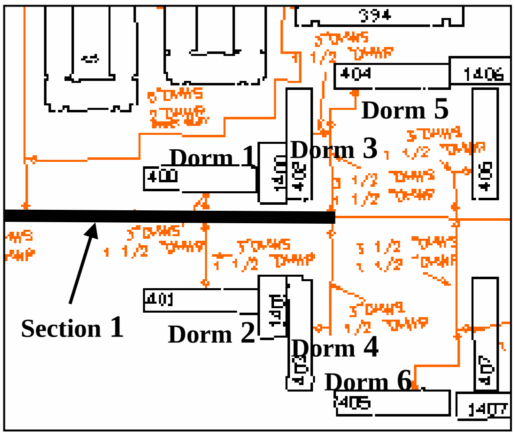


Figure 4. Section 1 with insufficient diameter

LOOP ANALYSIS

Because the return pump head is too high in some buildings, the pressure in the return line becomes higher than that in the supply line. When no pump is present in other buildings or the pump is not running, two problems can result:

- Reverse flow (figure 5): If no check valve is present, DHW flows through the building from the return line to the supply line, as the return line pressure is higher than the supply line pressure. This causes the temperature of hot water to be low in the building in question (building 1) and eventually in the adjacent building(s) (building 2) since the return water mixes with the supply line. When reverse flow occurs in a single building connected to the main supply line, the return water running through the building mixes with the main supply line.

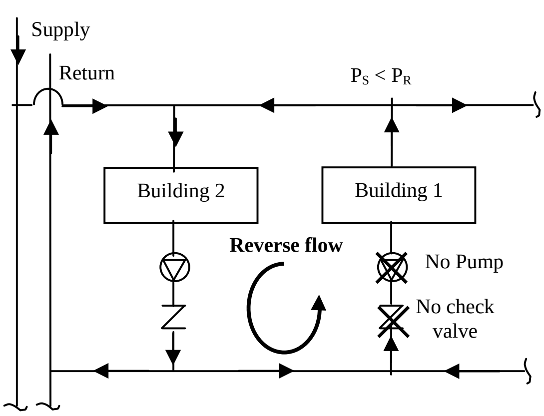


Figure 5. Reverse flow scenario

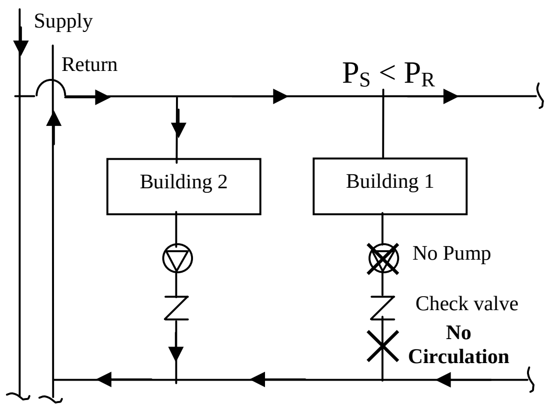


Figure 6. No circulation scenario

- No circulation (figure 6): If a check valve is installed, no DHW circulation occurs through the building (building 1). DHW doesn’t circulate through the building from the supply line to the return line because the pressure is lower in the supply line than in the return line. DHW doesn’t circulate through the building from the return line to the supply line because the installed check valve prevents reverse flow. Because no circulation occurs, hot water goes to the building only when a fixture is turned on, which causes a long delay in obtaining hot water. This can also cause significant potable water wastage as the water warms up.

The analysis was conducted for four sub-loops. The analysis revealed that, out of the 36 buildings, there was reverse flow in 16 buildings and no circulation in 5 buildings.

CONTROL STRATEGIES

Four possible control strategies are described in Table 1. They are variations of diversity and zone control strategies. Diversity control indicates that each building has a check valve and is served by its own pump. Some engineers believe this provides more reliable return flow at each building. In zone control, each building also has a check valve but a single pump serves all the buildings in a particular zone. A campus may be treated as a single zone with a single return pump, or as several smaller zones, each with its own return pump. Maintenance is reduced with one or a few pumps as compared with diversity control. Figures 7 to 10 show typical diagrams of these control strategies. Building "i" represents any building in the loop and building "i,j" represents building i of zone j. The magnitudes of initial cost and operation cost are compared for the renovation of the existing design on the Texas A&M University campus.

Table 1. Description of control strategies

	Diversity control with aquastat	**Diversity control without aquastat**	**Multiple zone control**	**Single zone control**
Definition	A pump, check valve and aquastat are installed for individual buildings as needed. The general control diagram consists of an aquastat-controlled pump and a check valve in the return line.	A pump and check valve are installed for individual buildings as needed. The general control diagram consists of a pump running continuously and a check valve in the return line.	Loop divided into several zones; each zone consisting of a group of buildings in a sub-loop.	All the buildings make up a single zone controlled by one pump.
Control scheme	- Install pumps and check valves for individual buildings as needed. - Control each pump with an aquastat so that it will run only when the return temperature falls below a setpoint. - Balance the loop and maintain its balance.	- Install pumps and check valves for individual buildings as needed with pumps operating continuously. - Balance the loop and maintain its balance.	- Divide the loop into zones. - Size zone pump to the maximum return flow. - Balance the loop and maintain its balance. - Install a check valve for each building as needed. - Rerun water from different sub-loops is mixed in main pipe and forced to plant.	- Size zone pump to the maximum return flow for all the buildings. - Install a check valve for each building as needed. - Balance each building as well as the entire primary loop.
Advanta ges	- Individual building control. - Suitable for diverse loads.	- Individual building control. - Suitable for diverse loads.	- More convenient when building loads are comparable.	- More convenient when building loads are comparable.
Disadvantages	- More pumps and aquastats. - Pump head adjustment and maintenance required. - Main loop pressure profile easily interrupted if one of the pumping heads is higher than required.	- More pumps and aquastats. - Pump head adjustment and maintenance required. - Main loop pressure profile easily interrupted if one of the pumping heads is higher than required.	- Different buildings in the same zone may have different loads and therefore different return pressures, which may cause circulation problems. - Balancing valves are required for return water pressure control of different sub-loops.	- Different buildings may have different loads and therefore different return pressures, which may cause circulation problems. - Balancing valves are required for return water pressure control of different sub-loops.
Cost	- Initial cost: High - Operation cost: 2nd highest	- Initial cost: 2nd highest - Operation cost: Highest[1]	- Initial cost: Medium - Operation cost: Medium	- Initial cost: Low - Operation cost: Low

[1] 3/8 hp required capacity while existing pumps are ¾ hp and more

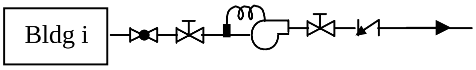
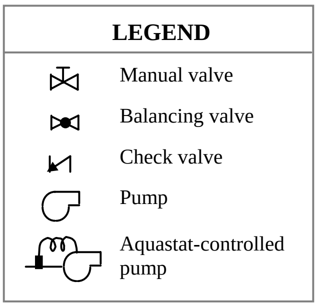


Figure 7. Diversity control with aquastat



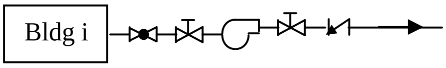


Figure 8. Diversity control without aquastat

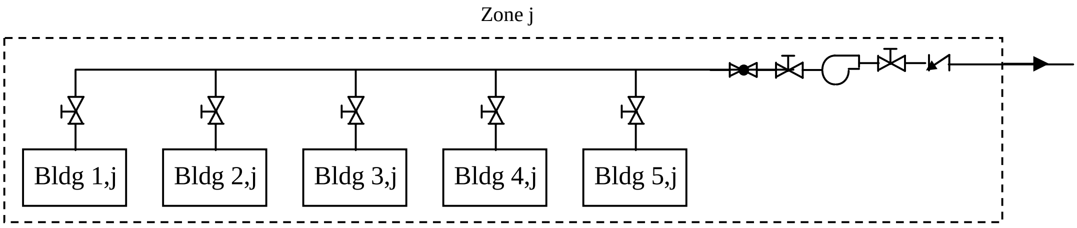


Figure 9. Multiple zone control

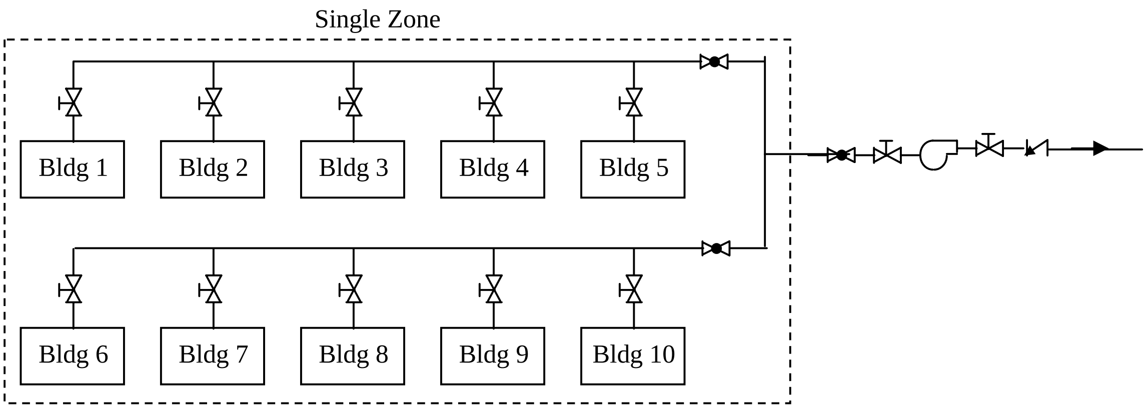


Figure 10. Single zone control

RECOMMENDATIONS

Based on the loop analysis and the comparison of initial cost and operation cost, one control strategy or a combination of the control strategies described in Table 1 may be adopted. It is recommended that a loop balance be performed afterwards and that this balance be maintained.

Figure 11 shows a sub-loop, which presents a good application for diversity control. The Bell building currently has a 3/4-hp supply pump and a 2/25-hp return pump. This building is at the end of the sub-loop and its two pumps provide too much pressure, causing the return line pressure of the entire sub-loop to be much higher than the supply line pressure. No pumps are installed in the other buildings, which produces reverse flow in the Davis-Gary building where no check valve is installed, and no DHW circulation through the Moore and Crocker buildings where check valves are installed.

As to zone control, one of the issues that arise with this type of control is that different buildings may have different loads in the same zone, and would therefore have different return line pressures. Different zones may also have different return pressures. Unless the return lines have relatively the same pressure, the circulated water will present a problem. One of the ways to resolve this problem is to install control valves to regulate the return flow and subsequently the return pressure on each zone return line.

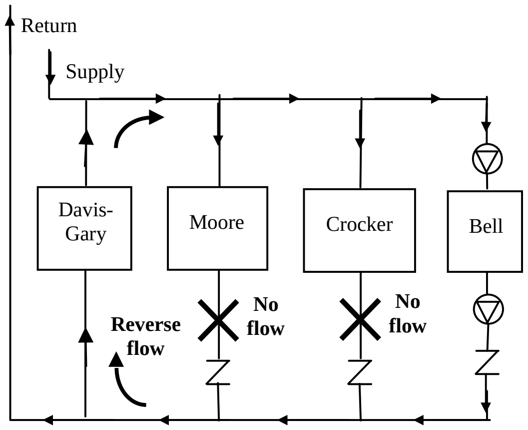


Figure 11. Application for diversity control

Figure 12 shows typical DHW supply and return pressure trends for the Wells dormitory that has a return pump that is too large. DHW usage decreases almost linearly between the maximum consumption (lowest pressures) at around 8am on weekdays and 12pm on weekends and the minimum consumption (highest pressures) at around 5am on weekdays and 7am on weekends. However, the pressure differential between the supply and return lines remains at a constant 22 psig. This differential pressure corresponds to the existing constant-speed pump head. This high return pressure causes the return pressure to be higher than the supply pressure for a neighboring dorm.

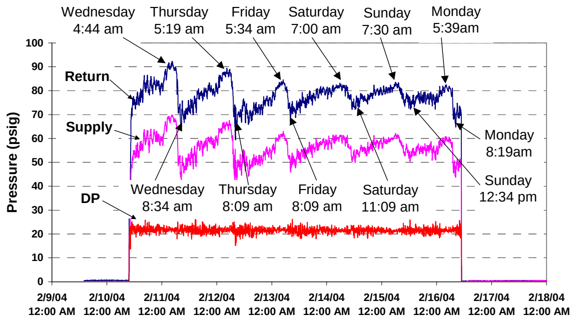


Figure 12. Typical DHW supply and return pressure for the Wells building

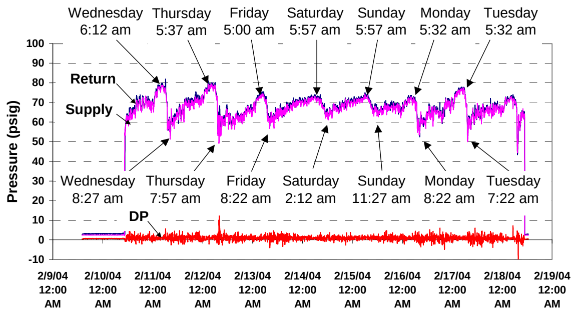


Figure 13. Dorms' DHW supply and return pressure trends

A group of 10 campus dorms presents a good candidate for the zone control strategy. Figures 13 shows supply and return pressure measurements one of these dorms. Pressure variations due to DHW usage are typical, except that the pressure differential between supply and return lines is 0 psig. This circulation problem is due to the absence of a pump in the sub-loop consisting of these dorms. The zone control strategy is a good solution for this sub-loop.

CONCLUSIONS

Occupant DHW calls have been reported from several buildings on campus. Seventy-one buildings were investigated. It was found that reported problems of low flows, low temperatures and long hot water lag time resulted from reverse flows and no hot water circulation caused by:

- Unadjusted return pumps with heads too high.
- Pumps not installed or not running where needed.
- Pumps with heads too low.
- Check valves not installed where needed.
- Insufficient piping capacity in two locations.

Based on the cost analysis and loop analysis described previously, it is suggested that one of the control strategies mentioned be adopted, or that a combination of these strategies be employed. It is recommended afterwards that a loop balance be conducted and maintained.

The problems encountered on this campus can be attributed partly to the expansion of the campus area in the years since the original DHW system design. As buildings were added to the loop, sufficient caution was not always exercised to ensure that the loop pressure balance could be properly maintained. This lack of planning, combined with system maintenance issues have left the system in its current situation. For many facilities of this nature, where significant growth has occurred over a period of time since the original design, similar problems may be encountered. For such locations, domestic hot water system commissioning should be considered as a means to ensure adequate performance of the system, increase occupant satisfaction, and prevent future problems.

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