Answers to the Chapter 1 Exercises

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

Hydronic heating or cooling systems

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

A closed system has only one interface point with a compressible gas (air) or surface. An open system has more than one interface with a compressible gas or surface.

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

- Tower basin
- Discharge pipe or nozzles

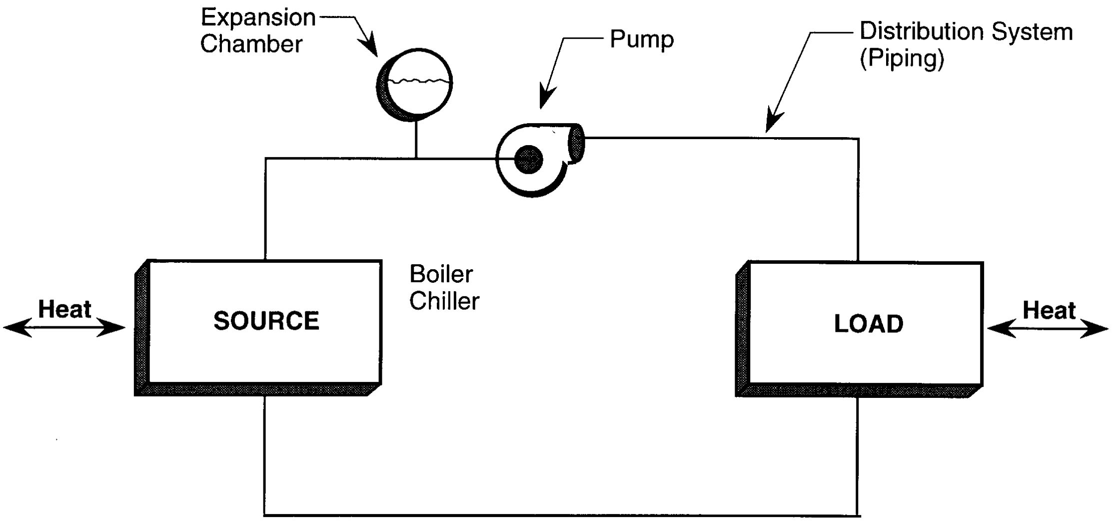
1-04. In accordance with the ASME Boiler Code, what is the maximum working pressure for LTW boiler systems?

- Usual maximum working pressure = 200 kPa
- Maximum allowable working pressure = 1100 kPa

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

CHW stands for Chilled Water system, and CW stands for a Condenser Water system. A CHW system is a hydronic cooling system that works at temperatures in the range of 4°C to 13°C. Brine or antifreeze solutions may have to be used if the temperatures required for an application require the cooling medium to be near freezing. Some ice storage systems circulate water at just above 0°C.

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.

Heating	**Cooling**
Boiler—Hot water	Electric centrifugal chiller
Heat exchanger	Electric compression chiller
• Steam-to-water	Thermal absorption chiller
• Water-to-water	Heat pump evaporation
• Air-to-water	Water-to-water heat exchanger
Solar panels	
Heat recovery/salvage device	

1-08. Explain what *load* means.

Load is the thermodynamic demand (weather, occupants, moisture, equipment) placed on the system by the space or process that is to be conditioned. In heating: heat is delivered by the system to the space or process. In cooling: heat and moisture are removed from the space or process.

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

- Ambient temperatures of the environment (extreme lows and highs)
- Ventilation air flow rates
- Fenestration (window area) – solar heat gain
- Lighting density and type
- Occupancy rates, activity of occupants
- Equipment heat characteristics
- Thermal properties of building shell (walls, windows, doors)

1-10. Define sensible heat transfer.

Sensible heat transfer is any type of heat transfer that produces a change of temperature of the air in that space (without changing moisture content). Heating is the transfer of energy to the air in a space by virtue of a difference in temperature between the source and the air in the space.

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

- Preheat coils in central units – Heating coils used to preheat (>temp) enter air prior to it entering the main heating coils. Improves energy efficiency of the system.
- Heating coils in central units – Primary heating component in the central unit. Used to supply air to system operating temperature.
- Zone or central reheat coils – Used to raise the temperature of supply air to meet load requirements.
- Radiant heating panel – Components that carry heated water and use radiation and convection heat transfer to convey heat to the space.
- Baseboard and finned tube radiation – Components that carry heated water to heat room air by natural convection and radiation.
- Fan coil unit – In an air-water system, the water-to-air heat exchanger that conveys heat or cooling to the air circulated by its fan.
- Convector – A component that conveys heat to the space by the process of convection. As air contacts the heat exchange component (hot water heated), heat is transferred to the air. The warm air rises and cooler air moves in to replace the space vacated by the warm air, creating convective air flow in the conditioned space.
- Water-to-water heat exchangers – Heat exchangers are devices designed to efficiently transfer heat between working fluids in two distinct and separate systems. For example, the exchanger transfers heat from a system containing hot water to a second system containing a glycol/water mixture. The water of each system is in a separate piping system and does not mix.

Answers to the Chapter 2 Exercises

2-01. What causes unequal flow rates in direct return piping arrangements?

- Establish design philosophy and objectives
- Size the piping system
- Determine pressure drops in the system

2-02. What is the most often used equation that relates to pressure drop?

Bernoulli's equation

2-03. Fluids can flow through a pipe under two different conditions. Name them. Explain the differences between these flow conditions.

- Laminar flow
- Turbulent flow

2-04. Explain friction factor.

The friction factor is an empirical factor used to include the effect of friction between the fluid (water) and the pipe walls on pressure drop. It is a function of flow velocity, pipe roughness and Reynolds number.

2-05. In commercial installations, it is suggested that ______% should be added to the friction loss to allow for aging.

Add approximately 15% to account for aging.

2-06. What is the Bernoulli principle?

The Bernoulli principle is a specific statement of the law of conservation of energy that pertains to fluid flow.

2-07. What factors determine pressure drop in piping?

- Pipe diameter, length, fittings
- Flow velocity
- Pipe roughness
- Fluid density, viscosity
- Flow require (laminar, turbulent)
- Reynolds number
- Flow conditions

2-08. What methods allow thermal expansion?

There are two aspects of thermal expansion that must be accounted for in a piping system design: thermal expansion of the working fluid (water); and thermal expansion of the pipe in the system.

- Water expansion (closed system only): This is handled by placing an expansion tank at one point in the system.
- Piping expansion: Allow freedom of movement:
  - Can use mechanical expansion joints
  - Use of offset piping designs
  - Use pipe hangars that allow movement with expansion and contraction of the pipe

2-09. What is the minimum distance upstream and downstream for a water flow measuring device (in pipe diameters)?

The 1995 *ASHRAE Handbook–HVAC Applications* (Chapter 34) recommends a minimum of 15 pipe diameters of straight pipe upstream and 5 pipe diameters downstream for a flow meter or measuring device to ensure accuracy of measurement.

Answers to the Chapter 3 Exercises

3-01. What is the safe working pressure (AS-1432 to 50°C) for each of the following copper pipe diameters:

Nominal Size and Pipe OD	Type	Working Pressure kPa (per *Table 3–4*)
200 mm, D=203	B	720
80 mm, D=76.11	B	1610
100 mm, D=101.48	A	1500
25 mm, D=25.35	B	3680

3-02. List three joining methods used with copper tubing:

- Soldered or brazed socket-end fittings
- Flare fittings
- Compression fittings

3-03. List five methods of joining metal pipe:

- Threading
- Welding
- Flared and compression joints
- Flanges
- Soldering and brazing

Other methods that can be counted as part of the five methods include: reinforced outlet fittings; grooved joint systems; sleeves; and unions.

3-04. Name and briefly describe the two main categories of plastic piping materials, and list at least three of each type of plastic pipe.

Plastic piping materials fall into two main categories: thermoplastic and thermoset. Thermoplastics melt and are formed by extruding or molding. They are usually used without reinforcing filaments. Thermosets are cured and cannot be reformed. They are normally used with glass fiber reinforcing filaments. Plastic piping materials include:

Thermoplastics are:

- PVC — polyvinyl chloride
- CPVC — chlorinated polyvinyl chloride
- PB — polybutylene
- PE — polyethylene
- PP — polypropylene
- ABS — acrylonitrile butadiene styrene
- PVDF — polyvinylidene fluoride

Thermosets are:

- Fiberglass reinforced epoxy resin
- Fiberglass reinforced vinyl ester
- Fiberglass reinforced polyester

3-05. List the AS/NZS-1477 long-term hydrostatic pressure test, allowed values (MPa at 20°C) for each of the following plastic pipe sizes:

PVC Pipe Size	**AS/NZS-1477 Hydrostatic Test Pressure (MPa at 20°C)**
Up to 150 mm	23.6 MPa
175 mm and above	26.0 MPa

3-06. List the five methods of corrosion control:

- Materials selection
- Cathodic protection
- Protective coating
- Environmental treatment
- Design

3-07. List the *k* values for each of the following screwed pipe fittings:

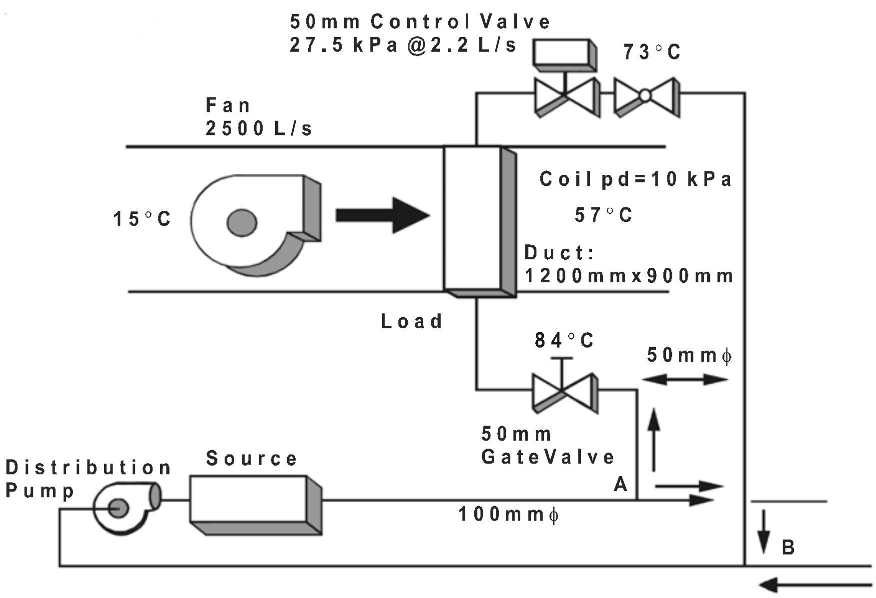
Nominal Pipe Dia. (mm)	**Fitting Type**	***k* Value (per *Table 3–7a*)**
32	90° ell long	0.65
15	Globe valve	14
80	Tee branch	1.2

3-08. What is the function of a backflow-prevention device?

Backflow-prevention devices prevent reverse flow of the city supply in a water system. A vacuum breaker prevents back-siphonage in a nonpressure system, while a backflow preventer prevents backflow in a pressurized system.

3-09. Determine the pipe sizing and total pressure drop for the piping system shown. You are given that the system consists of :

- 1 heating coil rated at 2.2 L/s and 10 kPa drop
- 1 gate valve — 50 mm
- 1 control valve — 50 mm rated at 2.2 L/s at 27.5 kPa pd
- 1 balance valve — 50 mm rated at 2.5 L/s at 7 kPa pd
- 2 tee branches
- 4 elbows
- Total pipe length = 60 m medium steel (screwed pipe)
- Assume water temperature of 82°C and density of 972 kg/m^3



Solution

1. Recalling the guideline of selecting pipe for a friction loss of < 5 *m*/100 m, consult *Figure 2–13b*. For 2.5 L/s, 50 mm pipe has a pressure drop of 250 Pa/m. Checking 40 mm pipe, the pressure drop is 800 Pa/m; 65 mm pipe has a pressure drop of 67 Pa/m. Therefore, the pipe size of 50 mm is selected as meeting the friction loss requirements and economics.

2. Determine the pressure loss due to the 60 m of piping:

pd = 60 m × 250 Pa/m = 15 kPa

adding in the effect of aging, (15% estimated)

pd = 1.15 × 15 kPa = 17.25 kPa

Also, from *Table 2-2*, the value of $V^2/2g$ (velocity head) = 0.065 m

3. Calculate the pressure drop (pd) for the gate valve. Looking at *Table 3–7a*, *k* for a 50 mm screwed gate valve is 0.17.

pd = $k\,(V^2/2g)\rho g$ = (0.17) (0.065)(972)(9.81) = 105.37 Pa = 0.105 kPa

4. Determine the pressure drop due to the 90° elbows:

pd = 4 elbows × $k(V^2/2g)\rho g$

we know:

k = 1 (from *Table 3–7a*)

pd = (4) × (1.0) (0.065)(972)(9.81) = 2479 Pa = 2.479 kPa

5. Similarly, the pressure drop for the tee joints is:

pd = 2 tee branches × $k(V^2/2g)\rho g$

k = 1.4

pd = (2) × (1.4) (0.065)(972)(9.81) = 1735 Pa = 1.735 kPa

6. The total pressure drop is the sum of all component contributions:

Total pd = coil + pipe + balance valve + control valve + gate valve + tee branches + elbows

= (10 kPa) + 17.25 + 7 + 27.5 + 0.105 + 1.735 + 2.479

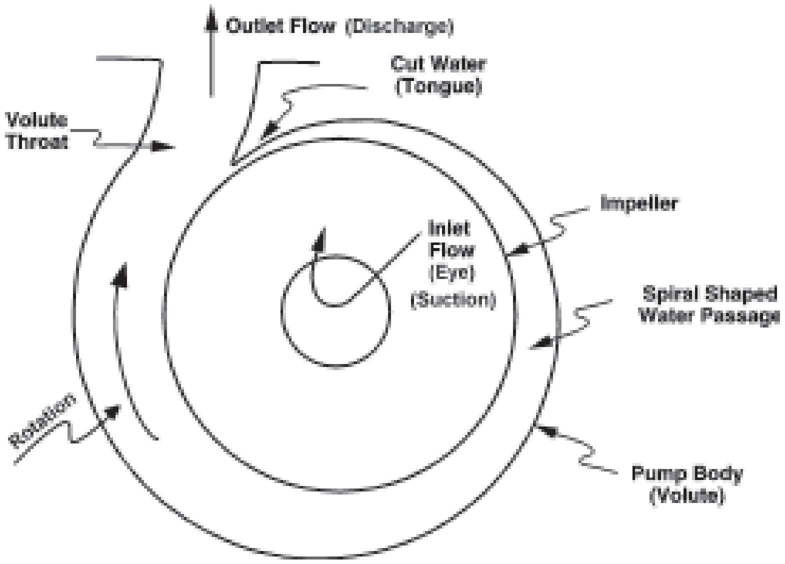
Total pd = 66 kPa, for flow of 2.2 L/s

Answers to the Chapter 4 Exercises

4-01. List three factors that influence the type of pump selected for a particular application.

- Total system pressure (kPa)
- Flow capacity (L/s)
- Piping arrangement (physical size, style)
- Pressure-capacity characteristic curve

4-02. Label the components of the centrifugal pump shown below. Describe the function of each component.

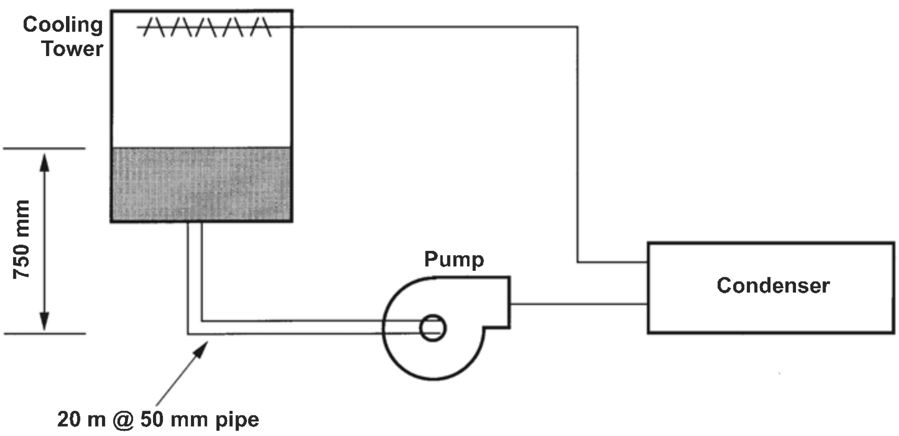


- Volute throat. The passage area of the water path leaving the pump body and entering the discharge nozzle diameter in the discharge flange. The kinetic energy is converted into pressure immediately after the volute throat.
- Cut water. The diameter machined in the pump volute body to provide a minimum gap between the impeller outer diameter and the volute lip to prevent noise, pulsation and vibration.
- Impeller. Rotation by the pump motor results in two forces on the liquid particles (outward, or normal, force and tangential, or tip, force) to increase the liquid velocity through the pump.
- Water passage. Designed with an increasing flow area to accommodate the increased flow through the pump body or volute as it flows from the suction inlet to the discharge outlet
- Pump body or volute. Provides for the conversion of the kinetic energy acting on the fluid into a resulting pressure

4-03. The suction flange gauge of a pump reads 70 kPa. If the temperature of water being pumped is 95°C and the atmospheric pressure is 101.325 kPa, what is the available NPS? At what temperature will the pump cavitate? (Water at 95°C vaporizes at 84.6 kPa abs, per the 1997 *Handbook–Fundamentals*, Table 3, p. 6.7).

Absolute pressure is 70 kPa + 101.325 kPa = 171.325 kPa abs. According to Table 3, water at 95°C vaporizes at 84.6 kPa abs, or 84.6 -101.325 = -16.725 kPa gauge.The NPS (available) in the example = 171.325 kPa abs; the NPS (required) = -16.725 kPa gauge, or 84.6 kPa abs. According to Table 3, water at 115°C vaporizes at 169.19 kPa abs, or 169.19 - 101.325 = 67.865 kPa; therefore, the water will form vapor near 115°C (assuming the gauge reading is correct and represents the inlet condition).

4-04. What is the net positive suction pressure on the inlet to a 1.5 kW pump rated at 9 L/s at 100 kPa for a cooling tower application (see diagram below)? The centerline of a pump inlet is to be 750 mm below the tower sump water surface; assume tower water at 40°C and piping equivalent to 20 m of 50 mm pipe on pump suction. Assume atmospheric pressure is 101.325 kPa abs; assume friction pressure in 50 mm pipe is 62.6 kPa (according to *Table 2-2*, 9 L/s flow in 50 mm pipe yields 3129 Pa/m of pipe: $20 \times 3.129 = 62.6$ kPa) and vapor pressure of water at 40°C is 7.383 kPa abs (per Table 3, above). Pump curve shows 30 kPa NPSR.



Assuming a density of 1000 kg/m³ static pressure above the pump:

$$
\begin{aligned}
p_z &= \rho g h = 1000 \times 9.81 \times 0.75 \\
&= 7357.5 \text{ Pa} \\
&= 7.358 \text{ kPa}
\end{aligned}
$$

Using the formula NPSA = $p_p + p_z - p_{vpa} - p_f$.

NPSA = 101.325 + 7.358 – 7.383 – 62.6 = 38.7 kPa

The calculation shows that the installation will have 38.7 – 30 = 8.7 kPa greater pressure than the pump requirement.

4-05. What is radial thrust?

Radial thrust is a force resultant acting on the impeller due to non-uniform pressure distribution around the impeller. In the extreme, radial forces can cause shaft deflection and possible failure.

4-06. Explain what pump cavitation is and how it can be avoided.

Cavitation is the formation of vapor pockets caused when the absolute pressure on the liquid at the suction nozzle approaches the vapor pressure of the liquid. The collapse of the vapor pockets is noisy and destructive to the impeller. It is avoided by operating the pump with a pressure sufficiently greater than the vapor pressure to prevent vapor pocket formation.

4-07. Write the NPSA formula for a proposed design, and explain what each variable represents.

$$\text{NPSA} = p_p + p_z - p_{vpa} - p_f$$

where:

p_p = absolute pressure on surface of liquid where pump takes suction, Pa
p_z = static pressure of liquid above pump centerline, Pa
p_{vpa} = absolute vapor pressure of liquid at pumping temperature, Pa
p_z = friction losses in suction piping, Pa

4-08. Write the pump affinity laws and explain how they are applied:

	Speed Change	**Diameter Change**
Flow:	$Q_2 = Q_1\left(\dfrac{N_2}{N_1}\right)$	$Q_2 = Q_1\left(\dfrac{D_2}{D_1}\right)$
Pressure:	$p_2 = p_1\left(\dfrac{N_2}{N_1}\right)^2$	$p_2 = p_1\left(\dfrac{D_2}{D_1}\right)^2$
Power:	$P_2 = P_1\left(\dfrac{N_2}{N_1}\right)^3$	$P_2 = P_1\left(\dfrac{D_2}{D_1}\right)^3$

Knowing the design flow (pressure or power) at a given speed, the performance in flow (pressure or power) can be modified to a new requirement by changing speed or impeller diameter according to the affinity laws and assuming a given system curve.

4-09. Explain how to determine the input power for a centrifugal pump.

$$P_W = \frac{(\text{kg liquid pumped/sec}) \times \text{Pressure increase}\,(\text{Pa})}{\text{Liquid density}\,\left(\text{kg/m}^3\right)}$$

or

$$P_W = \frac{\text{Flow}\,(\text{L/s}) \times \text{Pressure}\,(\text{kPa}) \times \text{Density}\,\left(\text{kg/m}^3\right)}{1000}$$

4-10. How does the capacity of a centrifugal pump change?

The capacity of a pump changes with speed and impeller diameter.

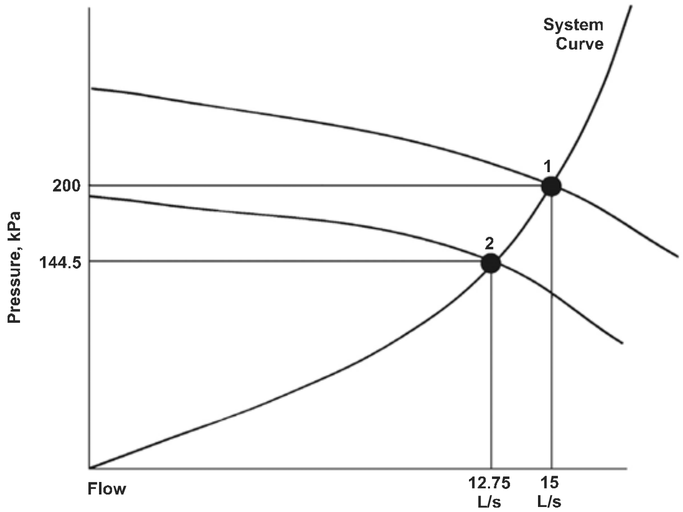
4-11. Name six types of centrifugal pumps and their mounting arrangements.

- Circulator pump — piping supported
- Close-coupled end-suction pump — base mounted
- End-suction pump — motor frame mounted
- Horizontal split case pump — base mounted
- Vertical inline pump — piping supports pump
- Vertical turbine pump — wet sump, floor mounted

4-12. A pump is rated at 15 L/s at 200 kPa of pressure. What are the flow and pressure if the impeller size is changed to 85% of its original diameter? Assume there is no static pressure.

$$Q_2 = Q_1\left(\frac{D_2}{D_1}\right) = (15\ \text{L/s})(0.85) = 12.75\ \text{L/s}$$

$$p_2 = p_1\left(\frac{D_2}{D_1}\right)^2 = (200\ \text{kPa})(0.85)^2 = 144.5\ \text{kPa}$$



Point 2 lies on the same system curve as Point 1

Answers to the Chapter 5 Exercises

5-01. A typical fan coil terminal requires 0.25 L/s. What valve K_v should be selected if a control valve is specified for a 30 kPa drop?

$$Q = \frac{K_v}{36}\sqrt{\Delta p} \quad \therefore \quad K_v = \frac{36Q}{\sqrt{\Delta p}}$$

where:

Δp = 30 kPa

Q = 0.25 L/s

$$K_v = \frac{36 \times 0.25}{\sqrt{30}} = 1.64$$

5-02. What piping components should be specified at the terminal?

Service valve, strainer, two-way control valve, balancing and service valve.

5-03. What type of control action should be considered to reduce discharge temperature cycle?

Proportional control or proportional-integral control.

5-04. A control valve is to be selected for a 3 L/s terminal coil; coil drop is 55 kPa. Select the correct size of control valve if the valve is specified for 50% of the coil drop, and the typical valve sizes and K_v (K_v is in parentheses) available are:

- 15 mm (2.2); 20 mm (5); 25 mm (8.7)
- 32 mm (14); 40 mm (18); 50 mm (26)

Q = 3 L/s

$$\Delta p_{valve} = 50\%\ \Delta p_{coil} = 0.5 \times 55 = 27.5\ \text{kPa}$$

since,

$$K_v = \frac{36Q}{\sqrt{\Delta p}} = \frac{36 \times 3}{\sqrt{27.5}} = 20.6$$

Select a 40 mm valve with K_v > 18; a 50 mm valve would be oversized.

5-05. What control valve flow characteristic should be specified for proportional control of a hot water heating control?

Specify an equal percentage characteristic to linearize heat output versus valve position.

5-06. An on-off thermostat controls a cabinet heater in a hallway. What valve flow characteristic should be specified?

Specify a quick-opening valve for on-off control.

5-07. A three-way valve is to be applied to a refrigeration condenser and cooling tower to maintain a 35°C condensing temperature. What type of three-way valve arrangement should be applied?

Specify a diverting valve, either three-way diverting body or a pair of linked two-way butterfly valves.

5-08. It is desirable to control flow in a chilled water coil down to a minimum of 5% of design flow before close-off. In addition to proper valve sizing for design flow capacity and proportional control, what else should be specified?

Specify valve rangeability for 20:1 ratio:

$$\text{Valve rangeability} = \frac{\text{Max. flow}}{\text{Min. flow}} = \frac{100\%}{5\%} = 20$$

5-09. What should be specified in the bypass circuit of a three-way valve?

A balancing valve, adjusted to equal coil flow with a control valve at full bypass.

5-10. What type of control method varies air flow through a terminal coil?

Face-bypass damper control.

5-11. Explain the difference between primary and secondary pumping systems.

The primary system provides flow through the main supply and return lines. The secondary pumping system connects to the main supply and return piping, and independently handles the flow requirements for a secondary circuit that is connected to the main circuit with a bridge arrangement.

5-12. Define valve authority, rangeability and selection.

$$\text{Authority} = \frac{\text{Valve pressure drop}}{\text{System pressure drop}} \qquad \text{Rangeability} = \frac{\text{Maximum flow}}{\text{Minimum flow}}$$

Selection is matching the valve characteristics and function to the performance requirements of the application.

5-13. How is terminal control valve size selected?

Selecting valve $K_v = \frac{36 \times \text{L/s}\,(\text{design flow})}{\sqrt{\text{kPa (pressure drop)}}}$

5-14. What are the three types of terminal control action?

- Water and air temperature
- Pressure drop
- Water and air flow