CAE 464/517 HVAC Systems Design

Spring 2023

April 06, 2023

Hydronic systems: Intro to hydronic systems and pipe design

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Dr. Mohammad Heidarinejad, Ph.D., P.E.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
muh182@iit.edu

ANNOUNCEMENTS

Announcements

- Do not forget about our Alumni Panel Event:

Alumni Panel Event

ASHRAE
Illinois Institute of Technology
Student Branch

Communicate with guests who were IIT alumni and previous ASHRAE IIT Student Branch!

SPEAKERs

ESD — Practice Leader **Saagar Patel**

Blinderman — Assistant Project Manager **Erica Acton**

FANNING HOWEY — Mechanical Designer **Jacob Sorenson**

CEPRO.inc — Critical Environments Professionals — Account Engineer **Ibrane R. Jaurez**

TOPICs

- ✔ Introducing each company
- ✔ Experiences
- ✔ Careers
- ✔ Q&A

WHEN

April 6th, 2023
12:40 pm – 1:40 pm

WHERE

Perlstein Hall, PH 131

For more information, feel free to contact ASHRAE official email
ashrae_iit@iit.edu

Lunch will be provided

Interested in Joining

Announcements

- How is the project Part 2 coming along?

- Revit Training videos are posted on Blackboard:
  - ❑ Any new topic(s)?
  - ❑ Are you using the AutoDesk Construction Cloud (BIM 360)?

Announcements

- The Midterm Exam 2 is graded, and the solution is posted.

Announcements

- Assignment 5 will be posted next week:
  - ❑ Remember best of four will be used for grading

RECAP

Recap

- There are two main component types:
  - ❑ Thermal components:
    - Heat source(s)
    - Heat load(s)
    - Expansion tank
  - ❑ Hydraulic components
    - Piping
    - Pump
    - Expansion tank

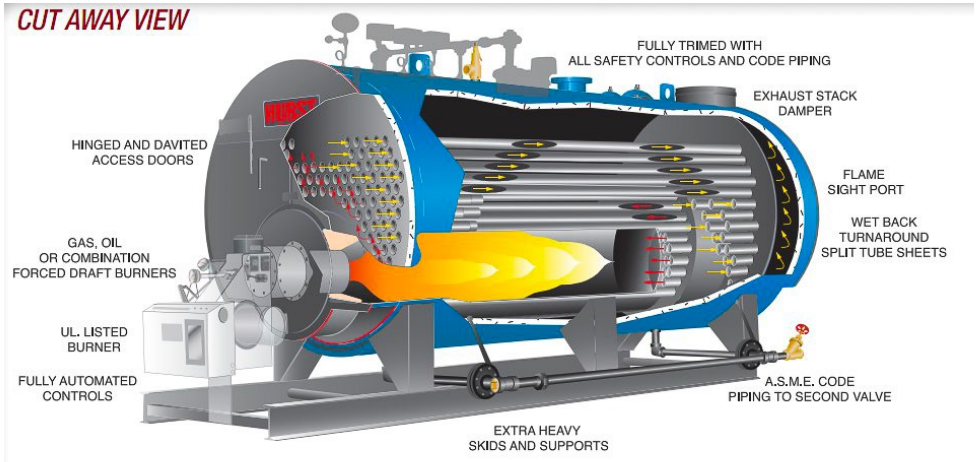
Recap

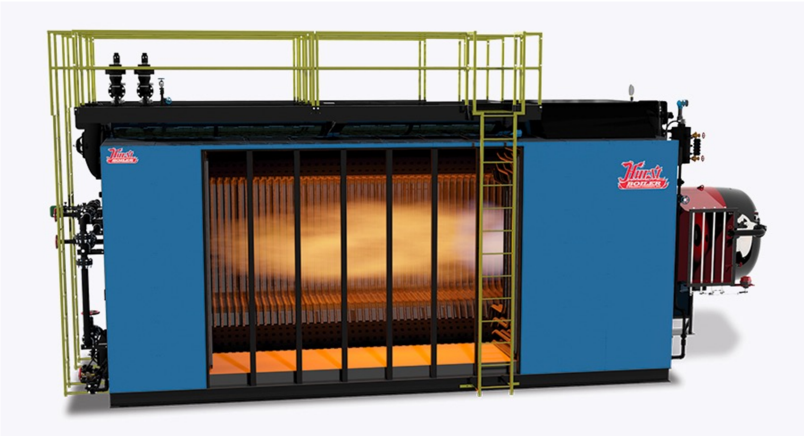
- There are different temperature ranges:
  - ❑ Chilled Water (CHW):
    - Temperature range: 39 ºF to 50 ºF
  - ❑ Condenser Water (CW):
    - Temperature range: 55 ºF to 100 ºF
  - ❑ Hot Water (HW):
    - Temperature range: 100 ºF to 210 ºF
  - ❑ High Temperature Water (HTW):
    - Temperature range: 212 ºF to 455 ºF

Recap

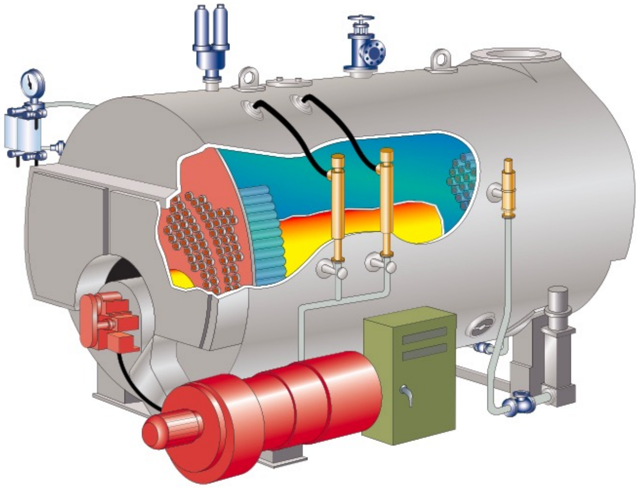
Recap

- Three common boiler types are:
  - ❑ Water tube boilers
  - ❑ Fire tube boiler
  - ❑ Cast iron boilers





Water tube boilers

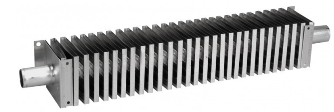


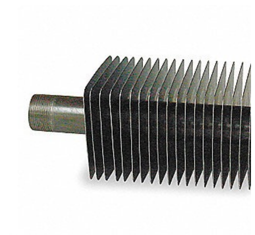
Fire tube boilers

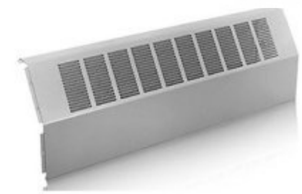
https://s3.amazonaws.com/hurstboiler/documents/HBC-09546-SERIES-600-A-2019.pdf. & https://www.hurstboiler.com/boilers/scotch_marine/series_400#group-4
https://www.spiraxsarco.com/learn-about-steam/the-boiler-house/shell-boilers

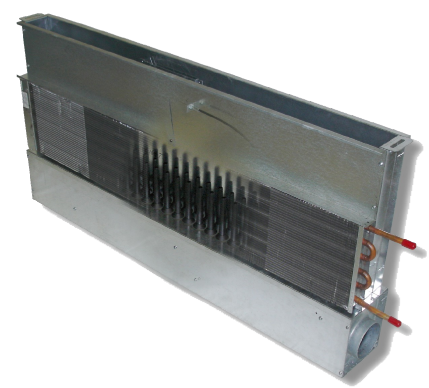
Recap

- Hydronic heating load devices are:
  - ❑ Preheat coils in central units
  - ❑ Convectors
  - ❑ Heating coils in central units
  - ❑ Unit heaters
  - ❑ Zone or central unit reheat coils
  - ❑ Fan-coil units
  - ❑ Induction unit and chilled beam coils
  - ❑ Finned-tube radiation
  - ❑ Baseboard radiation
  - ❑ Water-to-Water heat exchangers
  - ❑ Radiant heating panels









https://www.grainger.com/product/5E307?gclid=Cj0KCQjAn4PkBRCDARIsAGHmH3d3NEOg6gMpb4OY9bsiK3EYG0AXZTTJvzxhmUd1LmgZX_mbJXhaI4oaApISEALw_wcB&cm_mmc=PPC:+Google+PLA&ef_id=Cj0KCQjAn4PkBRCDARIsAGHmH3d3NEOg6gMpb4OY9bsiK3EYG0AXZTTJvzxhmUd1LmgZX_mbJXhaI4oaApISEALw_
https://www.grainger.com/category/hvac-and-refrigeration/heaters/hot-water-heating-and-supplies/hydronic-unit-heaters
https://www.alde.us/our-products/convectors/ & http://usacoil.com/tag/preheat-coils/

HYDRONIC COOLING SYSTEMS

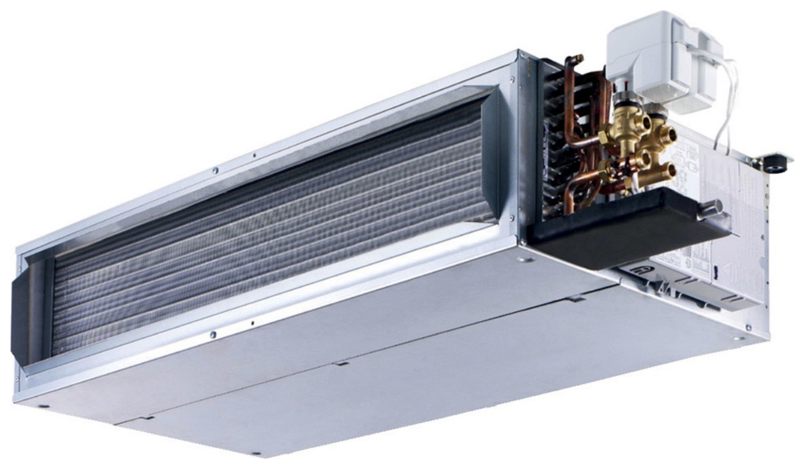
Hydronic Cooling Systems

- Hydronic cooling source devices are:
  - ❑ Electric compression chiller
  - ❑ Thermal absorption chiller
  - ❑ Heat pump evaporator
  - ❑ Air-to-water heat exchanger (heat recovery coil)
  - ❑ Water-to-water heat exchanger

https://instrumentationtools.com/difference-between-hvac-absorption-chillers-and-electric-chillers/

Hydronic Cooling Systems

- Hydronic cooling load devices are:
  - Coils in central units
  - Fan-coil units
  - Induction unit and chilled beam coils
  - Radiant cooling panels
  - Water-to-water heat exchangers



https://www.ahi-carrier.gr/en/product/42nl-42nh-idrofan-hydronic-ducted-fan-coil-units/
http://www.york.com/for-your-workplace/air-systems/fan-and-blower-coil-units/floor-mounted-vertical-fan-coil-units

HYDRONIC SYSTEM DISTRIBUTION CIRCUITS

Hydronic System Distribution Circuits

- The system between the source (boiler or chiller) and the terminal units (or devices) in rooms/zones can have the following configurations:
  - ❑ Series
  - ❑ One pipe main
  - ❑ Two pipe (Direct or reverse return)
  - ❑ Three pipe
  - ❑ Four pipe

https://heatinghelp.com/systems-help-center/a-steam-heating-primer/

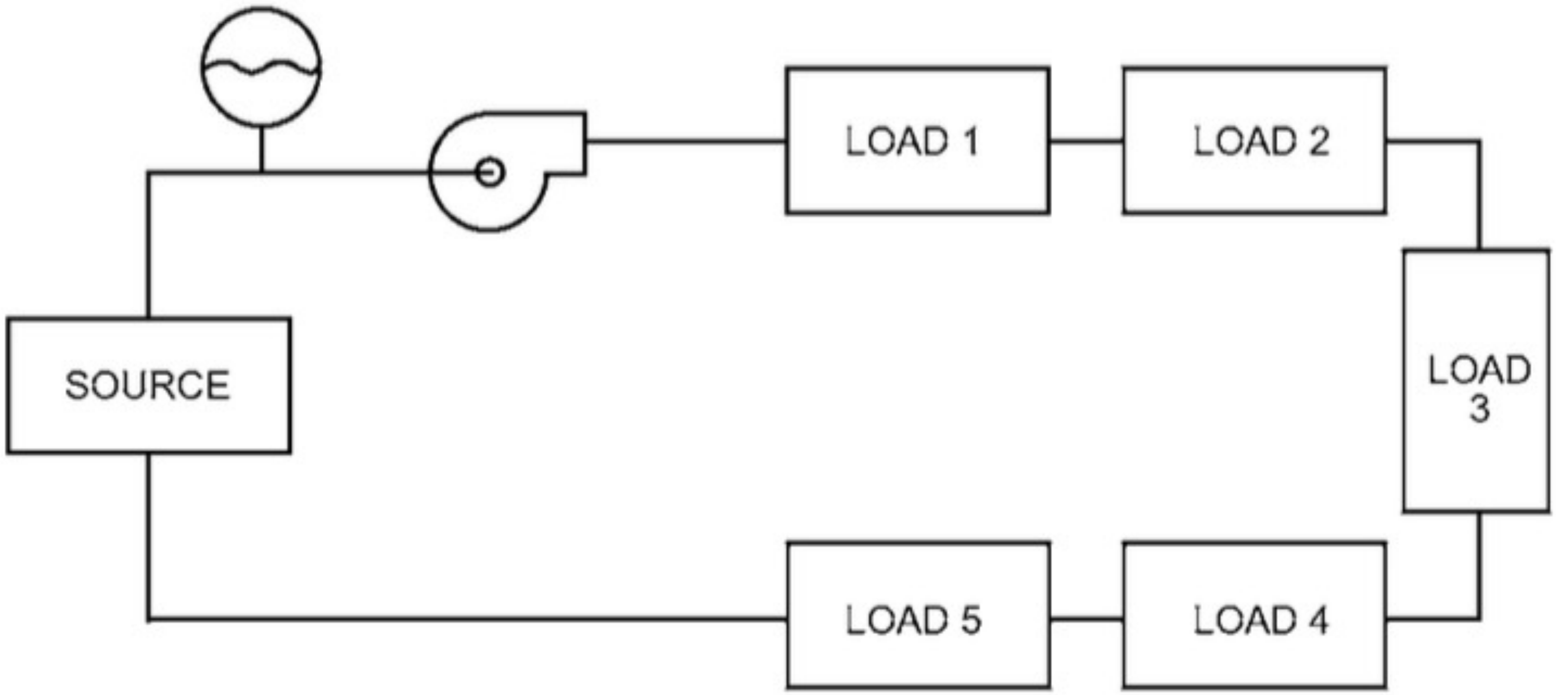
Hydronic System Distribution Circuits

- There are many piping arrangements, particularly for hot water systems

- Closed-loop systems are commonly classified as two-or four-pipe

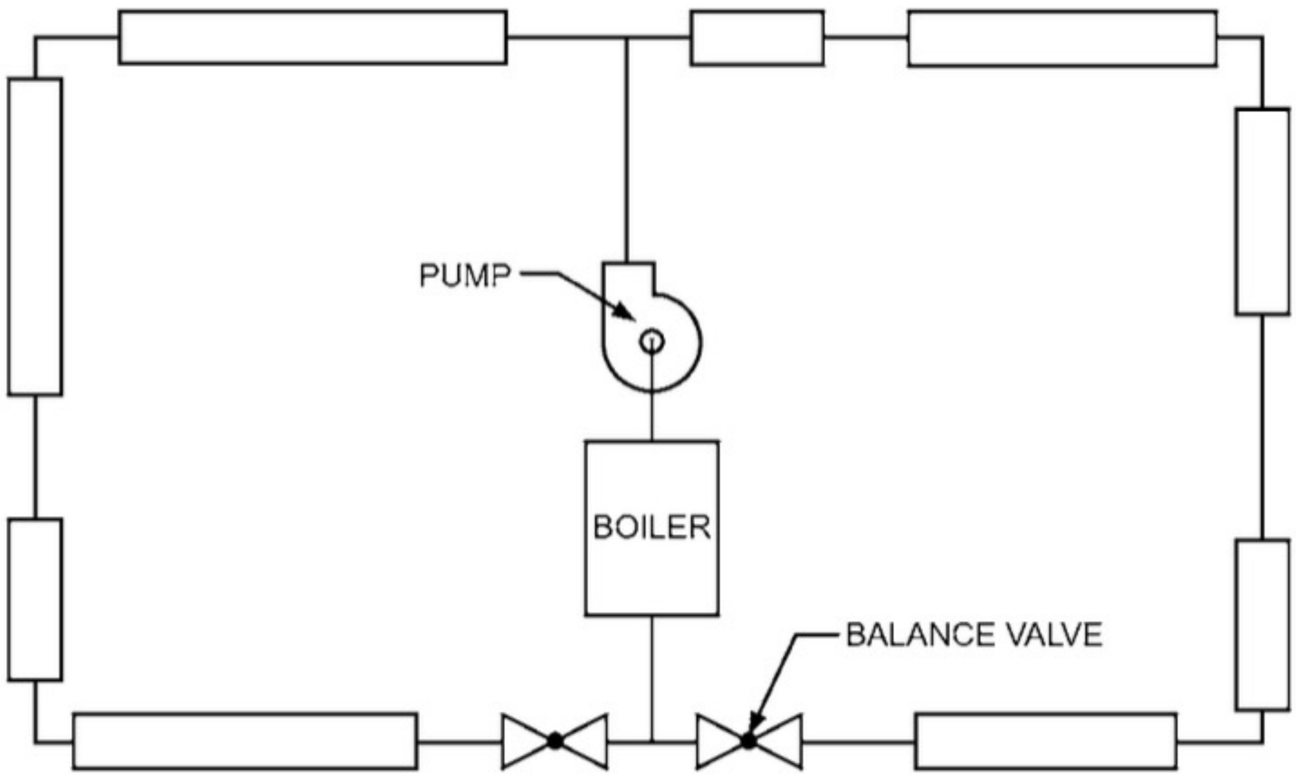
Hydronic System Distribution Circuits

- Simple series circuit is one approach:



Basic of Hydronic Systems

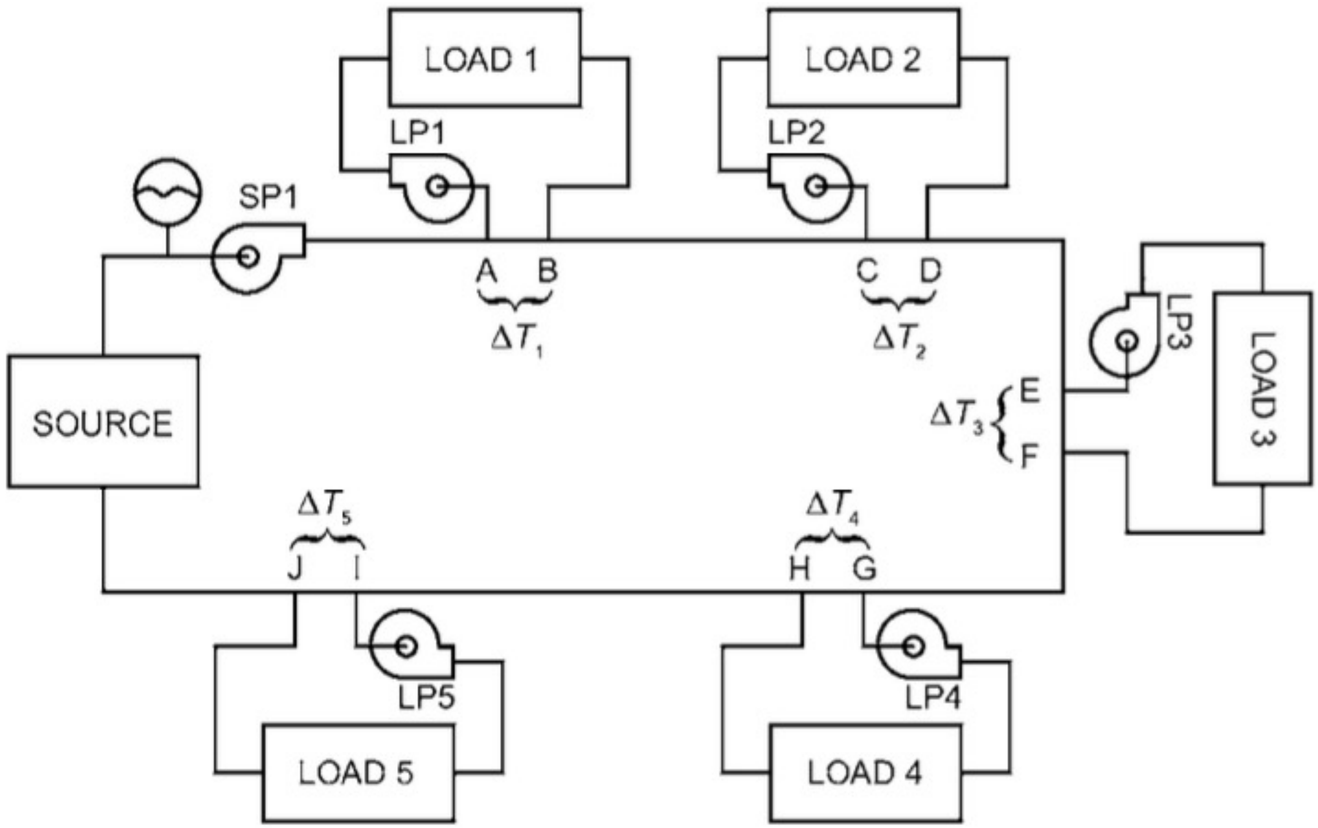
- Another approach is to use a pump in this configuration:



ASHRAE Systems, Chapter 13

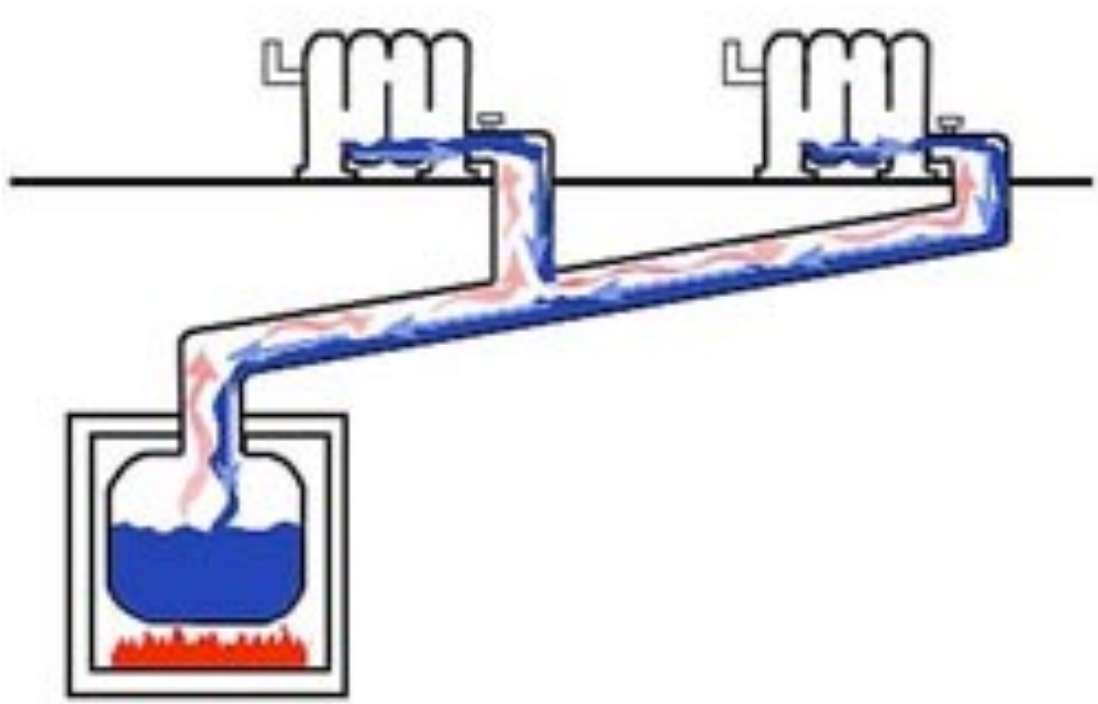
Hydronic System Distribution Circuits

- Another approach is the series circuit with distributed load pumps:



Hydronic System Distribution Circuits

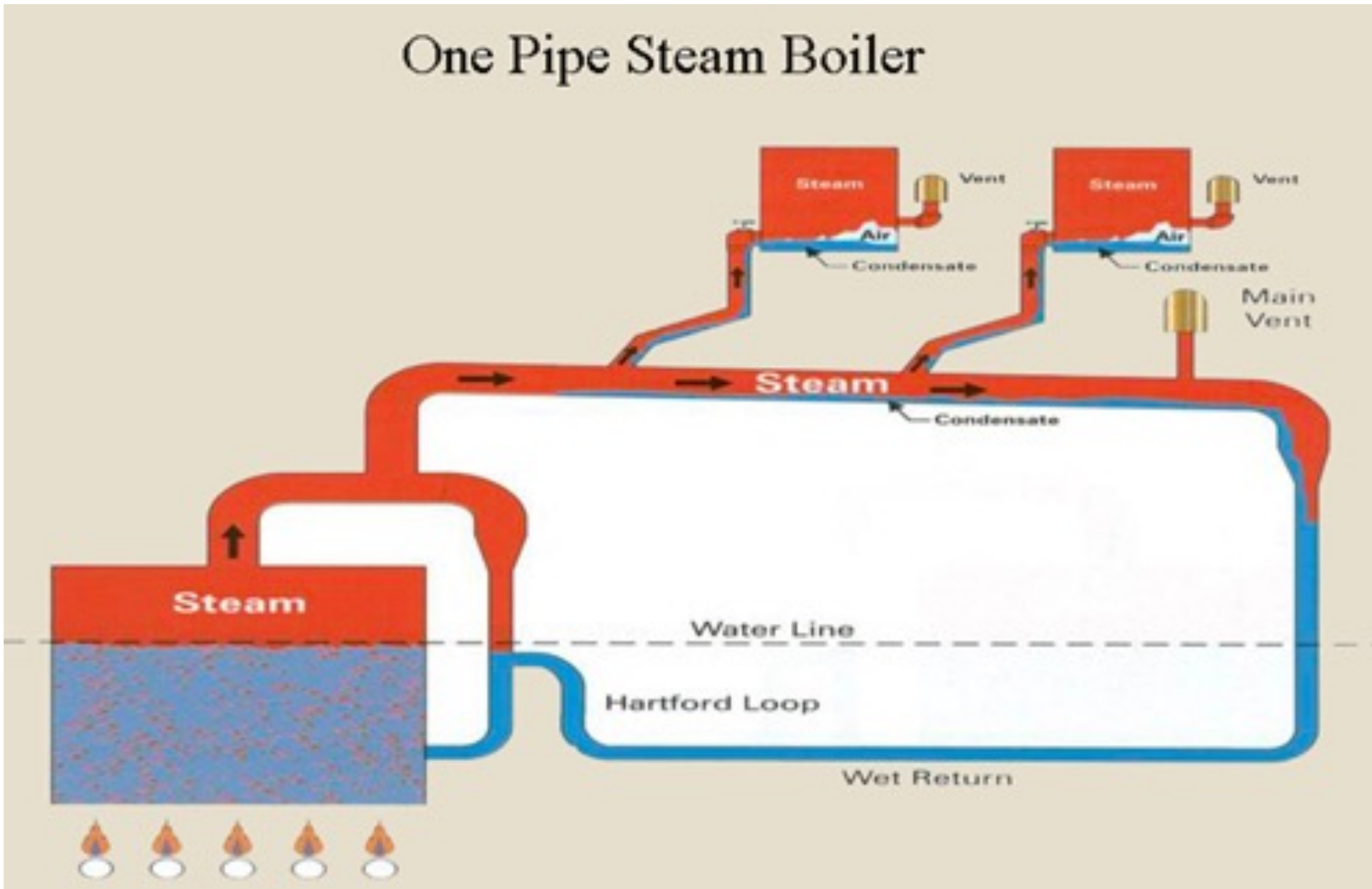
- One-pipe hydronic systems:
  - Have a single pipe that acts as the supply pipe and return pipe for the flow loop
  - Connects one terminal unit to the next terminal unit



http://c03.apogee.net/contentplayer/?coursetype=res&utilityid=mp&id=2379

Hydronic System Distribution Circuits

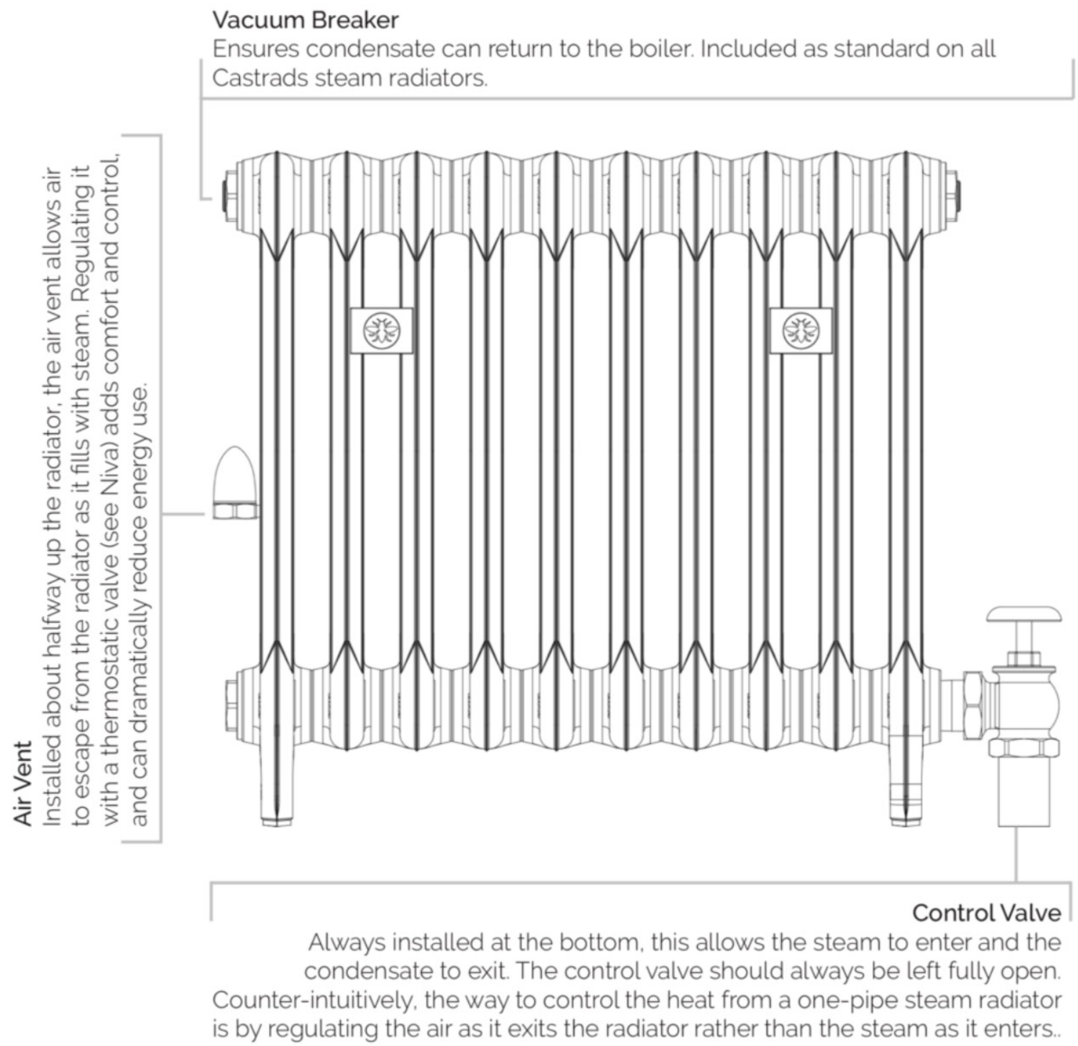
- One-pipe hydronic systems:



https://degraceplumbing.com/steam-boilers-in-nj/

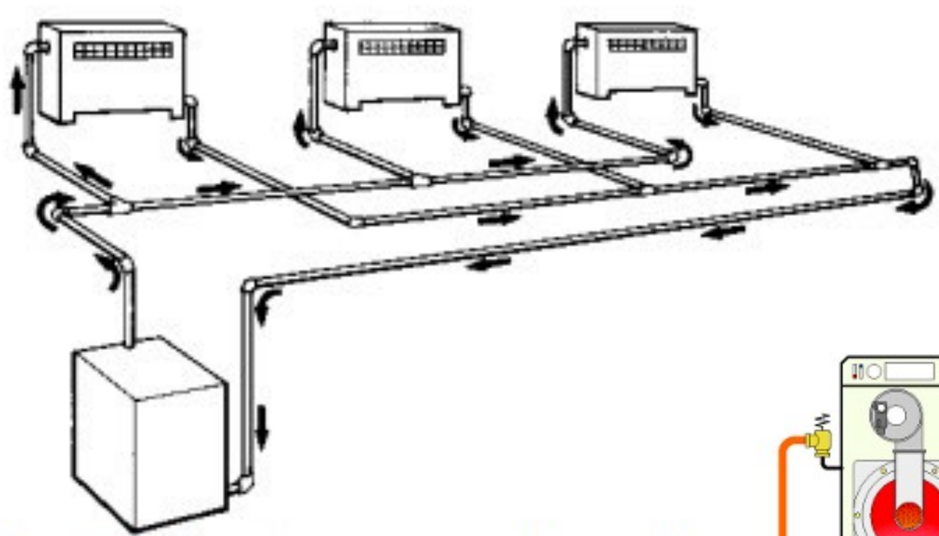
Hydronic System Distribution Circuits

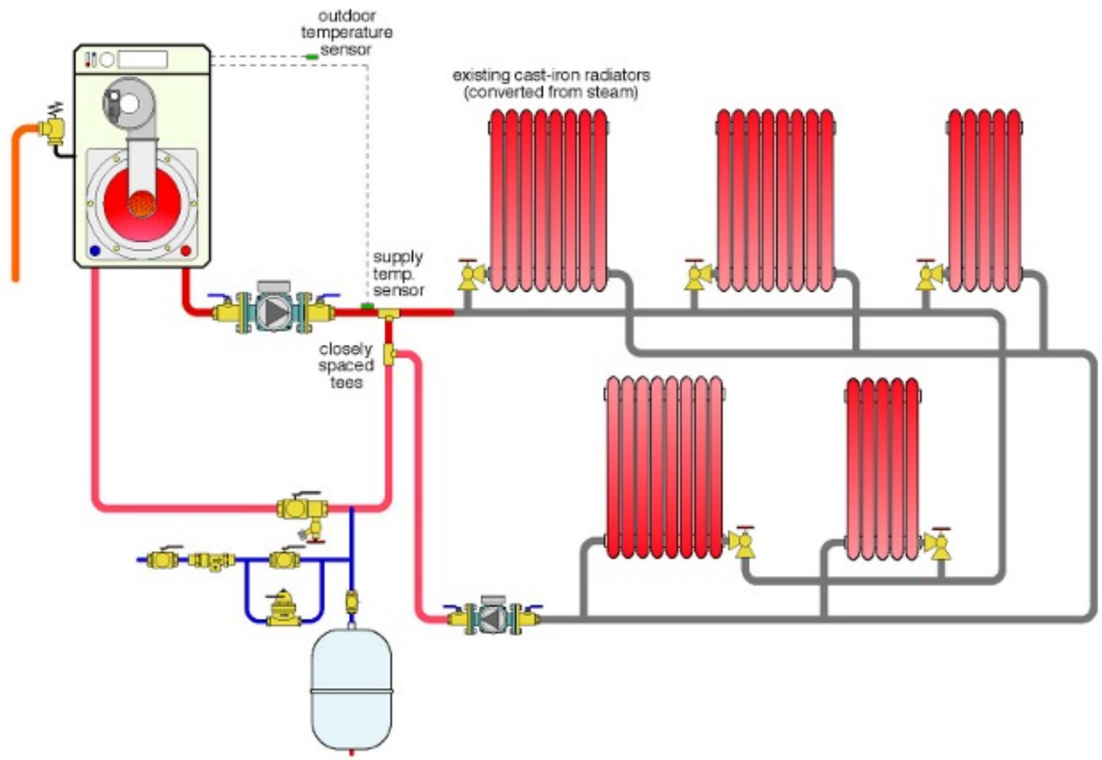
- One-pipe hydronic systems:



Hydronic System Distribution Circuits

- Two-pipe hydronic systems:
  - ❑ Have a separate supply pipe and return pipe at each terminal unit

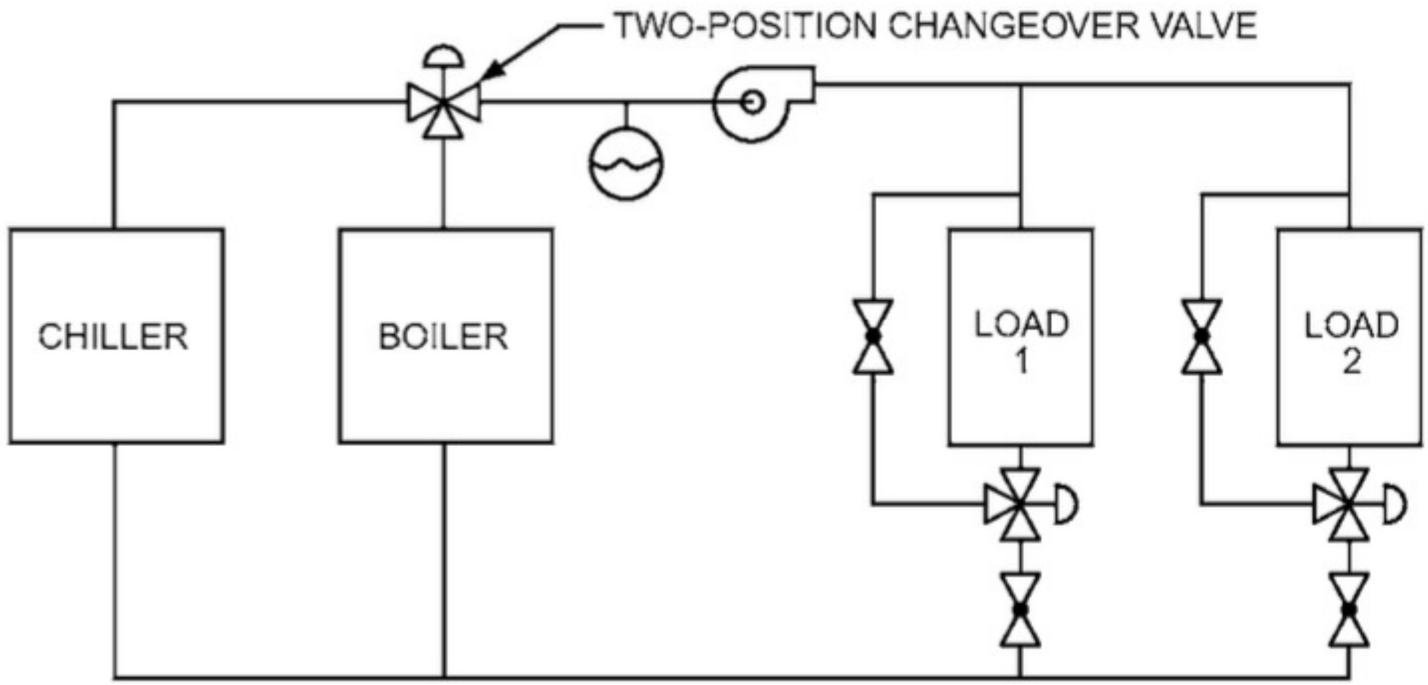




https://www.pmmag.com/articles/99627-iron-meets-microprocessor

Hydronic System Distribution Circuits

- Two-pipe hydronic systems:

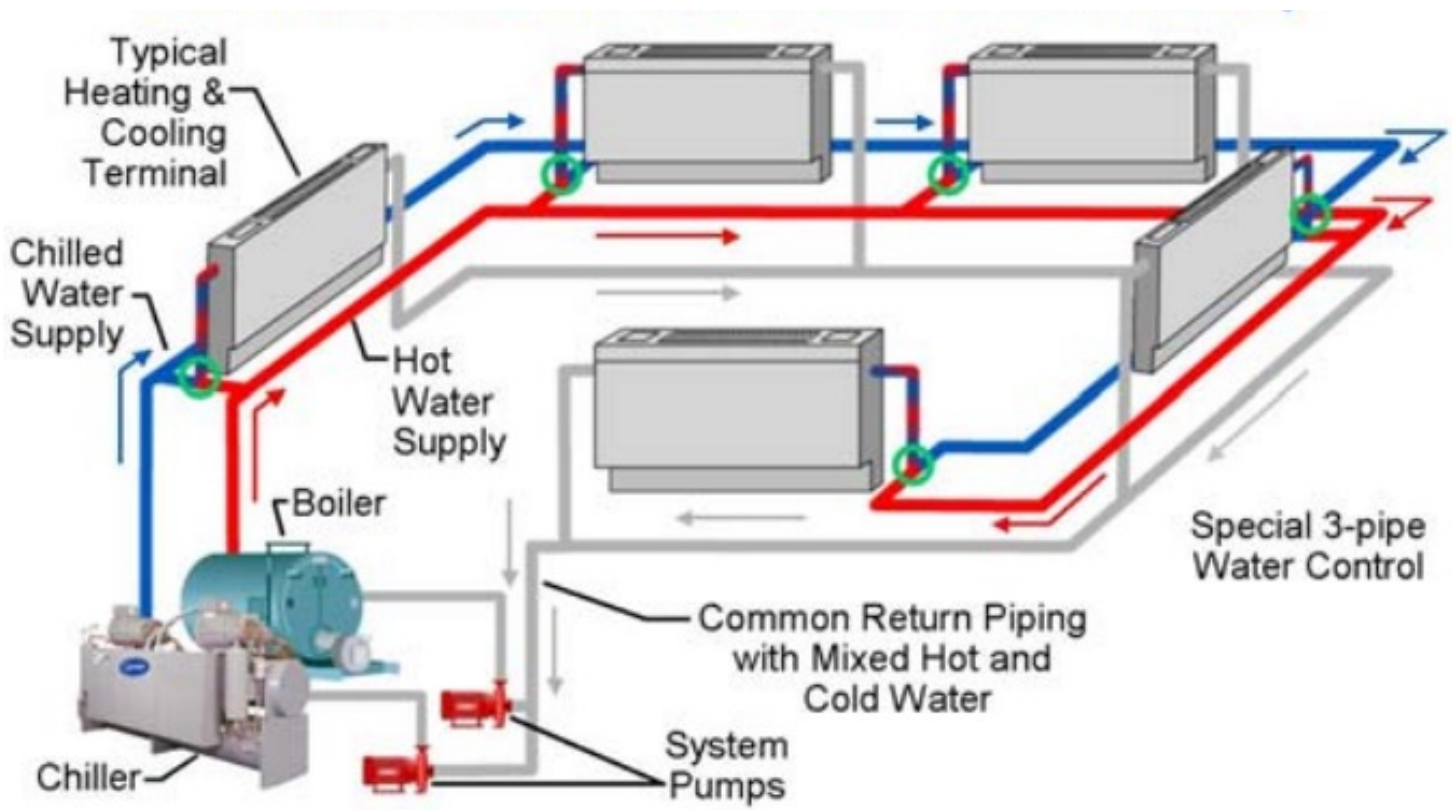


Hydronic System Distribution Circuits

- Two-pipe hydronic systems:

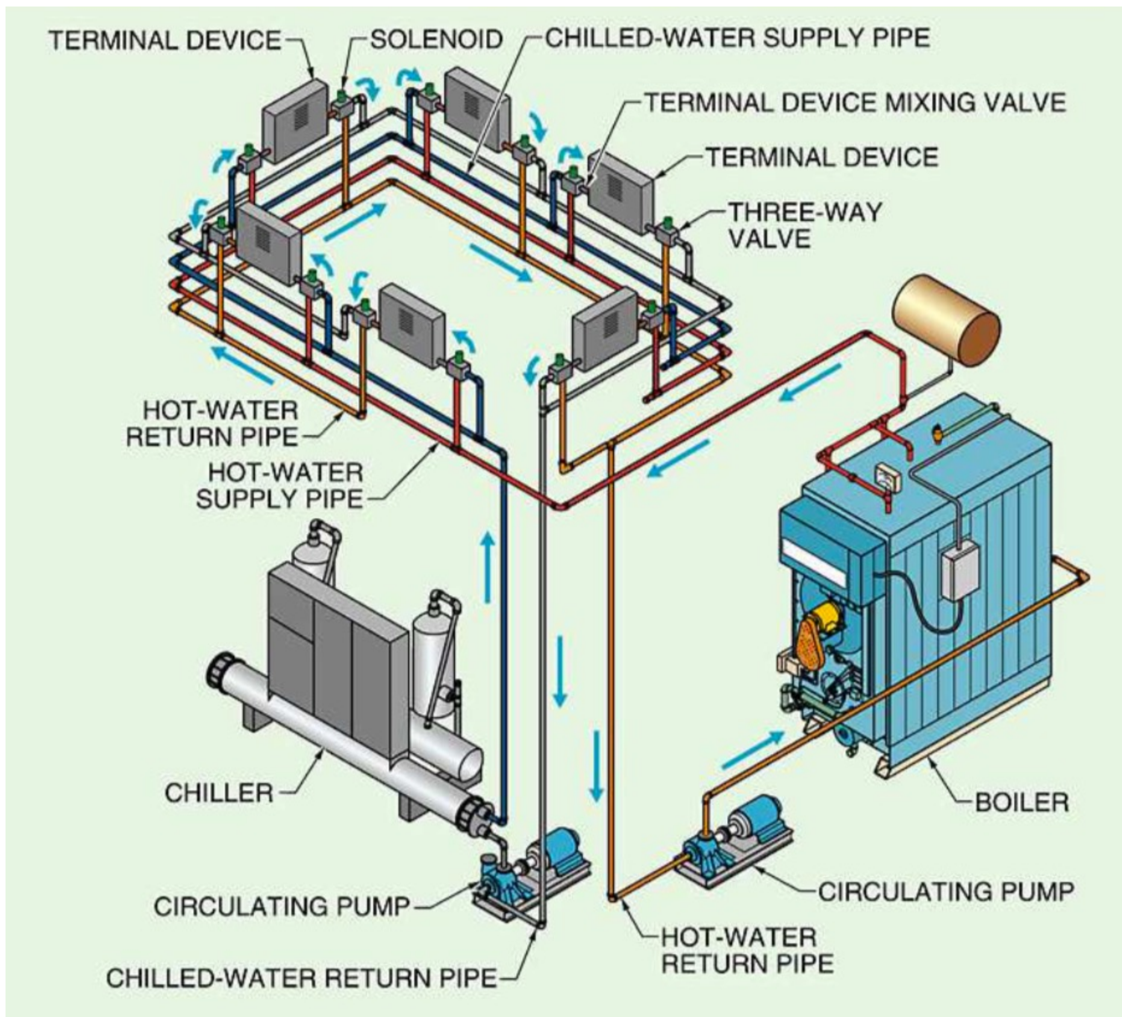
Hydronic System Distribution Circuits

- Three-pipe hydronic systems:
  - ❑ Have a hot-water loop and a cold-water loop so that hot or cold water can be introduced to any terminal unit at any time



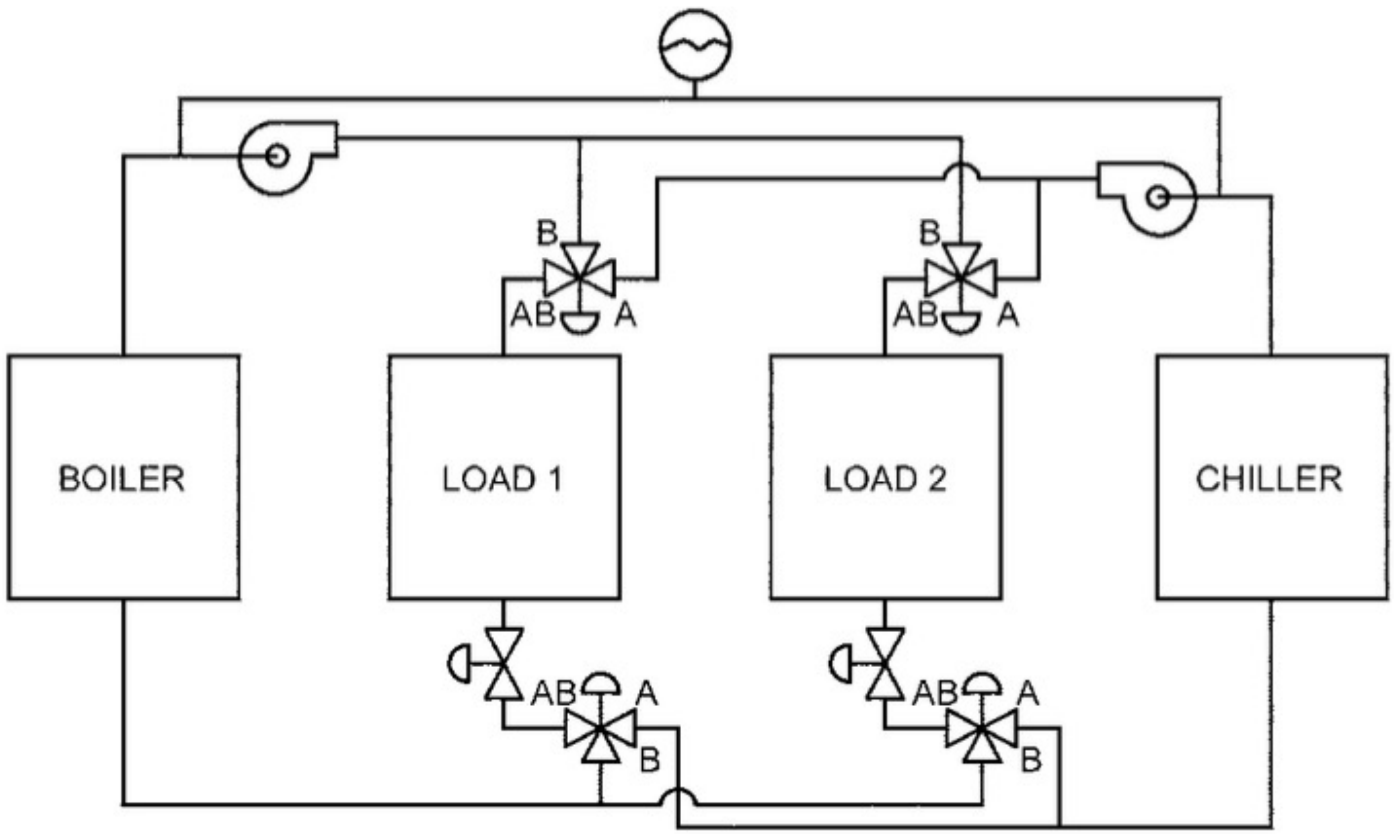
Hydronic System Distribution Circuits

- Four-pipe hydronic system:
  - ❑ Uses supply and return heating piping and supply and return cooling piping



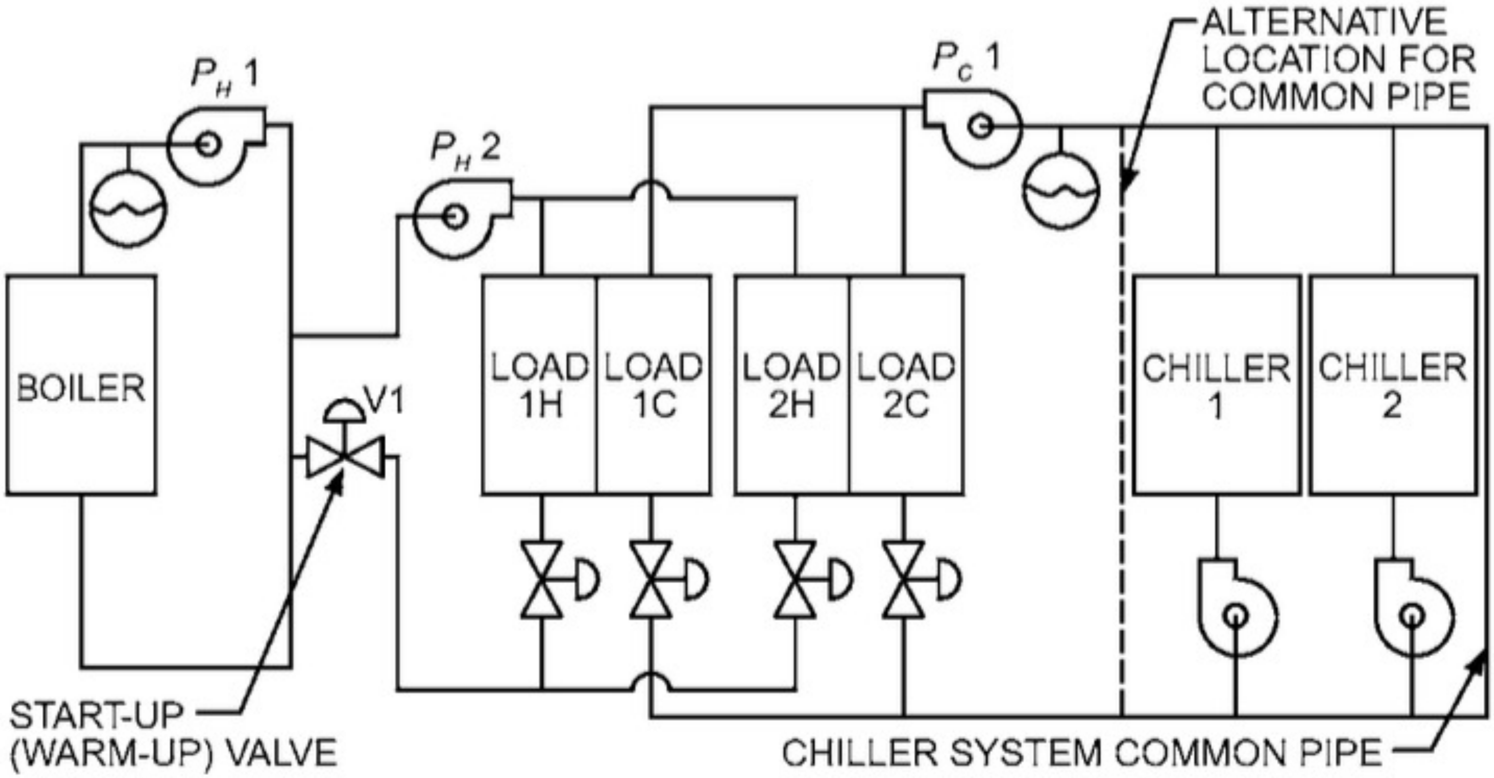
Hydronic System Distribution Circuits

- Four-pipe hydronic system (common loads):

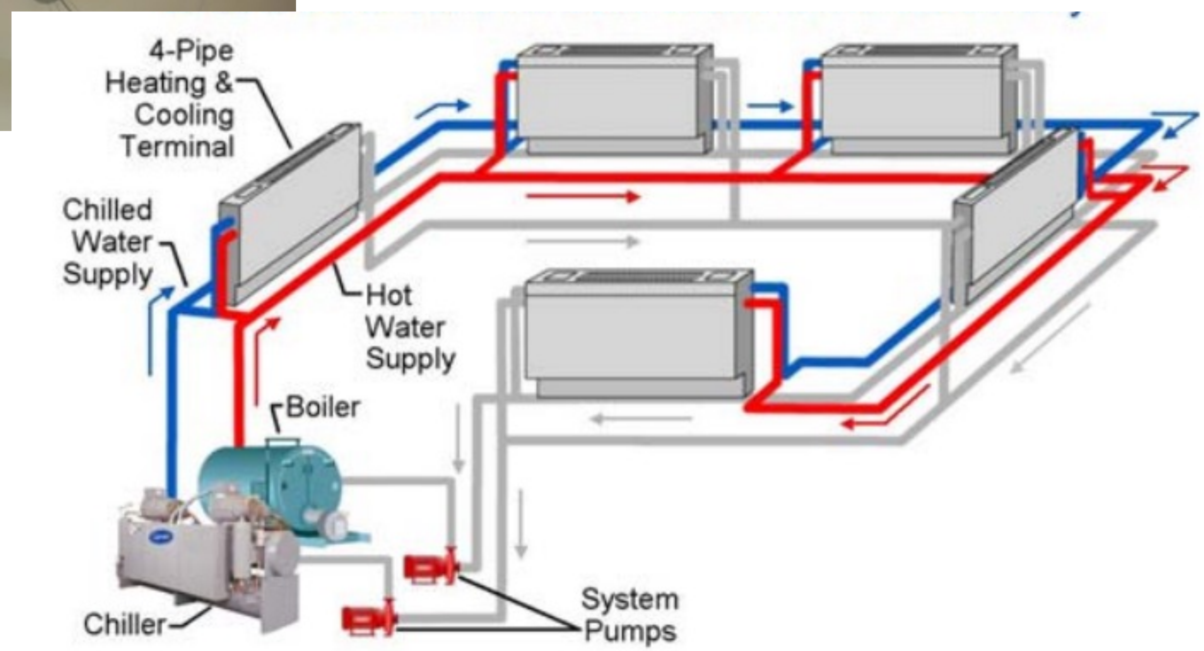


Hydronic System Distribution Circuits

- Four-pipe hydronic system (independent loads):



Hydronic System Distribution Circuits

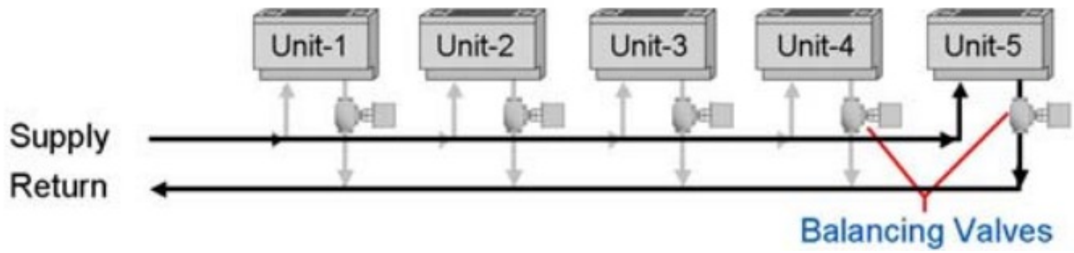


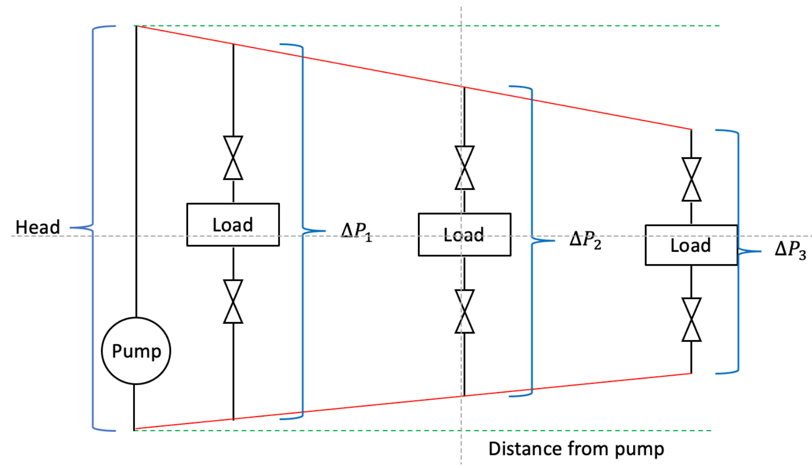
Hydronic System Distribution Circuits

- Four-pipe hydronic system:
  - ❑ Respond quickly to load changes
  - ❑ Simultaneously operation of heating and cooling system
  - ❑ Higher efficiency
  - ❑ Lower operating cost but higher initial cost

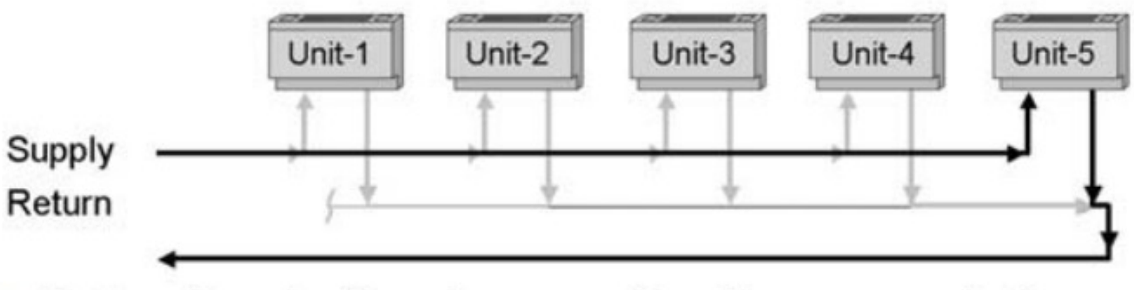
RETURN TYPES (REVERSE VS DIRECT)

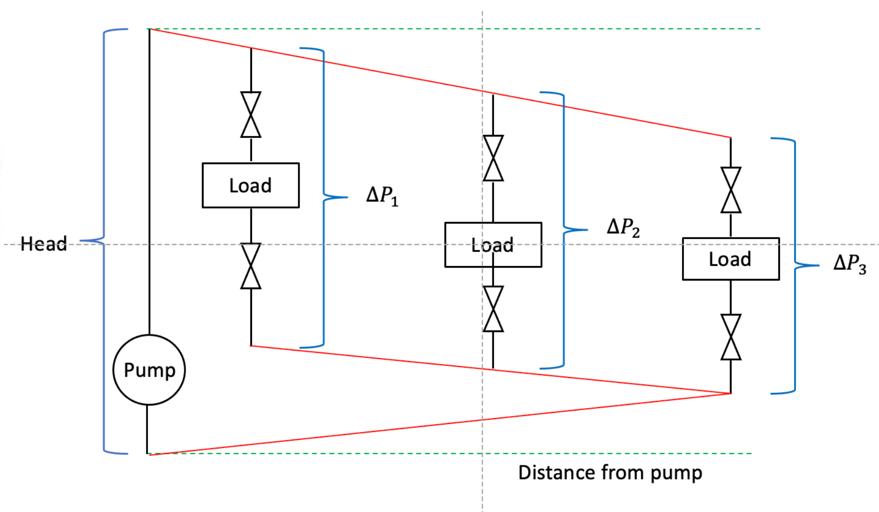
Return Types





Direct



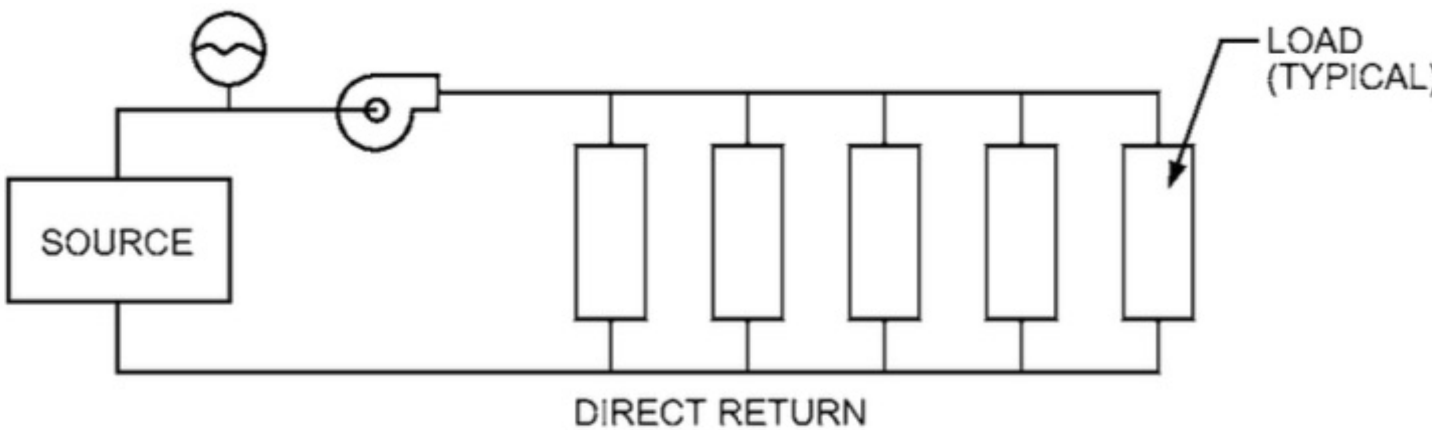


Reverse

http://siglercommercial.com/wp-content/uploads/2017/10/02-Chilled-Water-Piping-Pumps.pdf

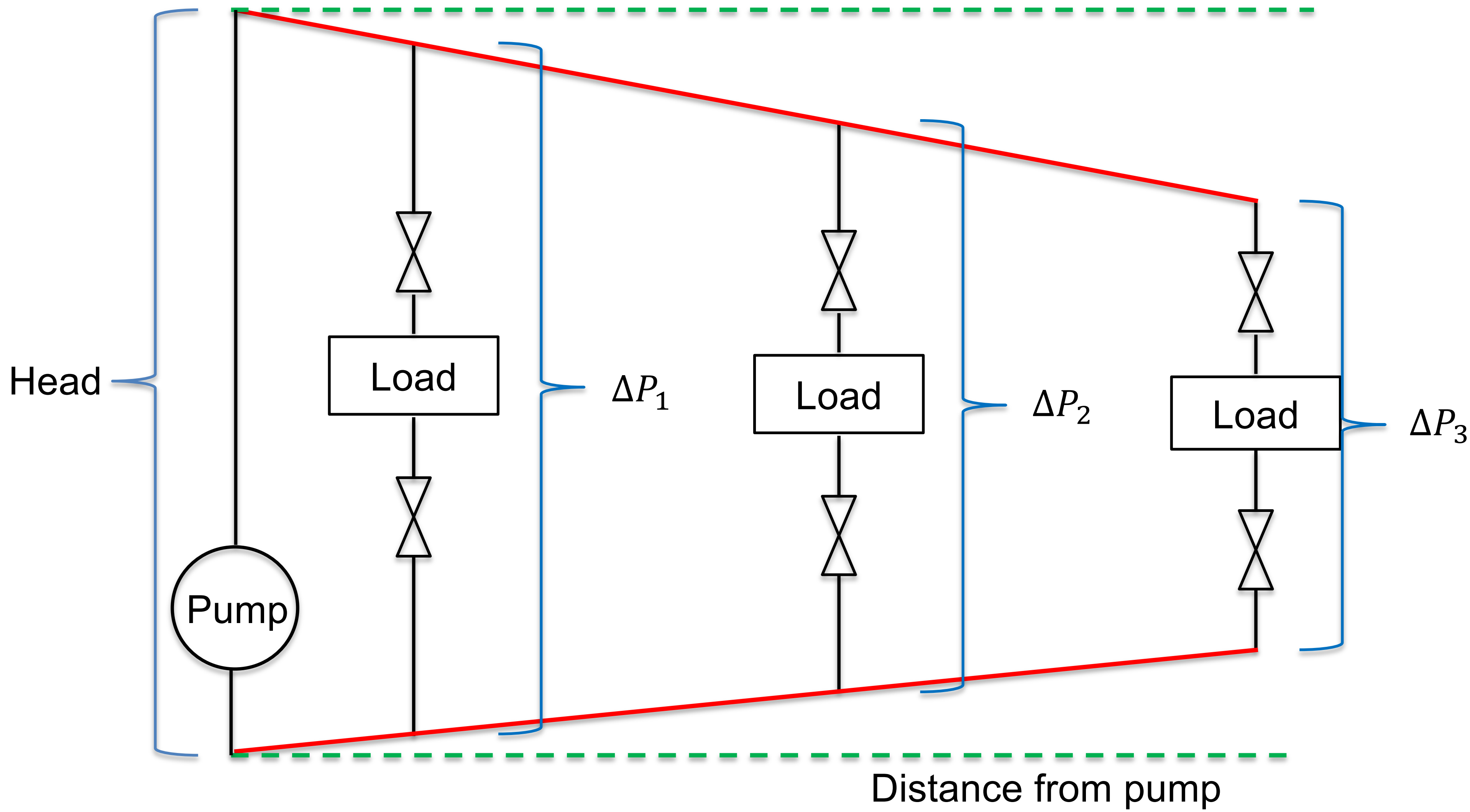
Return Types

- Direct return:
  - Water enters the first unit from supply
  - Water leaves the first unit and returns directly to the source
  - Unequal pressure drop
  - The first unit supplied is the first unit returned
  - Balancing vales are required



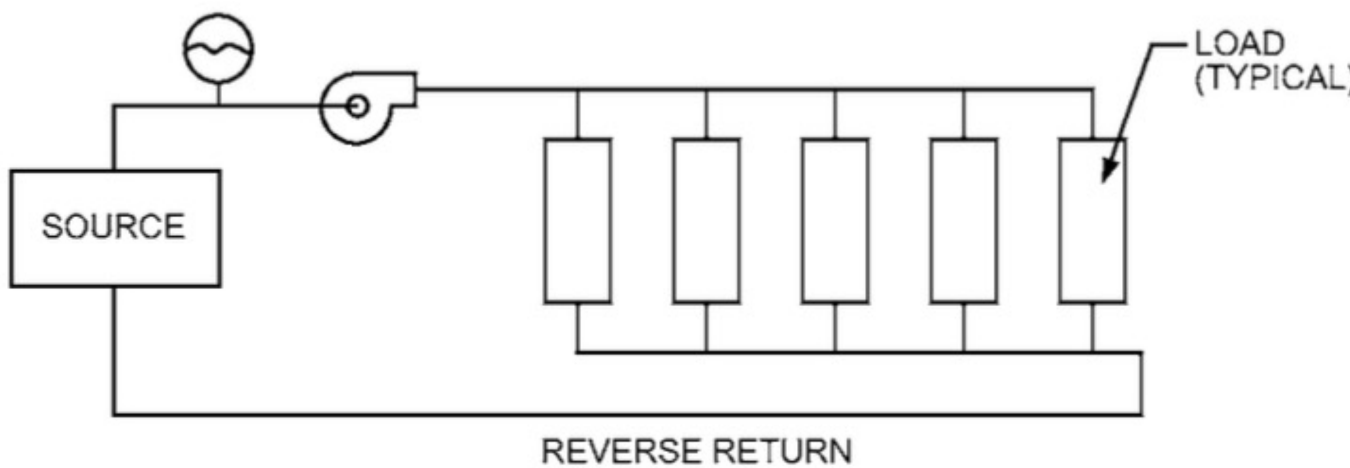
Return Types

- Direct return:



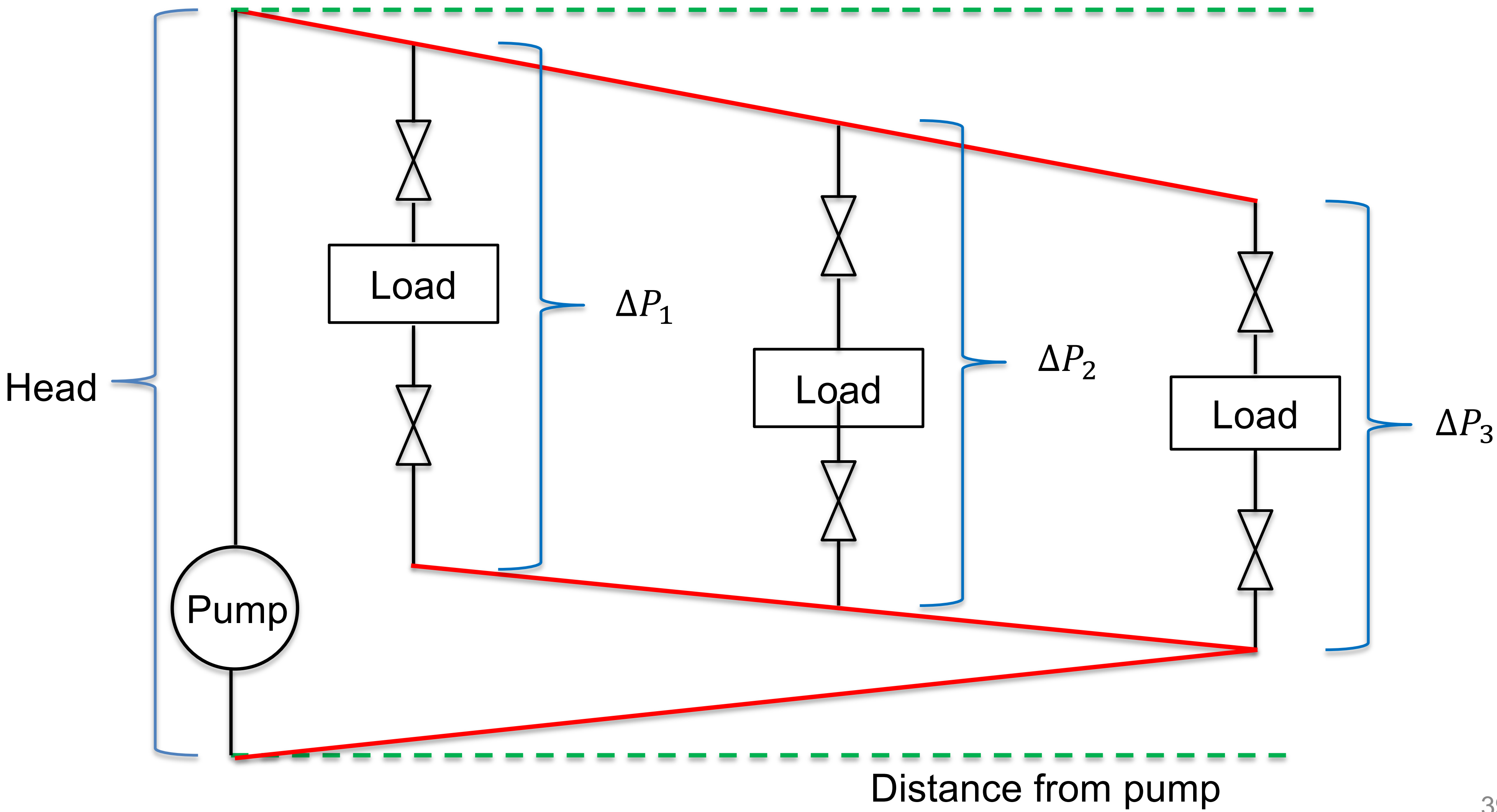
Return Types

- Reverse return:
  - ❑ Return direction is the same direction as the supply flow
  - ❑ Water leaves the first unit and goes all the way around in returning to the source
  - ❑ Equal pressure drop
  - ❑ The first unit supplied is the last unit returned
  - ❑ Balancing vales may be eliminated



Reverse Return

- Reverse return:



PIPE DESIGN

Pipe Design

- Similar to the duct design, we rely on the ASHRAE Handbook

CHAPTER 22

PIPE DESIGN

Pipe Design

- In hydronic systems pressure drop is calculated at feet per 100 feet of pipe at a given velocity

Pipe Size	Velocity (fps)
Large ($\geq 12''$)	6-8
Medium (Between 2” and $12''$)	3-4
Small ($\leq 12''$)	2

Pipe Design

- Common pipe types are:
  - ❑ M is used for very thin walls
    - ▪ Optimal for interior hot and cold supply lines
  - ❑ L is used for medium thickness
    - ▪ Optimal for interior hot and cold supply lines
  - ❑ K is used for thickest walls
    - ❑ Optimal for underground service lines
  - ❑ Schedule 40
    - ❑ Has a wall thickness of 0.1333” and ID of 1.049”

Pipe Design

- Some common fitting types are:
  - ❑ Welded
  - ❑ Threaded

https://www.theprocesspiping.com/a-short-article-on-elbow-as-pipe-fitting/

Pipe Design

- The schedule number represents the thickness of the wall on the pipe (e.g., Schedule 40 vs Schedule 80)
- As the schedule number increases, the thicker the wall thickness becomes
- The Nominal Pipe Size (NPS) represents the approximate inside diameter (not outside) of the pipe
- If the schedule number of a set size is changed, it affects the inside diameter (ID) but not the outside diameter (OD)

Pipe Design

- For steel pipes:

Table 16 Steel Pipe Data

Nominal Size, in.	Pipe OD, in.	Schedule Number or Weight[a]	Wall Thickness t, in.	Inside Diameter d, in.	Surface Area: Outside, ft^2/ft	Surface Area: Inside, ft^2/ft	Cross Section: Metal Area, in^2	Cross Section: Flow Area, in^2	Weight: Pipe, lb/ft	Weight: Water, lb/ft	Working Pressure[c] ASTM A53 B to 400°F: Mfr. Process	Joint Type[b]	psig
1/4	0.540	40 ST	0.088	0.364	0.141	0.095	0.125	0.104	0.424	0.045	CW	T	188
		80 XS	0.119	0.302	0.141	0.079	0.157	0.072	0.535	0.031	CW	T	871
3/8	0.675	40 ST	0.091	0.493	0.177	0.129	0.167	0.191	0.567	0.083	CW	T	203
		80 XS	0.126	0.423	0.177	0.111	0.217	0.141	0.738	0.061	CW	T	820
1/2	0.840	40 ST	0.109	0.622	0.220	0.163	0.250	0.304	0.850	0.131	CW	T	214
		80 XS	0.147	0.546	0.220	0.143	0.320	0.234	1.087	0.101	CW	T	753
3/4	1.050	40 ST	0.113	0.824	0.275	0.216	0.333	0.533	1.13	0.231	CW	T	217
		80 XS	0.154	0.742	0.275	0.194	0.433	0.432	1.47	0.187	CW	T	681
1	1.315	40 ST	0.133	1.049	0.344	0.275	0.494	0.864	1.68	0.374	CW	T	226
		80 XS	0.179	0.957	0.344	0.251	0.639	0.719	2.17	0.311	CW	T	642
1 1/4	1.660	40 ST	0.140	1.380	0.435	0.361	0.669	1.50	2.27	0.647	CW	T	229
		80 XS	0.191	1.278	0.435	0.335	0.881	1.28	2.99	0.555	CW	T	594
1 1/2	1.900	40 ST	0.145	1.610	0.497	0.421	0.799	2.04	2.72	0.881	CW	T	231
		80 XS	0.200	1.500	0.497	0.393	1.068	1.77	3.63	0.765	CW	T	576
2	2.375	40 ST	0.154	2.067	0.622	0.541	1.07	3.36	3.65	1.45	CW	T	230
		80 XS	0.218	1.939	0.622	0.508	1.48	2.95	5.02	1.28	CW	T	551
2 1/2	2.875	40 ST	0.203	2.469	0.753	0.646	1.70	4.79	5.79	2.07	CW	W	533
		80 XS	0.276	2.323	0.753	0.608	2.25	4.24	7.66	1.83	CW	W	835

Pipe Design

- For copper pipes:

Table 17 Copper Tube Data

Nominal Diameter, in.	Type	Wall Thick-ness *t*, in.	Diameter: Outside *D*, in.	Diameter: Inside *d*, in.	Surface Area: Outside, ft^2/ft	Surface Area: Inside, ft^2/ft	Cross Section: Metal Area, in^2	Cross Section: Flow Area, in^2	Weight: Tube, lb/ft	Weight: Water, lb/ft	Working Pressure[a,b,c] ASTM B88 to 250°F: Annealed, psig	Working Pressure[a,b,c] ASTM B88 to 250°F: Drawn, psig
1/4	K	0.035	0.375	0.305	0.098	0.080	0.037	0.073	0.145	0.032	851	1596
	L	0.030	0.375	0.315	0.098	0.082	0.033	0.078	0.126	0.034	730	1368
3/8	K	0.049	0.500	0.402	0.131	0.105	0.069	0.127	0.269	0.055	894	1676
	L	0.035	0.500	0.430	0.131	0.113	0.051	0.145	0.198	0.063	638	1197
	M	0.025	0.500	0.450	0.131	0.118	0.037	0.159	0.145	0.069	456	855
1/2	K	0.049	0.625	0.527	0.164	0.138	0.089	0.218	0.344	0.094	715	1341
	L	0.040	0.625	0.545	0.164	0.143	0.074	0.233	0.285	0.101	584	1094
	M	0.028	0.625	0.569	0.164	0.149	0.053	0.254	0.203	0.110	409	766
5/8	K	0.049	0.750	0.652	0.196	0.171	0.108	0.334	0.418	0.144	596	1117
	L	0.042	0.750	0.666	0.196	0.174	0.093	0.348	0.362	0.151	511	958
3/4	K	0.065	0.875	0.745	0.229	0.195	0.165	0.436	0.641	0.189	677	1270
	L	0.045	0.875	0.785	0.229	0.206	0.117	0.484	0.455	0.209	469	879
	M	0.032	0.875	0.811	0.229	0.212	0.085	0.517	0.328	0.224	334	625
1	K	0.065	1.125	0.995	0.295	0.260	0.216	0.778	0.839	0.336	527	988
	L	0.050	1.125	1.025	0.295	0.268	0.169	0.825	0.654	0.357	405	760
	M	0.035	1.125	1.055	0.295	0.276	0.120	0.874	0.464	0.378	284	532

Pipe Design

- Common pipe types for a chilled water application are:

Table 1 Common Applications of Pipe, Fittings, and Valves for Heating and Air Conditioning

Application	Size, in.	Material	Weight	Joint Type	Fitting Material	Class (When Applicable)	System[g] Temperature, °F	Maximum Pressure at Temperature,[a,b] psi
Chilled water	≤2	Steel Type F (CW)	Schedule 40	Thread	Cast iron	125	250	125
	2.5 to 12	Steel A or B, Type E (ERW)	Schedule 40	Weld	Wrought steel	Standard	250	400
				Flange	Wrought steel	150	250	250
					Cast iron	125	250	175
					Cast iron	250	250	400
		Copper, hard or soft	Type K or L	Solder Flared (soft) Rolled groove (2 to 8 in.) Press-connect (0.5 to 4 in.) Push connect (0.5 to 2 in.) Mechanical formed	Wrought or cast Cu		100	370 Type K soft 635 Type K hard 250 Type L soft 435 Type L hard
				Braze Weld	Wrought or cast Cu		100	250 Type L soft 370 Type K soft
		Copper, hard	Type M	Solder Rolled groove (2 to 8 in.) Press-connect (0.5 to 4 in.) Push connect (0.5 to 2 in.) Mechanical formed	Wrought or cast Cu		100	395 Type M hard
				Braze Weld	Wrought or cast Cu		100	230 Type M soft
	0.375 to 1.0	PEX (barrier)	SDR-9	Crimp Clamp Expansion Compression Push fit Proprietary	Bronze Brass Copper Engineered plastic		73	145
	0.5 to 6	PE	Schedule 40,[f] 80, SDR	Thermal fusion, compression	PE		120 (140 limit for some applications)	Varies with pipe wall thickness, grade, schedule, size. Check manufacturer's documentation for design ratings 30 to 110 at 130°F

Pipe Design

- Common pipe types for a heating application are:

Application	Size, in.	Material	Weight	Joint Type	Fitting Material	Class (When Applicable)	System[g] Temperature, °F	Maximum Pressure at Temperature,[a,b] psi
Heating and recirculating	2 and smaller	Steel Type F (CW)	Schedule 40	Thread	Cast iron	125	250	125
	0.25 to 12	Steel B Type E (ERW)	Schedule 40	Weld	Wrought steel	Standard	250	400
				Flange	Wrought steel	150	250	250
					Cast iron	125	250	125
					Cast iron	250	250	400
		Copper, hard or soft	Type K or L	Solder Braze Flared (soft) Rolled groove (2 to 8 in.) Press-connect (0.5 to 4 in.) Push connect (0.5 to 2 in.) Mechanical formed	Wrought or cast Cu		200	300 Type K soft 635 Type K hard 205 Type L soft 435 Type L hard
				Braze Weld	Wrought or cast Cu		200	300 Type K soft 205 Type L soft
	0.25 to 12	Copper, hard	Type M	Solder Rolled groove (2 to 8 in.) Press-connect (0.5 to 4 in.) Push connect (0.5 to 2 in.) Mechanical formed	Wrought or cast Cu		200	395 Type M hard
				Braze Weld	Wrought or cast Cu		200	200 Type M soft
	0.375 to 1.0	PEX (barrier)	SDR-9	Crimp Clamp Expansion Compression Push fit Proprietary	Bronze Brass Copper Engineered plastic		200	79

Pipe Design

- Common pipe types for a steam and condensate application are:

Application	Size, in.	Material	Weight	Joint Type	Fitting Material	Class (When Applicable)	System[g] Temperature, °F	Maximum Pressure at Temperature,[a,b] psi
Steam and condensate	2 and smaller	Steel Type F (CW) or S	Schedule 40[d]	Thread	Cast iron	125		90
				Thread	Malleable iron	150		90
				Socket	Forged steel	3000		90
		Steel B Type E (ERW) or S	Schedule 40[d]	Thread	Cast iron	125		100
				Thread	Malleable iron	150		125
				Socket	Forged steel	3000		400
		Steel B Type E (ERW) or S	Schedule 80	Thread	Cast iron	250		200
				Socket				
				Thread	Malleable iron	300		250
				Socket	Forged steel	3000		400
	2 to 12	Steel B Type E (ERW) or S	Schedule 40	Weld	Wrought steel	Standard		250
				Flange	Wrought steel	150		200

Pipe Design

- Common standards and codes are:
  - ASME B&PV: Boiler and Pressure Vessel Code
  - ASME B31.1: Power Piping
  - ASME B31.5: Refrigerant Piping
  - ASME B31.8: Gas Piping
  - ASME B31.9: Building Services Piping
  - NFPA 13: Installation of Sprinkler Systems
  - NFPA 54: National Fuel Gas Code
  - International, national, and local building codes

FRICTION LOSS IN WATER PIPES

Friction Loss in Water Pipes

- We can write the friction loss in the system as:

$$H_{lf} = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) + \sum_{fittings} K\left(\frac{V^2}{2g}\right)$$

Friction Loss in Water Pipes

- In hydronic systems, the general range of pipe friction loss used for design is between 1 and 4 ft. of water per 100 ft. of pipe

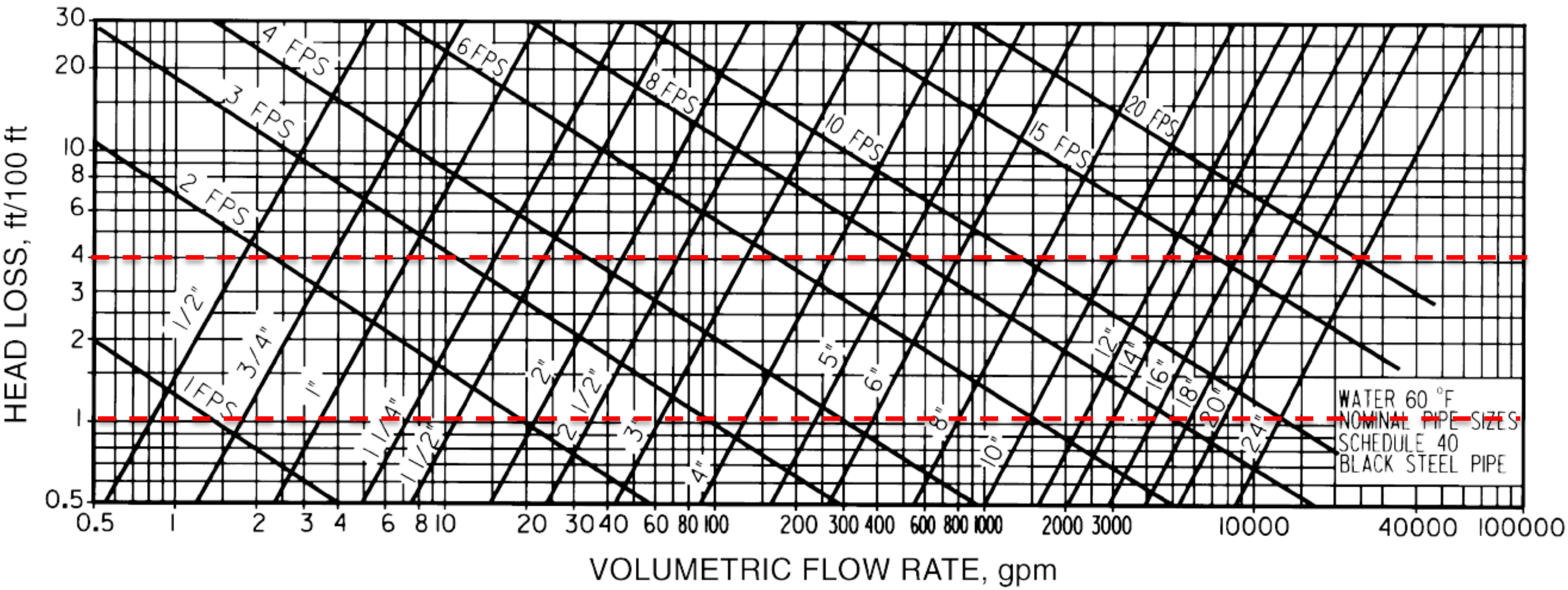


Fig. 4 Friction Loss for Water in Commercial Steel Pipe (Schedule 40)

Friction Loss in Water Pipes

- For Types K, L, M, we can use this chart:

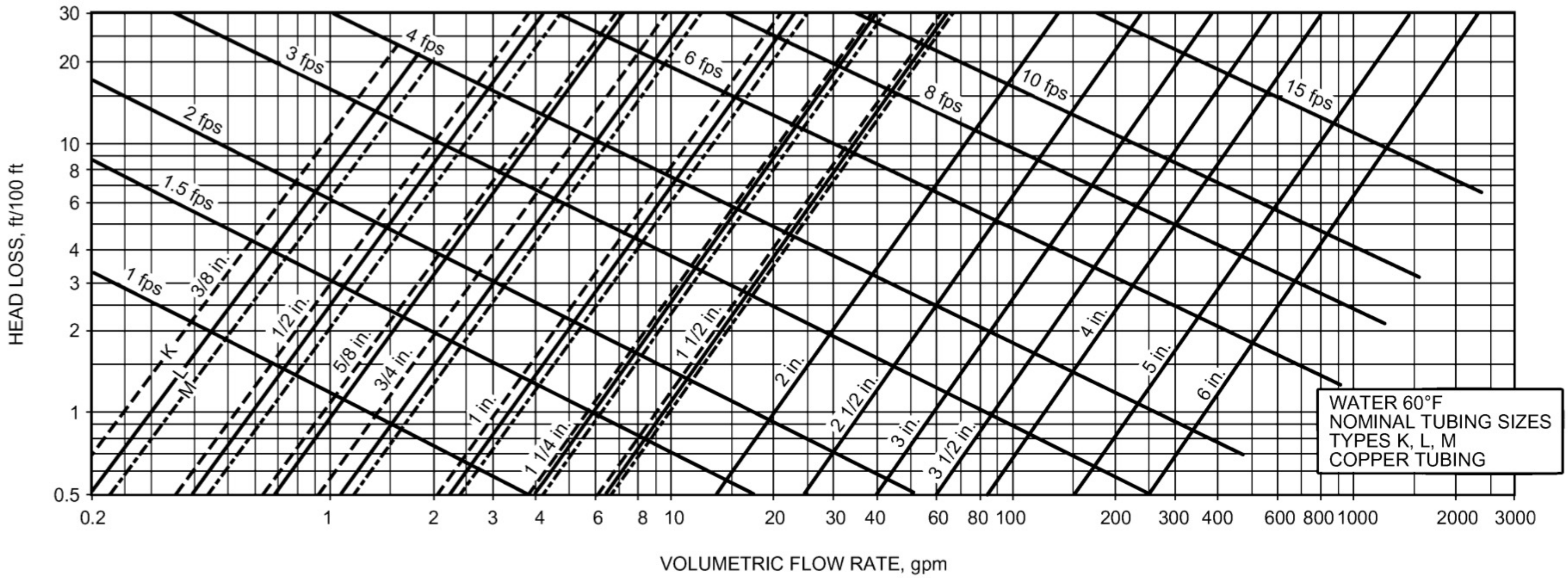


Fig. 15 Friction Loss for Water in Copper Tubing (Types K, L, M)

CLASS ACTIVITY

Class Activity

- **Example:** Using the commercial steel pipe (Schedule 40) answer the following pipe sizing questions.
  - ❑ Find the maximum capacity of 2” schedule 40 steel
  - ❑ Size and find the velocity for the upper and lower bound when gpm is 1000
  - ❑ Find the pipe diameter when gpm is 3000 and the maximum velocity is 10 ft/s

Class Activity

- **Solution:** In hydronic systems, the general range of pipe friction loss used for design is

Between 1 and 4 ft. of water per 100 ft. of pipe

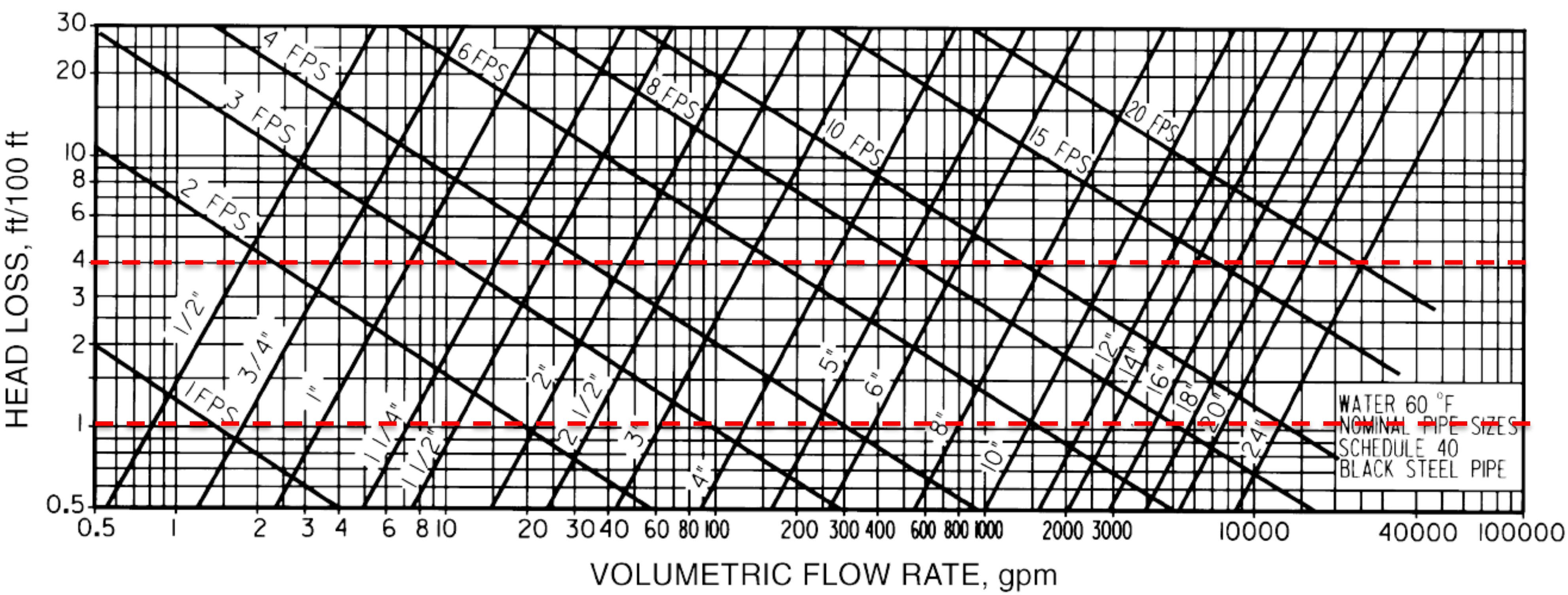


Fig. 4 Friction Loss for Water in Commercial Steel Pipe (Schedule 40)

FRICTION LOSS IN WATER FITTINGS

Friction Loss in Water Fittings

- Friction loss in a water pipe fitting is equal to:

$$H_{lf} = K\left(\frac{V^2}{2g}\right)$$

Table 3 *K* Factors: Threaded Steel Pipe Fittings

Nominal Pipe Dia., in.	90° Standard Elbow	90° Long-Radius Elbow	45° Elbow	Return Bend	Tee-Line	Tee-Branch	Globe Valve	Gate Valve	Angle Valve	Swing Check Valve	Bell Mouth Inlet	Square Inlet	Projected Inlet
3/8	2.5	—	0.38	2.5	0.90	2.7	20	0.40	—	8.0	0.05	0.5	1.0
1/2	2.1	—	0.37	2.1	0.90	2.4	14	0.33	—	5.5	0.05	0.5	1.0
3/4	1.7	0.92	0.35	1.7	0.90	2.1	10	0.28	6.1	3.7	0.05	0.5	1.0
1	1.5	0.78	0.34	1.5	0.90	1.8	9	0.24	4.6	3.0	0.05	0.5	1.0
1 1/4	1.3	0.65	0.33	1.3	0.90	1.7	8.5	0.22	3.6	2.7	0.05	0.5	1.0
1 1/2	1.2	0.54	0.32	1.2	0.90	1.6	8	0.19	2.9	2.5	0.05	0.5	1.0
2	1.0	0.42	0.31	1.0	0.90	1.4	7	0.17	2.1	2.3	0.05	0.5	1.0
2 1/2	0.85	0.35	0.30	0.85	0.90	1.3	6.5	0.16	1.6	2.2	0.05	0.5	1.0
3	0.80	0.31	0.29	0.80	0.90	1.2	6	0.14	1.3	2.1	0.05	0.5	1.0
4	0.70	0.24	0.28	0.70	0.90	1.1	5.7	0.12	1.0	2.0	0.05	0.5	1.0

Source: *Engineering Data Book* (Hydraulic Institute 1990).

Is there a difference between open or close valve?

Friction Loss in Water Fittings

- Friction loss in a water pipe fitting is equal to:

Table 4 *K* Factors: Flanged Welded Steel Pipe Fittings

Nominal Pipe Dia., in.	90° Standard Elbow	90° Long-Radius Elbow	45° Long-Radius Elbow	Return Bend Standard	Return Bend Long-Radius	Tee-Line	Tee-Branch	Globe Valve	Gate Valve	Angle Valve	Swing Check Valve
1	0.43	0.41	0.22	0.43	0.43	0.26	1.0	13	—	4.8	2.0
1 1/4	0.41	0.37	0.22	0.41	0.38	0.25	0.95	12	—	3.7	2.0
1 1/2	0.40	0.35	0.21	0.40	0.35	0.23	0.90	10	—	3.0	2.0
2	0.38	0.30	0.20	0.38	0.30	0.20	0.84	9	0.34	2.5	2.0
2 1/2	0.35	0.28	0.19	0.35	0.27	0.18	0.79	8	0.27	2.3	2.0
3	0.34	0.25	0.18	0.34	0.25	0.17	0.76	7	0.22	2.2	2.0
4	0.31	0.22	0.18	0.31	0.22	0.15	0.70	6.5	0.16	2.1	2.0
6	0.29	0.18	0.17	0.29	0.18	0.12	0.62	6	0.10	2.1	2.0
8	0.27	0.16	0.17	0.27	0.15	0.10	0.58	5.7	0.08	2.1	2.0
10	0.25	0.14	0.16	0.25	0.14	0.09	0.53	5.7	0.06	2.1	2.0
12	0.24	0.13	0.16	0.24	0.13	0.08	0.50	5.7	0.05	2.1	2.0

Source: *Engineering Data Book* (Hydraulic Institute 1990).

Friction Loss in Water Fittings

- Friction loss in a water pipe fitting is equal to:

Table 6 Summary of *K* Values for Steel Ells, Reducers, and Expansions

		ASHRAE Research[b,c]		
	Past[a]	4 fps	8 fps	12 fps
2 in. S.R.[e] ell (*R*/*D* = 1) thread	0.60 to 1.0 (1.0)[d]	0.60	0.68	0.736
4 in. S.R. ell (*R*/*D* = 1) weld	0.30 to 0.34	0.37	0.34	0.33
1 in. L.R. ell (*R*/*D* = 1.5) weld	to 1.0	—	—	—
2 in. L.R. ell (*R*/*D* = 1.5) weld	0.50 to 0.7	—	—	—
4 in. L.R. ell (*R*/*D* = 1.5) weld	0.22 to 0.33 (0.22)[d]	0.26	0.24	0.23
6 in. L.R. ell (*R*/*D* = 1.5) weld	0.25	0.26	0.24	0.24
8 in. L.R. ell (*R*/*D* = 1.5) weld	0.20 to 0.26	0.22	0.20	0.19
10 in. L.R. ell (*R*/*D* = 1.5) weld	0.17	0.21	0.17	0.16
12 in. L.R. ell (*R*/*D* = 1.5) weld	0.16	0.17	0.17	0.17
16 in. L.R. ell (*R*/*D* = 1.5) weld	0.12	0.12	0.12	0.11
20 in. L.R. ell (*R*/*D* = 1.5) weld	0.09	0.12	0.10	0.10
24 in. L.R. ell (*R*/*D* = 1.5) weld	0.07	0.098	0.089	0.089
Reducer (2 by 1.5 in.) thread	—	0.53	0.28	0.20
(4 by 3 in.) weld	0.22	0.23	0.14	0.10
(6 by 4 in.) weld		0.62	0.54	0.53
(8 by 6 in.) weld		0.31	0.28	0.26
(10 by 8 in.) weld		0.16	0.14	0.14
(12 by 10 in.) weld	—	0.14	0.14	0.14
(16 by 12 in.) weld	—	0.17	0.16	0.17
(20 by 16 in.) weld	—	0.16	0.13	0.13
(24 by 20 in.) weld	—	0.053	0.053	0.055
Expansion (1.5 by 2 in.) thread	—	0.16	0.13	0.02
(3 by 4 in.) weld	—	0.11	0.11	0.11
(4 by 6 in.) weld	—	0.28	0.28	0.29
(6 by 8 in.) weld	—	0.15	0.12	0.11
(8 by 10 in.) weld	—	0.11	0.09	0.08
(10 by 12 in.) weld	—	0.11	0.11	0.11
(12 by 16 in.) weld	—	0.073	0.076	0.073
(16 by 20 in.) weld	—	0.024	0.021	0.022
(20 by 24 in.) weld	—	0.020	0.023	0.020

Source: Rahmeyer (2003a).
[a]Published data by Crane Co. (1988), Freeman (1941), and Hydraulic Institute (1990).
[b]Rahmeyer (1999a, 2002a).
[c]Ding et al. (2005)
[d]( ) Data published in 1993 *ASHRAE Handbook—Fundamentals*.
[e]S.R.—short radius or regular ell; L.R.—long-radius ell.

Friction Loss in Water Fittings

- We also sometimes define equivalent length:

$$Head\ loss\ in\ a\ pipe = f\,\frac{L}{D}\frac{V^2}{2g}$$

$$K = f\,\frac{L}{D}$$

$$Head\ loss\ in\ a\ fitting = K\,\frac{V^2}{2g}$$

- $\frac{L}{D}$ is the equivalent length in pipe diameters of straight pipe that will cause the same pressure drop as the valve or fitting under the same flow conditions

Friction Loss in Water Fittings

- ASHRAE Chapter 22 has some list of equivalent lengths:

Table 27 Equivalent Length in Feet of Pipe for 90° Elbows

Velocity, fps	Pipe Size														
	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	5	6	8	10	12
1	1.2	1.7	2.2	3.0	3.5	4.5	5.4	6.7	7.7	8.6	10.5	12.2	15.4	18.7	22.2
2	1.4	1.9	2.5	3.3	3.9	5.1	6.0	7.5	8.6	9.5	11.7	13.7	17.3	20.8	24.8
3	1.5	2.0	2.7	3.6	4.2	5.4	6.4	8.0	9.2	10.2	12.5	14.6	18.4	22.3	26.5
4	1.5	2.1	2.8	3.7	4.4	5.6	6.7	8.3	9.6	10.6	13.1	15.2	19.2	23.2	27.6
5	1.6	2.2	2.9	3.9	4.5	5.9	7.0	8.7	10.0	11.1	13.6	15.8	19.8	24.2	28.8
6	1.7	2.3	3.0	4.0	4.7	6.0	7.2	8.9	10.3	11.4	14.0	16.3	20.5	24.9	29.6
7	1.7	2.3	3.0	4.1	4.8	6.2	7.4	9.1	10.5	11.7	14.3	16.7	21.0	25.5	30.3
8	1.7	2.4	3.1	4.2	4.9	6.3	7.5	9.3	10.8	11.9	14.6	17.1	21.5	26.1	31.0
9	1.8	2.4	3.2	4.3	5.0	6.4	7.7	9.5	11.0	12.2	14.9	17.4	21.9	26.6	31.6
10	1.8	2.5	3.2	4.3	5.1	6.5	7.8	9.7	11.2	12.4	15.2	17.7	22.2	27.0	32.0

Friction Loss in Water Fittings

- ASHRAE Chapter 22 has some list of equivalent lengths:

Table 28 Iron and Copper Elbow Equivalents*

Fitting	Iron Pipe	Copper Tubing
Elbow, 90°	1.0	1.0
45°	0.7	0.7
90° long-radius	0.5	0.5
90° welded	0.5	0.5
Reduced coupling	0.4	0.4
Open return bend	1.0	1.0
Angle radiator valve	2.0	3.0
Radiator or convector	3.0	4.0
Boiler or heater	3.0	4.0
Open gate valve	0.5	0.7
Open globe valve	12.0	17.0

Sources: Giesecke (1926) and Giesecke and Badgett (1931, 1932a).
*See Table 10 for equivalent length of one elbow.

Equivalent Length

- ASHRAE Chapter 22 has some list of equivalent lengths:

Table 8 Test Summary for Loss Coefficients *K* and Equivalent Loss Lengths

Schedule 80 PVC Fitting		*K*	*L*, ft
Injected molded elbow,	2 in.	0.91 to 1.00	8.4 to 9.2
	4 in.	0.86 to 0.91	18.3 to 19.3
	6 in.	0.76 to 0.91	26.2 to 31.3
	8 in.	0.68 to 0.87	32.9 to 42.1
8 in. fabricated elbow, Type I, components		0.40 to 0.42	19.4 to 20.3
Type II, mitered		0.073 to 0.76	35.3 to 36.8
6 by 4 in. injected molded reducer		0.12 to 0.59	4.1 to 20.3
Bushing type		0.49 to 0.59	16.9 to 20.3
8 by 6 in. injected molded reducer		0.13 to 0.63	6.3 to 30.5
Bushing type		0.48 to 0.68	23.2 to 32.9
Gradual reducer type		0.21	10.2
4 by 6 in. injected molded expansion		0.069 to 1.19	1.5 to 25.3
Bushing type		0.069 to 1.14	1.5 to 24.2
6 by 8 in. injected molded expansion		0.95 to 0.96	32.7 to 33.0
Bushing type		0.94 to 0.95	32.4 to 32.7
Gradual reducer type		0.99	34.1

HYDRONIC DRAWINGS

Hydronic Drawings

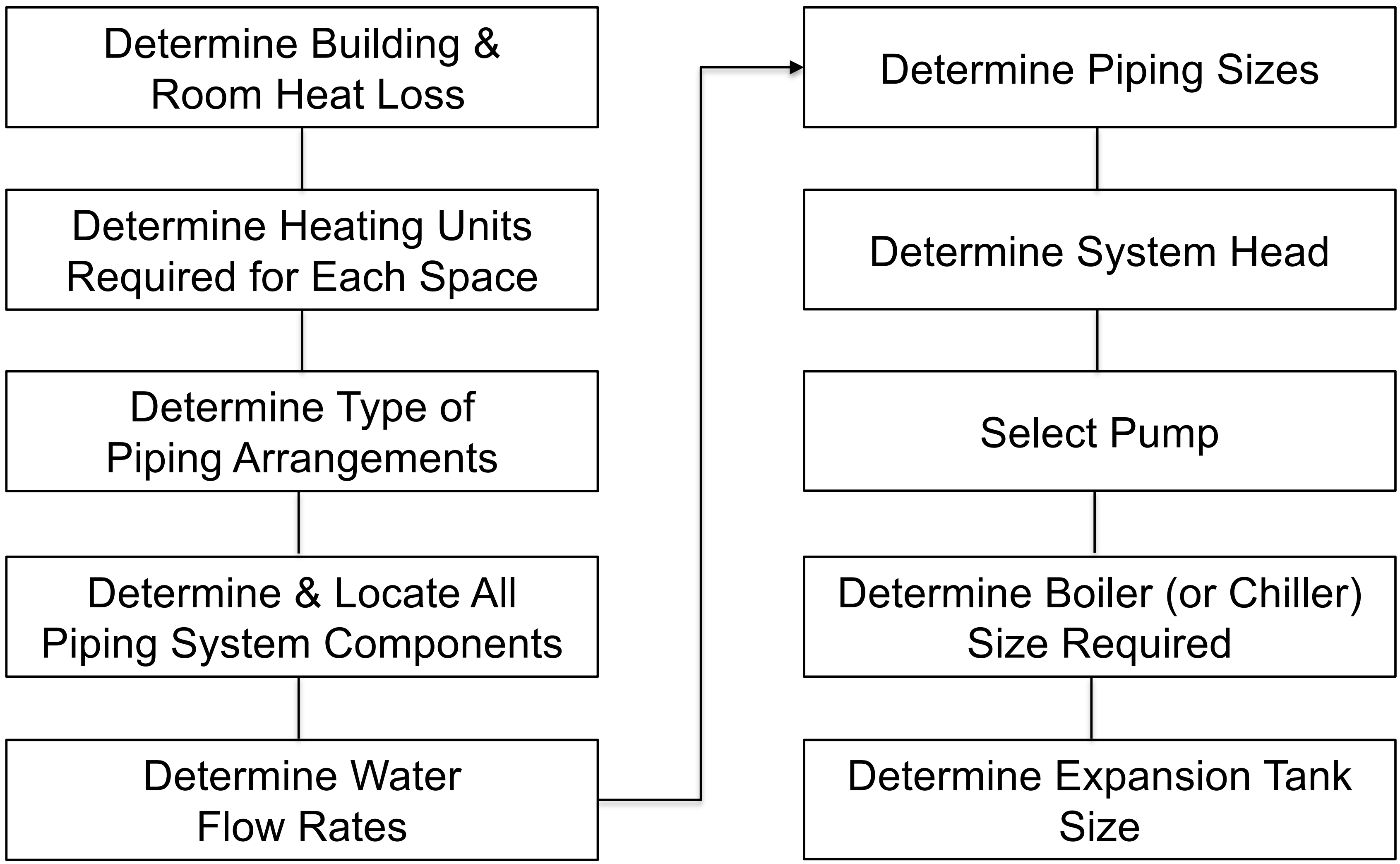
GENERAL PIPING SYMBOLS

- 2-WAY CONTROL VALVE
- 3-WAY CONTROL VALVE
- AIR VENT
- BALL VALVE
- BUTTERFLY VALVE
- CABINET HEATER
- CAP
- GATE VALVE
- CHECK VALVE
- CIRCUIT SETTER
- CIRCUIT SETTER
- CONTINUATION
- DIRECTION OF FLOW ARROWS
- EXPANSION JOINT
- FINNED TUBE RADIATION
- FLEX CONNECTOR
- FLOW METER
- PIPE DROP
- PIPE RISER
- POINT OF NEW CONNECTION

— CR —	STEAM CONDENSATE RETURN
— LPS —	LOW PRESSURE STEAM
— PCR —	PUMPED CONDENSATE RETURN
— HWS —	HEATING HOT WATER SUPPLY
— HWR —	HEATING HOT WATER RETURN
— BHWR —	BASEBOARD HOT WATER RETURN
— BHWS —	BASEBOARD HOT WATER SUPPLY
— HPS —	HIGH PRESSURE STEAM
— CHWS —	CHILLED WATER SUPPLY
— CHWR —	CHILLED WATER RETURN
— D —	CONDENSATE DRAIN

DESIGN PROCEDURE

Design Procedure of a Hot Water Heating System



PROJECT PART 2