Using Simulation Models for District Chilled Water Distribution Systems Design

Case Study – University of Texas at San Antonio 1604 Campus

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ABSTRACT

The capital investment for the distribution system is often the most expensive portion of a district heating and cooling system, which usually constitutes 50 to 70% of the total cost. Because of high initial cost, it is very important to optimize the design. The focus of this paper is to demonstrate how the using of the computerized simulation model can give the engineer the ability to explore many more alternative design scenarios and to identify more cost-effective and robust designs. The University of Texas at San Antonio needs to expand their central chilled water distribution system as a result of planned additions to the campus. After a simulation model was constructed and calibrated for the existing campus chilled water distribution system. Six different alternatives have been tried and compared with each other. One of the scenarios was identified to be the optimal design. More detailed models were built for preliminary design. Based on the simulation results, pipe sizes were selected for each scenario. The results indicated that though there are many scenarios, the optimal scenario is the one which has the lowest cost and it can be identified through simulation. The simulation models are very useful to find acceptable designs and to let the engineer to consider the most optimized and cost-effective designs.

INTRODUCTION

The capital investment for the transmission and distribution system is often the most expensive portion of a district heating and cooling (DHC) system, which usually constitutes 50 to 70% of the total cost (ASHRAE 2000). Because of the high initial cost, it is very important to identify the cost effective design. Engineers designed distribution systems without using computerized simulations for many years. However, systems are more complex nowadays. As a result, calculating the flow rates and pressures in a piping network with branches, loops, valves, and heat exchangers can be very difficult without the aid of a computer. The objective of this paper is to demonstrate through a case study that engineers can explore many more alternative scenarios and identify cost-effective designs by using a simulation model.

The basic method in this paper is to build and calibrate a simulation model for an existing chilled water distribution system and to use this model to predict the building primary differential pressure (DP) across the system by simulating many alternative scenarios. The optimal design not only meets the design specifications, but also carries the lowest construction cost. Once the preliminary design was identified, more detailed simulation can be conducted to further determine the size of the pipes and locations of various fittings.

The University of Texas at San Antonio 1604 Campus needs to expand its central chilled water distribution system as a result of planned additions to the campus. A simulation model was constructed for its existing chilled water distribution system and verified by comparing with other engineers' results. Many different scenarios were explored by using the models. The simulation results indicated that the best design is the one which takes advantage of the crawl space beneath Multidisciplinary Studies Building (BLDG 556). Most of the pipe goes along the existing pipes in the crawl space and underground tunnel toward the current Engineering Biosciences Building (BLDG 552). Therefore, construction cost and labor cost can be reduced.

CONSTRUCTION OF SIMULATION MODEL

Site Description

The University of Texas at San Antonio 1604 Campus has approximately 1.5 million square feet of gross building area. The exisiting central chilled water distribution system is accessable though the underground tunnel and crawl space beneath the buildings.

Simulation Software

The software used in the study is AFT Fathom 5.0, which is a product of Applied Flow Technology Corp (AFT 2000).

Loss Models

In this study, five main types of compnents considered are pipes, bends, tees, valves and area changes. Their losses are calculated in the simulation model. Table 1 lists the sources for the loss models used in AFT Fathom.

Assembling of Model

All the chilled water lines were traced and measured in the field. The physical structure of the simulation model is built upon field notes and draft report.

Chilled water consumption demand is based on the technical reports (CCPCS 1997). The simulation model appeared to be reliable, consistent, and conservative (Chen et al. 2002) by comparing with an earlier report (Smith 1997). The finished simulation model is illustrated in Figure 1. This mode is called the base model. All the alternative scenarios are constructed based on this model by changing the existing or adding piping structures.

Building Design Flow and Simulation Results

The building design flow used in this study is based on earlier report (Smith 1997). The simulation results are listed in the Table 2. Assume thermal energy plant differential pressure is 26psi.

Table 1: Loss Model

Junction Type	References
Pipe	Darcy-Weisbach loss model
Bend	Crane 1998
Area Change	Crane 1998 and Idelchik 1994
Tee/Wye	Idelchik 1994 and Miller 1990
Valve	Crane 1998, Idelchik 1994 and Miller 1990

(AFT 2000 and Methods et al. 2003)

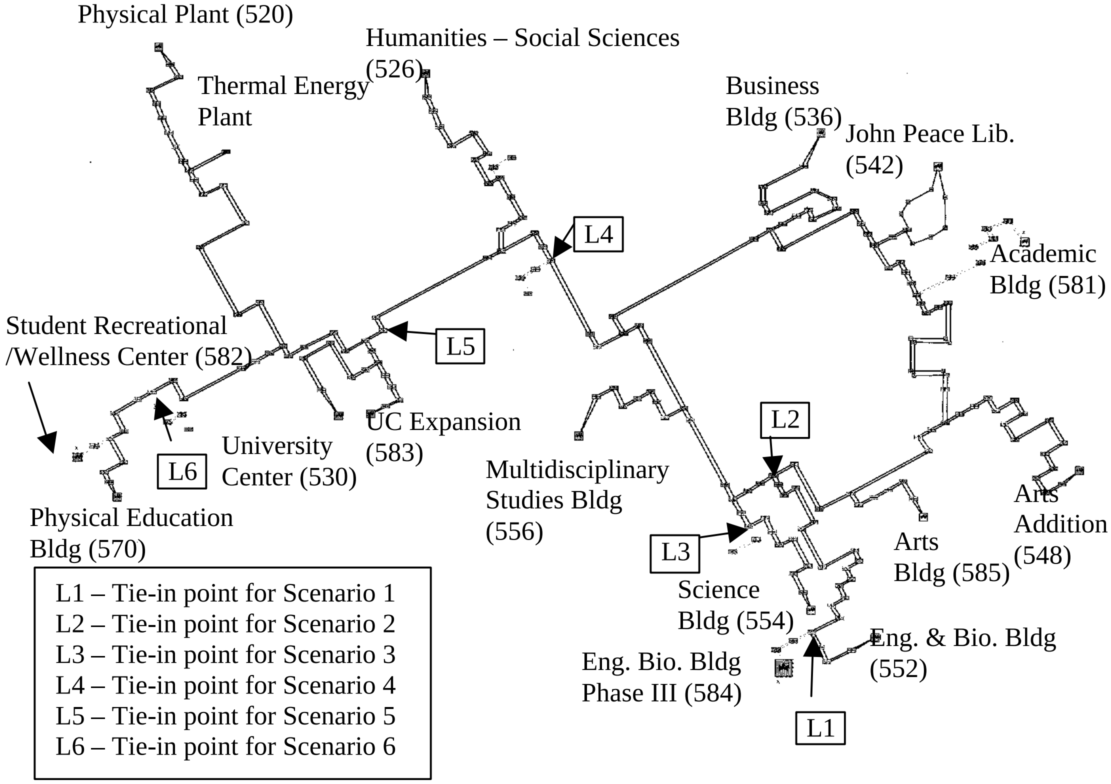

Figure 1: UTSA 1604 Campus Simulation Model and Potential Tie-in Points for Future Expansion.

Table 2: Building Design Flow and Simulation Results

BLDG No.	Building Name	Flow (GPM)	Building primary DP (psi)
520	Physical Plant	144	25.7
526	Humanities – Social Sciences	932	16.7
530	University Center	226	21.1
536	Business Building	921	12.9
542	John Peace Library	1163	10.9
548	Arts Addition	649	12.3
552	Engineering and Biosciences	1307	8.7
554	Science Building	955	10.3
556	Multidisciplinary Studies Building	813	12.5
570	Physical Education Building	584	22.0
583	University Center Expansion	513	20.9
585	Arts Building	100	13.1

MODEL VERIFICATION

The base model simulation results and previous calculation results (Smith 1997) are very close to each other (see Table 3) .

IDENTIFICATION OF PRELIMINARY DESIGN

A model that has been assembled properly is an asset to the facility owner. To get the most benefit from the model, the designer should examine a broad range of alternatives. The objective of the simulation is to study the impact of the additional buildings to the existing central chilled water distribution system and to identify and recommend a preliminary design for future system expansion. The future system will provide chilled water to three more buildings. They are the Student Recreational/ Wellness Center (Bldg 582), the Academic Building Phase 3 (Bldg 581) and Engineering Bioscience Bldg III (Bldg 584). The locations of these three buildings were previously decided upon as shown in Figure 1. The design of an optimal piping system for this will be the focus of this study. The estimated building chilled water flow is listed in Table 4.

Six potenial tie-in points were chosen and are illustrated in Figure 1. New supply and return pipes will be built to connect the future Engineering Bioscience Bldg III with the existing chilled water distribution system. Simulation models were built based on these designs. Six different scenarios are chosen in a way that one tie-in location is further upstream than another. The facility owner specifies that the proposed preliminary design should be able to have positive building primary DP for all buildings, which is one of the criteria of acceptable designs.

Scenario 6 design was proposed by Smith (1997) as the tie-in point for future campus expansion. This design requires excavating the parking lot on the southside the campus. The simulation results are in.

Based on the simulation results, the following conclusions can be made:

- According the simulation results of Scenario 1 and 2, running a branch to the new Engineering and Biosciences Building from near by loop will not result in acceptable designs.
- Scenario 3 further concludes that connecting the future Engineering Bioscience Building Phase III with nearby expansions such as from the Science Building is not a good design either. The loop should expand farther upstream.
- Scenario 4, 5 and 6 are all acceptable scenarios for preliminary design.
- Scenario 4 and Scenario 5 could take advantage of the crawl space and underground tunnel. Therefore the construction cost and labor cost could be drastically reduced for these scenarios.

The Scenario 4 has the lowest construction and labor cost and also it could take advantage of under ground tunnel and crawlspace. It also has benefit of the minimum interference to the university operation and utility plant operation. It was chosen as the preliminary design for future campus expansion.

Table 3: Comparison between ESL Base Model and Smith's Study

BLDG #	*BLDG Name*	*Flow (GPM)*	*Building Primary DP (psi)*	
			By ESL	By Smith
542	John Peace Library	1163	10.9	14.4
548	Arts Building (Arts Addition)	649	12.3	13.5
552	Engineering and Biosciences	1307	8.7	10.3
570	Physical Education Building	584	22.0	19.2

Table 4: Estimated CHW Flows

Bldg	Bldg Name	Flow (GPM)
581	Academic Building Phase 3	1163
582	Student Recreational Center	557
584	Engineering Bioscience Bldg III	2038

Table 5: Simulated Building Primary DP for Base Model and Six scenarios

Bldg	Bldg Name	Flow (GPM)	Differential Pressure (psi) for Various Designs						
			Base	1	2	3	4	5	6
520	Physical Plant	144	25.69	25.65	25.65	25.65	25.65	25.65	25.65
526	Humanities - Social Sciences	932	16.67	10.38	10.38	10.38	10.38	10.54	12.72
530	University Center	226	21.09	16.30	16.3	16.3	16.3	16.3	17.44
536	Business Building	921	12.88	-0.30	-0.3	0.2	4.18	5.75	7.36
542	John Peace Library	1163	10.94	-4.47	-4.47	-3.5	1.69	3.37	4.82
548	Arts Addition	649	12.28	-4.62	-4.62	-3.08	3.09	4.87	6.21
552	Engineering and Biosciences	1307	8.71	-22.15	-7.73	-5.77	1.74	4.15	4.61
554	Science Building	955	10.32	-4.48	-4.48	-5.84	1.9	3.64	5.03
556	Multidisciplinary Studies Bldg	813	12.51	-0.09	-0.09	-0.44	4.3	5.88	7.47
570	Physical Education Building	584	21.84	17.85	17.85	17.85	17.85	17.85	15.88
581	Academic Building Phase 3	1163	N/A	-5.13	-5.13	-3.87	1.96	3.71	5.09
582	Student Recreational Center	557	N/A	18.51	18.51	18.51	18.51	18.51	16.54
583	University Center Expansion	513	20.88	16.09	16.09	16.09	16.09	16.09	17.22
584	Engineering Bioscience Bldg III	2038	N/A	-22.81	-8.39	-5.52	2.03	4.07	4.53
585	Arts Building	100	13.07	-4.08	-4.08	-2.28	4.19	6.01	7.28

Optimization of Preliminary Design

Further more detailed simulation was conducted to investigate where to place the pipes and fittings and where to connect them with the existing central chilled water distribution system. Assume the future Engineering Bioscience Building Phase III (BLDG 584) uses 3900GPM chilled water, instead of 2038GPM.

After several rounds of simulation and discussion with the facility owner, the refined preliminary design was put together (Figure 2). This design takes advantage of the crawl space beneath Multidisciplinary Studies Building. Pipes are Scenarioed to connect right before the reduction of 24” pipe to 20” in the tunnel and the future Engineering Bioscience Building Phase III. Most of the pipe goes along the existing pipes in the crawl space toward the current Engineering Biosciences Building. The first part is a 790 feet long 20” pipe, which connect location A and B. Then another 20” branch starts from location B and tie in location C, which is about 710 feet long. Then another 18” pipe connects location C and the future Engineering Bioscience Building Phase III, which is about 430 feet long. Tees, valves, and area changes are selected accordingly.

This Scenario is so detailed that the facility owner can actually go into the field and locates the valves, tees and pipes for the future expansion. Also with most of the information known, they could also estimate the accurate material cost, construction cost and labor cost. Obviously, since a lot of different designs had been studied through the simulation and all concerns from various aspect been taken into account, this design is an optimal design.

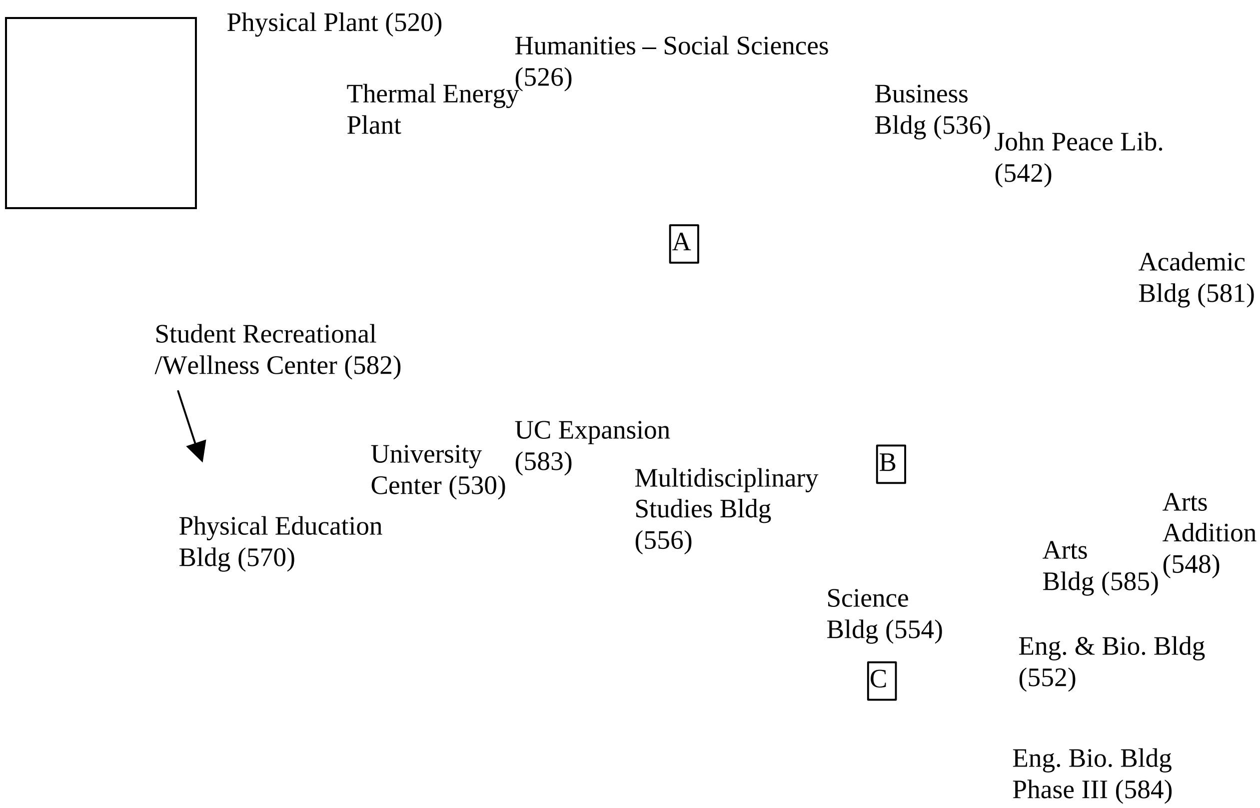

Figure 2: Refined Preliminary Design.

CONCLUSIONS

By presenting a case study, this paper demonstared how to use computerized simulation to construct and verify simulation model for existing DHC system. With detailed field survey and proper building load estimation, the application of advanced water distribution system simulation software can yield very accurate results nowadays. Based on the simulation model, engineer can basically explore all possible scenarios by evaluating the simulation results, the preliminary design can be identified. Once the preliminary design was accepted, further simulation can be conducted to optimize the design by checking proper pipe size, locating tees and valves. The simulation model can be used to simulate the operation of future central chilled water system by opening or closing valves. Using the simulation can result in more cost-effective and robust designs. This paper presents a case study that identified and optimized designs for a district cooling and heating system in the hope that other design engineers can apply the same technique.

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