# DEVELOPMENT OF A WATER LOOP SIMULATION AT THE TEXAS A&M UNIVERSITY MAIN CAMPUS

Huanyu Xue
Research Assistant
Energy System Laboratory
Texas A&M University
College Station, TX 77843-3581

David E. Claridge, Ph.D., P.E.
Professor, Associate Director
Energy System Laboratory
Texas A&M University
College Station, TX 77843-3581

Mingsheng Liu, Ph.D., P.E.
Associate Professor
Architecture Engineering Department
University of Nebraska
Lincoln, NE

Song Deng
Senior Research Associate
Energy System Laboratory
Texas A&M University
College Station, TX 77843-3581

## ABSTRACT

A computer simulation model is an economic and convenient tool to perform analysis of chilled water loop. The primary objective of this paper is developing procedure for simulating and optimizing chilled water loop with computer simulation model. A simulation model of chilled water loop at the TAMU main campus was set up with commercial hydraulic simulation software. This model was applied to chilled water loop on TAMU main campus to estimate pumping power saving potential, compare energy consumption for different operation modes in power plants, identify system operation problems, optimize and predict system behaviors.

## INTRODUCTION

Chilled water distribution systems are very important parts of many large spaces conditioning systems. Chilled water from central utility plants is conveyed to each building through these systems. By interconnecting multiple air conditioning loads with a central chilled water system, the following significant economic advantages and energy conservation opportunities can be achieved. First, taking advantage of non-simultaneous occurrence of individual peak loads can reduce the total installed cooling capacity. Second, high system efficiency can be achieved by operating one or more central cooling and heating plants instead of operating separate cooling and heating equipment in each building. Third, the system operation and maintenance cost can be reduced by central cooling and heating system administration instead of administration of each building separately. Normally, a chilled water distribution system is a very complicated two line (supply and return) piping network.

The basic requirement for a chilled water piping network is to provide enough flow and pressure difference to the water required by each building connected to it. This system is composed of a variety of components, including heating or cooling sources, pipes, pumps, valves, bends, etc. In piping network system, pipes are the links and pipe intersections and other components are the nodes of the networks. Pumps are one of the major components that consume much energy in chilled water piping network system. Pumps are used to increase pressure and flow in the system. They may be fixed or variable speed and occur in parallel and serial configurations. The relationship between pump flow, head, and efficiency is non-linear. Valves are another kind of important component in a piping network system. They are used to control flow and pressure throughout the system. They also have a non-linear relationship between flow and head loss. Also, all of the buildings are hooked together through the chilled water and hot water piping networks. A flow change in any building influences flow in other buildings. These factors combine to make the operation and analysis of the chilled water piping network very complicated.

Due to complicated system properties of chilled water piping networks, analysis and administration of chilled water systems are difficult. A computer simulation model is an economic and convenient tool to perform analysis of chilled water loop. With the aid of computer simulation model, many engineering and operational decisions can be made based on the simulation results without much more investment. Much research and applications has been done on modeling and simulation of chilled water loop (Hawks, 1976; Lee, 1987; Raymond, 1982; Atherton, 1983; Grondzik, 1980; etc). Keith H. Hawks from Purdue University developed a computer simulation program to detect operational problems and try different operational modes for system improvement (Hawks, 1976). Euy-Joon Lee developed a methodology for predicting the behavior of the central chilled water system on the Oklahoma State University (OSU) campus (Lee, 1987). Stoecker has contributed to the modeling and simulation of HVAC equipment and chilled water system operation since the mid-seventies (Stoecker, 1971, 1976, 1980, 1985).

## SIMULATION SOFTWARE

With the development of software engineering, more commercial software for piping network analysis has appeared. The common characteristic of these programs is that they provide an interface between the user and a complex pipe network analysis procedure. The user is prompted to input necessary piping network information and the program will calculate the result automatically. This greatly simplifies the analysis process and also makes it useable by engineers who lack programming knowledge.

The characters of the commercial hydraulic piping network simulation software that we used in our simulation are as follows:

(1) This simulation software is a totally visual platform for analyzing the hydraulic aspects of pipe flow networks. It combines traditional engineering hydraulic analysis with the windows graphical user interface (GUI). It can simplify the pipe network modeling process by implementing a drag-and-drop method of pipe flow modeling. Model builder can control the arrangement, and at the same time, benefit from the direct visual feedback regarding the layout of the model. It shows model builder both input data and analysis results in visual form, allowing rapid analysis of the model's validity. Identifying poor assumptions, catching typographical errors, and rerunning models are all accelerated because its graphical environment. Whether a piping system model will be used to evaluate and improve an existing system or design a new one, this software greatly increases the productivity in the modeling process.

(2) This simulation software employs two fundamental pipe system constructs: pipes and junctions. Pipes are conduits for steady state, incompressible, one-dimensional, Newtonian fluid flow. The flow rate through the entire length of the pipe is always constant. Because pipes have constant diameters, the fluid velocity is also constant, Pressure drop due to friction occurs in pipes. Junctions are connector points for pipes and are elements at which flow balances are made. Some junction types can only connect to one pipe; others can connect with up to ten. This software provides a total of twenty junction types. These junction types allow model builder specify special kinds of irrecoverable pressure losses or fluid behavior.

(3) This simulation software has five primary windows and each window plays a different role in the analysis process. The primary windows are subordinate to the main window and can be maximized or minimized within the boundaries of the main window. The primary windows are permanent in that you work in one of these windows at all times. These five primary windows work together to provide tools for entering model input, analyzing results for accuracy, and preparing results for documentation. Workspace window is used to set up visual model and input simulation parameters based on the practical piping system layout and component models it provided. These component models include pipe, pump, valve, branch, etc. All of theses component models will be used to simulate the practical components in the piping network. This window is the mostly used window in the software. Model data window is used to check the model and input data validity. If error found in the model or input data, the error would be corrected in the workspace window. Output window is used to display model simulation results. User can choose any parameters and units. Graph results and visual report windows are used to process model simulation results and to write report. Figure 1 summarizes the workflow using the primary windows.

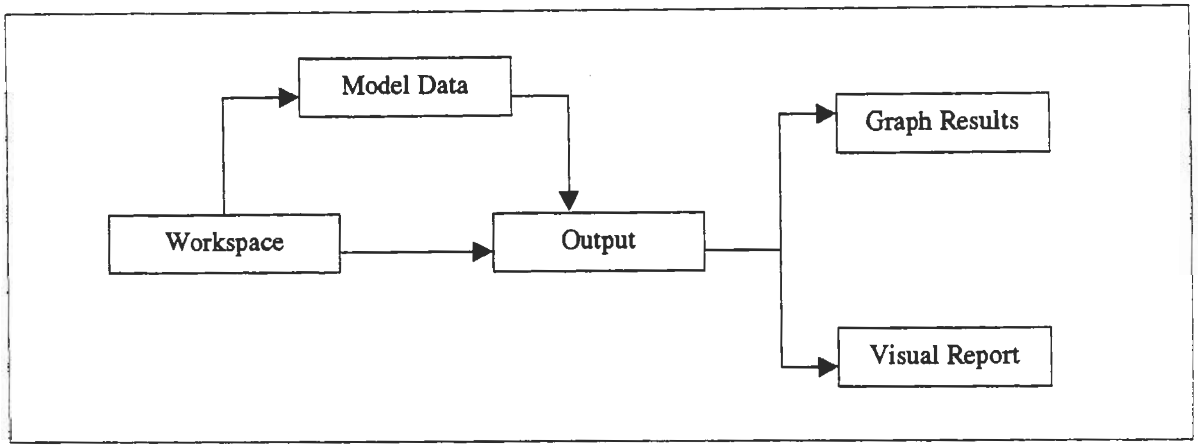


Figure 1. Primary window workflow in the commercial simulation software

## SURVEY OF CHILLED WATER LOOP AT THE TAMU MAIN CAMPUS

There are 104 buildings on main campus. The total air-conditioned area of these buildings is about 8,598,515 ft$^2$. There are two utility plants: Central Utility Plant and South Satellite Plant. The total installed cooling capacity is 24,700 tons. The Central Utility Plant is located in the central north of the main campus and the South Satellite Plant is located in the central south of the main campus. All of the buildings and utility plants are connected with each other through chilled water loop.

For the chilled water loop at TAMU main campus, both these two utility plants supply chilled water to all of these buildings. There are four loops: west, east, south, central. The Central Utility Plant send chilled water to buildings through these four loops. The South Satellite Plant, which is connected with the south loop, supplements chilled water to the south part of the campus buildings (see Figure 2).

## SIMULATION MODEL SIMPLIFICATIONS

Due to complicated system properties, chilled water system was simplified before simulation model was set up.

Because we simulate the flow and pressure distribution among the whole campus loops, and there are more than one hundred buildings on main campus, it is unnecessary and impossible to include each building detailed inside loop pattern into the model. A flow control valve which keep constant flow at a certain junction in the piping network can be used to represent a building flow consumption at certain outside weather condition. It is also can be used to represent a chiller which provide chilled water to the campus. Through these simplifies, the complexity of the system is greatly reduced and make it possible to handle within the ability of this commercial hydraulic simulation software. This simplification also speeds up the model building and simulation process.

Another simplification is flow consumption for each building. In the practical situation, the flow consumption is directly related to the load change for each building. The load change is directly related to the outside weather change. These dynamic behaviors greatly increase the complexity of the problem. In order to reduce the complexity and simplify the simulation procedure, through statistical method, the average water consumption for each building at certain outside air temperature will be used to input model to simulate loop behavior at that weather condition. Different flow consumption at different outside air temperature for each building can be input into the model to simulate loop behavior at different weather conditions. This simplification can also be considered as using static model to simulate dynamic system.

## MODEL INPUT DATA COLLECTION

In order to build an accurate model, important and necessary model input information and data should be collected first. The following information and data are needed:

(1) Campus chilled water loop original design blueprints and updated information and data
(2) Campus utility plants loop layout and equipment information and data

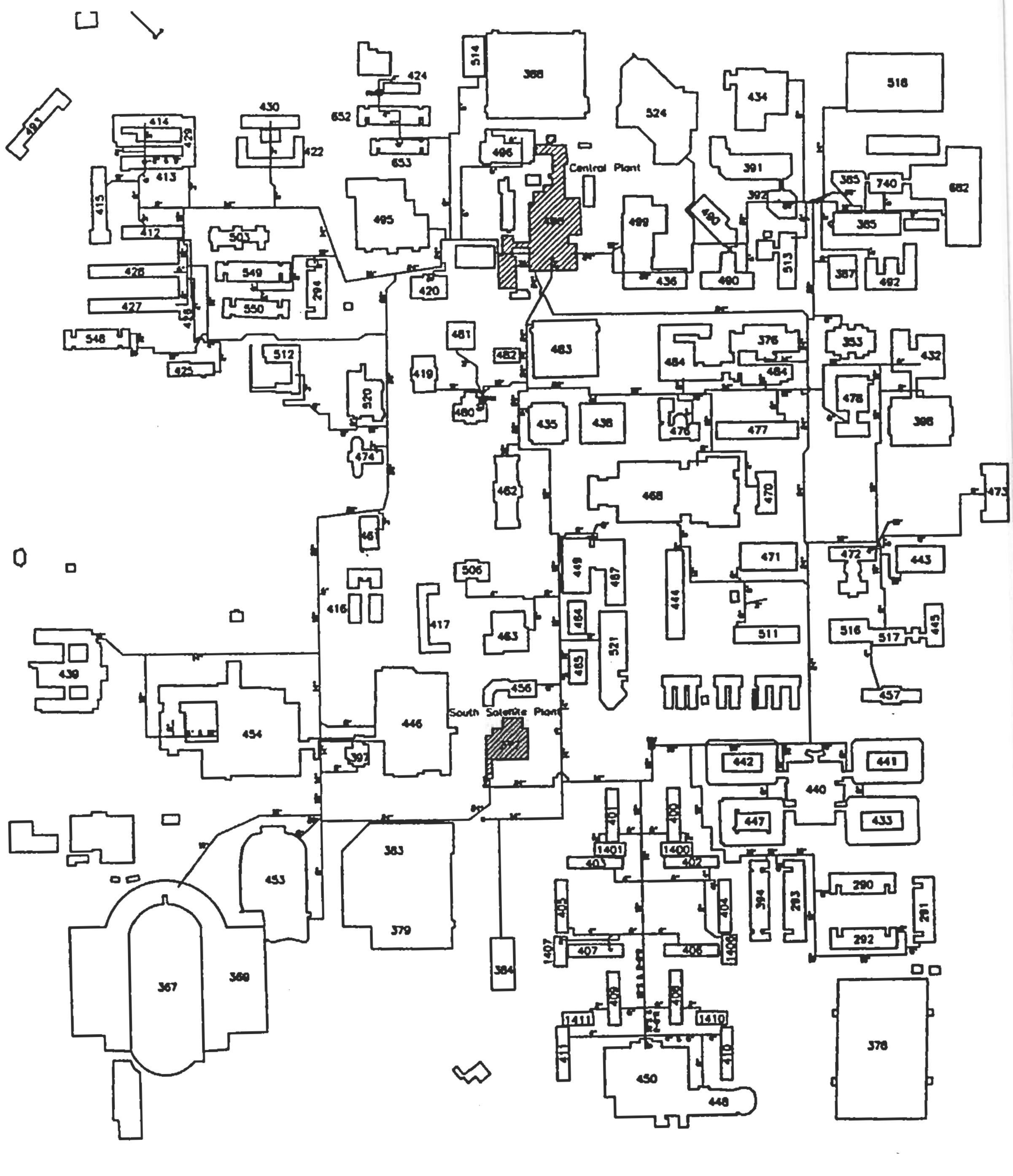


Figure 2. Texas A&M University Main Campus Chilled Water Loop

(3) Campus building inside loop and pump information and data
(4) Campus loop each pipe information and data
(5) Campus building chilled water consumption data at different outside weather condition

## SIMULATION MODEL SETTING UP AND DATA INPUT

The hydraulic calculation of piping network is very complicated. The commercial software that we used is very powerful hydraulic piping network simulation software. It provides user with a very friendly interface, which hides all of the complicated calculation procedure behind it.

According to the chilled water loop layouts on campus, the utility plant layouts, building inside loop layouts, visual simulation model can be set up on the visual platform that the simulation software provided. The simulation software also provides many piping network visual model components, such as pump, pipe, branch, etc, which can be inputted parameters and used to simulate the practical components.

After setting up visual model on the simulation software visual platform, the necessary data that the model system simulation required needs to be inputted into the models. The following model data should be inputted:

(1) Each pipe data in the model

For each individual pipe in the model, at least pipe length and pipe diameter should be inputted. The simulation software has its own database to input roughness after pipe size data has been inputted. The pipe size data can be read and measured on the design blueprints.

(2) Each pump curve in the model

For each pump in the model, pump curve should be inputted. Several evenly distributed points on the pump curve can be inputted into the table in the pump model component. The pump curve will be regressed based on these points. In the simulation process, the operation point will move along this curve.

(3) Each building chilled water flow in the model

Because building chilled water flow requirement is represented by flow control valve in the model, the flow requirement data at certain operation and weather condition for each building should be inputted into corresponding flow control valve. This flow data input process is also relatively simple. By double clicking the flow control valve icon in visual model, a specification window appears. The flow data can be directly input into corresponding block. In the simulation process, the flow control valve can automatically adjust its loss coefficient to keep flow constant.

(4) Other components in the model

There are many other components in the model, such as valves, tees, branches, etc. Each component has its own characters and input parameters. The simulation software provides a large database to let user select these components and input parameters. This feature will greatly reduce the model setting up time.

## SIMULATION MODEL RUNNING AND MAKING IT CONVERGED

After all of the model required data and parameters were inputted into the model, we run the model and try to make it converged. Due to complicated system property, it was difficult to get a converged simulation result at the first time model running. The simulation software provides many solution control tools and methods to dynamically monitor the calculation process and change converged parameters settings. These tools and methods include changing converged precision, changing relaxation factor, calculation history tracking, and divide model into several sub models, etc. All of these tools and methods make it possible to identify and correct problems in the model running process and make it toward the converged direction.

## MODEL SIMULATION RESULT ANALYSIS AND TUNING UP

After model converged simulation results was obtained, it was analyzed and see if it was consistent with the practical operation conditions. In the model building up process, many assumptions and simplifications have been made, so it is inevitable to introduce some deviations into the model from the practical operation condition. This makes it necessary to continue tune up model after getting the first time converged model. Table 1 shows the simulation results of chilled water loop at TAMU main campus for part of buildings. We assumed the outside air temperature is 60F and the supply pressure difference from main plant is 10psi.

| Buiding # | Pump # | VFD | Loop DP (psi) | Building DP (psi) | Pump DP (psi) | Pump Flow (gal/min) | Efficiency (%) | Pump hp (hp) |
|---|---|---|---|---|---|---|---|---|
| 290 | 290 | y | -9.61 | 15.00 | 24.61 | 340 | 72.96 | 6.69 |
| 291 | 291 | y | -9.63 | 15.00 | 24.63 | 430 | 78.39 | 7.88 |
| 292 | 292 | y | -9.89 | 15.00 | 24.89 | 250 | 64.08 | 5.66 |
| 293 | 293 | y | -8.45 | 15.00 | 23.45 | 450 | 79.61 | 7.73 |
| 367 | 367 | y | 2.06 | 20.00 | 17.94 | 499 | 35.96 | 14.52 |
| 369 | 369 | y | 1.93 | 11.64 | 9.71 | 370 | 72.57 | 2.89 |
| 376 | 376 | y | 5.35 | 12.00 | 6.65 | 700 | 75.65 | 3.59 |
| 392 | 392 | y | 5.08 | 12.00 | 6.92 | 1120 | 43.45 | 10.40 |
| 394 | 394 | y | -8.44 | 15.00 | 23.44 | 400 | 77.44 | 7.06 |
| 397 | 397 | y | 2.45 | 15.00 | 12.55 | 400 | 65.40 | 4.48 |
| 398 | 398 | n | 3.51 | 34.17 | 30.66 | 350 | 52.28 | 11.97 |
| 401 | 401 | n | 0.24 | 32.48 | 32.24 | 154 | 58.54 | 4.95 |
| 402 | 402 | y | -3.60 | 13.92 | 17.52 | 154 | 66.37 | 2.37 |
| 403 | 403 | n | -3.46 | 28.78 | 32.24 | 154 | 58.54 | 4.95 |
| 404 | 404 | y | -3.22 | 13.92 | 17.14 | 154 | 72.15 | 2.13 |
| 405 | 405 | n | -5.50 | 29.55 | 35.05 | 154 | 67.55 | 4.66 |
| 406 | 406 | y | -5.07 | 13.92 | 18.99 | 154 | 70.99 | 2.40 |
| 407 | 407 | n | -4.01 | 31.04 | 35.05 | 154 | 67.55 | 4.66 |
| 408 | 408 | y | -3.79 | 13.92 | 17.71 | 154 | 71.78 | 2.22 |

Table 1. Simulation results of chilled water loop at TAMU main campus for part of buildings (assumed outside air temperature 60F and the supply pressure difference from main plant is 10psi.)

## SIMULATION MODEL APPLICATIONS

There are many applications for the simulation model. Many engineering decisions that are difficult to make due to complicated system properties can be made with the aid of the model. The chilled water loop simulation model at TAMU main campus has been used in the following applications:

(1) Energy saving potential estimation for building chilled water pumps on main campus

There are many buildings on main campus do not have VFD devices for their chilled water pumps, that means energy saving potential exists in these buildings if VFD are installed. According to the simulation results, the energy saving potential for each chilled water pump in these buildings was estimated. The estimation results are important for engineer in TAMU to make decisions if it is suitable to install VFD for some buildings.

(2) Simulating and comparing different loop operation conditions

Different operation conditions exist in the power plant, which supply chilled water to main campus. Simulation model was used to simulate these different operation conditions and find the economic and good loop performance operation.

(3) Loop optimizing and balancing

The simulation model is an economic and convenient tool to optimize and balance loop operation. It is easy for the engineer to identify loop operation problems and solve the problems with the aid of simulation model. Engineer can also optimize and balance loop by changing some parameters, such as pipe size, flow, open or close valves, etc, the changing results and the influence on the whole loop can be seen immediately.

(4) Predicting loop performance when add new building to system

More and more buildings will be built on campus. The simulation model can be used to aid finding the best connection point in the loop and see the influence on the loop. This application is extremely useful when design a new building and make engineering decision on the loop.

## CONCLUSIONS

A computer simulation model is an economic and convenient tool to perform analysis of chilled water loop. Many engineering design and operation decisions can be made with the aid of computer simulation model. The chilled water loop as complicated as the ones at Texas A&M University main campus can be successfully modeled using commercially available software and the simulation procedure we developed.

## REFERENCES


1. Lee, Euy-Joon. 1987. " Modeling and simulation of a campus central chilled water system." Ph.D. dissertation, Oklahoma State University.

2. Atherton, William J. 1983 "On the simulation and analysis of large-scale chilled water systems." Ph.D. dissertation, University of Cincinnati.

3. Hawks, Keith H. 1976. "Computer studies of the Purdue University chilled water system." Central Chilled Water Conference-1976 Proceedings.

4. Raymond, Andrew 1982. "Computer simulation of central chilled water system-a program with user and reference manuals." MS Thesis of University of Illinois at Urbana-Champaign.

5. Grondzik, Walter T. 1980. "Analysis of a central chilled water distribution system." Ph.D. Dissertation, Washington University.

6. Stoecker, W. F. 1971. "A general program for steady-state system simulation." ASHRAE Semiannual Meeting, Philadelphia, Pennsylvania.

7. Stoecker, W. F., S. R. Richter, G. E. Higges, and A. R. Baker. 1976. "A computer program to simulate the flow raters, temperatures, and pressure of a central chilled water system." ASHRAE Transactions, Vol. 82, part I.

8. Stoecker, W. F. 1985. "Refrigeration and air conditioning." 2nd Ed., McGraw-Hill Book Co., New York.

9. Stoecker, W. F. 1980. "Design of thermal systems." 2nd Ed., McGraw-Hill Book Co., New York.