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FUNDAMENTALS OF WATER SYSTEM DESIGN (SI EDITION)

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Self-Directed Learning Course

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Fundamentals of Water System Design
(SI Edition)

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Fundamentals of Water System Design SI
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Karen M. Murray
Manager of Professional Development

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Chapter 1
Water System Design Concepts

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Instructions

Read Chapter 1 and, at the end of the chapter, answer all of the questions.

Study Objectives for Chapter 1

After studying the material in this chapter, you should:

- Know what determines the load.
- Understand the difference between closed and open systems.
- Know the components of a hydronic system.
- Understand heating versus cooling source devices.
- Understand how systems meet part-load conditions.
- Be able to identify temperature and pressure ranges for low, medium and high temperature water systems.
- Know what sensible, latent and total heat loads are and how they affect design water flow.
- Be able to identify examples of heating and cooling load devices.
- Know how load diversity suggests a reduction in total cooling capacity required.

1.1 Introductory Concepts

Water system design depends on the designer's ability to evaluate the space loads, occupancy patterns and indoor environment requirements. This chapter examines the actual process of water system design and provides information on how to evaluate space loads. It also provides strategiesand formulas for mastering the key requirements for water systems.

Water systems that convey heat to or from a conditioned space or process with hot or chilled water are frequently called hydronic systems. In general, these systems employ centrifugal pumps to force water flow from a heating or a cooling source to the conditioned space or load by means of various piping, pumping, control and terminal arrangements.[1]

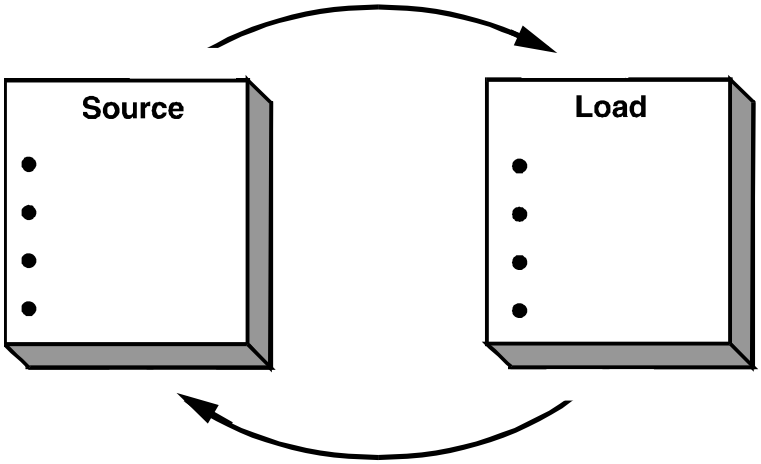


Figure 1–1. Source-Load

Given the design requirements, it is the designer's task to evaluate the space loads resulting from building construction, weather distribution, occupancy patterns, indoor environment requirements and other internal loads to determine the total load (see *Figure 1–1*), subject to the local building codes. The loads include: transmission, solar radiation, infiltration, ventilation air, people, lights, power, appliances and materials in and out.[2,3]

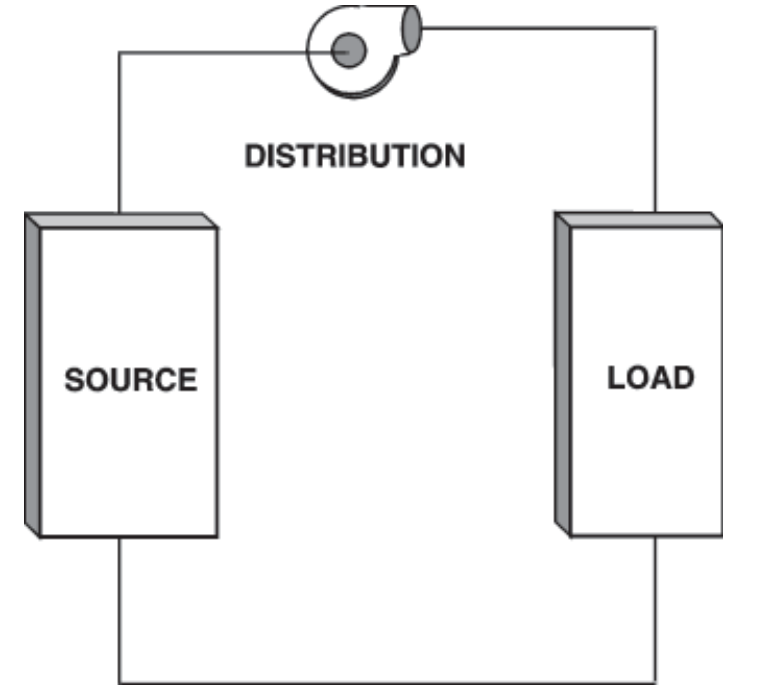


Figure 1–2. Source–Distribution–Load

The historical weather distribution for the project location is important, and a means to control the systems at part-load conditions to maintain comfort conditions for the occupants must be studied for proper design. The designer must weigh the cost of the source utilities available, and also the efficiencies of boilers and chillers or other hydronic sources to determine the most efficient system design (see *Figure 1–2*). The system must

be able to operate between part-load and full-load conditions. In many cases, the hydronic system is a support system providing the heating or cooling medium for heat transfer equipment in an air distribution system. This course is intended to acquaint the student with the various hydronic principles and practices available for consideration in a project's design concept.

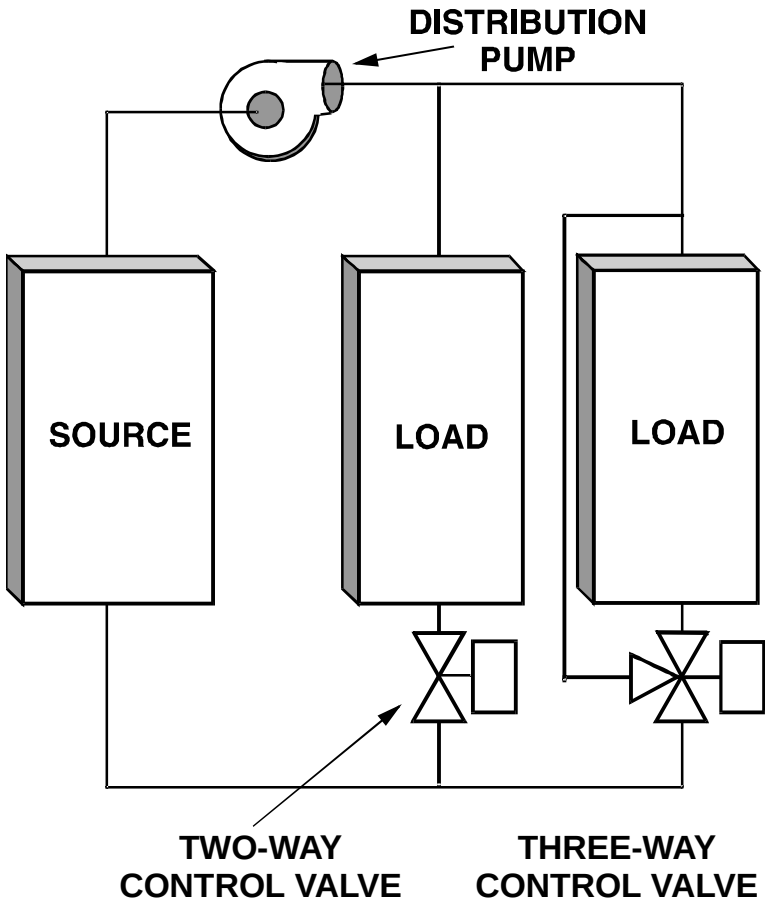


Figure 1–3. Source – Distribution – Part-Load

Figure 1–3 shows the basic components of a hydronic system that the designer must define for an HVAC system; namely, a source of heating or cooling, a distribution system and the load components. There are different classifications of hydronic systems; the most common types are summarized below. As you familiarize yourself with the various systems, remember that different factors may come into play for each.

Water systems may be closed or open types. The fundamental difference between them is the interface of the water with a compressible gas (such as air) or an elastic surface (such as a diaphragm). A closed water system is defined as one with no more than one point of interface with a compressible gas (air) or surface (see *Figure 1–4*). This definition is fundamental to understanding the hydraulic dynamics of these systems (to be discussed under expansion chambers).

An open system has more than one such interface. For example, a cooling tower has at least two points of interface: the tower basin and the discharge pipe or nozzles entering the tower.

In *Figure 1–5*, the difference between the hydraulics of the systems becomes evident as one analyzes the two systems. However, one major difference is that certain hydraulic characteristics of open systems do not occur in closed systems. For example, in a closed system:

- Flow cannot be motivated by static head differences;
- Pumps do not provide static lift; and,
- The entire piping system is always filled with water.

These factors affect the installation and operating costs of the system over its service life.

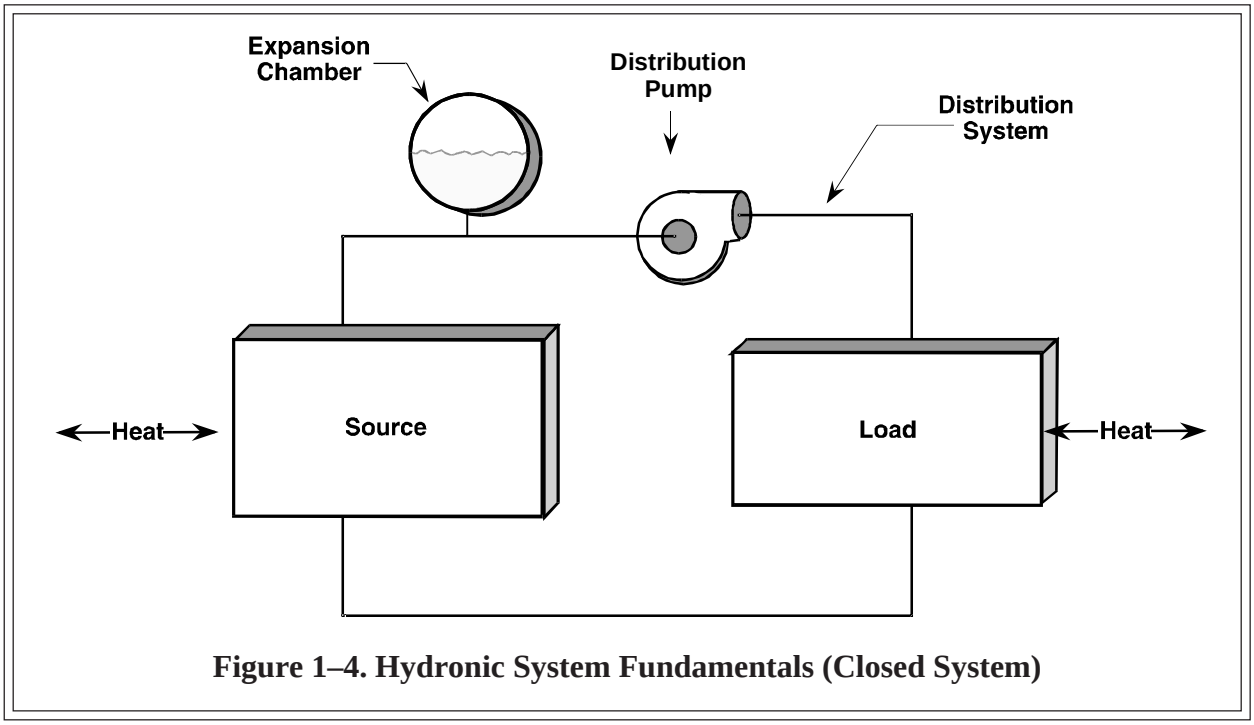


Figure 1–4. Hydronic System Fundamentals (Closed System)

Closed water systems are classified by operating temperature. (While these classifications are defined by the ASME Boiler Codes and provide a useful means of categorizing water systems, Australasian students should be aware that boiler systems are also classified under Australian Standards according to construction, type, pressure rating, output capacity and fuel type.) Closed water systems are classified as follows:

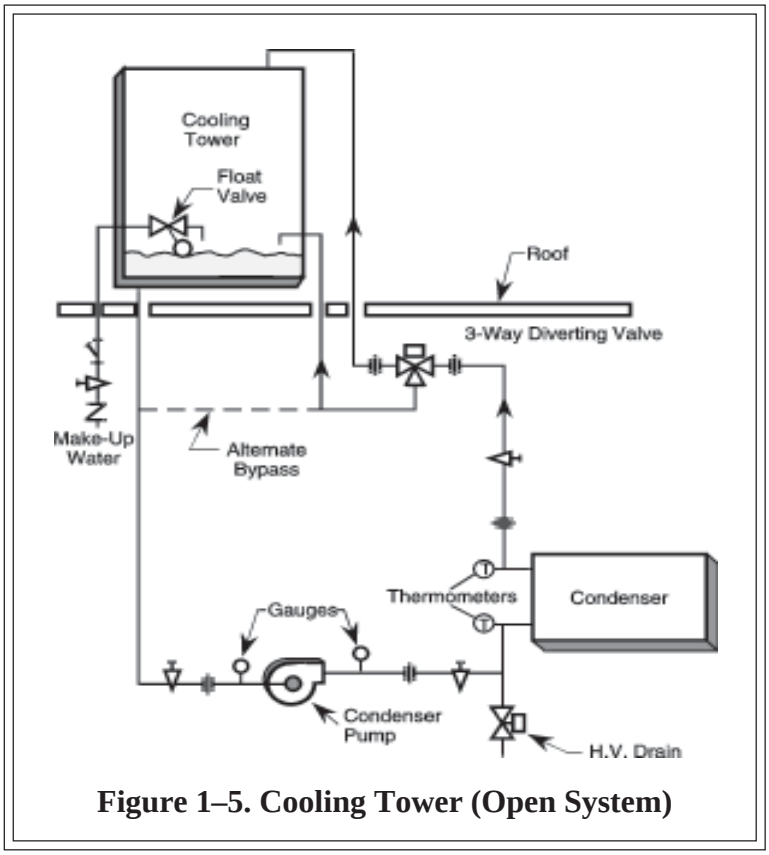


Figure 1–5. Cooling Tower (Open System)

• Low temperature water (LTW) system. This hydronic heating system operates within the pressure and temperature limits of the ASME Boiler Code for low-pressure boilers (see *Figure 1-6*). The maximum allowable working pressure for low pressure boilers is 1100 kPa, with a maximum temperature of 120°C. The usual maximum working pressure for LTW boiler systems is 200 kPa, although boilers specifically designed, tested and stamped for higher pressures are frequently used. Steam-to-water and water-to-water heat exchangers are also used for heating low temperature water.

• Medium temperature water (MTW) system. This hydronic heating system operates at temperatures between 120°C and 125°C, with pressures not exceeding 1100 kPa (see *Figure 1–7*). The design supply water temperature is approximately 120°C to 150°C, with a pressure rating of 1000 kPa for boilers and equipment.

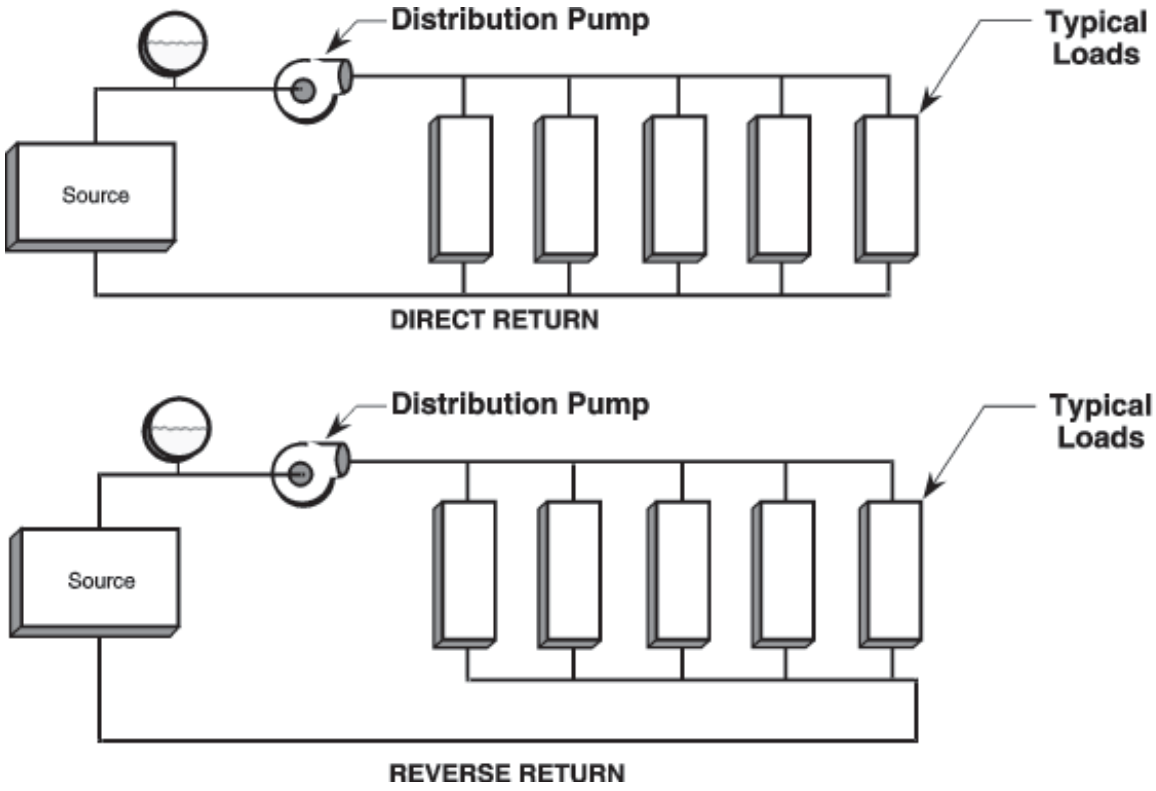
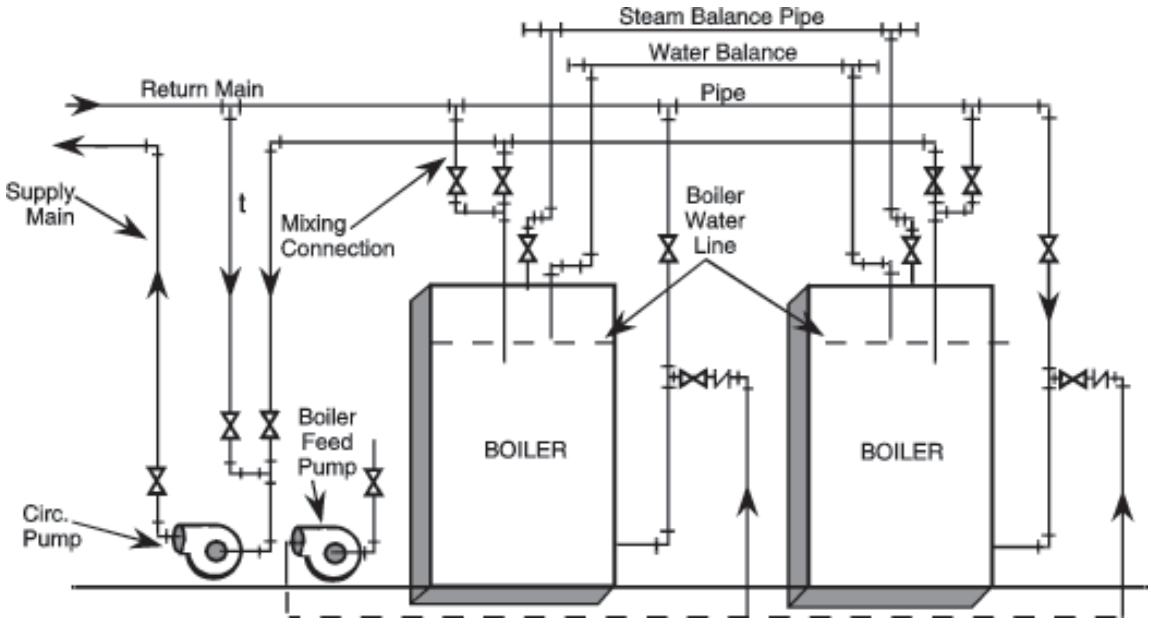


Figure 1–6. Low Temperature Water System – Direct or Reverse Return



Piping Connections for Two or More Boilers in HTW Systems
Pressurized by Steam or Nitrogen Gas

Figure 1–7. Medium or High Temperature Water System

• High temperature water (HTW) system. This hydronic heating system operates at temperatures over 175°C, with pressures not exceeding 2070 kPa. The maximum design supply water temperature is about 200°C, with a pressure rating for boilers and equipment of 2070 kPa (see *Figure 1–7*). The pressure/temperature rating of each component should be checked for compliance with the system's design versus the manufacturer's rating.

• Chilled water (CHW) system. A hydronic cooling system normally operates with a design supply water temperature of 4°C to 13°C (usually 6°C or 7°C) within a pressure range of 825 kPa. *Figure 1–8* shows a small- to medium-sized system with constant speed pumping employing three-way valves to ensure constant flow in the chiller source and balancing valves on each load for flow measurement and adjustment. Larger systems may employ two-way control valves and different chiller piping and pumping arrangements to reduce pumping power.

Antifreeze or brine solutions may be used for applications (process applications) that require temperatures below 4°C or for coil freeze protection. Well or bore water systems can use supply temperatures of 15°C or higher.

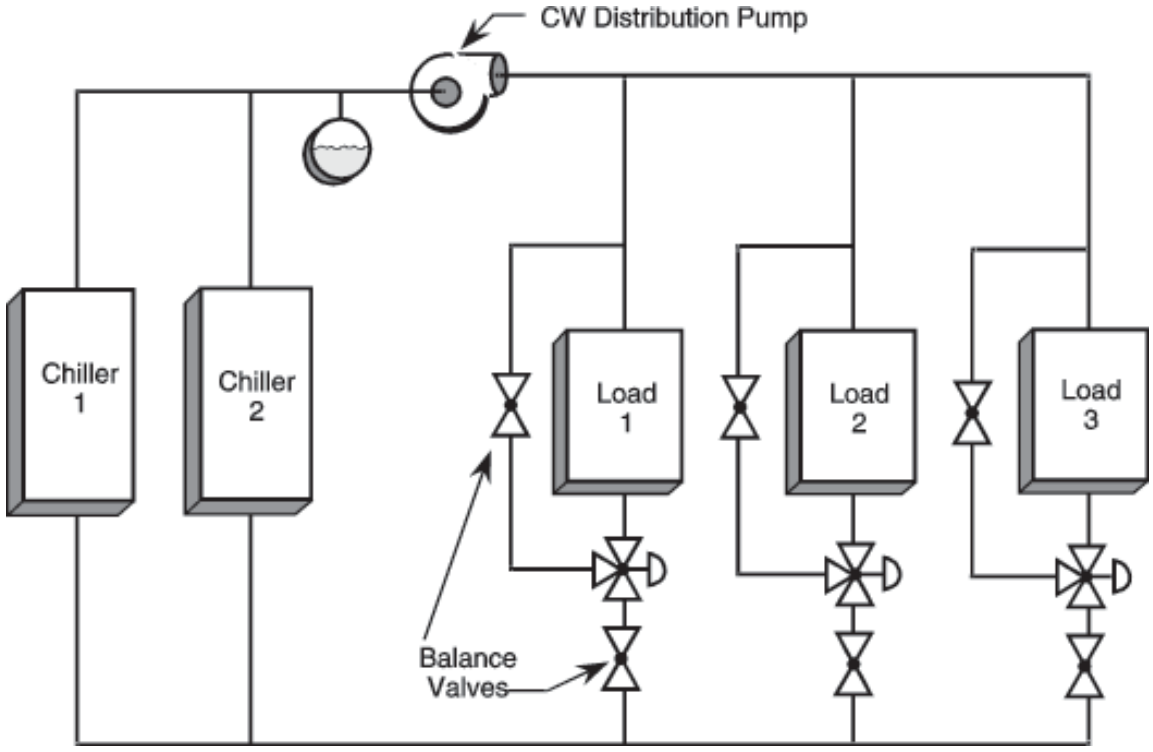


Figure 1–8. Chilled Water System – Direct Return Piping

• Dual temperature water system. This hydronic combination heating and cooling system circulates hot and/or chilled water through separate supply and return pipes to common terminal coils (see *Figure 1–9*). This system operates within the pressure and temperature limits of LTW systems, with usual winter design supply water temperatures of about 35°C to 65°C and summer supply water temperatures of 4°C to 7°C. System design should consider protection to prevent temperature shock to the chiller or boiler on cycle changeover.

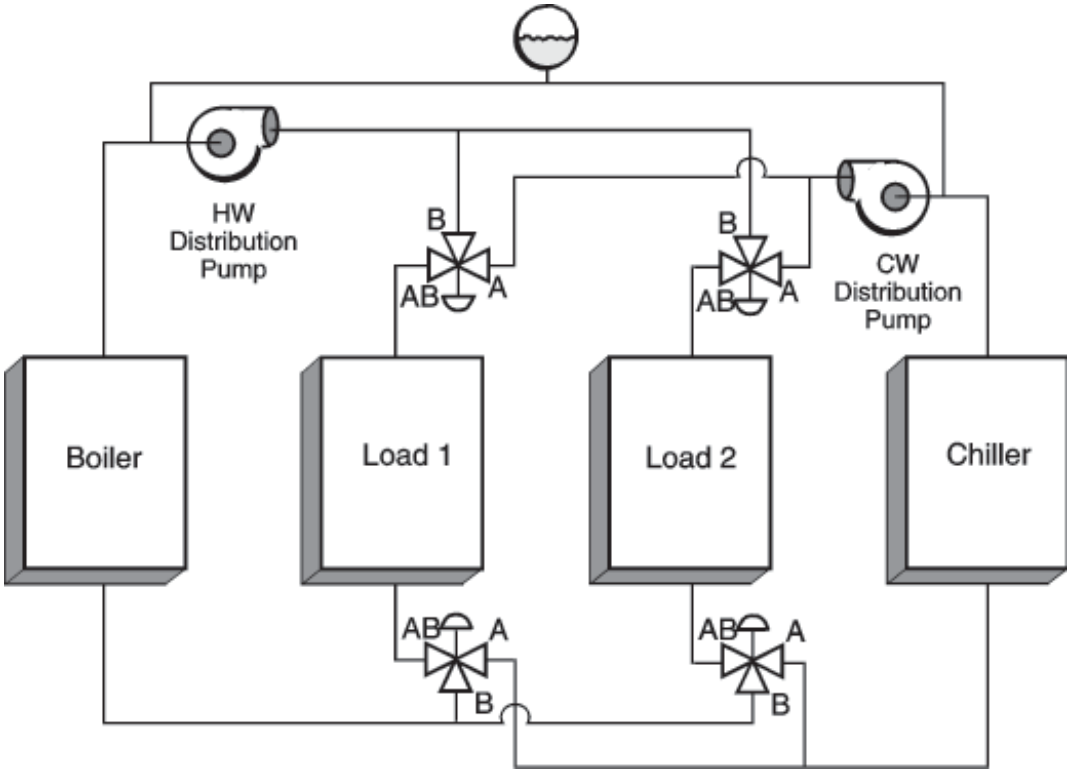


Figure 1–9. Dual Temperature, Four Pipe Water System

• Condenser water (CW) system. Open water systems are typically used in refrigeration condenser water systems as once-through or cooling tower systems. (Once-through systems may not be legally allowed in Australia and other countries if connected to mains water supply.) *Figure 1–10* shows a water cooled condenser using bore or river water. The return is run higher than the condenser so that the condenser is always full of water. Water flow through the condenser is modulated by a control valve in the supply line. This is usually actuated by condenser head pressure to maintain a constant condensing temperature with load variations.

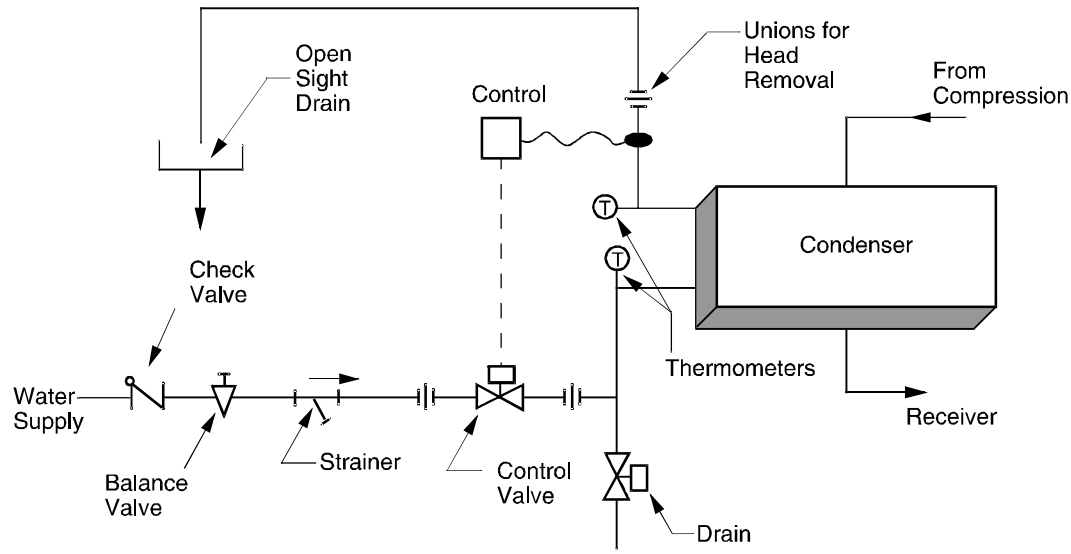


Figure 1–10. Condenser Open Water System (Once Through)

Figure 1-11a shows a cooling tower application.[4] The basic requirements for any cooling tower pipework are to ensure that the condenser water pump suction is flooded so that it has sufficient net positive suction head to operate without cavitation and to ensure a positive head on the pump flanges and seals. The pipework arrangement should also prevent water from draining back to the cooling tower on pump shutdown; this may cause the sump to overflow, resulting in loss of water and chemicals to waste. This is often facilitated by using a check valve fitted on the discharge side of the pump. *Figure 1–11b* shows two cooling tower applications to protect against low outdoor temperature conditions. Water flows to the pump from the tower basin, and the level should be above the top of the pump casing for positive prime, and piping pressure drop should be minimized.

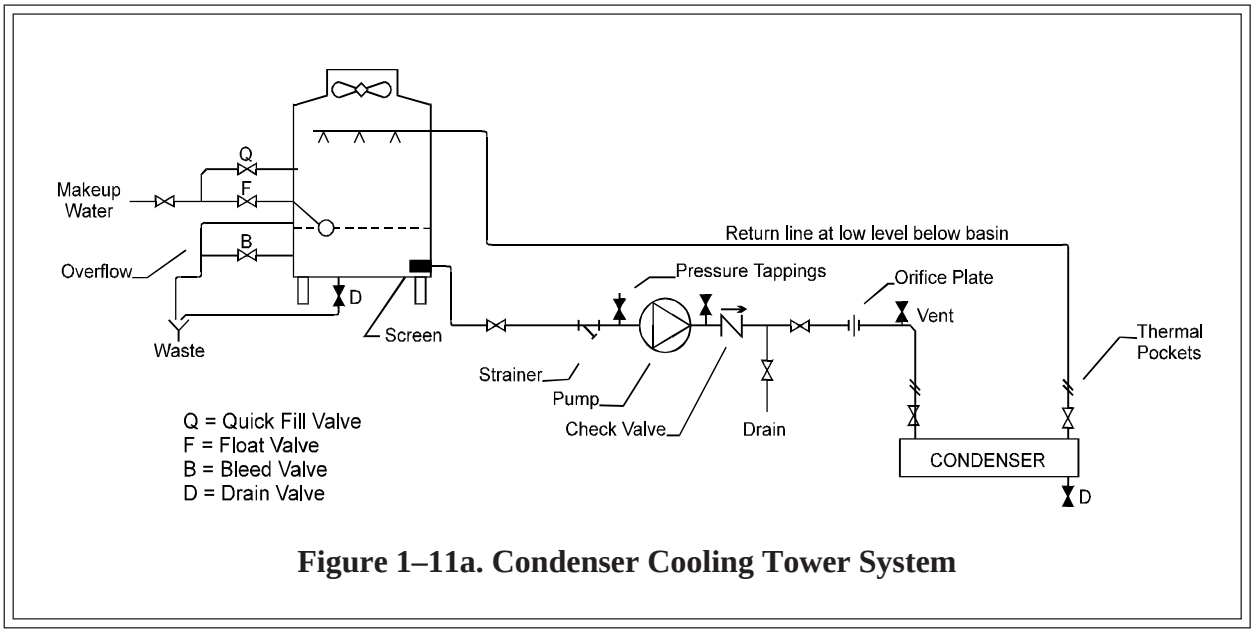


Figure 1–11a. Condenser Cooling Tower System

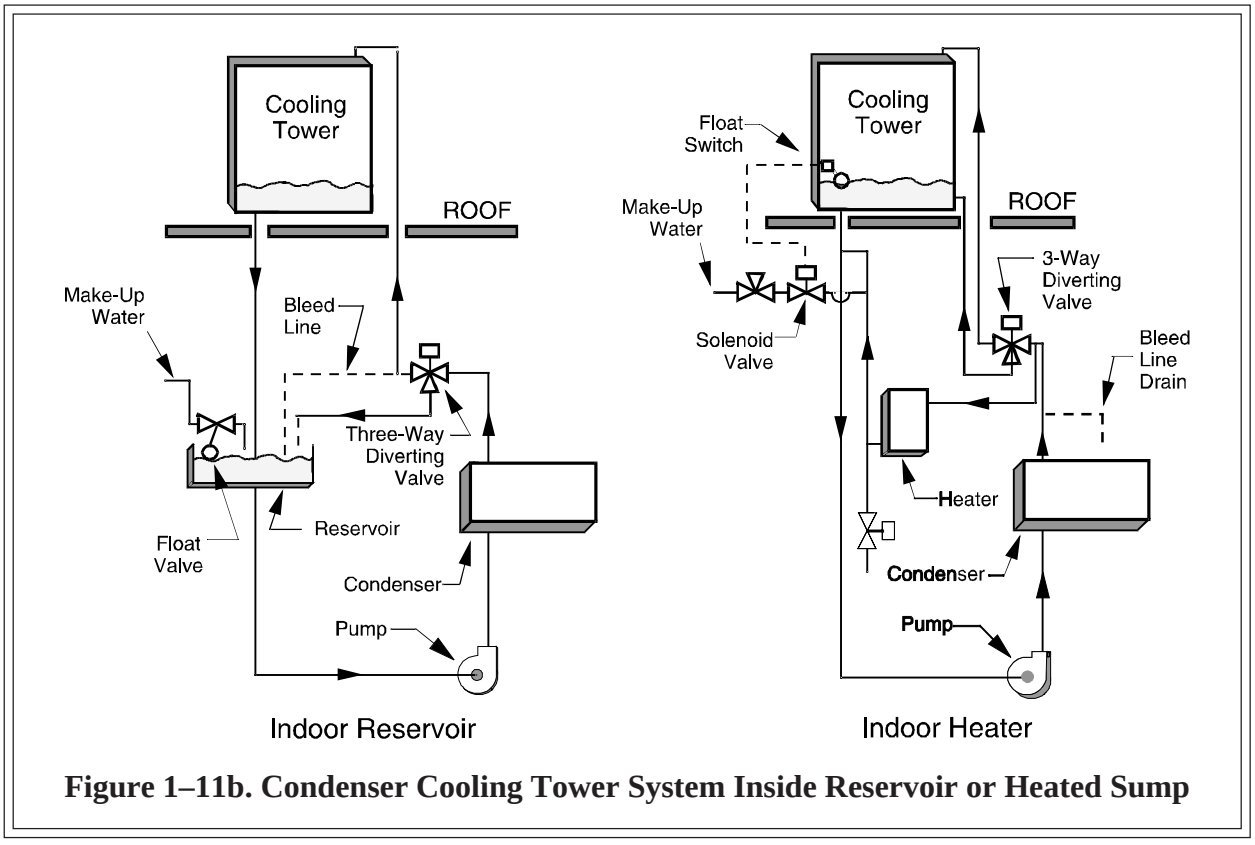


Figure 1–11b. Condenser Cooling Tower System Inside Reservoir or Heated Sump

1.2 Basic System Components

Figure 1–12 shows the fundamental components of a closed hydronic system. Actual systems generally have additional components (such as valves, vents, etc.), but these are not essential to the basic principles underlying the concept of the system. These fundamental components are:

- Source system
- Load system
- Pump system
- Distribution system
- Expansion chamber

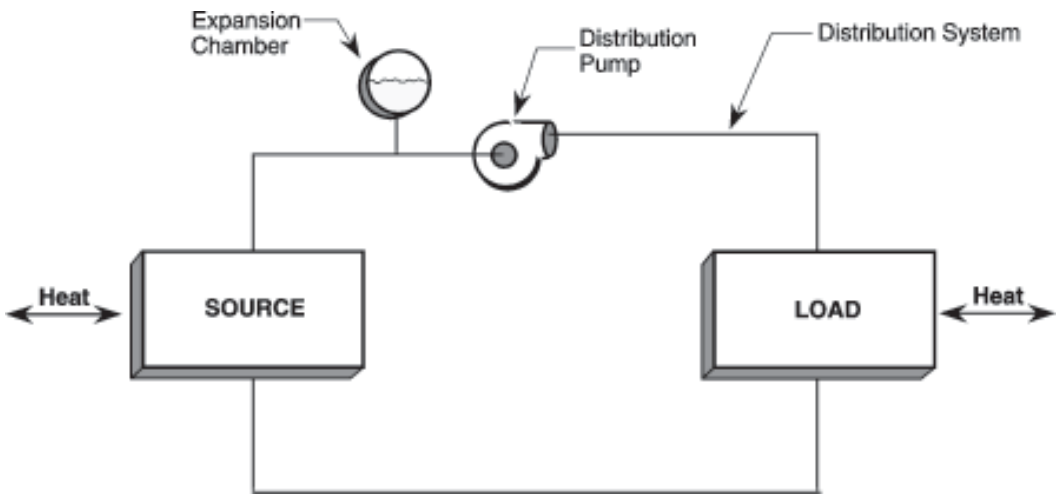


Figure 1–12. Hydronic System Fundamental Components

Source. The source is the point where heat is added in a heating system or removed from a cooling system. Ideally, the amount of energy entering or leaving the source equals the amount entering or leaving through the load system. Under steady-state conditions, the load energy and source energy are equal and opposite. In reality, energy conversion and/or transfer is not perfect and the source has an efficiency of less than 100%. Each type of source has its own efficiency characteristics as a function of load. You must consider this source efficiency in the system design process. Any device that can be used to heat or cool water under controlled conditions can be used as a source device. Sources typically function in one of two ways:

- By converting chemical, electrical or solar energy to heat, which is then transferred to water in the system; or
- By transferring heat from one system to another.

The most common source devices for heating and cooling systems are:

- Heating source devices: Hot water generator or boiler; steam-to-water heat exchanger (see *Figure 1-13*); water-to-water heat exchanger (see *Figure 1-13*); solar collector panels; heat recovery or salvage heat device; exhaust gas heat exchanger; incinerator heat exchanger; heat pump condenser; and air-to-water heat exchanger.

• Cooling source devices: Electric compression chiller (see *Figure 1-14*); thermal absorption chiller (see *Figure 1-14*); heat pump evaporator; air-to-water heat exchanger; and water-to-water heat exchanger.

A typical large chilled water system with multiple chillers, various load controls and compound pumping is shown in *Figure 1–14*. This system provides variable flow, constant supply temperature chilled water, multiple chillers, two-way valve control and the advantage of adding chilled water storage. One design issue shown is the placement of the common pipe for the chillers. With the common pipe located at the opposite end of the chiller production section, the chillers will unload from right to left. With the common pipe in the alternate location (between the chilled water production and the loads), the chillers will load and unload equally in proportion to their capacity (see Chapter 9 for further discussion).

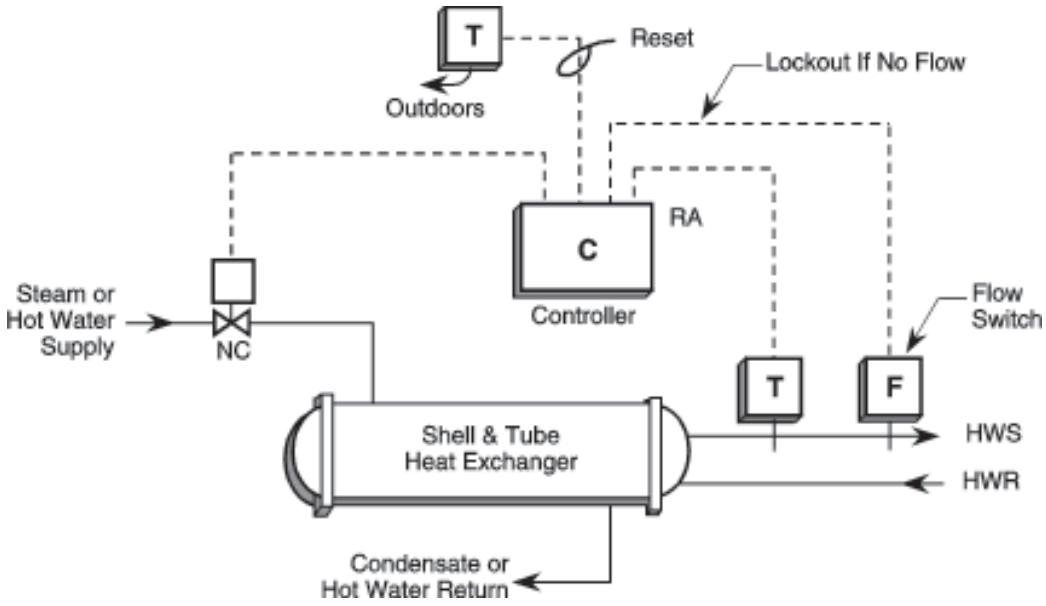


Figure 1–13. Steam-to-Water or Water-to-Water Heat Exchanger

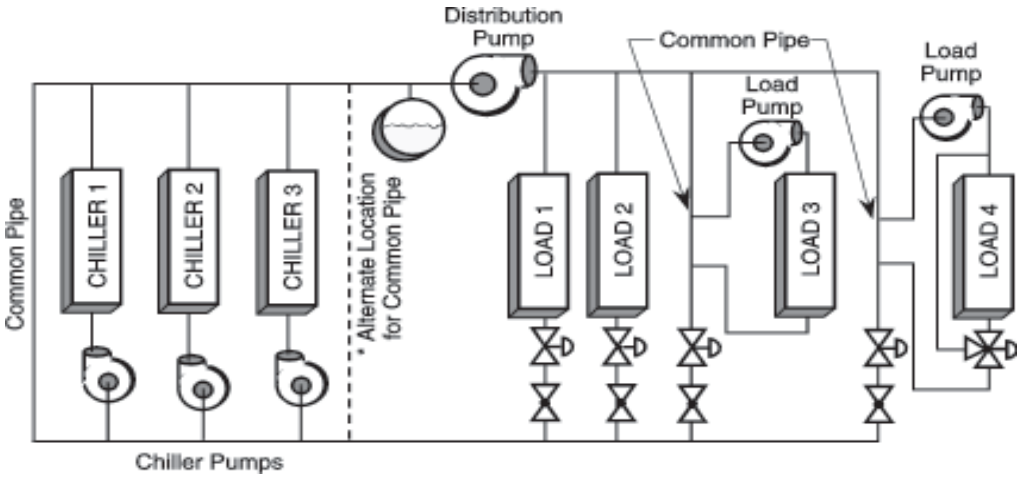


Figure 1–14. Multiple Chiller-Variable Flow Chilled Water System

The two primary considerations in selecting a source device are the design capacity and the part-load capability, which when combined define the turndown ratio. The turndown ratio, expressed in percent of design capacity, is:

$$\text{Turndown Ratio} = 100\left(\frac{\text{Minimum Capacity}}{\text{Design Capacity}}\right) \qquad 1\text{–}1$$

The reciprocal of the turndown ratio is sometimes used. For example, a turndown ratio of 25% may also be expressed as a turndown ratio of 4.

The turndown ratio has a significant effect on the successful performance of a system, and lack of consideration for this capability of the source system has been responsible for many systems that do not function properly or do so at the expense of excess energy consumption. The turndown ratio has a significant impact on the ultimate system design selection because operating efficiencies tend to decrease as the turndown ratio decreases.

Generally, the larger the boiler or chiller on a single unit basis, the more difficult it is to achieve acceptable operation efficiencies and, therefore, acceptable costs for the low load portion of its seasonal operation. Seasonal operation at less than 50% load can, in the case of heating, be over 50% of its total duty hours; in northern climates, a similar ratio may occur during cooling seasons. This presents the designer with a dilemma. You must specify a system that meets the maximum requirements, but in doing that, the system may operate ineffectively for most of its duty season. One approach to solving this dilemma is by using multiple sources of lower capacity (see *Figure 1-14*).

Another design consideration is the diversity of the cooling load. Carrier[5] states that “diversity of cooling load results from the probable non-occurrence of part of the cooling load on a design day. Diversity factors are applied to the refrigeration capacity in large air-conditioning systems. These factors vary with location, type and size of the application, and are based entirely on the judgment of the engineer.”

The diversity factor, as a ratio of actual load/design load, can be applied to people and lighting loads in large multistory office, hotel or apartment buildings. For example, in an office building, the diversity factor for the refrigeration capacity due to people may be from 0.75 to 0.90 and, due to the lighting, from 0.70 to 0.85. In addition, the design engineer must consider the storage load factors for heat gain due to lighting and solar gains by glass.

Specific methods of load control for chilled water plants will be discussed later in this course. But, the following example shows that improved control and reduced operating costs will result if two or more chillers of lower capacity are considered rather than a single large unit. Under part-load operation, the excess capacity is reduced by phasing out units, allowing the remaining units to operate at greater efficiencies and with lower costs. Consider multiple chillers, in the following arrangements (see *Figures 1-15a* and *1–15b*):

Two Units	**Three Units**
1 @ 60% load	1 @ 50% load
1 @ 40% load	1 @ 25% load
	1 @ 25% load

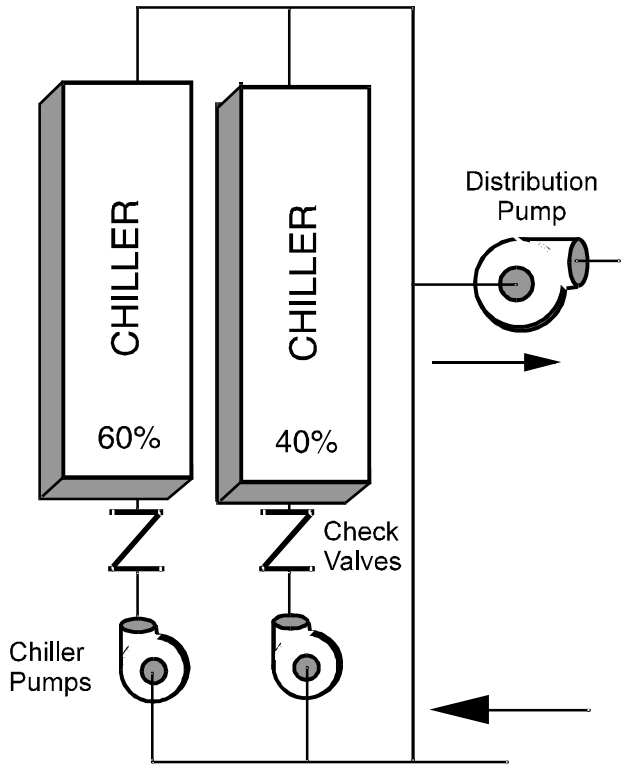


Figure 1–15a. Multiple Chiller Example

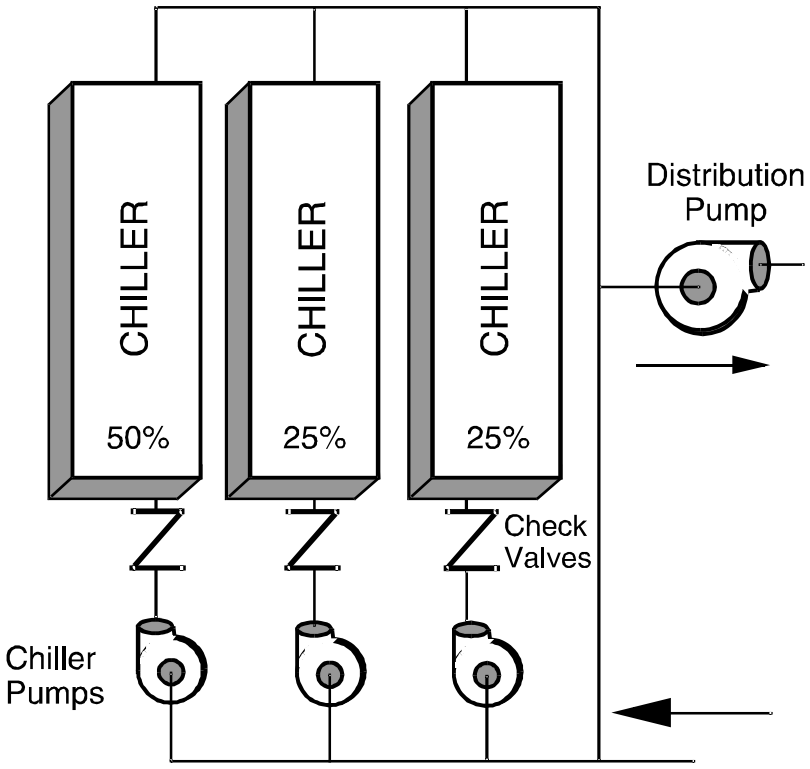


Figure 1–15b. Multiple Chiller Example

In addition to offering the potential of improved operational efficiencies, we can eliminate the expense of providing a standby should it be a project requirement. Full standby can be accomplished by duplicating the largest unit of either set, or duplicating the smallest is practical and can provide 80% (two at 40%) for the two-unit group and 75% (three at 25%) minimum standby for the three-unit group.

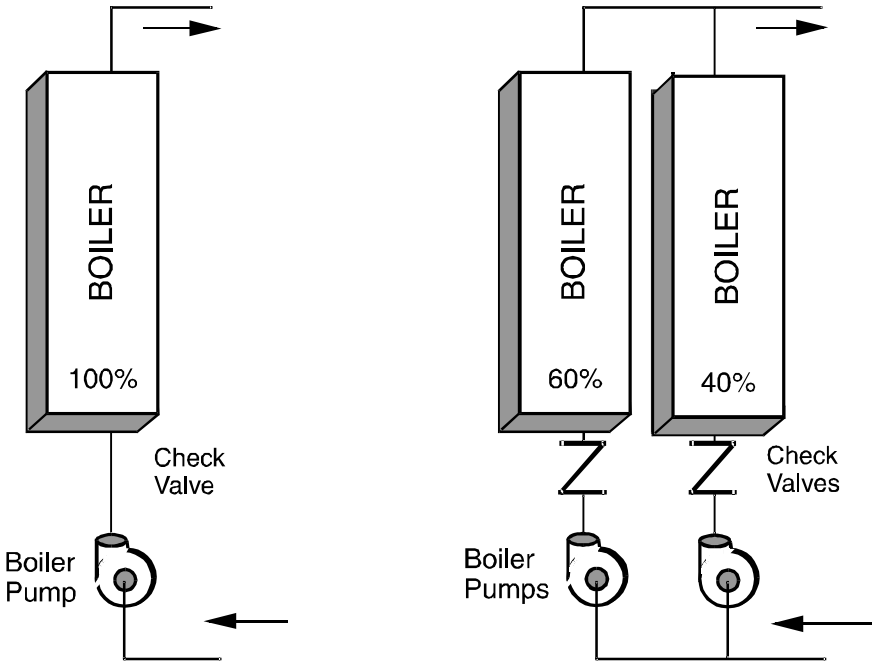
The economics available for a single boiler versus a multiple boiler hot water plant, including power required for ancillary equipment, are illustrated by the following chart (for system schematics, see *Figures 1–16a, 1–16b* and *1–16c*).

System	1	2		3		
Boiler Output, kW	6000	3500	2500	3000	1500	1500
Blower, kW	15	12	5.5	5.5	3.5	3.5
Pump, kW	7.5	2.5	1.5	1.5	1	1
Part-Load Ancillary, kW	22	13.5	7	7	5	5
Full-Load Ancillary, kW	22	20	20	16.5	16.5	16.5

Note that a light load condition for System 1 requires 22 kW for the ancillary equipment to operate, while System 2 requires 7 kW ancillary and System 3 requires only 5 kW ancillary. Because the system will operate at light loads many hours of the year, the operating cost of such ancillary equipment must be compared over the operating season.

In addition, some boiler manufacturers may require a separate pump to circulate the boiler, with a minimum boiler flow at light loads to reduce thermal shock and tube burnout.

Note check valves in the pump discharge to prevent backflow through an idle boiler or chiller when multiple units are provided (see *Figures 1-15a, 1-15b, 1-16b* and *1-16c*).



Figures 1–16a and 1–16b. Multiple Boiler Examples

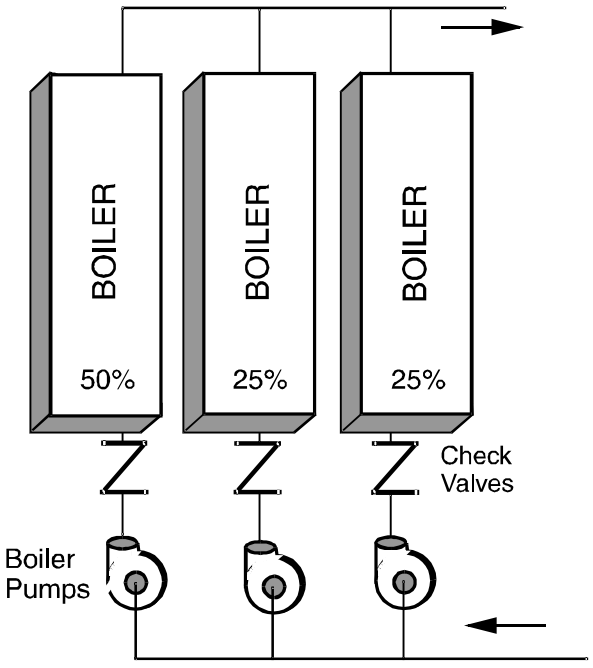


Figure 1–16c. Multiple Boiler Example

Design trade-offs. Remember, the improved efficiency comes with an initial installation cost penalty. As the designer, you must work out the acceptable trade-off in initial installation cost that a customer will accept for reduced operational expenses over the life of the system. This will be easier to accomplish when backup system requirements are considered in the decision.

System temperatures. As the designer, you must design temperatures and temperature ranges by considering the performance and economics of the components. For example, for a cooling system that must maintain 50% RH at 25°C (see *Figure 1–17*), the dewpoint temperature is 13°C, which sets the maximum return water temperature near 13°C (15.5°C maximum); the lowest practical temperature for refrigeration, considering the freezing point and the economics, is about 4.5°C. This temperature spread then sets constraints for a chilled water system.

For a heating system, the maximum hot water temperature (as established by the ASME Low Pressure Code) is normally 120°C, with low pressure systems operating at about 90°C, and with space temperature requirements of little over 24°C, the actual operating supply temperatures and the temperature ranges are set by the design of the load devices. Most economic considerations relating to the distribution and pumping systems favor the use of the maximum possible temperature range Δt.

Load. The load is the point where heat flows out of or into the system from the space or process; it is the independent variable to which the remainder of the system must respond. Outward heat flow characterizes a heating system, and inward heat flow characterizes a cooling system. The quantity of heating or cooling is calculated by one of the means discussed in the following section.

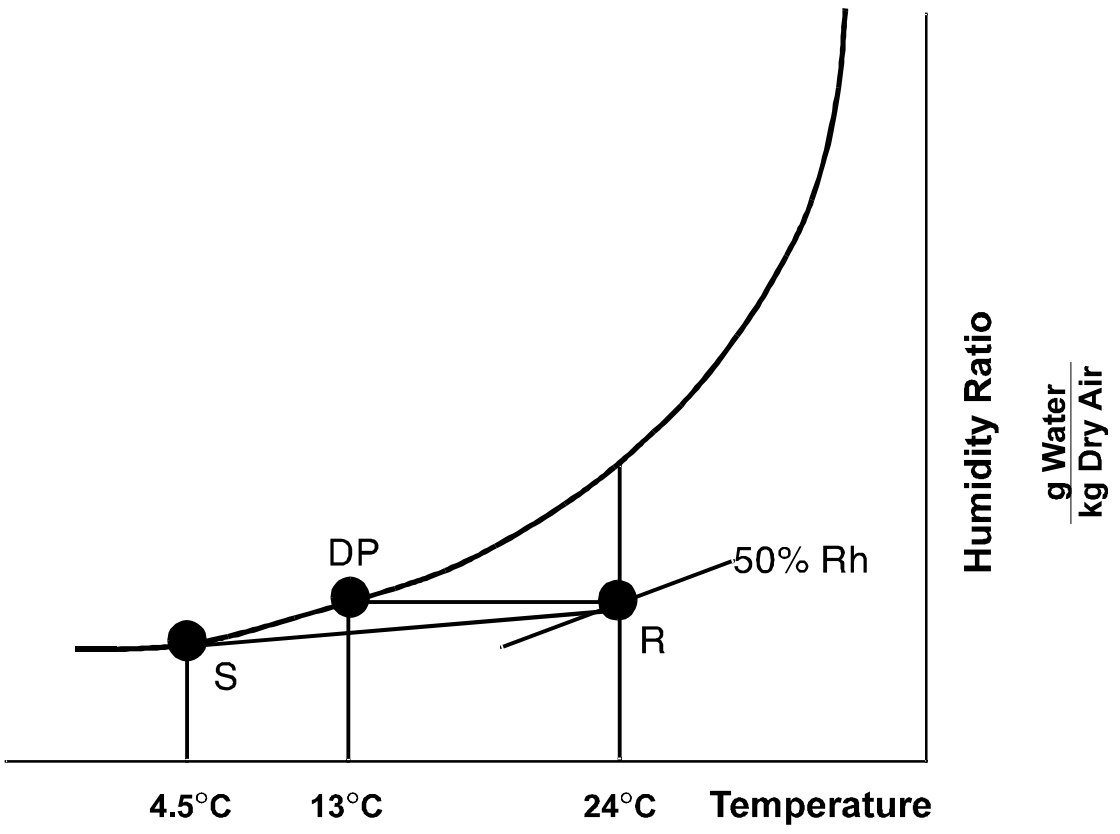


Figure 1–17. Psychrometric Chart-Chilled Water Example

1.3 Heat Transfer in Hydronic Systems

Sensible Heating or Cooling of Air

The quantity of heat entering or leaving the airstream (see *Figure 1–18*) is expressed by:

$$q = Q_a \rho_a c_p \Delta t \qquad 1–2$$

where:

q = heat transfer rate, kW
Q_a = air flow rate, m^3/s
ρ_a = density of air, kg/m^3
c_p = specific heat of air, kJ/kg·°C
Δt = air temperature change, °C

For standard air with density of 1.2 kg/m^3 and specific heat of 1.0 kJ/kg·°C, this equation becomes:

$$q = 1.0 \text{ kJ/kg·°C} \times 1.2 \text{ kg/m}^3$$

$$q = 1.2\, Q_a \Delta t \qquad 1–3$$

Example 1-1

Assume in the system shown in *Figure 1–18* that the air upstream of the heating coils is 15°C and the air temperature leaving the heating coils is 55°C. Given that c_p = 1.0 kJ/kg·°C, Q_a = 2500 L/s and the density is 1.2 kg/m^3, calculate the heat transfer rate of the system:

$q = 1.2\, Q_a \Delta t$
$= 1.2 \text{ m}^3/\text{s·°C}$
$q = (1.2)\ (2.5 \text{ m}^3/\text{s})\ (55°C – 15°C)$
$q = 120 \text{ kW}$

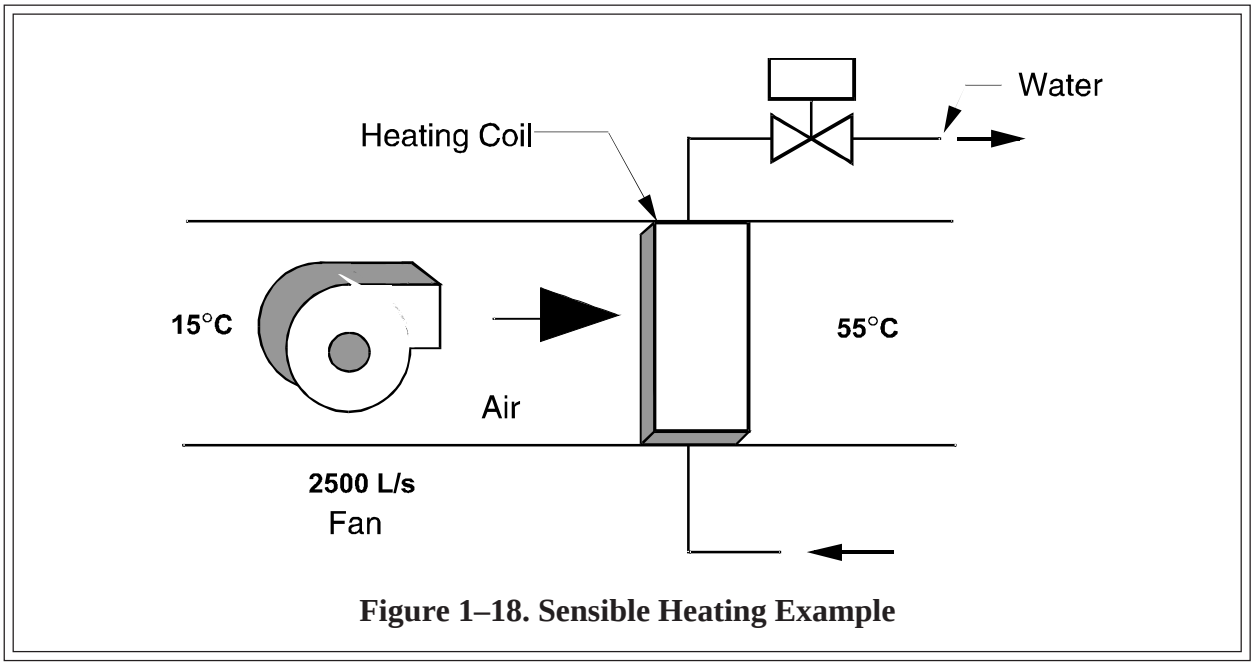


Figure 1–18. Sensible Heating Example

The heat exchanger or coil must then transfer this heat to the water. The quantity of sensible heat transferred to the heated or cooled medium in a specific heat exchanger is a function of the surface area, the mean temperature difference between the water and the medium, and the overall heat transfer coefficient, which is a function of the fluid velocities, properties of the medium, geometry of the heat transfer surfaces and other factors (see *Figure 1–19a*). It may be expressed by:

$$q = UA\,(\text{LMTD}) \qquad 1\text{–}4a$$

where:

q = heat transfer rate, W
U = overall coefficient of heat transfer, W/m^2·°C
A = surface area, m^2
LMTD = logarithmic mean temperature difference, heated medium to water, °C

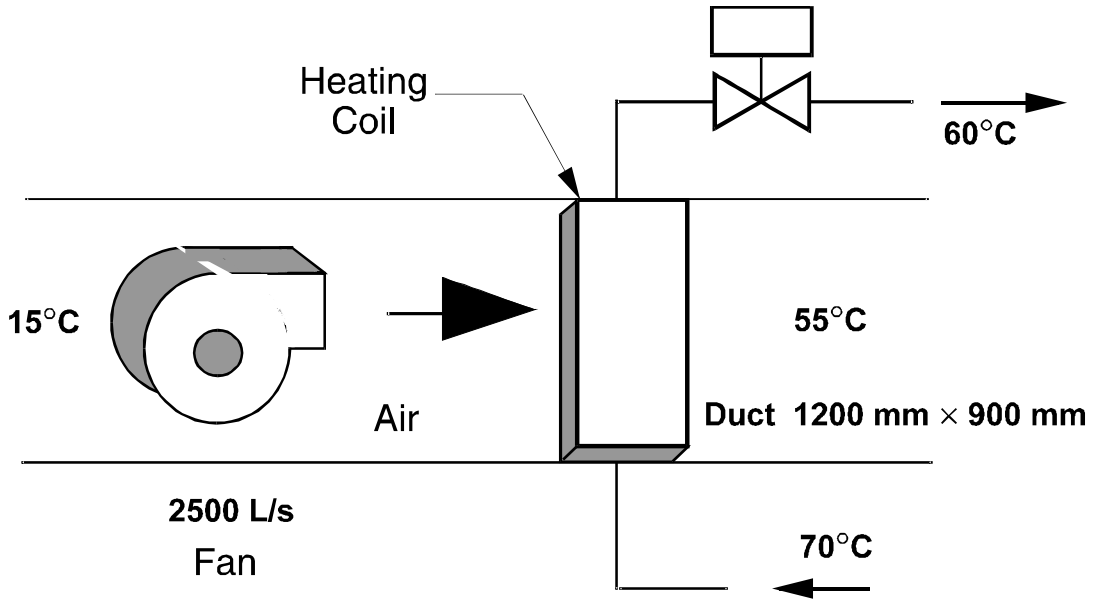


Figure 1–19a. Coil LMTD Example

EXAMPLE 1-2

In *Figure 1–19a*, assume that the coil has a U of 850 W/m^2·°C/row. The upstream temperature is 15°C and the air temperature leaving the coil is 55°C. Water enters the heating coil at 70°C and leaves at 60°C. The duct size is 1200 mm × 900 mm and the coil has four rows. Find the heat transfer rate (see also *Figure 1-19b*):

First, determine the LMTD: 1-4b

$$\text{LMTD} = \frac{\Delta t_{\max} - \Delta t_{\min}}{\text{In}\left(\frac{\Delta t_{\max}}{\Delta t_{\min}}\right)}$$

$$= \frac{45 - 15}{\text{In}\left(\frac{45}{15}\right)}$$

$$= 27.3°\text{C}$$

Δt_{max} = 60 – 15 = 45
Δt_{min} = 70 – 55 = 15

Next, using LMTD, find *q*:

q = UA (LMTD)

= [850 (W/m^2·°C)/row] (1.2 m × 0.9 m) (27.3°C) (4 rows)

= 100 246 W (100.25 kW)

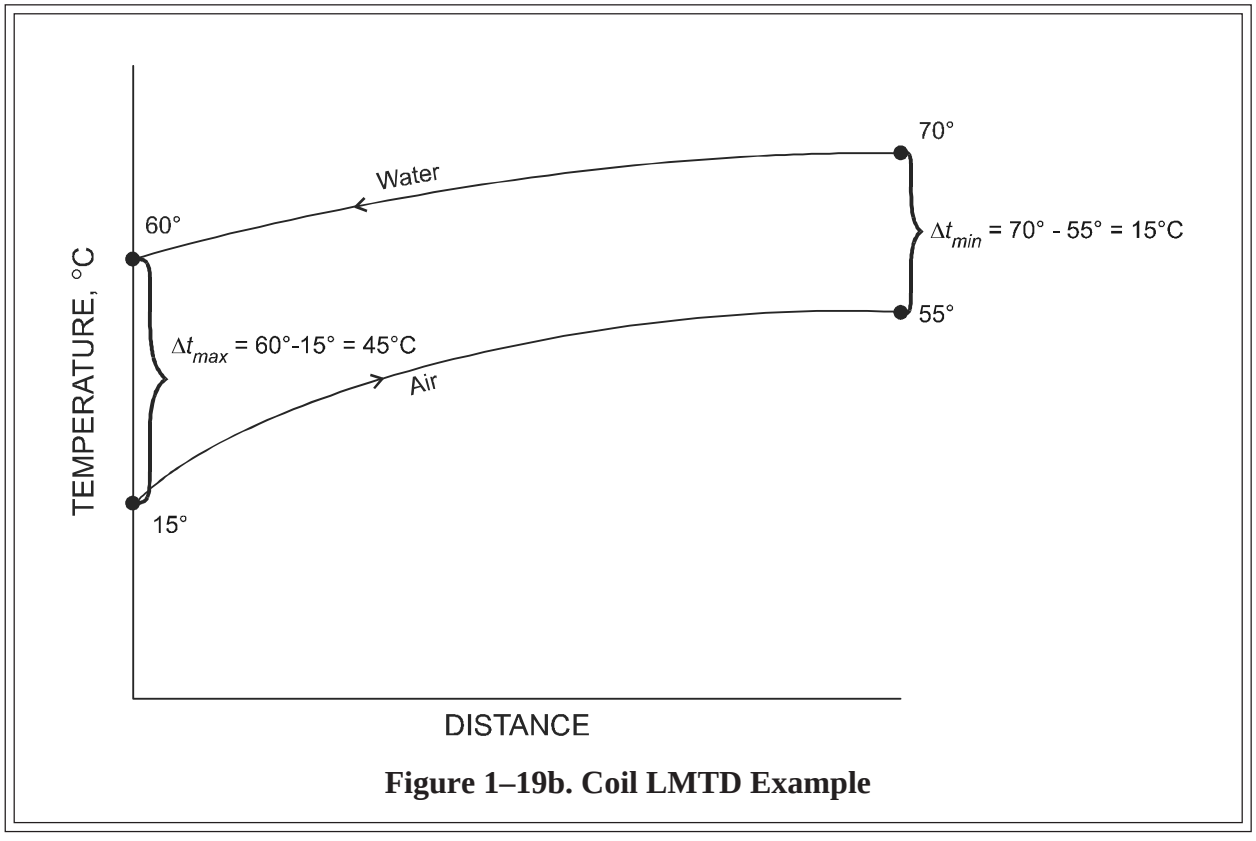


Figure 1–19b. Coil LMTD Example

Latent Cooling and Dehumidification of Air

The quantity of heat removed from the cooled medium (see *Figure 1–20*) when both sensible cooling and dehumidification are present is expressed by:

$$q_t = W\Delta h \qquad 1–5$$

where:

q_t = total heat transfer rate, kW
W = mass flow rate of cooled medium, kg/s
Δh = enthalpy difference of entering and leaving conditions of cooled medium, kJ/kg

Expressed for a cooling coil, this equation becomes:

$$q_t = Q_a \rho_a \Delta h \qquad 1–6$$

where:

Q_a = air flow rate, m^3/s
ρ_a = density of air, kg/m^3

For standard air, the density is 1.2 kg/m^3 and the formula reduces to:

$$q_t = 1.2\ Q_a\ \Delta h \qquad 1–7$$

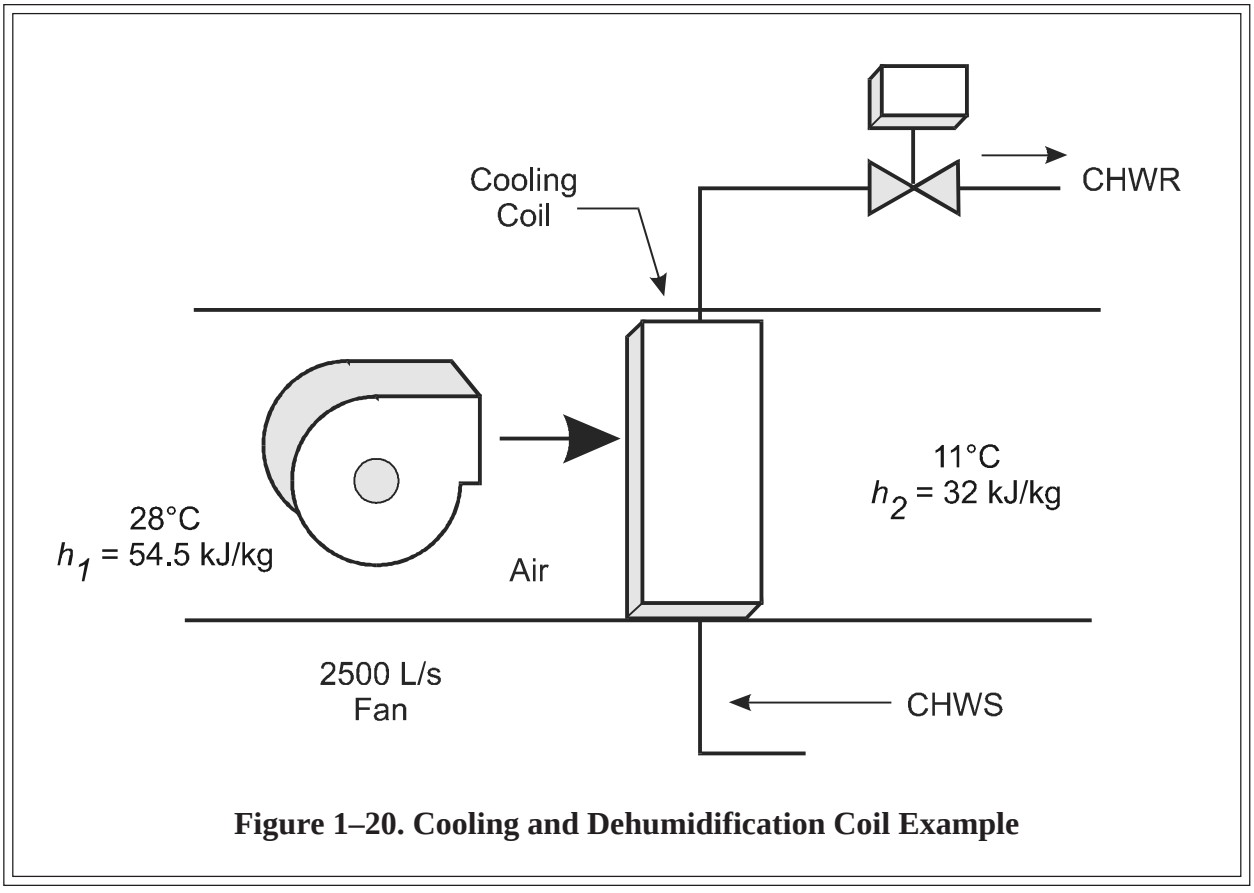


Figure 1–20. Cooling and Dehumidification Coil Example

EXAMPLE 1-3

For the system shown in *Figure 1–20*, determine the heat transfer rate for the sensible cooling/ dehumidification process, assuming entering air is 28°C and enthalpy is 54.5 kJ/kg, and discharge air is 11°C and saturated at enthalpy of 32 kJ/kg:

$q_t = 1.2\ Q_a\ \Delta h$
$= 1.2\ (2.5\ m^3/s)\ (54.5 – 32)\ kJ/kg$
$= 67.5\ kW$

HEAT TRANSFERRED TO OR FROM WATER

The quantity of heat transferred to or from the water is a function of the flow rate, the specific heat and the temperature drop or rise of the water as it passes through the heat exchanger. The heat transferred to or from the water is expressed by:

$$q_w = m\ c_p\ \Delta t \qquad 1–8$$

where:

q_w = heat transfer rate from water, kW
m = mass flow of water, kg/s
c_p = specific heat of water, kJ/kg·K (at constant pressure)
Δt = temperature increase or decrease across unit, °C
(Note: temperature difference °C is often expressed in terms of kelvin, K)

These equations are also used to express the heat carrying capacity of the piping or distribution system of any portion of that system. In this regard, the temperature differential Δt, sometimes called the temperature range, is established or identified. For any flow rate through the piping, q_w is called the heat carrying capacity.

With water systems, it is common to express the flow rate in litres per second (L/s), in which case the equation becomes:

$$q_w = 0.001\ \rho_w\ c_p\ Q_w\ \Delta t \qquad 1–9$$

where:

Q_w = water flow rate, L/s
ρ_w = density of water, kg/m^3

For typical conditions in which density is 1000 kg/m^3 and specific heat is 4.19 kJ/kg·K, the equation becomes:

$$q_w = 4.19\ Q_w\ \Delta t \qquad 1–10$$

The last two equations can be used to express the heat transfer across a single load or source device, or any quantity of such devices connected across a piping system. In the design or diagnosis of a system, the load side may be balanced with the source side by these equations.

Example: Heating Coil

For a single system similar to that shown in *Figure 1–18*, assume the heat transfer rate across the coil is 120 kW and the Δt of the water supplying the coil is 10°C (water and air at standard conditions). Find the water flow rate required for the system:

$$q_w = 4.19\ Q_w \Delta t$$

Solving for Q_w, we get:

$$Q_w = \frac{q_w}{4.19\Delta t}$$

$$Q_w = \frac{120\ \text{kW}}{\left(\frac{4.19\ \text{kJ}}{\text{kg}\cdot\text{K}}\right)(10\ \text{K})}$$

$$Q_w = 2.88\ \text{L/s}$$

Example: Cooling Coil

Assume q_t (cooling coil) = 67 kW and Δt = 7°C:

$$Q_w = \frac{67\ \text{kW}}{\left(\frac{4.19\ \text{kJ}}{\text{kg}\cdot\text{K}}\right)(7\ \text{K})}$$

$$Q_w = 2.3\ \text{L/s}$$

1.4 Load Systems

Load systems are the devices (terminal units) that convey heat from the water for heating or to the water for cooling of the space or process. Most load systems are basically water-to-air finned coil heat exchangers or water-to-water heat exchangers. The specific configuration is usually used to describe the device. Common configurations include:

- Heating load devices: Preheat coils in central air-handling units; heating coils in central air-handling units (see *Figure 1–21*); zone or central reheat coils; finned-tube radiation; baseboard radiation; convectors; unit heaters; fan coil units; water-to-water heat exchangers; radiant heating panels; and snow melting panels.
- Cooling load devices: Coils in central units (see *Figure 1–21*); fan coil units (see *Figure 1–22*); induction unit coils; radiant cooling panels; and water-to-water heat exchangers.

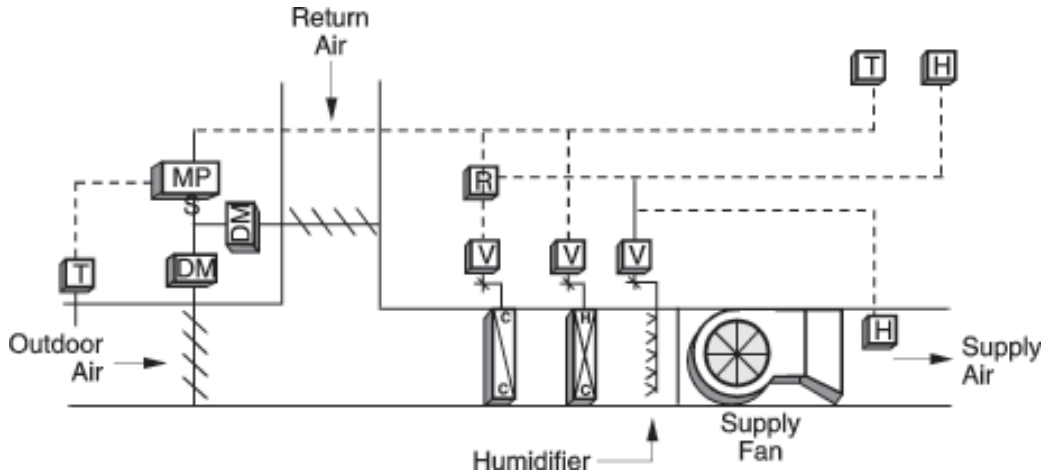


Figure 1–21. Single-Zone Central AHU – Heating and Cooling Coils

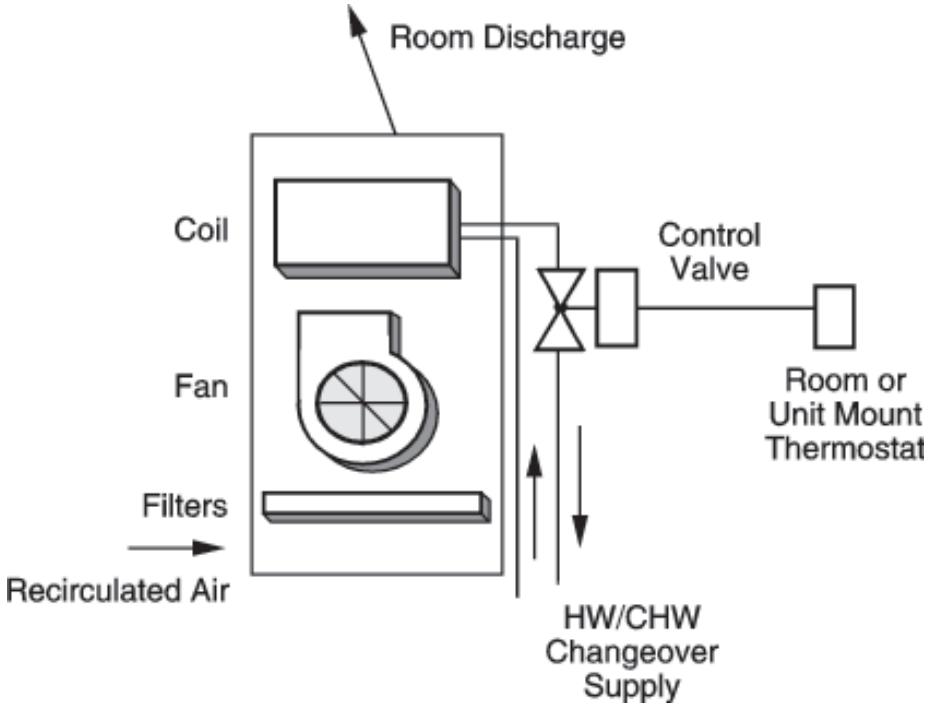


Figure 1–22. Fan Coil Unit

The Next Step

In Chapter 2, you will be introduced to piping system design.

Summary

Chapter 1 covered the following topics:

- What determines the load.
- The difference between closed and open systems.
- Components of a hydronic system.
- Heating versus cooling source devices.
- How systems need to meet part-load conditions.
- Temperature and pressure ranges for low, medium and high temperature water systems.
- Sensible, latent and total heat loads and how they affect design water flow.
- Examples of heating and cooling load devices.
- How load diversity suggests a reduction in total cooling capacity required.

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Skill Development Exercises for Chapter 1

Complete these questions by writing your answers on the worksheets at the back of this book.

1-01. Water systems that convey heat to or from a conditioned space or process with hot or chilled water are frequently called _____ .

1-02. What is the fundamental difference between closed and open types of water systems?

1-03. A cooling tower has at least two points of interface. What are they?

1-04. What is the maximum working pressure for LTW boiler systems?

1-05. What is a CHW system? How is it different from a CW system?

1-06. What are the fundamental components of a closed hydronic system?

1-07. Explain the most common source devices for heating and cooling systems.

1-08. Explain what *load* means.

1-09. What factors influence the heating and cooling load requirements?

1-10. Define sensible heat transfer.

1-11. Name five heating load devices and describe how each is used in system applications.