

## Using PIPE-FLO<sup>®</sup> to Design New HVAC Chilled Water Systems

White Paper by Ray Hardee, P.E., Chief Engineer for Engineered Software, Inc.

### **Introduction**

After talking with our customers at engineering firms serving the commercial HVAC market, we discovered they use PIPE-FLO<sup>®</sup> primarily when adding to or troubleshooting existing HVAC piping systems. Much to our surprise, the majority of our customers in this market continue to use their Excel<sup>®</sup> spreadsheets when designing new systems. We decided to investigate a little further, why these users chose this route.

When asked why they did not use PIPE-FLO on new systems, the most common response was they did not want to enter the entire piping system only to find the most hydraulically remote circuit needed for pump sizing. With a spreadsheet, they only enter the pipelines going to and returning from the most hydraulically remote circuit,

eliminating the need to enter all the pipelines in the system.

Once we discovered more about the way these customers were using electronic spreadsheets in determining the head loss for their most hydraulically remote circuit, we came up with a method for using PIPE-FLO to quickly build a model rivaling the simplicity of the spreadsheet method. The remainder of this article describes the process.

### **Finding the Most Hydraulically Remote Circuit**

First, let's review how to calculate the pumping requirements for any circuit in an HVAC chilled water system, and then see if we can simplify the process to find the pumping requirements of the most hydraulically remote circuit. In this article, we will be using the piping system shown in Figure 1.

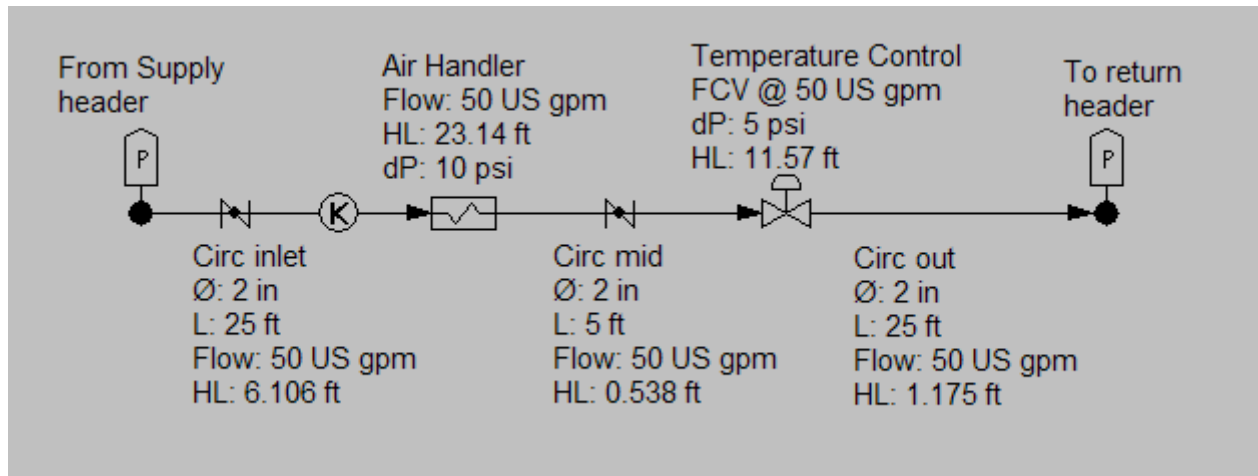
*Figure 1. (follows) This is the example HVAC chilled water system used in this article. To simplify the example we will be concentrating on the secondary loop only. The primary loop has not been included.*



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The system consists of four branches supplying cooling water to four risers. Each riser feeds cooling water to the air handler located on the four floors within the building. With four branches and four floors there are a total of 16 air handlers within the building, each of the air handlers is sized for 50 gpm, resulting in a total system flow rate of 800 gpm.

To simplify the system, the elements in each of the circuits are broken out and the head loss across the circuit is listed. Figure 2. shows the various items found in each circuit from where it leaves the supply to the return riser:



*Figure 2. Typical circuit used in this example showing the details of the pipelines, air handler, and temperature control valve. In the example system all the circuits are identical.*

The details of the circuits are as follows:

- The pipe lengths are shown on the drawing.
- All pipe material in the circuit is 2 inch steel schedule 40.
- The isolation valves are 2 inch butterfly valves.
- The strainer on the inlet of the air handler has a 2 psi drop at 50 gpm.
- The temperature control valve has a minimum differential pressure requirement of 5 psi at 50 gpm.

The objective is to design the system and select a pump with sufficient head that can deliver 50 gpm to each of the 16 circuits in the system.

## **Procedure for Determining Pump Requirements**

The following procedure can be followed when designing an HVAC chilled water system to identify the most hydraulically remote circuit to be used for determining the system pump requirements.

1. The first step is to determine the amount of heat that must be removed from each space within the building. (This is accomplished prior to any hydraulic calculations and is based on the heat generated in each space.)
2. Once the heat removal requirements are known for each space, the chilled water flow rate to each air handler can be determined using the heat removal requirement and chiller differential temperature. (The calculations were performed and in this example it was determined that each air handler needs a chilled water flow rate of 50 gpm.)
3. Determine the routing of the pipelines to and from the individual air handlers based on the location of each air handler in the building. This provides the lengths of the pipelines along with the design flow rate through each pipeline in the system. (The length data is provided on the layout drawing, and the flow rate can be determined by the routing information provided on Figure 1.)
4. The diameters of each pipeline in the system are determined using the design flow rates. (In this example the pipe sizes were calculated to achieve an average fluid velocity of 8 feet per second and the pipe sizes appear on Figures 1 and 2.)
5. Using the pipe diameter, length of the pipeline, along with the valves and fittings the head loss in each pipeline can be calculated.
6. Sum the losses for each circuit including the losses through the pipelines, air handlers, and the minimum required differential pressure across the control valve, along with the other components found in the circuit.
7. Calculate the losses for every circuit within the system and compare the results for each circuit. The circuit with the greatest head loss is the most hydraulically remote circuit.
8. Determine a design factor for the additional pump head required based on the assumptions made in the above calculations. (This is to insure that once the pump is selected and the system built, there will be sufficient margin for proper operation.)
9. Select a pump using the design flow rate of the system along with the total head required determined in step 8 to ensure the design flow rate through the most hydraulically remote circuit.

The method presented above will always ensure that the most hydraulically remote circuit is used in calculating the total head requirement for the pump. This involves calculating the head loss in every circuit in the system; which can be a very tedious process.

In the next section we will see how to make some assumptions to streamline the process, eliminating the need to calculate the head loss for each circuit in the system.

## **Using a Simplified Method**

In looking at the system outlined in Figure 1 it becomes apparent that this system is extremely symmetric. Notice that all the flow goes through a single supply and return header. Each of the four branch supply and return lines are identical, and in fact all circuits in the system are identical. This greatly simplifies the process.

We will demonstrate the process outlined above for finding the most hydraulically remote loop, by calculating the pump head requirements for a variety of circuits within the system. We will start out by calculating the total head loss for the circuit for *Air Handler B1-F1*. We will start the process at the pump discharge and calculate the head loss for all the pipelines as well as items in the B1-F1 circuit returning to the pump suction.

### **Calculating the losses for Circuit B1-F1**

In looking at Figure 1 we can easily determine the details for the pipelines in circuit B1-F1. The pipelines have been listed in the Table 1 along with the flow rate and head loss in each pipe, air handler, and control valve in the circuit:

<b>Pipeline and Components</b>	<b>Flow rate (gpm)</b>	<b>Head loss (feet)</b>
Main supply	800	8.10
B1S-1	200	2.67
<i>Circ inlet B1-F1 (circuit)</i>	<i>50</i>	<i>6.11</i>
<i>B1-F1 (circuit)</i>	<i>50</i>	<i>23.14 (10 psid)</i>
<i>Circ mid B1-F1 (circuit)</i>	<i>50</i>	<i>0.54</i>
<i>Temperature control for B1-F1 (circuit)</i>	<i>50</i>	<i>11.57 (5 psid)</i>
<i>Circ out B1-F1 (circuit)</i>	<i>50</i>	<i>1.18</i>
Total for circuit B1-F1	50	42.54
B1R-1	200	2.67
Main return	800	8.10
Bridge	800	2.03
Pump Suction	800	2.03
<b>Total Head required for circuit B1-F1</b>		<b>68.14</b>

*Table 1. The pipelines and components found in circuit B1-F1 along with the associated flow rates and corresponding head losses.*

In calculating the head loss for each pipeline notice that the main supply pipeline has the entire 800 gpm going through it. That is because when the entire system is operating there will be 800 gpm through the pipeline (supplying 50 gpm to all 16 circuits).

The next pipeline in the calculation is the branch supply header for *Branch 1* (B1S-1) and it has a 200 gpm flow rate, equal to the sum of the flows for the four circuits in *Branch 1*.

The flow rate for the circuit B1-F1 (The air handler for the first floor in *Branch 1*) is 50 gpm. The head loss for each item in the circuit is calculated and totaled. Since all 16 circuits in our system are identical we will use this total in all future circuit calculations.

The common return header for *Branch 1* from the first floor to the main return header (pipe B1R-1) is the next pipeline in the system and once again the flow rate in this pipe is 200 gpm. Since the supply and return branch headers are mirror images of each other the head loss in the supply and return branch pipelines are equal.

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The head loss calculations for the remaining items in the system are based on the full system flow rate of 800 gpm because head loss and flow rates are common elements for all circuits within the system.

As shown in Table 1, the total head loss to pass 50 gpm through circuit B1-F1 is 68.14 feet.

Remember that each circuit will have a total head loss needed to pass the circuits design flow rate. When it comes time to select a pump, the pump head requirement will be determined by the most hydraulically remote circuit. As a result, the procedure outlined above requires us to perform the above calculation for each of the 16 circuits in the system.

Let's follow through the process for circuit B1-F4 (the air handler on the fourth floor for *Branch 1*).

### Calculating the losses of Circuit B1-F4

The pipelines, flow rates, and associated head losses for circuit B1-F4 are listed in Table 2.

Pipeline Component	Flow rate (gpm)	Head loss (ft)
Main supply	800	8.10
B1S-1	200	2.67
B1S-2	150	1.55
B1S-3	100	0.72
B1S-4	50	0.20
Total for circuit B1-F4	50	42.54
B1R-4	50	0.20
B1R-3	100	0.72
B1R-2	150	1.55
B1R-1	200	2.67
Main return	800	8.10
Bridge	800	2.03
Pump Suction	800	2.03
<b>Total Head required for circuit B1-F4</b>		<b>73.08</b>

*Table 2. The pipelines and components found in circuit B1-F4 along with the associated flow rates and corresponding head losses.*

The following items should be pointed out in Table 2.

- The flow rate in the *Branch 1* supply header decreases as it proceeds up the supply riser; because 50 gpm is being removed from the branch header on each floor to feed the circuit on that floor.
- The flow rate in the *Branch 1* return header increases as it proceeds down the return risers; this is because 50 gpm is being returned to the branch header from the circuit on that floor.
- The difference in the head loss for circuit B1-F4 over that required by circuit B1-F1 (a value of 4.94 feet of fluid) is attributed to the head loss in pipelines B1S-2, B1S-3, B1S-4, B1R-4, B1R-3 and B1R-2.
- Since circuits B1-F2, and B1-F3 have fewer pipe segments than circuit B1-F4 their circuit head losses will be less than the loss for circuit B1-F4.
- By inspection, circuit B1-F4 is the most hydraulically remote circuit in *Branch 1*.

By using this reasoning we were able to eliminate the need for calculating the losses through circuits B1-F1, B1-F2, and B1-F3 when considering the total head loss for *Branch 1*.

### **How the System is Balanced**

In looking at the four circuits in *Branch 1*, the total head loss for each branch is different because of the distance the fluid must flow through the system.

Since the total head across the pump is supplied to all the circuits in the system, the circuits with the lower total head loss would have a greater flow rate than the circuits with the greater total head loss. As a result, the distribution of fluid would not meet the system requirement of 50 gpm per circuit.

This is why there is a control valve in each circuit. Without a control valve, the flow rate through each circuit would be different. The control valve provides additional head loss to the circuit so that the total head loss through all the circuits is identical. For example, when the system is balanced the difference in head loss between the control valve in circuit B1-F1 and circuit B1-F4 will be 4.94 feet of fluid, which is equal to the difference in head loss in the pipelines between the circuits.

This is what happens when the balancing contractor adjusts the throttle valves in the system.

Now we'll jump ahead to our next circuit calculation. We'll calculate the total head loss for the air handler on the fourth floor of *Branch 4* (Circuit B4-F4).

### **Calculating the losses for Circuit B4-F4**

The pipelines, flow rates, and head losses for circuit B4-F4 are listed in Table 3.

<b>Pipeline Component</b>	<b>Flow rate (gpm)</b>	<b>Head loss (ft)</b>
Main supply	800	8.10
MS 2	600	2.34
MS 3	400	8.52
MS 4	200	8.92
B4S-1	200	2.67
B4S-2	150	1.55
B4S-3	100	0.72
B4S-4	50	0.20
Total for circuit B4-F4	50	42.54
B4R-4	50	0.20
B4R-3	100	0.72
B4R-2	150	1.55
B4R-1	200	2.67
MR 4	200	8.92
MR 3	400	8.52
MR 2	600	2.34
Main return	800	8.10
Bridge	800	2.03
Pump Suction	800	2.03
<b>Total Head required for circuit B4-F4</b>		<b>112.64</b>

*Table 3. The pipelines and components found in circuit B4-F4 along with the associated flow rates and corresponding head losses.*

After looking at the remaining branches in the system, we can assume the head loss in circuit B4-F4 would be the greatest for the entire system because it has the longest pipe run.

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The only reason we can make this assumption is because:

- All the fluid in the system passes through a single supply header and single return header that do not branch.
- The supply header and return headers are mirror images of each other.
- Each of the branch supply and return headers in the system are identical in pipe diameter and pipe length.
- All the circuits in the system require the same flow rate and are identical.

If this were not the case then we would need to perform multiple circuit head loss calculations to determine the most hydraulically remote load in the system.

By having a very symmetric system we are able to greatly simplify the calculations needed to determine the most hydraulically remote circuit in a system of multiple loads. This is why one of the design goals in a HVAC chilled water system is to have the system as symmetric as possible thus minimizing the number of circuit calculations that must be performed.

These circuit calculations can be easily performed using an electronic spreadsheet program. The spreadsheet can be set up to calculate the head loss for the design flow rate in each pipeline based on the pipe diameter and losses due to the valves and fittings. In addition, the losses for the air handlers and control valves can be entered so the spreadsheet can add up the total losses for each item in the circuit.

The major disadvantage with the spreadsheet method is that information must still be read from the piping connection drawing, and manually entered for all of the pipelines, components, and controls data onto the spreadsheet for the calculations to be performed.

### ***Using PIPE-FLO for the Preliminary Sizing***

In this section we will discuss how to determine the head loss for the most hydraulically remote circuit using the PIPE-FLO program.

The piping schematic is typically the first drawing created. It shows the pumps, air handlers and control valves along with the connecting pipelines. This drawing can be developed as a sketch, or done using a CAD program. The central feature of the schematic drawing is that it shows both the system loads for each air handler along with the pipeline connections. When using an electronic spreadsheet pipelines must be manually determined in each circuit from the information displayed on the piping schematic.

The PIPE-FLO program also employs a drawing interface, enabling users to create a piping schematic in the same program used for calculations. The piping schematic shows all the items in the piping system, in addition the pipeline connections on the drawing are used by the program to set up the various equations needed to perform all the head loss calculations.

The important thing to remember is that the piping system model can start out as a skeleton of the system and as more details become available that information is used in the design calculations.

Using PIPE-FLO's drawing features we will draw a skeleton of the piping system model assuming the circuit B4-F4 is the most hydraulically remote. Our objective is to enter the minimum amount of information required to determine the most hydraulically remote circuit.

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This is the approach we will take:

1. First enter the pump and specify the total system flow rate we will need for the design condition.
2. Enter the details for the main supply header from the pump discharge.
3. Complete the main supply header by entering the supply header pipelines MS2, MS3, and MS4.
4. Enter the *Branch 4* supply riser by entering pipelines B4S-1, B4S-2, B4S-3 and B4S-4.
5. Enter the circuit for B4-F4, including the pipelines and air handler. Instead of inserting a flow control in the circuit we will enter a second component with a fixed differential pressure of 5 psid (the desired minimum differential pressure across a control valve).
6. Enter the *Branch 4* return header and the main return header.
7. Enter the Surge tank.
8. Enter the Bridge, Pump Suction, along with the pipeline from the surge tank to the junction in the pump suction.

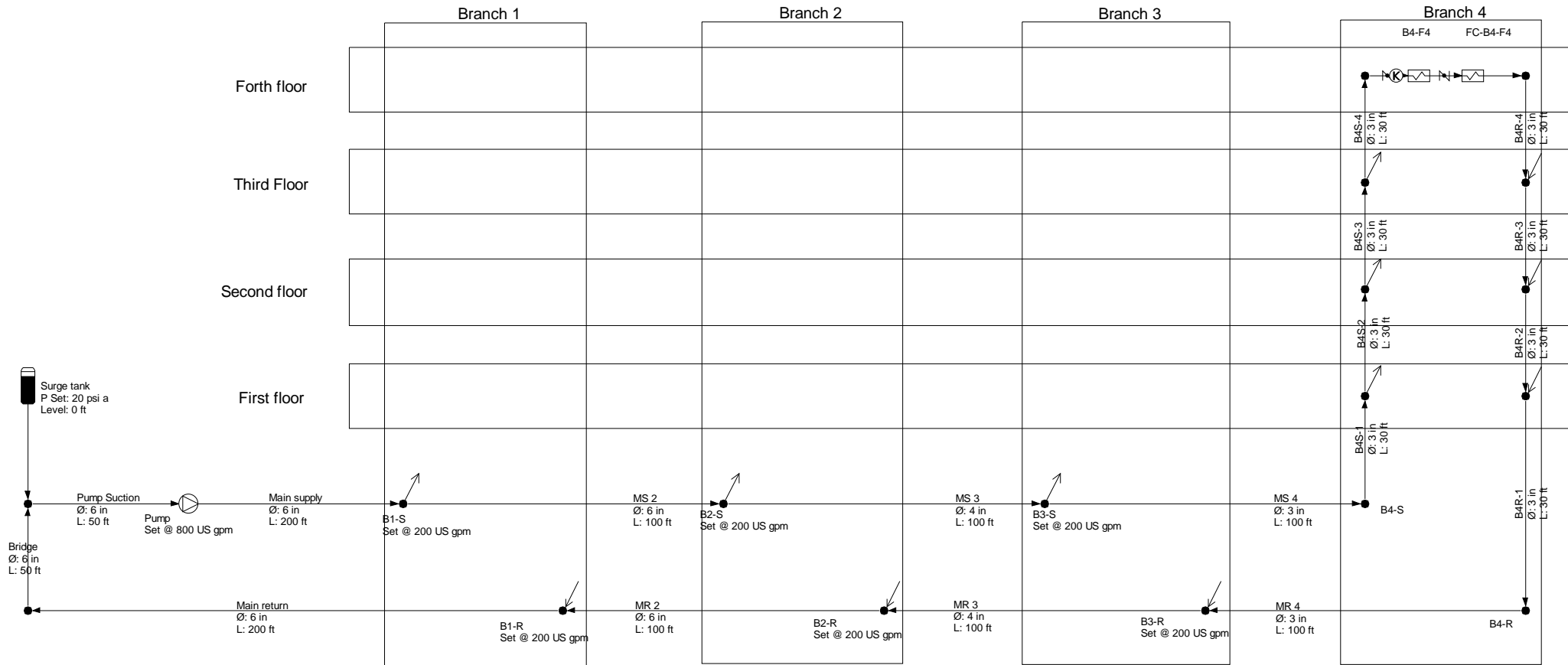
This completes the skeleton of what we believe to be our most hydraulically remote circuit. The next step is to set up for the calculations. As before, in the general method fluid had to be removed from the system at the various branches and circuits to account for the flow going to and returning from the other circuits in the system that are not the most hydraulically remote.

To account for the flows to the non-remote circuits we will:

9. Add demands on the main supply and return headers of 200 gpm for branches 1, 2, and 3.
10. Add demands on the Branch 4 supply and return headers of 50 gpm for circuits B4-F1, B4-F2, and B4-F3.

*Figure 3. (follows) This is a piping schematic of the example project showing only the pipelines going to the most hydraulically remote circuit. Notice the demands show where fluid enters and leaves the system for the branches and circuits.*

# Figure 3.



Lineup: <Design Case>	Darcy-Weisbach	PIPE-FLO 2007
System: Example system hydraulic circuit		Flow: US gpm
Date: 11/29/07 9:53 am		Pressure: psi a
Company: Engineered Software		Size: in
Project:		Elevation: ft
by: Ray Hardee		Velocity: ft/sec
Figure 3 -Model of HVAC Chilled W ater System most hydraulically remote circuit		Length: ft
		Volume: gallons

Now that the system skeleton is complete the calculations can be performed to determine the head loss around the most hydraulically remote circuit. PIPE-FLO calculates the total head required for the pump to meet the requirements of the most hydraulically remote circuit. Notice the pump total head is 112.6 ft.

## ***Evaluating Other Circuits***

In the example, based on the symmetry of the system it was easy to determine the most hydraulically remote loop. The only challenge was performing the necessary calculations to determine the total head needed for pump selection. If there is a doubt as to the most hydraulically remote circuit then a prudent engineer or designer would perform the calculations on the other circuits under question to arrive at the most hydraulically remote circuit.

Unlike the electronic spreadsheet where one must create a separate spreadsheet for each circuit, PIPE-FLO users can add onto the existing model. Simply draw the new circuit on the existing skeleton and then perform the calculation. Not only does this calculate the total head for the new circuit, but it also adds further detail to the piping system model.

## ***Comparing PIPE-FLO with Excel***

Both Excel and PIPE-FLO are powerful tools and can help engineers and designers properly size HVAC chilled water systems. Excel's ubiquitous spreadsheet interface has its roots as an accounting and business application. The program has been adopted by engineers and designers and has become a very powerful calculation, graphing, and data management program. With the introduction of macros it has also become a powerful software development tool.

PIPE-FLO was designed specifically from the ground up as a fluid piping design and analysis tool. Many features are built into the program to streamline the design and data entry process.

With the drawing interface the program automatically uses the connection information on the drawing to set up the equations needed for the circuit calculations. In addition, the program uses engineering data tables to look up properties for pipes, fluids, valves, and fittings used in the project. This not only streamlines the process, but it insures the correct information is consistently entered.

Finally there are the calculations, with an Excel spreadsheet formulas must be entered and tested in the cells to perform the calculation, and then arranged in the spreadsheet so the correct pipelines and flow rates are entered in each circuit. The last step is to compare the total head losses for each circuit being evaluated to arrive at the most hydraulically remote.

Since the piping system model created by PIPE-FLO has all the system connection information, there is no need to manually determine the pipelines and components in each circuit. The head loss calculation routines within the PIPE-FLO program have been tested and validated, so that the amount of checking needed to be performed on the model is minimized. Finally PIPE-FLO's calculation engine automatically uses the connection information to calculate the total losses for each circuit, and will warn users if the most hydraulically remote circuit was not selected.

By using PIPE-FLO, a program that is specifically designed for piping systems, one has a tool that will save time by:

- Automatically looking up much of the information needed in the calculations.

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- Configuring the system connection information needed for the calculations based on the piping schematic.
- Providing for easy addition of circuits to allow for accurate determinations of the most hydraulically remote circuit.
- Presenting calculated results in an easy to use form.
- Eliminating the need to know how to program an electronic spreadsheet.

### ***Extending the Piping System Model***

The determination of the most hydraulically remote circuit is the first step in designing a HVAC chilled water system. The following tasks need to be performed to complete the design:

- Select the pump or pumps needed for system operation.
- Complete the routing of pipelines in the system.
- Evaluate the system under diverse operating conditions.
- Optimize the system design by considering VFD operation.
- Install balancing valves and balance the system.

Unlike a spreadsheet model that has limited value after the most hydraulically remote circuit is performed, the PIPE-FLO model can be added to as the design progresses.

PIPE-FLO incorporates pump selection into the program. With over 95 pump manufacturers supporting the program one can select a pump and insert it into the piping system. If selecting a pump from a manufacturer that does not support the program, the user can manually enter the pumps performance data into the model from a pump curve. After the pumps are selected and the performance information added to the piping system model, that model can be used for further analysis.

The pipelines for the remaining circuits in the system need to be sized and this can be done easily using the PIPE-FLO program. This process is streamlined by using the various copy and paste features available in the software. A major advantage of using PIPE-FLO is all the design information about the system is in one location improving the value of the piping system model.

One can determine how the piping system model operates under a diverse set of operating conditions using PIPE-FLO's lineup feature. Simply create a lineup and adjust the set points for all the flow controls in the various circuits. The program then simulates the systems operation under each of the defined operating conditions.

After performing a diversity analysis the next step is to determine the best method of reducing pumping costs. PIPE-FLO has the capability to determine the pump operating cost for both fixed speed and variable speed operation. Not only can PIPE-FLO perform the operating cost calculation but the total system simulation can be used to optimize the system design, determine how changes in system operation can minimize power consumption, and increase system efficiency.

### ***Conclusion***

Both electronic spreadsheets and the PIPE-FLO program can provide the results to determine the most hydraulically remote circuit in a cooling water system. With the additional benefit of adding to the piping system model as the design progresses, along with the ability to optimize the system within the same application, PIPE-FLO provides incentives for all HVAC system design calculations.