

So, you've decided to enter this unique realm of Chilled Water Cooling. Whether you're an experienced Hydronicist or Radiantologist, whether you have only some limited experience, or even if you're a beginner, there's sure to be something in this chapter which will get your mind working. This chapter covers some important basics of hydronics as it relates to chilled water cooling systems. It does not cover everything hydronic, but the information included in this chapter has provided me with 30 years of pleasurable chilled water cooling experiences. Throughout these next chapters, you will undoubtedly say to yourself many times, Hey, these are the same requirements which hydronic boilers and radiant systems have. **Bingo !**

Throughout the rest of this book (chapter 4 and on), I will be using a numbering logic for the specific topics and subject matter being discussed (e.g. X.x - X = the chapter number, while .x = the topic's number). In a sincere effort to reduce repetitiveness and redundancy, I may find it necessary at times, to refer you back to a specific topic.

4.1 Getting Started

The basic starting point for any chilled water cooling system is to do (or have someone do) a load calculation to determine the required size of the cooling system (chiller's size). You then have to choose the air distribution system's style (type and number of load zones). Now enters the hydronic basics. Having a proper chiller and the chosen fan coil (s) (air handler or handlers), you must design and install the piping system which will deliver the chiller's cooling capacity to the applied load zone (s).

One other item which must be considered up-front is the method of water pumping for the designed system. Many manufacturers supply water pumps in their chillers while others may not. Also, even if a manufacturer does provide a water pump, there is absolutely no reason why you must use that pump. Water pumping variables for chilled water cooling systems will be discussed fully in chapter 5.

Once a proper chiller size has been chosen, you will now have the starting point for designing your applied and installed system. GPM = Gallons Per Minute. Every chiller, if it is to perform properly, will have a manufacturer's rated GPM requirement per chiller's size.

4.2 GPM - Gallons Per Minute

Chilled water cooling systems have a fairly standard GPM industry requirement; **2.4 GPM per ton of cooling capacity**. While this may vary a little by manufacturer and/or chiller type (electric chiller or gas-fired chiller), it is an important value to remember. It is also very, very important to **always consult a manufacturer's installation, operation manual** to determine the proper total GPM requirement for a given chiller size. Many manufacturers list this as two (2) entries; Maximum GPM and Minimum GPM. **The important value to note here, is the Minimum GPM**. This means there must **never** be less than the minimum flowing through the chiller when it is operating.

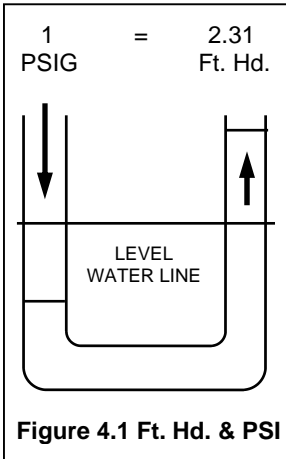
Just like a boiler, which is never fired without water in it and water flowing through it, a chiller has the same requirements. Chillers, like boilers, also have a means of controlling this factor. A manufacturer installed water flow switch in the chiller, or a mandated field applied requirement for adding a water flow switch. This prevents chiller operation under a no flow condition. Some chiller's have a post operational period at the end of their cooling cycle. This may be an operational pump down period for an electric chiller and it is definitely a post operational cool down period for gas-fired chillers. Water flow is normally **mandated** during this period. Always consult a manufacturer's literature.

Special Note: Most chillers, especially gas-fired chillers, have a water flow requirement which many designers and installers totally over look. Even with a full water system, even with a properly set GPM flow rate, it does not mean that the chiller's operation is proper. Look at any designed and installed piping system. Note all the valves which are controlling water flow through the system. Then ask yourself, could any of these devices cause a reduction in a chiller's minimum mandated flow rate during system operation? If the answer is yes, than something is wrong. No chiller's mandated and proper flow rate should be changed in any way when the chiller is operating (this includes the post operational period too, if applicable). A chiller's mandated flow rate, per manufacturer and chiller size, must be set properly and it must be constantly flowing through a chiller when it is operating.

Chiller manufacturers will also provide you with a second chiller value which must be incorporated into the system for designing and installing the chiller. A Ft. Hd. Value (foot of head).

4.3 Ft. Hd. - Foot of Head

Everything through which water flows (piping, valves, etc.), creates a resistance to flow due to the movement of the water (friction). The hydronic industry has created two (2) values for dealing with this factor; **Ft. Hd and PSI** (pounds per square inch, a.k.a. psig = pounds per square inch gauge). Each value has been assigned its own rating and not by chance either.



By using a U-tube, water was added to create an equal water level line in both tubes. Then, one (1) pound of pressure (1 psi) was applied into the opening of one tube. When this was done, the water in the tube on the other side rose up 2.31 feet. This test gives us the **Formula:**

1 PSIG = 2.31 Ft. Hd. This formula is used over and over again for pipe sizing, valve sizing and water pump sizing. Also, all manufacturers of chillers and air distribution devices (fan coils and air handlers) will provide a rating value for their products based on its operational and performance requirements (specified GPM flow rate).

Everything through which system water flows (chiller, fan coil (s), air handler (s), piping and valves) must be calculated into a system's design, to ensure that; 1- the manufacturer supplied water pump, or 2- the separately purchased and installed water pump, is capable of moving a proper GPM flow rate through the designed and installed system. The problem which can occur from time to time, is that some manufacturers (chiller and/or air handler) may provide you with a Ft. Hd value, or it may be a PSI value. Ft. Hd. values are what you require and it is your job to convert PSI values to Ft. Hd. values.

4.4 Chiller & Fan Coil Values

If a manufacturer provides you with a Ft. Hd value, you are basically all set. If they provide you with a PSI value, it must be converted to a Ft. Hd. value. This is where the above formula comes into play. For any known Ft. Hd. value or PSI value, they can easily be converted from one to the other. Take any known Ft. Hd. value (50.0 Ft. Hd.) and divide that value by 2.31 ($50.0 \div 2.31 = 21.64$ PSI) and you will have the PSI equivalent value. Take any known PSI value (5.6 PSI) and multiple that value by 2.31 ($5.6 \times 2.31 = 13.0$) and you will have the equivalent Ft. Hd. value. Note: Water pumps are typically purchased by two (2) operating values; A GPM value and an operational pressure value, Ft. Hd.

4.5 Chiller Systems & Water Pumps

Some chiller manufacturers provide chilled water pumps right inside of the chiller, while others do not provide a pump at all. This factor will create two (2) system designing issues; 1- If the manufacturer does provide a pump, they will also provide you with this pump's total pressure capability, Ft. Hd. This value may also be provided in two (2) different ways; A- as a total Ft. Hd. for the pump, or B- as an available Ft. Hd. for the pump. A- Means that you must deduct the chiller's operational Ft. Hd. from the total value. B- Means that the manufacturer has already deducted the chiller's value and the available value is what you have to design your piping system around (Note: fan coils are considered as part of the piping system). 2- If the manufacturer does not provide a water pump, then it will be your job to properly size and purchase a water pump. For this requirement, you must use the manufacturer's Ft. Hd. value of the chiller in your pump sizing calculations.

4.6 Open Loop versus Closed Loop

Over the years of manufacturing, most chillers were designed as **Closed Loop Systems**. This simply means that every part of the water circulation system (chiller, fan coil (s), piping, valves, etc.) operated as a "Positive" pressure system. There have been some chillers which were designed as **Open Loop Systems**. This simply means that in some part of the chiller, the closed piping loop was "Opened" (special cooling tank area and water reservoir holding tank) and this created a three (3) pressure zone operational chiller; 1- a positive pressure to and into the chiller. 2 - a zero pressure zone in the special cooling tank. 3 - a negative pressure zone in the piping where an applied water pump must suck water out of the holding tank.

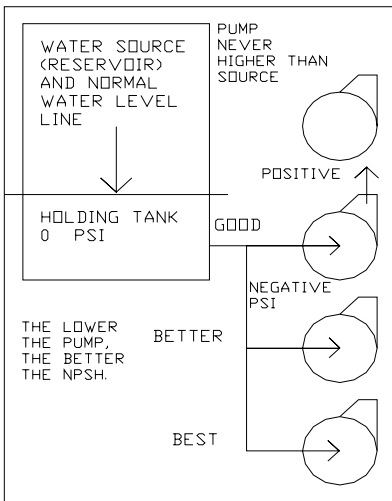


Figure 4.2 Proper Pump Location.

If you ever run across an "Open Loop Chiller", or a New Purchased Chiller is designed this way, there is a very important water pumping requirement which must always be remembered. No water pump, may ever be installed Higher than the operational water level in the holding tank. Lower than yes, and the lower the better, but never higher. There is a special definition for this operational requirement too. It's called NPSH (Net Positive Suction Head). This simply means, that the water holding tank must provide a natural, gravity flow of water to and into the water pump.

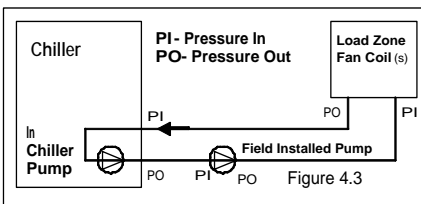
4.7 NPSH - New Positive Suction Head

When any water pump is being applied to an open system, there are several installation and application requirements for the pump, to ensure proper pump operation and proper system (cooling) operation. You already know the most important requirement, "Always install a pump lower than its water source". Here are some more factors to ensure good and proper operation; 1- **Never** down size piping from the water source to the pump. 2- **Never** install a strainer in a pump's suction line. 3- Even if a pump is lower than the water source, **Never** raise any supply piping to the pump, higher than the pump. 4- **Always** minimize the number of piping installed items in the pump's supply line (valves, fittings, etc). 5- **Always** keep the pump's supply piping as straight as possible. 6- **Always** install the water pump as close to the water source as possible. "**IF**", these rules of the road are followed, any installed and applied pump should have an NPSH requirement of 10 feet or less.

In the chapter on water pumps, I will point out a particular pump style which can typically have high NPSH requirements and it is not a good choice for "Open Loop Systems". We now have our chiller, our chosen fan coil (s) (air handlers understood) and our chiller either has a water pump in it or you have to size and purchase a pump. Most of these pumping requirements will be discussed in other chapters, but there is another basic factor which needs to be understood. Pressure Drop values.

4.8 Pressure Drop Values

Pressure drop values are used for many reasons; 1- setting water flow rates. 2- pipe sizing. 3- valve sizing (special flow control devices) and more. You already know the pressure values (Ft. Hd. & PSI); you just need a little more information on their use and purpose.



Pressure readings may be taken at any point of a piping system and many important operational factors may be determined; 1- the GPM flow rate through a chiller (field installed pump applications). 2- the GPM flow rate through a load zone (s).

3- The pumping capability of a water pump. 4- The total PD of the entire water circulation system. Note: A chiller with a pump in the chiller, uses a special flow rate setting method. You cannot read a chiller's PD across a pump too. Referring to Figure 4.3, the pressure in value will always be higher than the pressure out value (Note; the water pump is the only typical exception to this rule).

Any given flow rate will create a drop in pressure as water flows through an item (chiller, fan coil, piping, etc.). As the flow rate increases, so does the PD. PD values are typically read as PSI values, but manufacturers normally provide Ft. Hd. values. You must do the conversion (e.g. a 5 ton chiller's gpm flow rate requirement is 12.0 and the manufacturer lists the chiller as having a 13.0 Ft. Hd. PD with this flow rate. $13.0 \div 2.31 = 5.6$ PSI). If this chiller had a pressure in reading of 12 PSI, and the flow rate was set proper at 12.0 GPM, the pressure out reading would read 6.4 PSI ($12 \text{ PSI} - 5.6 \text{ PSI} = 6.4 \text{ PSI}$). This same logic follows for fan coils too, and you must use the manufacturer's GPM and Ft Hd values for the fan coils.

Any operational water pump will have a pressure in reading and a pressure out reading. For a pump, the pressure out will always be higher than the pressure in. This is the pump's job, to create a high enough pressure to continually move a proper GPM flow rate through the system. For a pump, pressure out, minus pressure in, equals the pump's total capacity (all flow devices normally wide open). It also provides the total PD of the designed and installed system (all flow devices set). More information will be provided in the water pumping chapter. We now need to start thinking about the designing of the piping system. While this will be discussed in its own chapter, there are a few new basic terms you need to know.

4.9 PD Calculator

There is a real neat device available which can really simplify your life for working with Pressure Drop Calculations. Also, when a manufacturer provides a GPM value and Ft. Hd. Value for this gpm, it is normally for typical equipment operation as specified by the manufacturer. But, the manufacturer also provided you with a Minimum and Maximum GPM value which is also appropriate for the chiller's operation. The problem is, you do not have a Ft. Hd. Value for these other GPM values. A PD Calculator can solve this problem easily. You can take the manufacturer's known and provided values, enter them on the calculator wheel, and you can find other Ft. Hd. (PSI) values by simply moving up or down the GPM portion of the wheel. The PD Calculator I use is called, "The System Syzer® Calculator" which has been produced by B&G (Bell & Gossett) a division of ITT Fluid Handling Corporation¹.

1- A large portion of my success over the years has been due to great information and products provided by B&G. Especially their great local distributor/representative. There's no equal to a knowledgeable supplier.

4.10 Friction Charts & Equivalent Length Formulas

Every designed and installed piping system must have a starting point and this was one of the first items I mentioned, the GPM Flow Rate Requirement. A **Friction Chart** lists many different flow rate factors (GPM) and it provides an appropriate pipe size for a given flow rate. As the flow rate increases, so does a pipe's size. This pipe size increase accounts for several potential operational issues; 1- it keeps the flow rate velocity to a minimum for a given pipe size to prevent water flow noise in the piping. 2- higher than normal flow rates through a small pipe will also cause erosion in the pipe. 3- to keep the PD value at a low and acceptable value for a given pipe size. In every appropriate row (GPM per Pipe Size) this chart will provide a pressure drop value for them and for a particular piping material type (copper, pvc, iron, etc.). This pressure drop value may be listed as Ft. Hd., or it could be listed as PSI. Also, these values will be for 100 feet of a given pipe size. This chart is used to design and size the piping system and eventually to be added into the pump's sizing calculation.

Every designed and installed piping system will also have many other items besides the piping itself (elbows, tees, valves, strainers, etc.). All these items create a resistance to water flow too. Each item must be accounted for as to its PD value for the designed system and they must be added into a system's total PD calculation. Unlike piping, these items do not have their own PD values. Each item style, per a given pipe size, is assigned an **Equivalent Length Value**, meaning that item equals X feet of a particular pipe size (e.g. a 1" 90° elbow, has the same PD as 3.0 feet of 1" pipe). Your job is to convert every item to an equivalent length of feet (per a given pipe size) and then add it into you system's PD calculation. There is one item which is used in piping systems and its PD value cannot be obtained from this chart, Zone Valves.

4.11 Zone Valves & Cv Ratings

Today's air conditioning systems have a higher potential for constant air circulation within the load zone areas than they ever had. This is mainly due to the electronic gadget age. Computers, printers, copiers, televisions, increased lighting, and on and on. The bottom line is, that there really isn't any location any more, which may be considered as being ideal for locating and mounting a central thermostat. Heating/Cooling loads and heat loss factors vary more than they ever have. This is one of the biggest reasons why a multiple zone system can be so highly efficient and effective. You cannot have a cooling system with two or more zones and constant blower operation without over cooling one or more areas.

The days of circulating water constantly through all load zone coils are basically gone. But, because we **cannot** install just any type of a valve which would decrease system flow, it will be necessary to install by-pass valves (3-way zone valves) which either supply a coil or by-pass the coil. These valves have a PD rating all of their own. This is due to valve sizing (namely internal flow ports) which can be smaller than the valve's pipe size connection. These valves are designed around typical flow rates for a given size pipe. Then they are assigned a **Cv Rating** based on their design and a given flow rate (GPM).

Example: A valve having a Cv Rating of; Cv 5.5 means, when this valve has water flowing through it at a rate of 5.5 GPM, a 1.0 PSI PD will be created across the valve. It is very important to note Cv ratings for any valve which you may be considering the use of in your system. A System Syzer® Calculator can provide other PD's for other GPM's. One big issue which arises all too many times, is the cost of the valve. Yes, smaller valves are cheaper, but they are also trouble. Down Sizing never accomplishes any good. Always try to limit a valve's PD to 2.0 PSI or less.

4.12 Down Sizing - The Fatal Mistake

Down sizing is rationalized by many as a necessity for being able to make a little extra profit on a job. It is also rationalized by some as a physical requirement due to various connection sizes on chillers and fan coils. Well, at least they're partially right on this point. The main issue which arises for this problem is that the system was designed and engineered properly, but at the time of installation, the installing contractor made some changes and the job's general superintendent didn't catch these minor changes (not).

Yes, for any given designed system, the piping system's size may be larger than a chiller's connection point and/or a fan coil's connection point. But, the piping system's size was designed around a water pump's capabilities (in-chiller or system sized by designer). Any changes and/or deviations in the field will increase a system's total PD and the pump may no longer be capable of moving a proper GPM through the system. Down Sizing, if needed and required at a chiller and/or fan coil, must be done right at the device, by one reducing item and as close to the device as possible. **No appreciable length of piping should ever be down sized.**

Field installed valves can create a similar problem. If the right size valve is not used and smaller and/or cheaper valves are used, oops, there goes the PD again. This is especially important for 3-way valves which have Cv ratings (e.g. a 3/4" valve could have 2 or more Cv ratings based on the internal port sizing, and they not only vary for a valve's size, but also by manufacturer).

4.13 The Farthest Zone

Almost every installed chiller system today will be adapted to two (2) or more fan coils. One of the installed and applied fan coils will be farther away from the chiller than any of the others. This fan coil will have the longest run of piping to get the chilled water from the chiller, to and through this fan coil and to provide a proper GPM flow rate through the coil. This fan coil will be designated as the Farthest Zone, meaning it and its water circulation piping loop, has the largest PD requirement of the entire applied system. If a water pump can circulate a proper GPM flow rate, from the chiller, to and through the farthest zone, and back to the chiller, there will be proper flow through all the other middle zones.

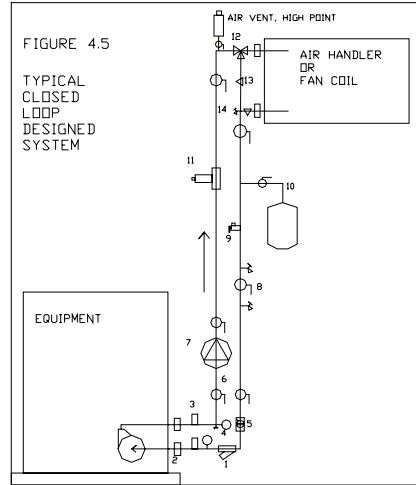
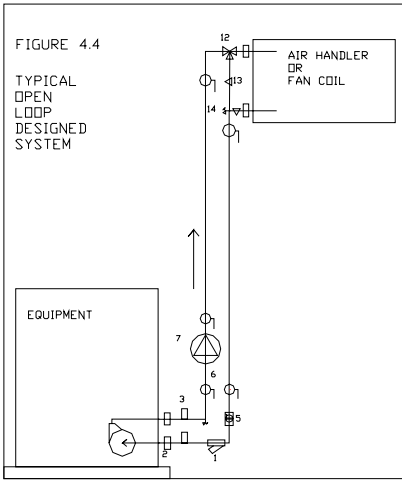
Special Note: There could be exceptions to this rule. A middle zone, due to design and application, may at times have a higher PD requirement than the farthest zone. The important item to remember is you must always use the zone with the highest PD requirement, and this will normally be the farthest zone. The farthest zone logic is used for sizing a water pump.

4.14 Pressure Drop & Antifreeze

Every chiller manufacturer that I know of requires some percentage of a good quality inhibited antifreeze to be added to the water circulation system. Antifreeze products are heavier by weight than water is and this can also vary by the antifreeze's type (ethylene glycol verses propylene glycol). This factor is referred to as viscosity. A water pump has to work harder to move a water/antifreeze mixture, than it does for pure water. This typically means that a larger pump will be required for antifreeze mixture systems. This can also vary by the percentage of antifreeze which will be used in the system. This factor can be calculated into a water pump's sizing by using manufacturer provided calculation charts, or you could have a good pump supplier calculate this need for you. Calculation charts and more information may be found in the designing chapter.

4.15 Typical Piping System Requirements

Every installed and applied chilled water cooling system will have many items included in the field installed piping system, other than the piping and general directional fittings themselves. Figures 4.4 and 4.5 show drawings of two (2) typical applied systems; 4.4 is a typical open loop system and 4.5 is a typical closed loop system.



By design and application, each system will have many items added into the piping circuit and, as is easily noticed in figure 4.5, a closed loop system's requirements are much greater than an open loop system. In finishing up this chapter on hydronics 101, I just want to provide a simple list of these items. Why they may or may not be needed in a system, and whether or not some of them may be code required.

Item 1- Strainer: Strainers can be useful in water systems for filtering debris, but they should never be used in lieu of a good cleaning and flushing. Be sure to purchase strainers which are easily cleanable and don't forget isolation valves for cleaning. Some manufacturers even provide strainers right in their equipment. While not necessarily mandated and/or code required, they can be advantageous for a system. Strainers have a PD value which must be calculated into system designing.

Item 2- Unions: Unions allow for the easy dismantling of piping for servicing and repairing of equipment and fan coils. It's especially handy too, if isolating valves have been installed.

Item 3- Thermometers (or Wells): Having some means of accessing the operational chilled water temperatures of a system can be really important at times, especially if one is trouble-shooting the system. Fixed thermometers and thermometer wells typically penetrate into the flowing water stream. This creates a PD issue which must be addressed for some piping circuits (smaller piping may require up-sizing to account for wells). Pete's Plugs® can be used in lieu of wells and they are adapted to side outlet tees.

Item 4- Pressure Gauges: Pressure gauges are not normally required on “Open” loop systems, but there should always be at least one gauge on a closed loop system. Ideally this one gauge should be in the lowest pressure zone area of the piping system (suction inlet area of the water pump). Pete’s Plugs® can be used in lieu of more gauges and they may be located at all the areas noted in figure 4.3 for taking PD readings.

Item 5- Flow Control Valve: Every system will require at least one (1) flow control device for setting the proper GPM flow rate of the system. “IF” any applied water pump has been sized properly (or in the case of a manufacturer supplied pump, the piping is sized properly), the water pump will be providing a greater GPM than required. The flow control valve will be closed down to a point where an accurate and proper flow is established. Some manufacturers make special flow control devices which have pressure taps right on the valve for easy setting and adjusting of flow rates (e.g. B&G Circuit Setter®).

Item 6- Service Ball Valves: Many codes require valves for isolation of equipment when servicing and/or repairs are required. Many good contractors even install extra valves for isolation of other potential servicing needs (pumps, strainers, etc.). Who knows, you may be the person who has to service and/or repair something one day?

Item 7- Water Pump: Every system will have a water pump. It may be a manufacturer supplied pump as shown in figures 4.4 and 4.5 (pump in equipment), or it may be a properly sized and purchased pump which has to be located in the system’s piping circuit.

Item 8- Fill Valve Assembly: Open loop designed chillers typically have the water/antifreeze mixture added right into the chiller’s reservoir holding area (special design tank which created the open system). Closed loop systems do not have this ability and they will require a means of filling the system. As shown in figure 4.5, this is simply a ball valve with a boiler drain on either side of the valve. It will be fully explained in the installation chapter.

Item 9- Relief Valve: This is not required on an open system due to its open reservoir area, which in itself, acts as a relief/expansion area. Closed loop systems, on the other-hand, do not provide for relief and/or expansion and per code, a relief valve must be installed.

Item 10- Expansion Tank: By code, an expansion tank is required on all positive pressure closed loop systems. Even chilled water systems, which could be exposed to minor expansion due to the ambient of the day, must have an expansion tank. Expansion tanks for chilled water systems are typically smaller due to the reduced potential of a high water temperature factor.

Item 11- In-Line Air Separator: Closed loop systems must have some means of air removal from the piping system. Some systems, due to size and length of piping, are more adequately handled by using an in-line air separator which typically removes air at a faster rate. An independent air vent may be adapted directly to the separator, or the separator may be part of an expansion tanks application. Small automatic air vents are also typically installed at high points of the piping system. **Special Note:** Air separators and air vents **are not used for "Open" loop systems**. The open reservoir area allows for air removal. High point air vents can be detrimental to open systems by allowing air to enter the system during system off periods.

Item 12- 3-Way Valves: Most chilled water applied cooling systems are going to be multiple zoned systems which will require a 3-way zone valve at each fan coil (supply water to and through the coil or to by-pass the coil). Each flow circuit of the 3-way valve will have a different flow resistance factor and each circuit will require its own flow control valve (∇).

Item 13- Flow Control Valve: One FCV installed for the fan coil's flow circuit and one FCV installed for the 3-way valve's by-pass circuit.

Item 14- Boiler Drains: Many codes require some means of draining the equipment and/or other items of a system when servicing and/or repairing is required. Some contractors like to install them because they know that they may be the servicing contractor. The two (2) boiler drains installed for the fill valve assembly are not part of any code requirement. They are specific use items related to the filling and/or maintaining of a full system.

Item 15- Automatic Fill System: Although not noted in figure 4.5 for the closed loop system, there is an automatic water/antifreeze filling system now available for chilled water systems. This is a stand-alone system which acts just a city water make-up system. This system provides a fluid pump, pressure regulation, pressure reducing valve and fluid holding tank. All you have to do is keep the holding tank full of its water/antifreeze mixture.

Special Author's Comment: *Some people have criticized me for my simplicity. They say that there is a lot more to this than I have cared to acknowledge. They are absolutely right. But, why in the world would you or I want to make anything more difficult or confusing than it needs to be.*

IF $2 + 2 = 4$ gets the job done, then why turn an easy method into this;

$$1^2 + (1 \div 2) + (50\%/1) + 0.125 + 0.675 + 1.2 = 4.000$$

Ok, we have finished the general introduction for chilled water systems, a. k. a. Hydronics 101. Chapters 6 (Designing and Engineering) and Chapter 7 (Installation) will expand upon this chapter and much more information will be given for the application and requirements of the topics discussed in this chapter.

But, before we get down to the nitty-gritty of chilled water cooling systems, I want to discuss one other very important aspect of every installed system, The Water Pump. Knowing how a water pump functions and how water pumps may be applied is a very, very important part of every applied system.