CAE 464/517 HVAC Systems Design
Spring 2023

April 20, 2023
Hydronic systems: Coil selection selection and intro to vapor compression cycle

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ANNOUNCEMENTS

Announcements

- Solution to Assignment 5 is posted
- If you need more extra problems on how to calculate the pressure loss in a piping system, please see the extra examples in the previous lecture
- Project Part 3 is due Tuesday night (no extension)
- We will have a building tour next Thursday (Stuart and Kaplan)

RECAP

Recap

- An example from the campus

Recap

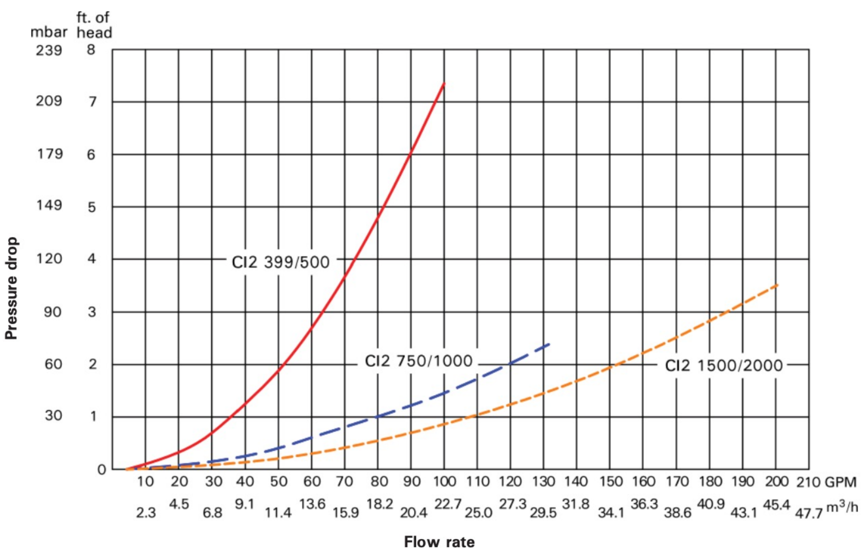
- Find the pressure drop, GPM, and temperature difference

Vitocrossal 200, CI2 Series Technical Data — Specifications

Flow Rate

Pressure drop (primary circuit)

The Vitocrossal 200, CI2 is only suitable for fully pumped hot water heating systems.



Recommended Flow Rates CI2

CI2 model		399	500	750	1000	1500	2000
20°F △t	GPM	39	48	73	97	146	194
40°F △t	GPM	19	24	36	49	73	97
100°F △t	GPM	8	10	15	19.5	29	39
11°C △t	m^3/h	8.9	10.9	16.6	22.0	33.2	44.1
22°C △t	m^3/h	4.3	5.5	8.2	11.1	16.6	22.0
56°C △t	m^3/h	1.8	2.3	3.4	4.4	6.6	8.9

△t = temperature difference
This boiler does not require a flow switch.

Minimum flow rate based on: 100°F △t (56°C △t)
Maximum flow rate based on: 20°F △t (11°C △t)

https://www.viessmann-us.com/content/dam/public-brands/us/pdf/technical-data-manuals/vitocrossal_200_ci2_tdm.pdf/_jcr_content/renditions/original./vitocrossal_200_ci2_tdm.pdf

Recap

- Determine the chiller size, coolant type (e.g., chilled water with glycol), temperature, and flow rate

$$\Delta T = LWT - EWT$$

$$\frac{Btu}{hr} = GPM \times 8.33 \Delta T(°\mathrm{F})$$

$$Ton = \frac{\Delta T(°\mathrm{F}) \times GPM}{24}$$

$$ton = \frac{\frac{Btu}{hr}}{12{,}000}$$

$$\Delta T(°\mathrm{F}) = \frac{12{,}000 \times Ton}{500 \times GPM}$$

Recap

- Review the temperature difference and impact of outdoor air temperature on the performance:

Cooling (ΔT = 10°F)

AG010KSV***

LWT	Outdoor Air Temperature (°F, DB)																							
	55			65			75			85			95			105			115			118.4		
	TC	PI	Water flow	TC	PI	Water flow	TC	PI	Water flow	TC	PI	Water flow	TC	PI	Water flow	TC	PI	Water flow	TC	PI	Water flow	TC	PI	Water flow
	Ton	kW	GPM	Ton	kW	GPM	Ton	kW	GPM	Ton	kW	GPM	Ton	kW	GPM	Ton	kW	GPM	Ton	kW	GPM	Ton	kW	GPM
14[2]	7.671	5.763	18.410	7.499	7.002	17.995	7.251	7.814	17.401	6.575	8.425	15.800	5.930	9.488	15.800[3]	5.258	10.745	15.800[3]	4.004	10.629	15.800[3]	3.583	9.781	15.800[3]
23[2]	9.853	6.179	23.646	9.844	7.431	23.624	9.738	8.213	23.369	9.293	8.845	22.302	8.844	9.977	21.224	7.793	11.179	18.701	6.340	11.531	15.800[3]	5.673	11.091	15.800[3]
32[2]	9.954	6.257	23.887	9.946	7.624	23.867	9.839	8.530	23.611	9.394	9.160	22.544	8.945	10.299	21.466	7.914	11.567	18.992	6.795	11.881	16.308	6.081	11.521	15.800[3]
41	10.859	6.421	26.059	10.857	7.819	26.054	10.748	8.742	25.792	10.299	9.463	24.715	9.749	10.621	23.395	8.660	11.886	20.783	7.274	12.268	17.456	6.550	11.988	15.800[3]
44	11.110	6.490	26.653	11.108	7.904	26.653	11.004	8.828	26.412	10.550	9.550	25.314	10.000	10.710	24.000	8.860	11.977	21.272	7.430	12.273	17.820	6.646	11.909	15.949
48	11.820	6.607	28.368	11.820	8.027	28.368	11.670	8.950	28.013	11.250	9.780	27.003	10.620	10.920	25.487	9.410	11.900	22.577	7.890	12.090	18.936	7.095	11.697	17.026
52	12.390	6.722	29.733	12.390	8.150	29.733	12.240	9.070	29.371	11.730	9.870	28.153	11.178	11.130	26.826	9.887	11.824	23.724	8.310	11.870	19.941	7.370	11.393	17.686
56	12.947	6.843	31.072	12.950	8.280	31.072	12.797	9.193	30.710	12.290	9.830	29.492	11.642	10.910	27.936	10.330	11.550	24.799	8.690	11.582	20.858	7.750	11.083	18.599
60	13.500	6.967	32.394	13.500	8.403	32.394	13.350	9.320	32.032	12.820	9.860	30.774	12.172	10.900	29.213	10.760	11.280	25.830	9.060	11.310	21.735	8.106	10.847	19.453
64.4	14.073	7.038	33.773	14.078	8.480	33.785	13.927	9.406	33.422	13.320	10.019	31.966	12.663	11.070	30.389	11.195	11.447	26.865	9.400	11.424	22.558	8.387	10.979	20.127

Recap

- Include the impact of correction factors:

1) Correction factor by % glycol

Anti-freeze	Ethylene glycol					Propylene glycol				
%wt	Freezing point (°F)	Min. LWT (°F)	Correction factor			Freezing point (°F)	Min. LWT (°F)	Correction factor		
			Capacity	Power Input	Pressure drop			Capacity	Power Input	Pressure drop
0%	32.0	41.0	1.000	1.000	1.000	32.0	41.0	1.000	1.000	1.000
10%	24.8	33.8	0.989	0.995	1.010	26.6	35.6	0.988	0.994	1.029
20%	15.8	24.8	0.975	0.990	1.023	19.4	28.4	0.973	0.988	1.061
30%	3.2	14.0	0.960	0.985	1.041	8.6	17.6	0.955	0.982	1.098
40%	-9.4	14.0	0.943	0.980	1.064	-7.6	14.0	0.933	0.976	1.142
50%	-34.6	14.0	0.924	0.975	1.082	-31.0	14.0	0.910	0.970	1.193

Recap

- Review the performance data:

Unit Tag	Qty	Model No	Net Cooling Capacity (ton.R)	Nominal Voltage	Refrigerant Type
CH-1	1	YCAL0052EE46XEBSDTX	46.23	460-3-60.0	R410A

PIN:								
YCAL0052EE	46XEBSDTXA	XXRLXXXX44	XX1XXXXXXX	SXXXPXX7XX	BXXNXXXXXX			
....5...10	....5...20	....5...30	....5...40	....5...50	....5...60	....5...70	....5...80	....5...90

Evaporator Data			Evaporator Data (Cont.)		Performance Data	
EWT (°F)	54.00		Min. Flow Rate (USGPM)	59.99	EER (Btu/W·h)	10.16
LWT (°F)	44.00		Max. Flow Rate (USGPM)	300.0	IPLV.IP (Btu/W·h)	15.05
Design Flow Rate (USGPM)	110.6		**Condenser Data**			
Pressure Drop (ft H2O)	9.22		Ambient Temp. Design (°F)	95.0	**Physical Data**	
Fluid	Water		Altitude (ft)	0.000	Rigging Wt. (lb)	3170
Fouling Factor (h.ft².F/Btu)	0.000100		Compressor Type	Scroll - Hermetic	Operating Wt. (lb)	3208
Fluid Volume (USGAL)	3.500					

Electrical Data				
Circuit	1	2	3	4
Compressor RLA	23 / 23	23 / 23		
Fan QTY/FLA (each)	2 / 3.4	2 / 3.4		
High LRA Current	150 / 150	150 / 150		

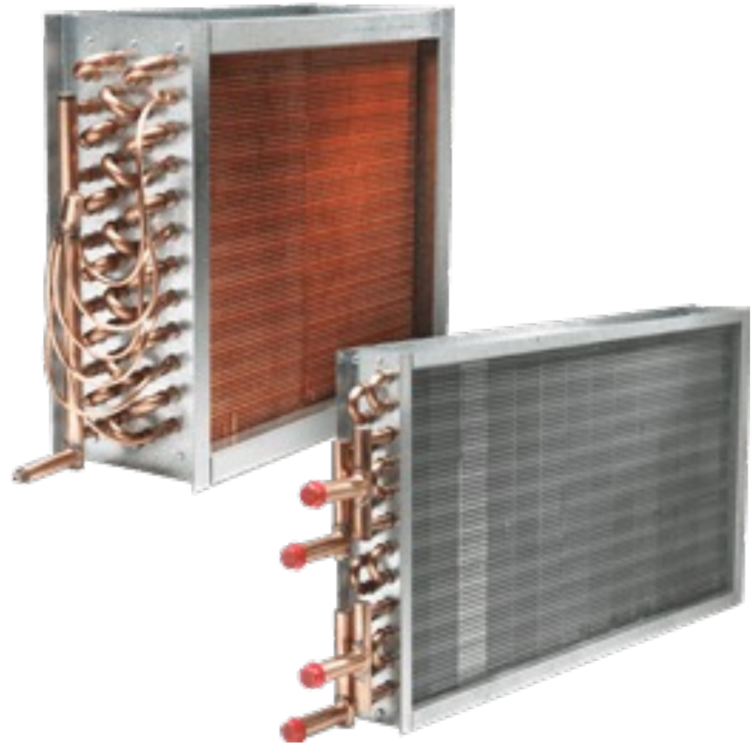
Single Point				
Min. Circuit Ampacity	113			
Recommended Fuse/CB Rating	125			
Max. Inverse Time CB Rating	125			
Max. Dual Element Fuse Size (A)	125			
Unit Short Circuit Withstand (STD)	5 [kA]		**Operating Condition Electrical Data**	
Wires Per Phase	1		Compressor kW	47.90
Wire Range (Lug Size)	4 AWG - 300 kcmil		Total Fan kW	6.720
Starter Type	Across The Line		Total kW	54.62

COIL SELECTION

Coil Selection

- Example of coils

Chilled/Hot Water Coil

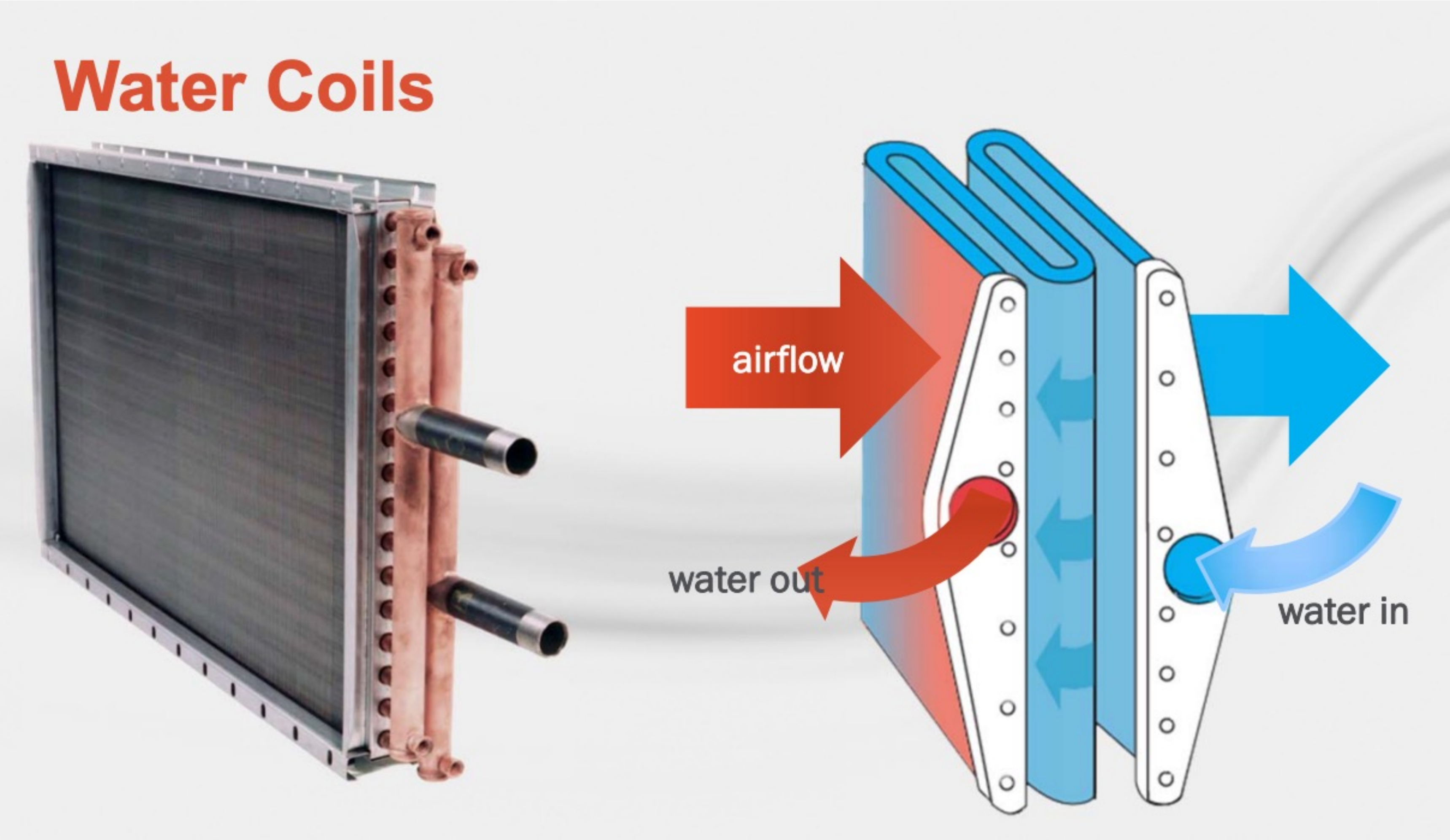


DX coils

https://www.greenheck.com/products/air-conditioning/hvac-coils

Coil Selection

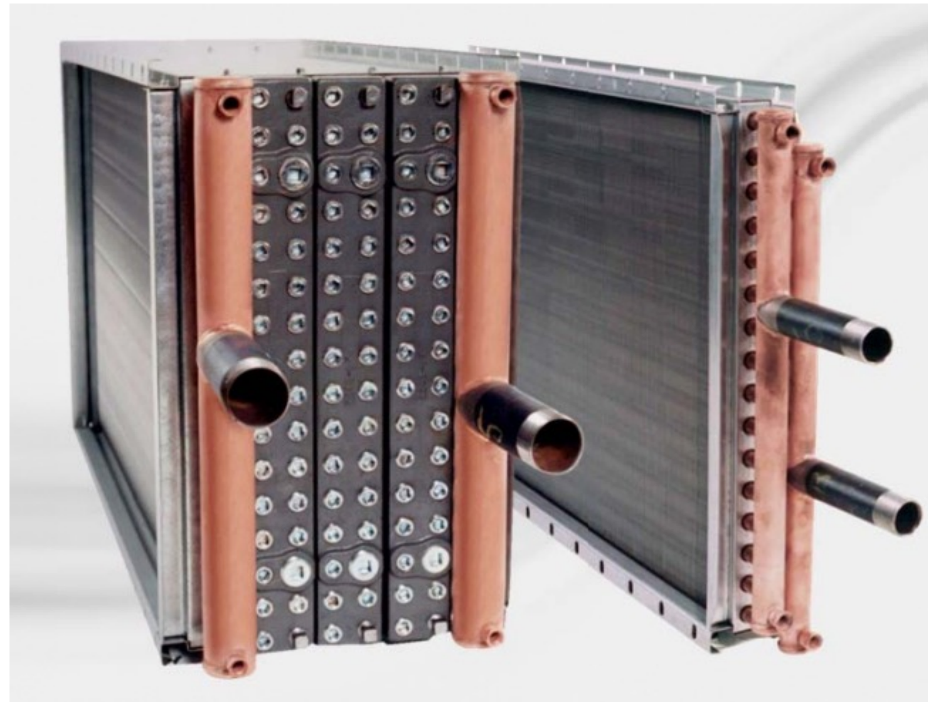
- Example of coils



https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/continuing-education-gbci-aia-pdh/HVAC-Coil-Selection-and-Optimization/APP-CMC054-EN_course%20material.pdf

Coil Selection

- What are important variables?
  - ❑ Coil face area
  - ❑ Number of rows of tubes
  - ❑ Tube diameter
  - ❑ Number of fins
  - ❑ Fin surface design
  - ❑ Coil circuiting
  - ❑ Turbulators



https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/continuing-education-gbci-aia-pdh/HVAC-Coil-Selection-and-Optimization/APP-CMC054-EN_course%20material.pdf

Coil Selection

- What do you see in this photo?

Coil Selection

- ASHRAE Chapter 23: Systems and Equipment

CHAPTER 23

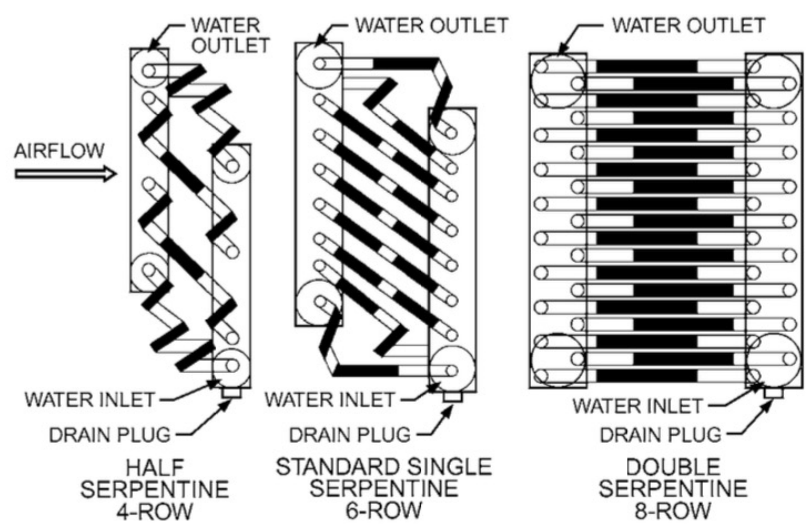
AIR-COOLING AND DEHUMIDIFYING COILS

Uses for Coils 23.1
Coil Construction and Arrangement 23.1
Coil Selection 23.5
Airflow Resistance 23.6
Heat Transfer 23.6
Performance of Sensible Cooling Coils 23.7
Performance of Dehumidifying Coils 23.9
Determining Refrigeration Load 23.14
Maintenance 23.15
Symbols 23.16

MOST equipment used today for cooling and dehumidifying an airstream under forced convection incorporates a coil section that contains one or more cooling coils assembled in a coil bank arrangement. Such coil sections are used extensively as components in room terminal units; larger factory-assembled, self-contained air conditioners; central station air handlers; and field built-up systems. Applications of each coil type are limited to the field within which the coil is rated. Other limitations are imposed by code requirements, proper choice of materials for the fluids used, the configuration of the air handler, and economic analysis of the possible alternatives for each installation.

1. USES FOR COILS

Coils are used for air cooling with or without accompanying dehumidification. Examples of cooling applications without dehumidifi-



Coil Selection

- There are too many coil sizing tools:
  - ❑ Greenheck: https://www.greenheck.com/resources/software/coil-software-selection-program
  - ❑ CoilCalc: http://www.coilcalc.com/

Coil Selection

- For Greenheck:

GREENHECK
Building Value in Air.

JOB SUMMARY

, USA

888-921-COIL (2645)
200 Morgan Street
Brownsville, TN 38012

Selection Summary

Tag	Comment	Model	Quantity
C-1		HW58S01B14-54x36-RH	12

Coil Selection

- For Greenheck:

SUBMITTAL DATA

GREENHECK
Building Value in Air.

Greenheck Coil C-1

888-921-COIL (2645)
200 Morgan Street
Brownsville, TN 38012

Hot Water Coil

Tag	Qty	Model	Footnotes	Comment
C-1	12	HW58S01B14-54x36-RH	a,b	

Construction and Performance Details

Tag	C-1
Air flow (SCFM)	67335
Altitude (ft)	0
Total capacity (MBH)	2489.5
Entering dry bulb (°F)	55.0
Leaving dry bulb (°F)	89.1
Face velocity (ft/min)	416
Air pressure drop (in of water)	0.12
Air fouling factor (h·ft²·°F/Btu)	0.00000
Fluid	W
Entering fluid temp. (°F)	180.0
Leaving fluid temp. (°F)	95.7
Fluid flow rate (GPM)	60.0
Fluid velocity (ft/s)	2.73
Fluid pressure drop (ft of water)	5.8
Fluid fouling factor (h·ft²·°F/Btu)	0.00000
Fluid freezing temp. (°F)	32.0
Min. tube wall temp. (°F)	83.3
Coils per bank	12
Coil type	5/8
Fin height (in)	54.0
Fin length (in)	36.0
Face area (ft²)	162.00
Rows	1
Fin spacing (fins/in)	14
Fin material	Al
Fin type	Sine
Fin thickness (in)	0.006
Tube wall thickness (in)	0.020
Turbulators	No
Number of feeds	2
Supply conn. size (in)	0.750
Return conn. size (in)	0.750
Weight (lb)	69
Est. operating wt. (lb)	82
Est. internal volume (ft³)	0.25

Footnotes

(a) Certified in accordance with the AHRI Forced-Circulation Air-Cooling and Air-Heating Coils Certification Program which is based on AHRI Standard-410 within the Range of Standard Rating Conditions listed in Table 1 of the Standard. Certified units may be found in the AHRI Directory at www.ahridirectory.com.

Coil Selection

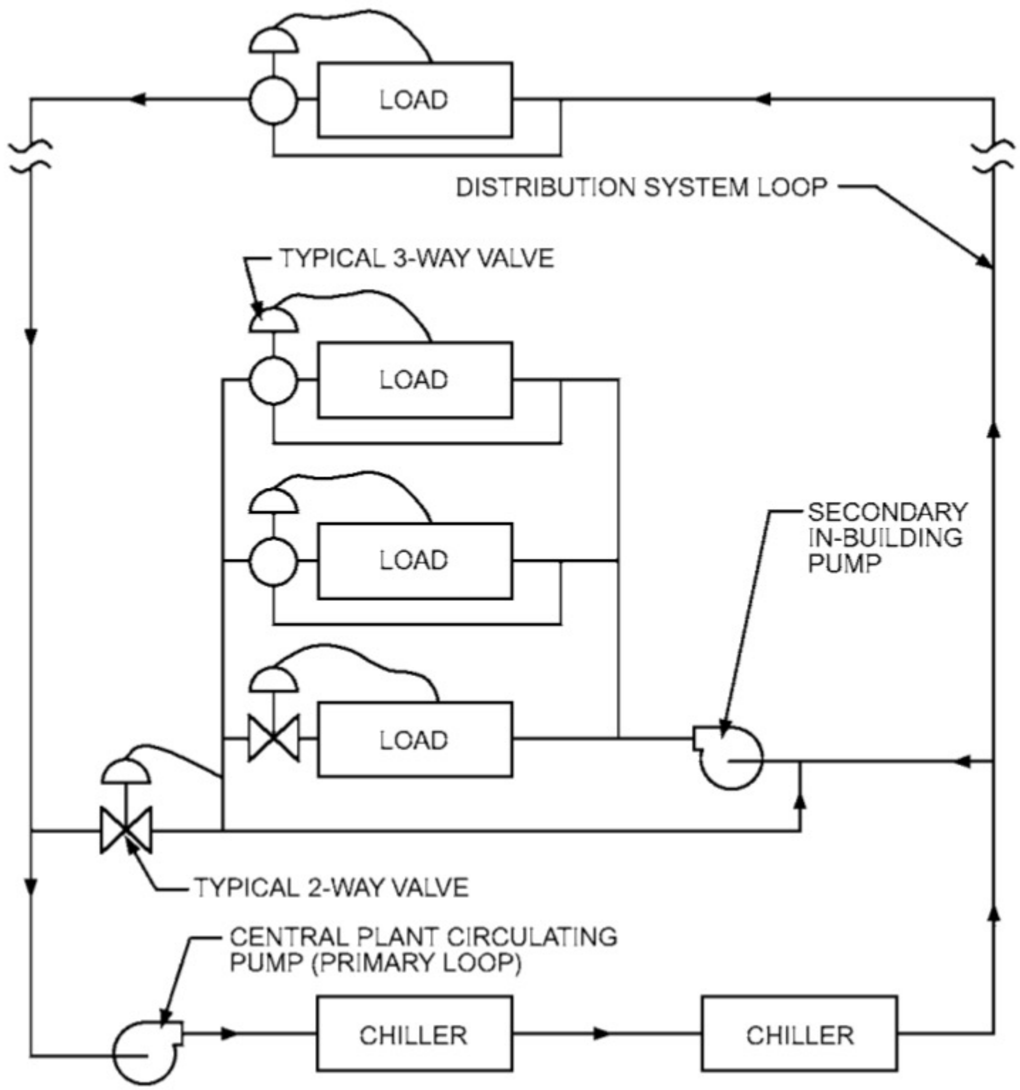
- For Greenheck, you can use the following steps:

https://docs.google.com/document/d/1jp7TtvRoR_WWA4Dgi8ve-x4jNaz8c0pyK56guhv9MTo/edit#heading=h.37y7dtapaf

PRIMARY AND SECONDARY SYSTEMS

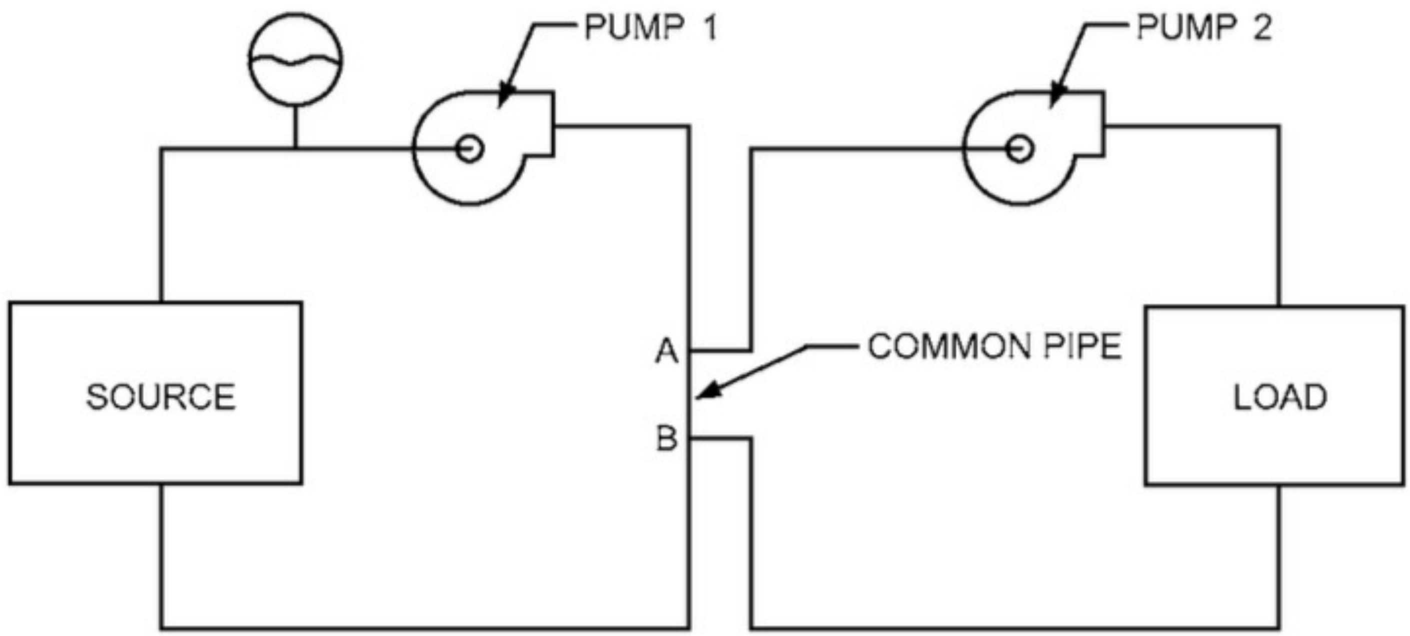
Primary and Secondary Systems

- Constant-flow primary distribution with secondary pumping:



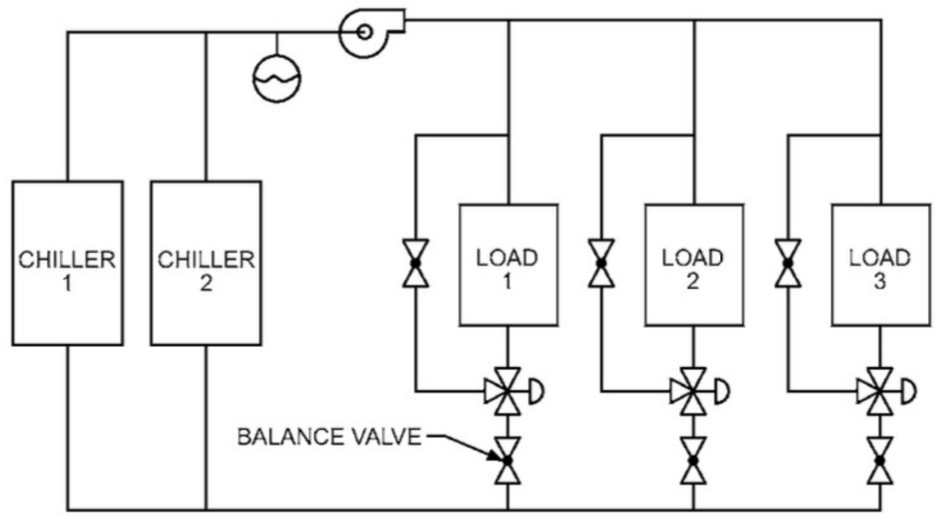
Primary and Secondary Systems

- Compound pumping

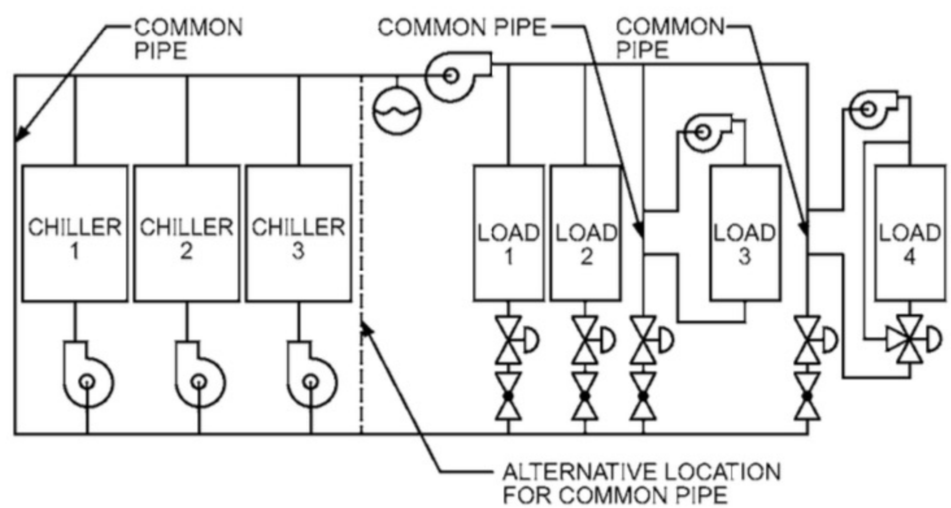


Primary and Secondary Systems

- Constant flow chilled water system

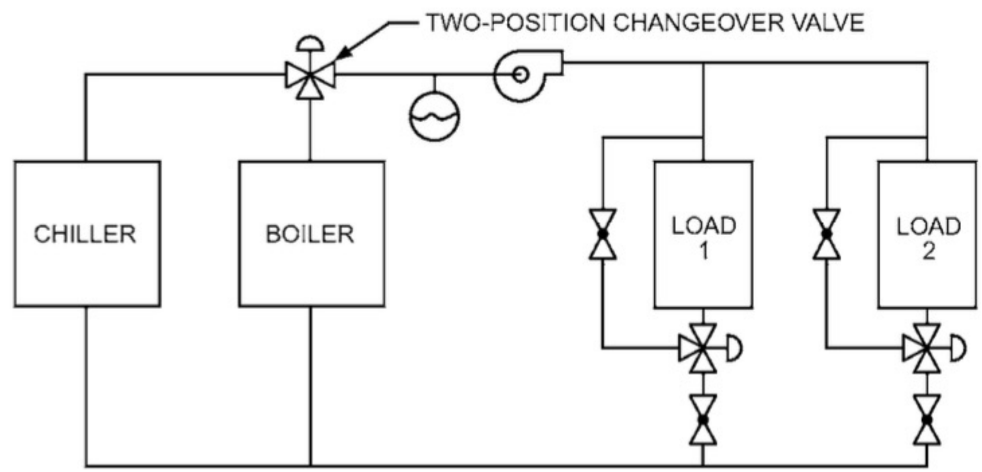


- Variable flow chilled water system

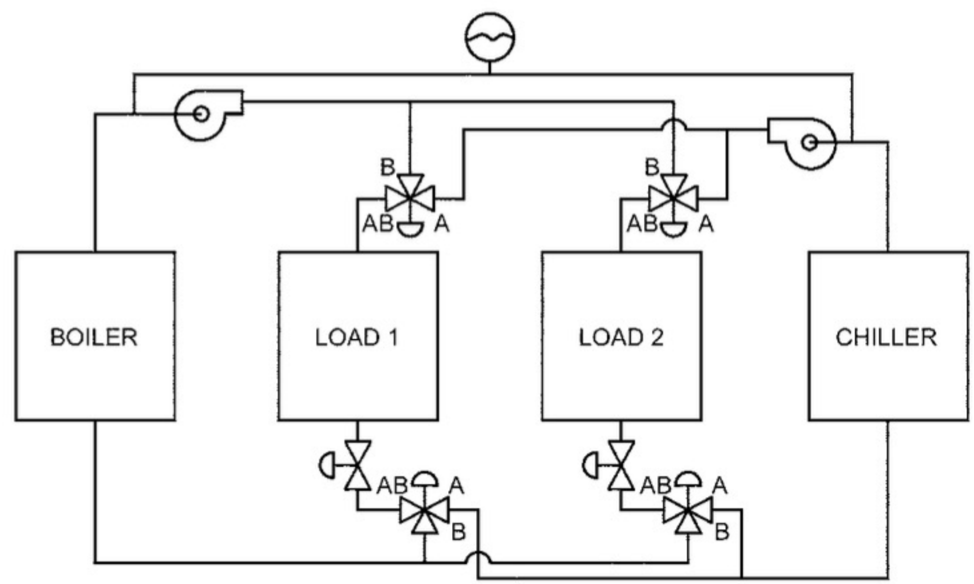


Primary and Secondary Systems

- Simplified two pipe diagram



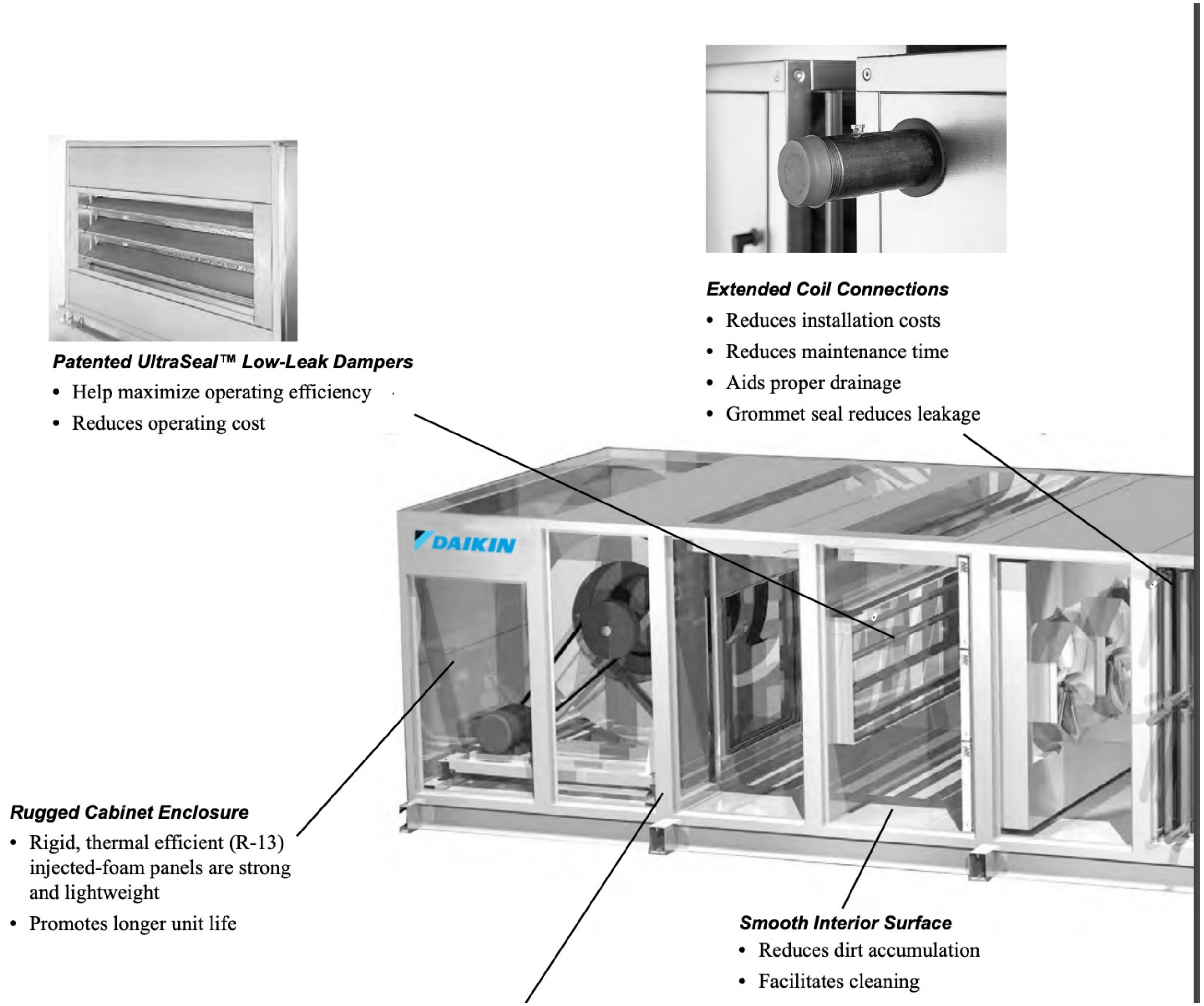
- Simplified four pipe diagram (common loads)



OTHER ITEMS

Other Items

- Account for all the head losses



https://www.daikinapplied.com/o365/api/graphapi/GetDocument/Doc100/CAT_565-2_Vision_107-169_AH-Ext.pdf/

Other Items

- Account for all the head losses

Table 6: Component Pressure Drops (Inches of Water)

Unit Size	CFM	Dampers		Face & BP face		Face & BP by-pass		Plenum		Diffuser	Blender**			Attenuator		
		MXB	Econ.	Int. med.	External Large	Int. med.	External Large	Top inlet	Top outlet		One	Two	Three	3 ft.	4 ft.	5 ft.
107	29100	0.08	0.08	0.02	0.02	0.21	0.11	0.06	0.01	0.15	0.03	0.17	-	0.02	0.02	0.02
	38750	0.08	0.08	0.03	0.02	0.38	0.11	0.05	0.01	0.15	0.05	0.30	-	0.03	0.04	0.05
	48400	0.08	0.08	0.05	0.03	0.59	0.17	0.06	0.02	0.15	0.08	0.47	-	0.05	0.07	0.08
	58100	0.08	0.08	0.07	0.05	0.85	0.24	0.06	0.03	0.15	0.11	-	-	0.07	0.10	0.11
124	33600	0.07	0.07	0.02	0.01	0.21	0.06	0.06	0.01	0.15	0.02	0.09	0.33	0.02	0.02	0.03
	44800	0.07	0.07	0.04	0.02	0.43	0.12	0.06	0.02	0.15	0.04	0.18	-	0.03	0.05	0.06
	55900	0.07	0.07	0.05	0.03	0.57	0.16	0.06	0.02	0.15	0.05	0.25	-	0.04	0.07	0.08
	67100	0.08	0.08	0.07	0.04	0.82	0.23	0.06	0.03	0.15	0.07	0.35	-	0.06	0.10	0.12
141	40300	0.07	0.07	0.02	0.01	0.16	0.06	0.06	0.01	0.15	0.03	0.14	-	0.02	0.03	0.03
	53650	0.07	0.07	0.04	0.02	0.29	0.11	0.06	0.02	0.15	0.05	0.24	-	0.03	0.05	0.05
	67100	0.08	0.08	0.06	0.03	0.45	0.17	0.06	0.02	0.15	0.08	0.38	-	0.05	0.08	0.09
	80600	0.08	0.08	0.09	0.05	0.64	0.24	0.06	0.03	0.15	0.11	-	-	0.07	0.11	0.13
160	45600	0.08	0.08	0.02	0.01	0.16	0.06	0.06	0.01	0.15	0.04	0.12	0.35	0.02	0.03	0.03
	60900	0.08	0.08	0.04	0.02	0.28	0.10	0.06	0.02	0.15	0.07	0.21	-	0.03	0.05	0.05
	76100	0.08	0.08	0.06	0.03	0.43	0.16	0.06	0.02	0.15	0.11	0.33	-	0.05	0.08	0.09
	91400	0.08	0.08	0.09	0.05	0.62	0.24	0.06	0.04	0.15	0.16	0.48	-	0.07	0.12	0.13
169	48400	0.08	0.08	0.02	0.01	0.18	0.06	0.06	0.01	0.15	0.05	0.09	0.29	0.02	0.03	0.03
	64500	0.08	0.08	0.04	0.02	0.31	0.10	0.06	0.02	0.15	0.08	0.16	-	0.03	0.05	0.05
	80600	0.08	0.08	0.06	0.03	0.49	0.16	0.06	0.02	0.15	0.13	0.25	-	0.05	0.08	0.09
	96700	0.07	0.07	0.08	0.04	0.71	0.23	0.06	0.04	0.15	0.18	0.36	-	0.07	0.11	0.13

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Other Items

- Account for all flow rate (both chiller and boiler)

5 CHILLED WATER COIL(24 ins)					SECTION 3
Coil model	5WM1005C		Number of coils	2	
Total capacity	1937893	Btu/h	Number of rows	5	
Sensible capacity	1351492	Btu/h	Fins per inch	10	
Air volume	48400	cfm			
Entering db/wb	80.0 / 67.0	F	Entering water	45.0	F
Leaving db/wb	54.5 / 54.0	F	Leaving water	55.0	F
Finned height x length	45 x 155	ins	Water flow rate	387.60	gpm
Face area	96.88	ft2	Water pressure drop	18.90	ftHD
Face velocity	500	ft/m	Water velocity	4.60	ft/s
Coil air pressure drop	1.00	ins WC			
			Fluid volume	62.0	gal
			Fluid weight	523.00	lb
Connection type	Threaded		Fin material	Aluminum (.0075)	
Connection Qty x size	2 x 3.00	ins	Tube material	Copper (.020)	
Connection location	Drive side		Header material	Copper	
Connection material	Carbon steel		Case material	Galv. steel	
Glycol type (%)	- (0 %)		Drain pan	Stainless steel	
Fouling Factor	0		Drain pan side	Drive side	
			Turbospirals	None	
Coil code	5WM1005C		Electro-fin coat	None	
DOOR DATA					
Door location	Drive side		Window size	None	
Door width	8	ins	Light	Marine light kit and switch only	
Door opening	Outward				

https://www.daikinapplied.com/o365/api/graphapi/GetDocument/Doc100/CAT_565-2_Vision_107-169_AH-Ext.pdf/

Other Items

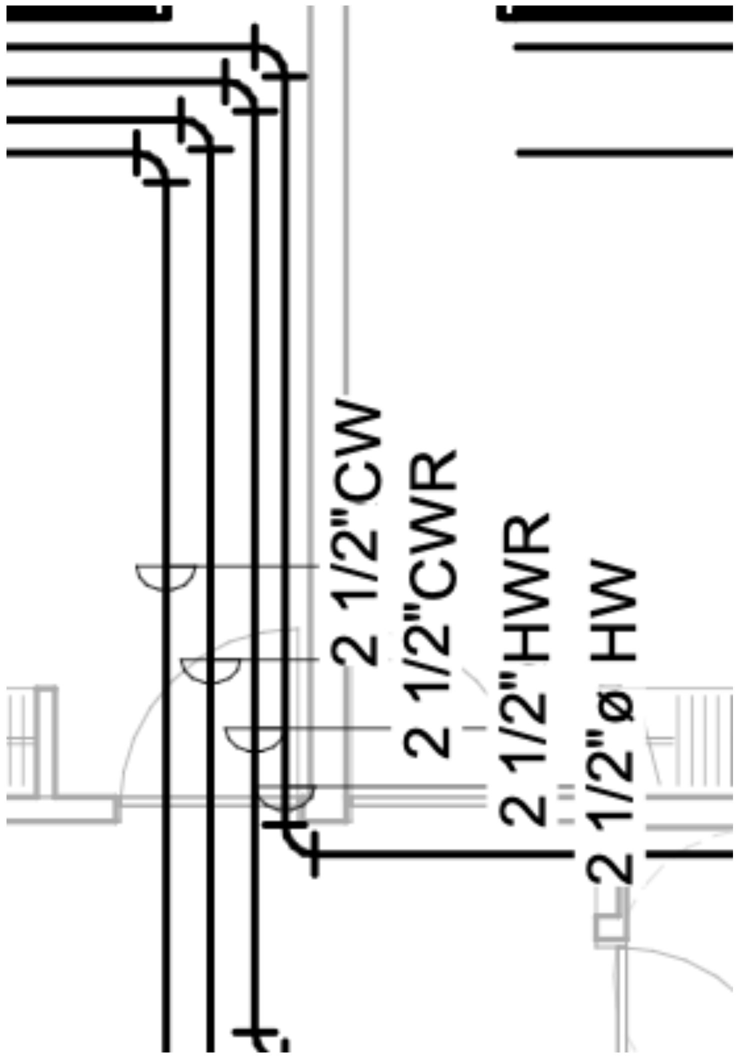
- Make sure to adjust your flow rate (i.e., chiller or boiler) based on the requirements of boilers, chillers

Table 29 — 30XA Minimum and Maximum Cooler Flow Rates

ITEM					MINIMUM		MAXIMUM	
Cooler Leaving Water Temperature*					40 F (4.4 C)		60 F (15 C)	
Cooler Entering Water Temperature†					45 F (7.2 C)		70 F (21.1 C)	
30XA UNIT SIZE	Nominal Flow Rate		Cooler	Number of Passes	Minimum Flow Rate**		Maximum Flow Rate	
	(gpm)	(L/s)			(gpm)	(L/s)	(gpm)	(L/s)
			Standard, Flooded	2	134	8.5	538	33.9
140	317.8	20.1	Plus One Pass, Flooded	3	73	4.6	293	18.5
			Minus One Pass, Flooded	1	324	20.4	1296	81.8
142	303.5	19.1	DX Cooler	—	152	9.6	607	38.2
			Standard, Flooded	2	165	10.4	660	41.6
160	365.1	23	Plus One Pass, Flooded	3	98	6.2	391	24.7
			Minus One Pass, Flooded	1	354	22.3	1418	89.5
162	347	21.9	DX Cooler	—	174	10.9	694	43.7
			Standard, Flooded	2	202	12.7	807	50.9
180	409.6	25.8	Plus One Pass, Flooded	3	73	4.6	391	24.7
			Minus One Pass, Flooded	1	416	26.2	1662	104.9
182	401.7	25.3	DX Cooler	—	201	12.6	803	50.6
			Standard, Flooded	2	223	14.1	892	56.3
200	463.9	29.3	Plus One Pass, Flooded	3	98	6.2	391	24.7
			Minus One Pass, Flooded	1	458	28.9	1833	115.6
202	447.1	28.2	DX Cooler	—	224	14.1	894	56.3
			Standard, Flooded	2	235	14.8	941	59.4
220	505.9	31.9	Plus One Pass, Flooded	3	122	7.7	489	30.9
			Minus One Pass, Flooded	1	501	31.6	2004	126.4
222	493	31.1	DX Cooler	—	246	15.5	950	59.9
			Standard, Flooded	2	266	16.8	1063	67.1
240	545.8	34.4	Plus One Pass, Flooded	3	147	9.3	587	37.0
			Minus One Pass, Flooded	1	538	33.9	2151	135.7
242	530	33.5	DX Cooler	—	265	16.7	950	59.9
			Standard, Flooded	2	257	16.2	1027	64.8
260	600.3	37.9	Plus One Pass, Flooded	3	141	8.9	562	35.5
			Minus One Pass, Flooded	1	584	36.8	2334	147.3
262	583	36.8	DX Cooler	—	292	18.4	950	59.9
			Standard, Flooded	2	293	18.5	1173	74.0
280	642.2	40.5	Plus One Pass, Flooded	3	141	8.9	562	35.5
			Minus One Pass, Flooded	1	620	39.1	2481	156.5
282	627	39.5	DX Cooler	—	313	19.8	950	59.9
			Standard, Flooded	2	327	20.6	1308	82.5
300	687.5	43.4	Plus One Pass, Flooded	3	174	11	697	44.0
			Minus One Pass, Flooded	1	687	43.3	2750	173.5
302	665	42.0	DX Cooler	—	333	21.0	1331	83.9
			Standard, Flooded	2	361	22.8	1442	91.0
325	733.4	46.3	Plus One Pass, Flooded	3	211	13.3	843	53.2
			Minus One Pass, Flooded	1	724	45.7	2897	182.8
327	720	45.4	DX Cooler	—	360	22.7	1440	90.8
			Standard, Flooded	2	379	23.9	1516	95.6
350	775.4	48.9	Plus One Pass, Flooded	3	244	15.4	978	61.7
			Minus One Pass, Flooded	1	767	48.4	3068	193.6
352	757	47.8	DX Cooler	—	379	23.9	1514	95.5

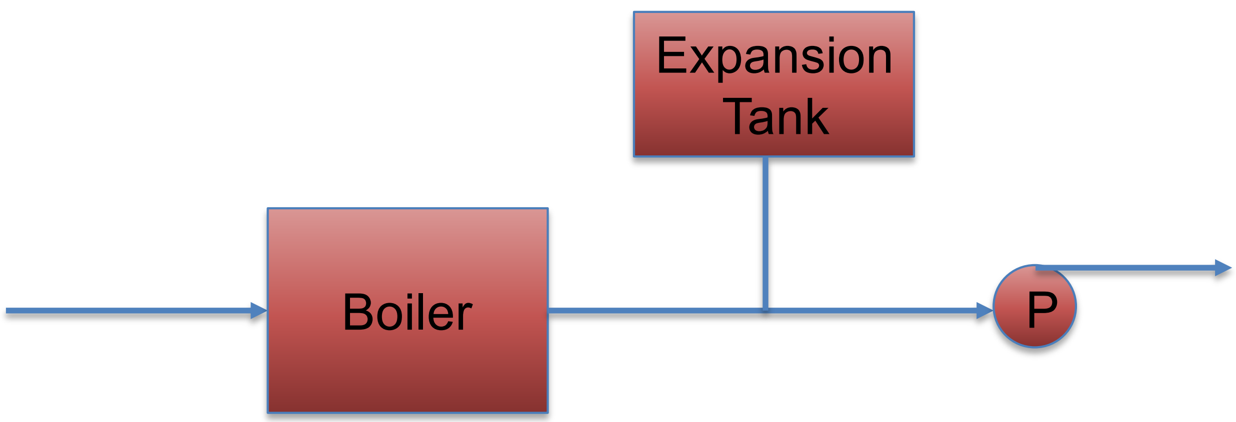
Other Items

- Add descriptions:



Design Procedure

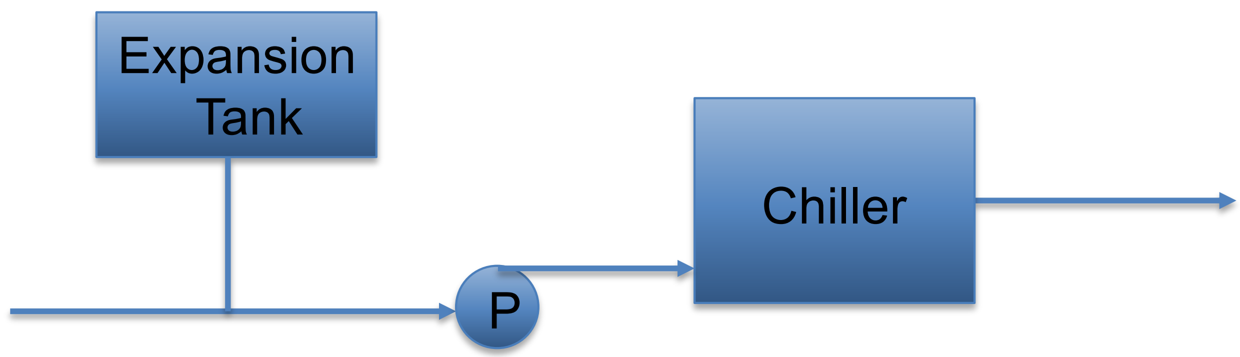
- The usual sequence of heating system equipment is the boiler, expansion tank and pump



- The one location where the absolute pressure stays constant is at the “expansion tank”

Design Procedure

- The usual sequence of cooling system equipment is the expansion tank, pump and chiller



- If the expansion tank is placed after the pump, the outlet pressure remains constant and the inlet pressure drops, which may cause cavitation

Design Procedure

- Point of no pressure change for the expansion chambers:
  - The system connection of an expansion is known as “the point of no pressure change”
  - The pressure will always have the same as the pressure inside the tank
  - This is true if the tank is a plain steel or bladder/diaphragm type
  - This is also true whether the system pump is on or off
  - This pressure is only changed as water or air are added to or removed from the tank

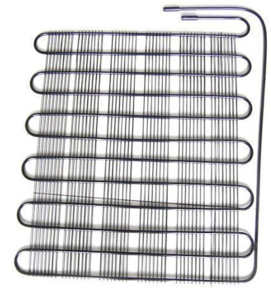
HOW TO PREPARE SUBMITTALS

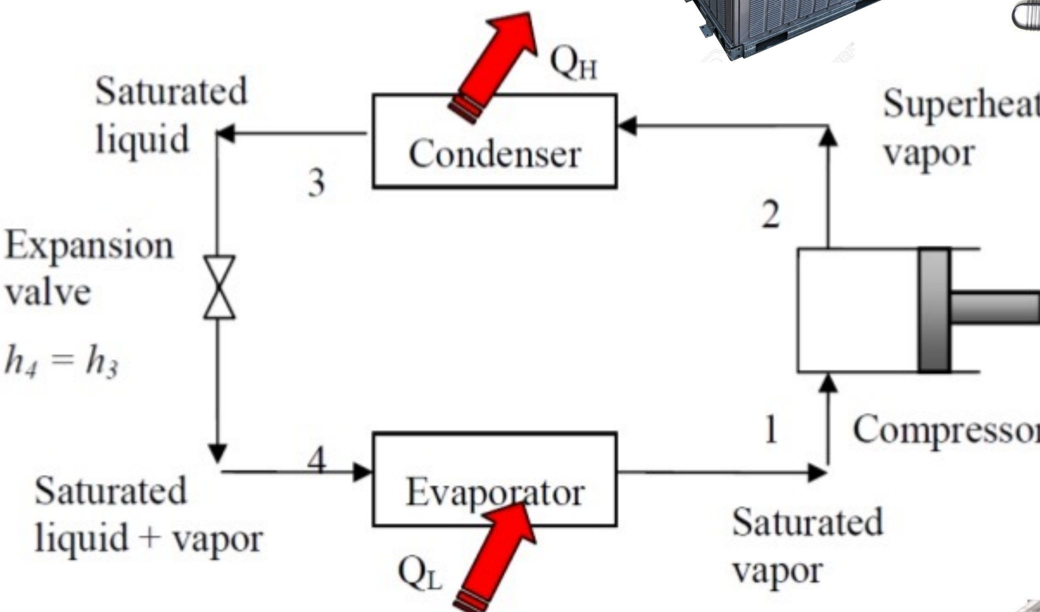
How to Prepare Submittals

INTRO TO VAPOR COMPRESSION CYCLE

Intro to Vapor Compression Cycle

- Vapor compression cycle

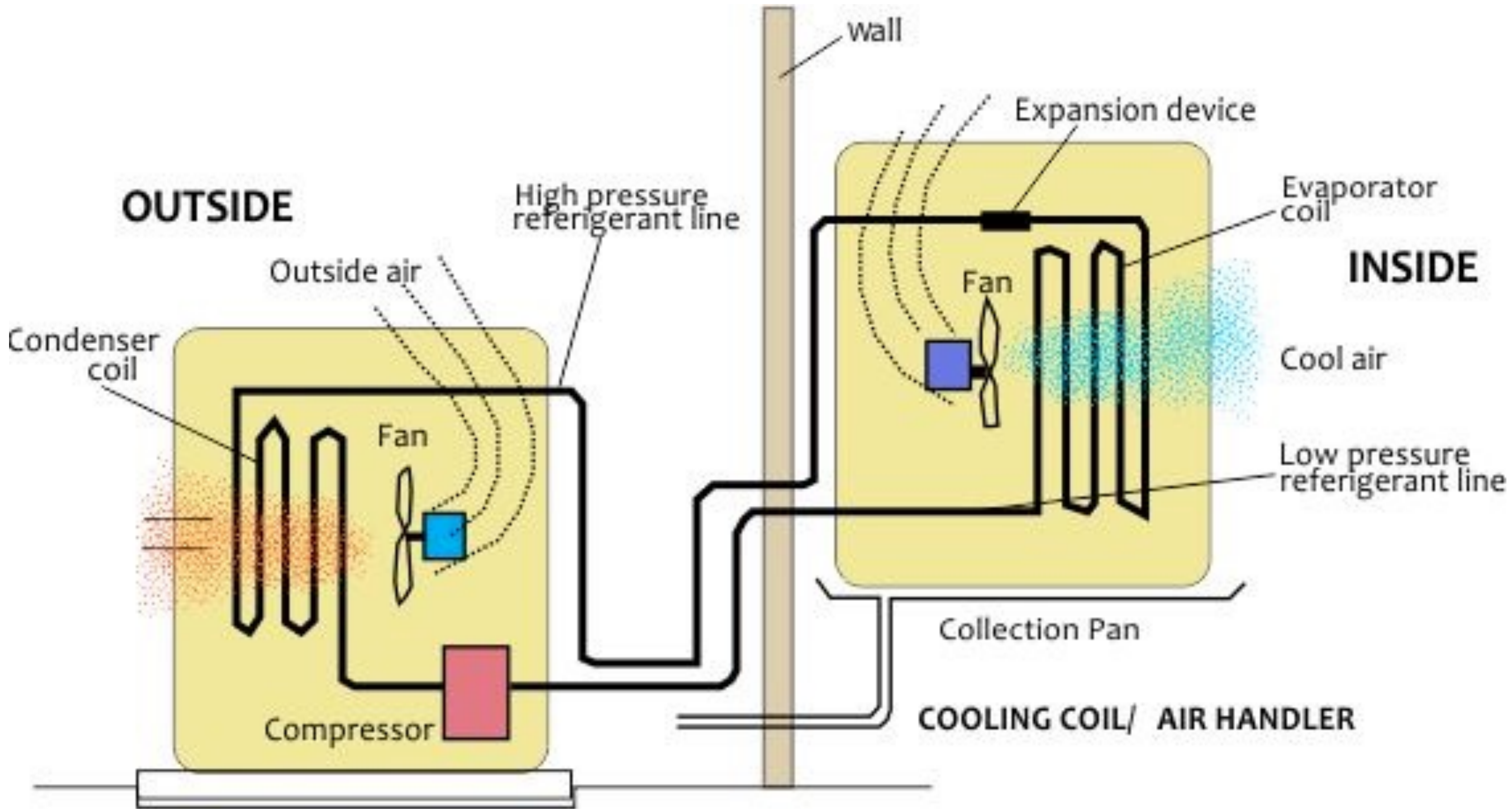




https://www.slideshare.net/ilovemylifesomuch/simple-vapour-compression-refrigeration-system http://valveproducts.net/expansion-valve/guides-to-choose-a-expansion-valve, https://www.indiamart.com/proddetail/refrigerator-condenser-16049771448.html
https://www.webstaurantstore.com/taylor-057011-58-compressor/HP05701158.html?utm_source=Google&utm_medium=cpc&utm_campaign=GoogleShopping&gclid=EAIaIQobChMIttzNpoGl4QIVgx-tBh0KVAIFEAQYAiABEgIS4_D_BwE
https://www.123rf.com/photo_41197404_commercial-cooling-hvac-air-conditioner-condenser-evaporator-fan-ac-unit-for-building-climate-contro.html

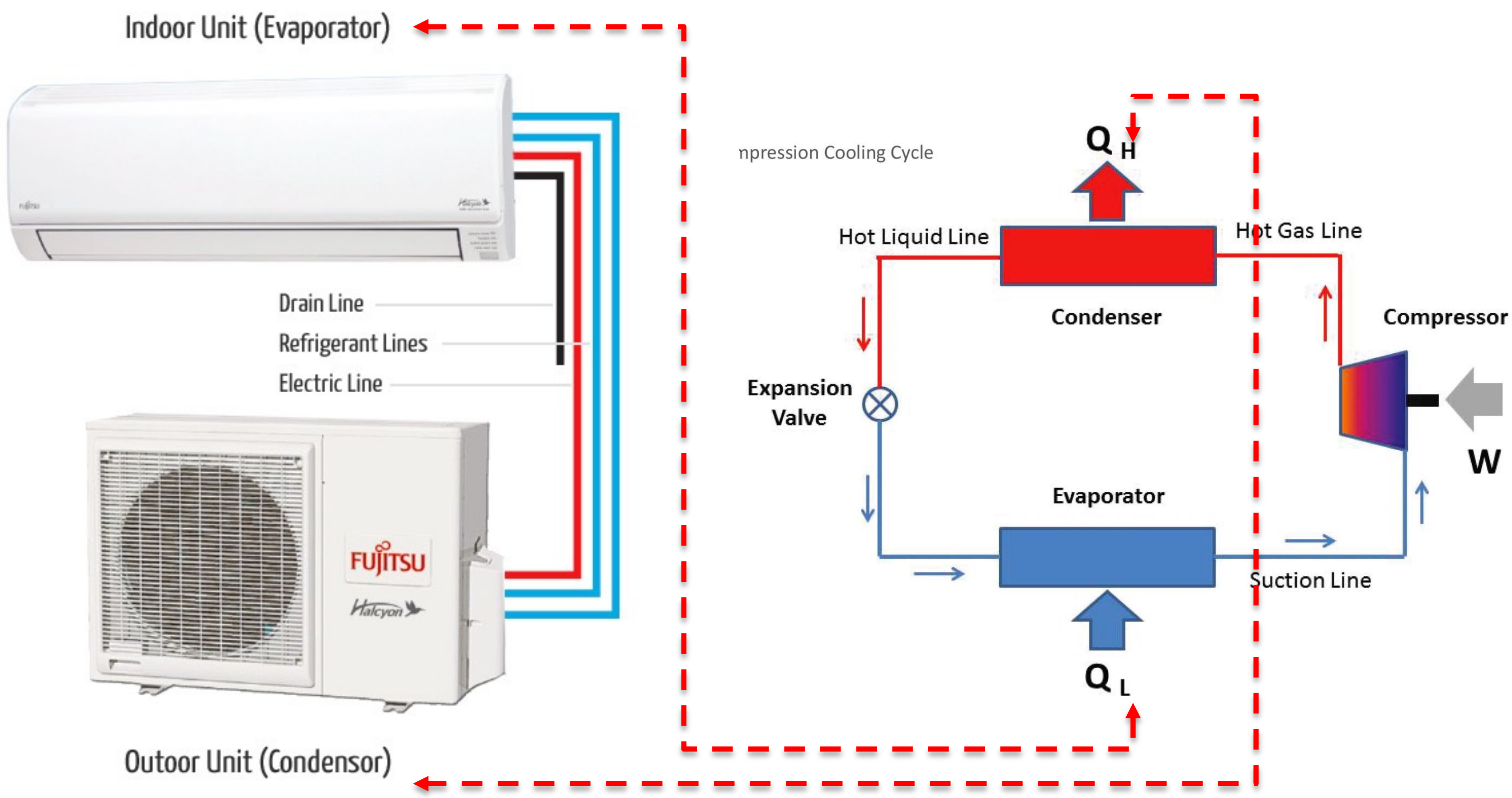
Intro to Vapor Compression Cycle

- Vapor compression cycle



http://www.nzeb.in/knowledge-centre/hvac-2/cooling-equipment/

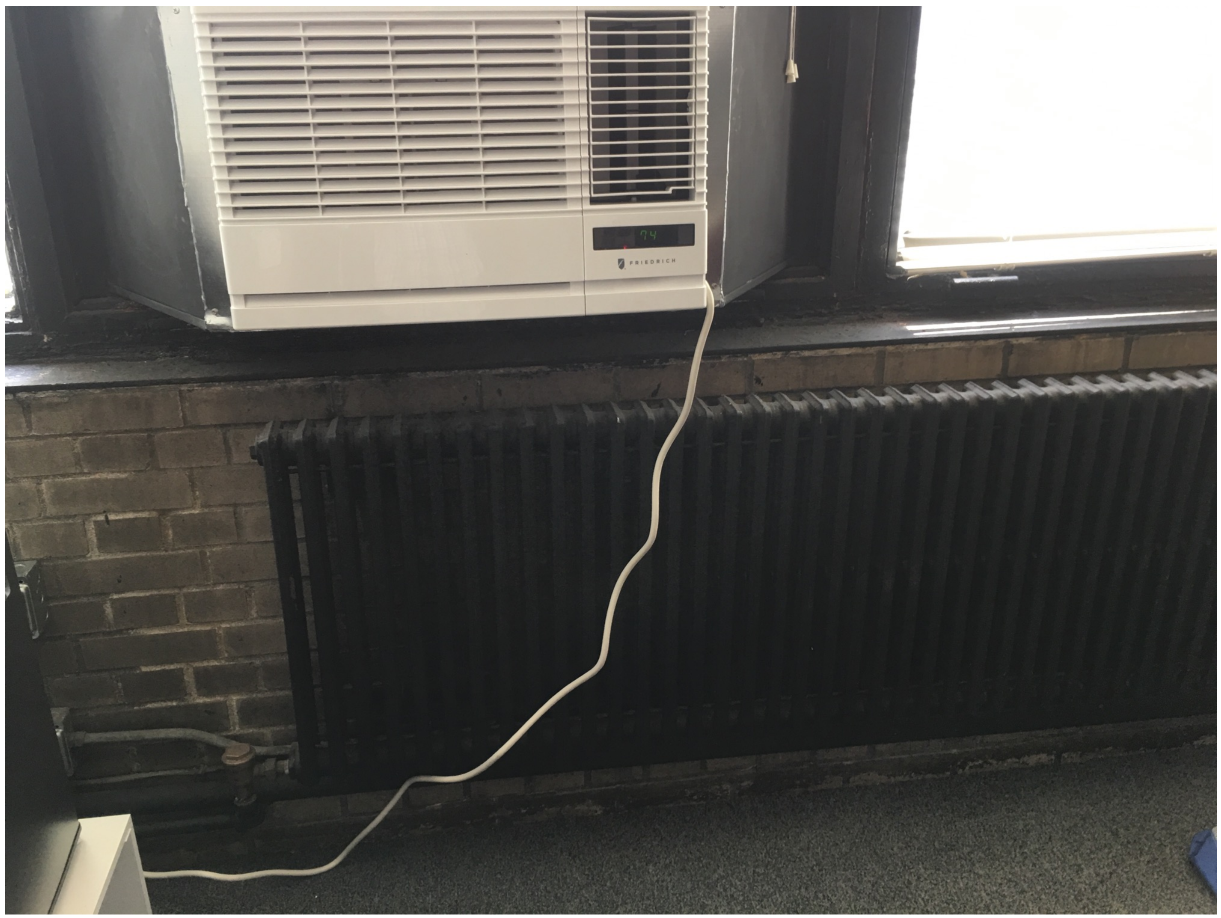
Intro to Vapor Compression Cycle



https://insulation.org/io/articles/understanding-thermal-systems-industrial-refrigeration-systems/ http://www.fujitsugeneral.com/us/residential/what-is-a-mini-split.html

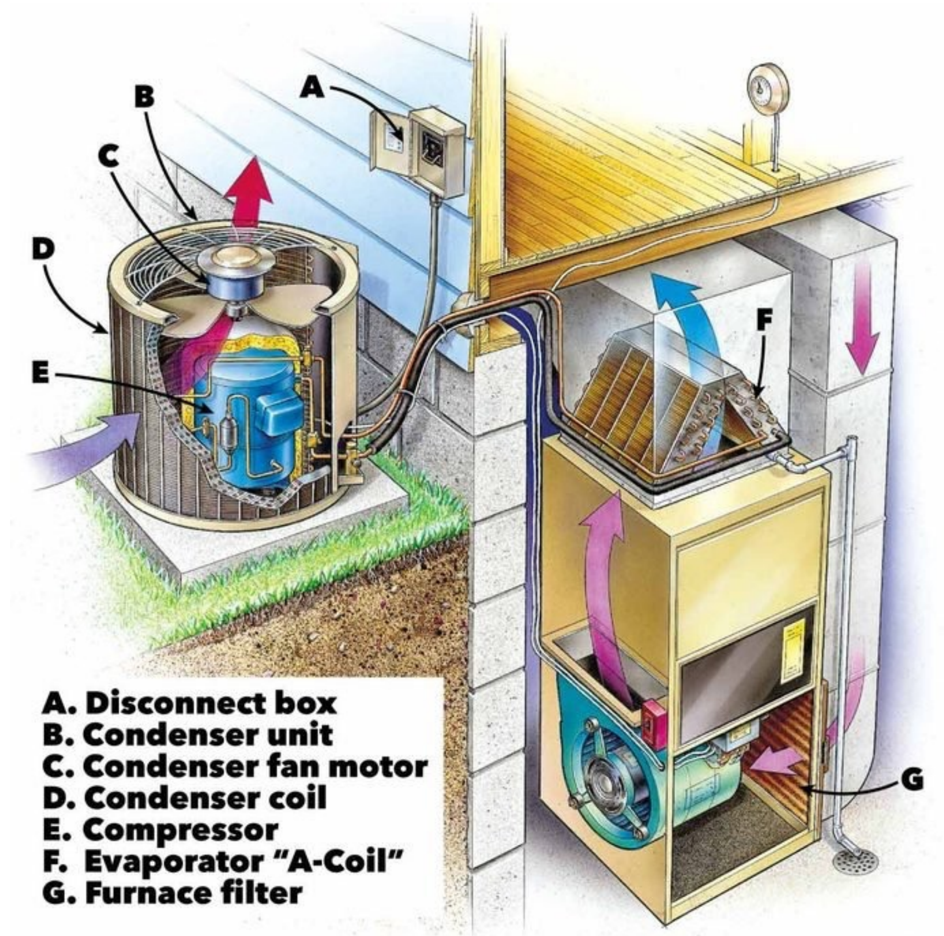
Into Vapor Compression Cycle

- One type of unitary or packaged terminal unit is Packaged Terminal Air Conditioning (PTAC)



Intro Vapor Compression Cycle

- Residential unitary systems
  - ❑ Two separate systems:
    - Furnace: Heating
    - AC: Cooling
  - ❑ Minimum maintenance required to change filter



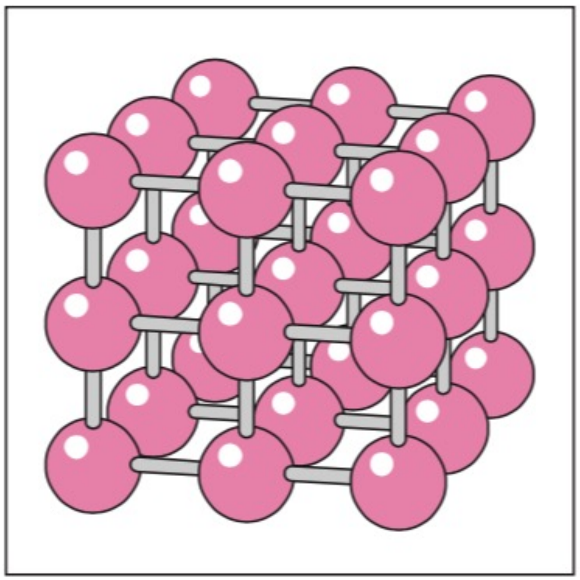
https://www.familyhandyman.com/project/diy-air-conditioner-repair/

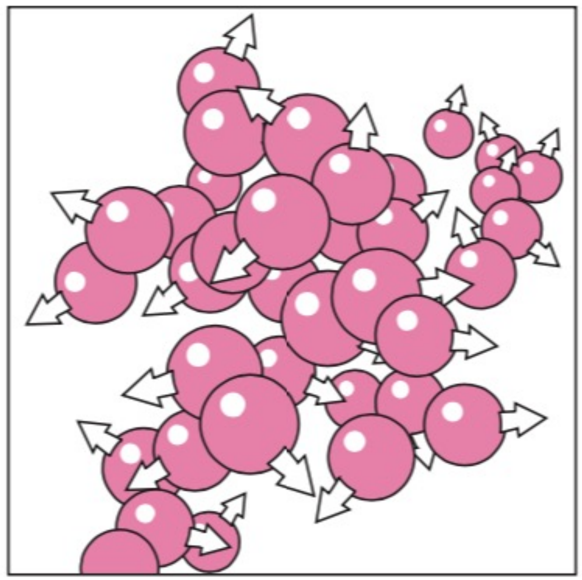
RECAP OF CAE 208/MMAE 320: PROPERTIES OF PURE SUBSTANCES

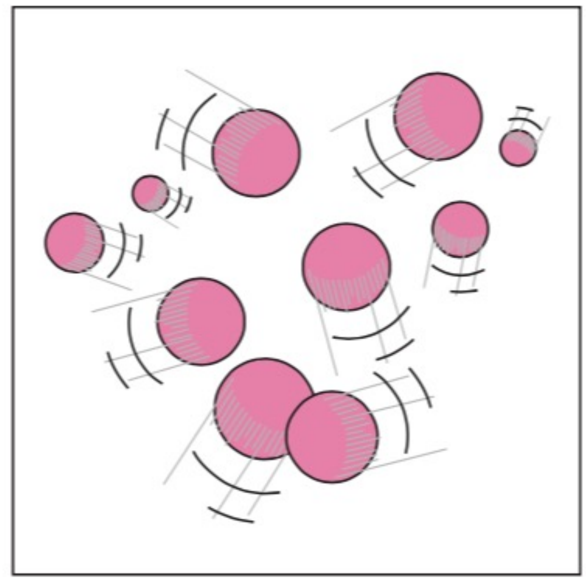
(From Thermodynamics By Cengel)

Properties of Pure Substances

- How many phases do exist?

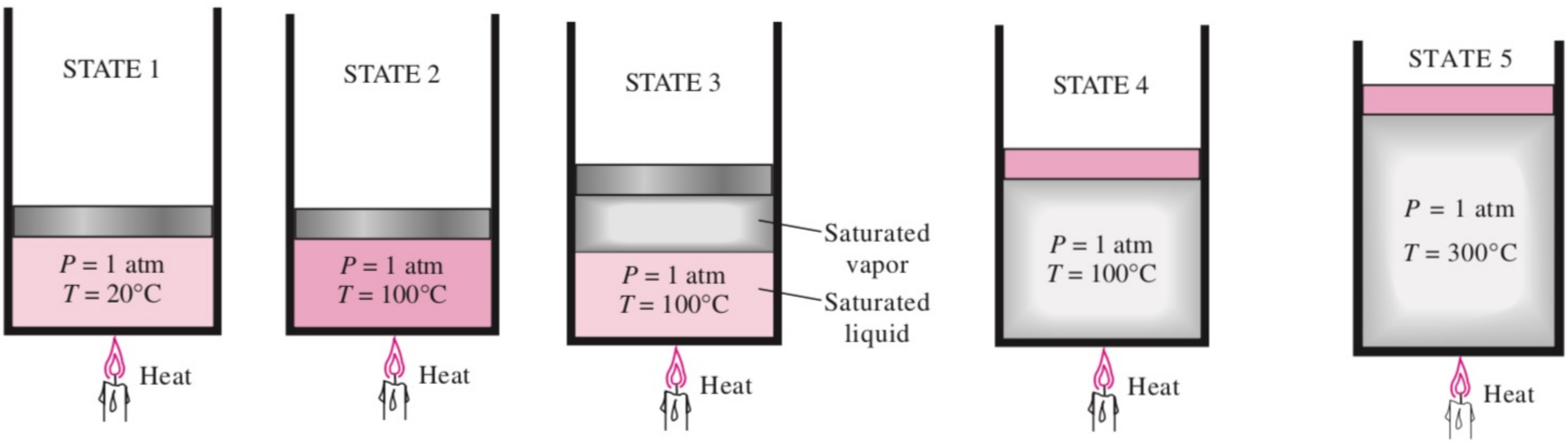






Properties of Pure Substances

- Let's assume heating up under a constant pressure



Subcooled Or Compressed liquid

Saturated liquid

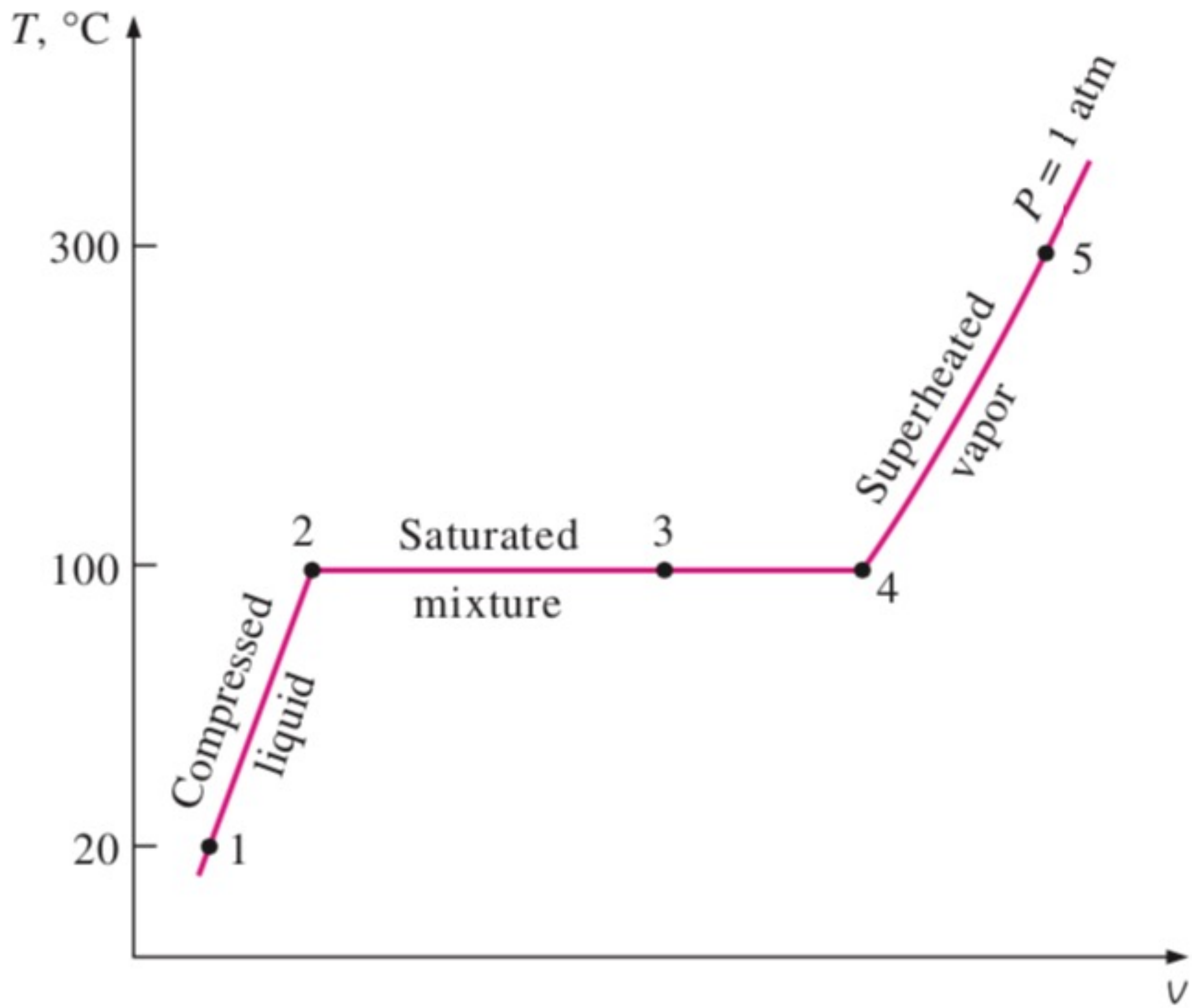
Saturated liquid + Saturated vapor

Saturated vapor

Superheated

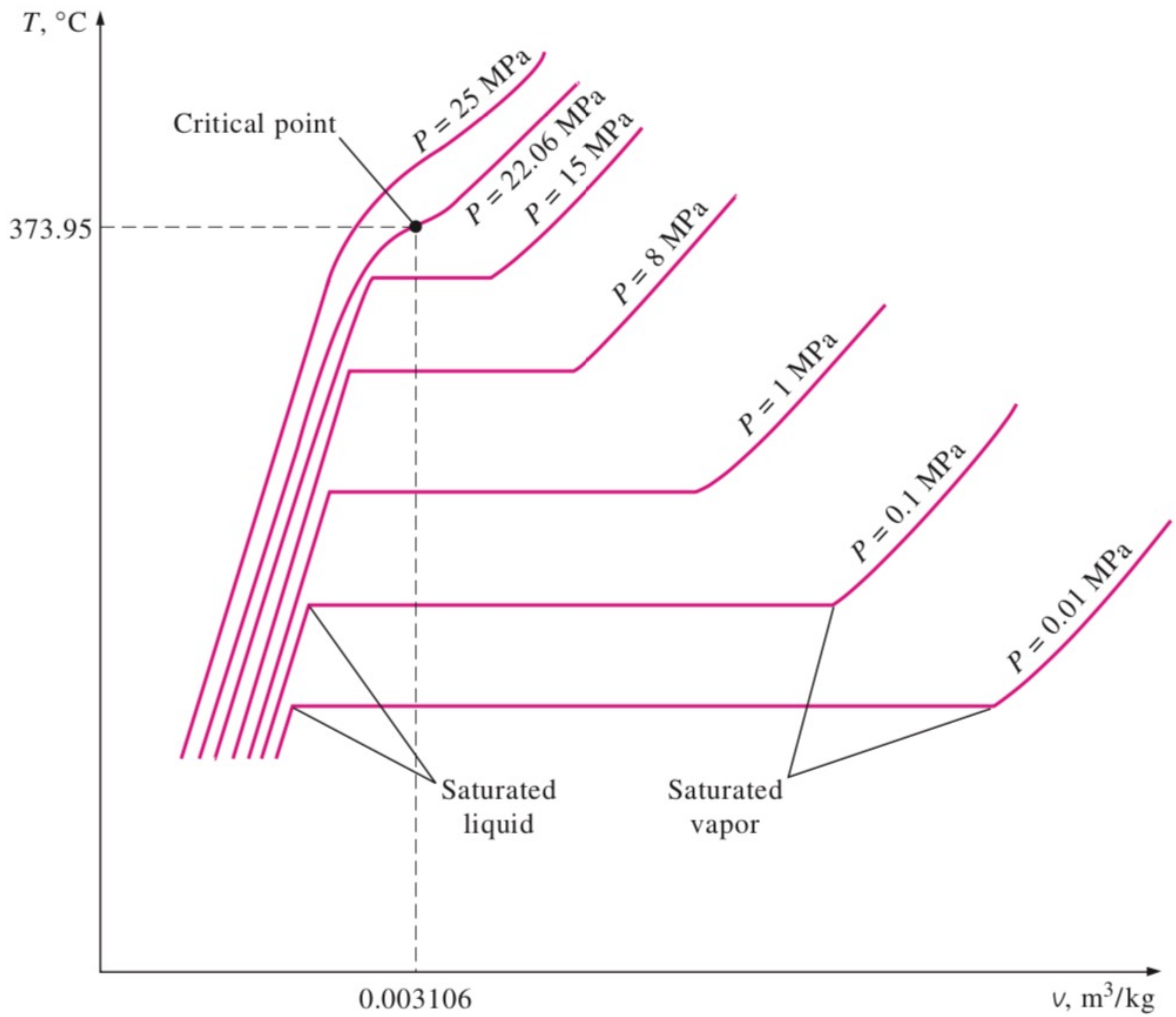
Properties of Pure Substances

- Let's put it in a temperature vs volume diagram



Properties of Pure Substances

- Let's put it in a temperature vs volume diagram

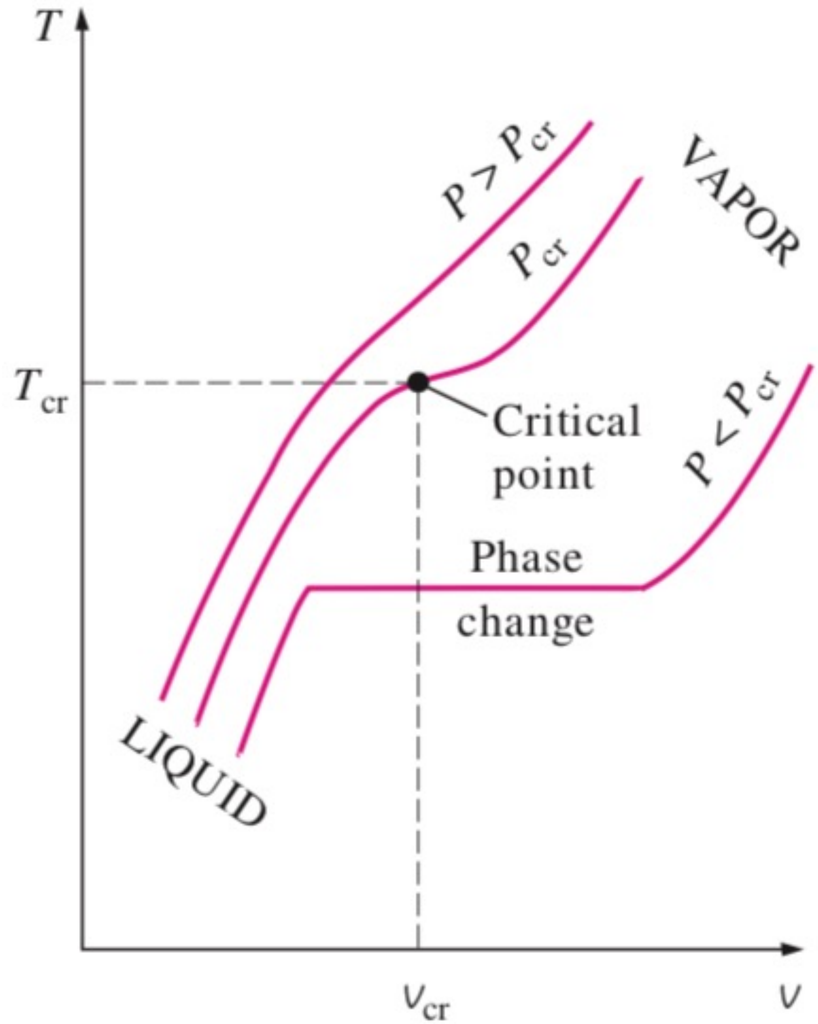


Properties of Pure Substances

- Why do we use pressure cookers in cooking?

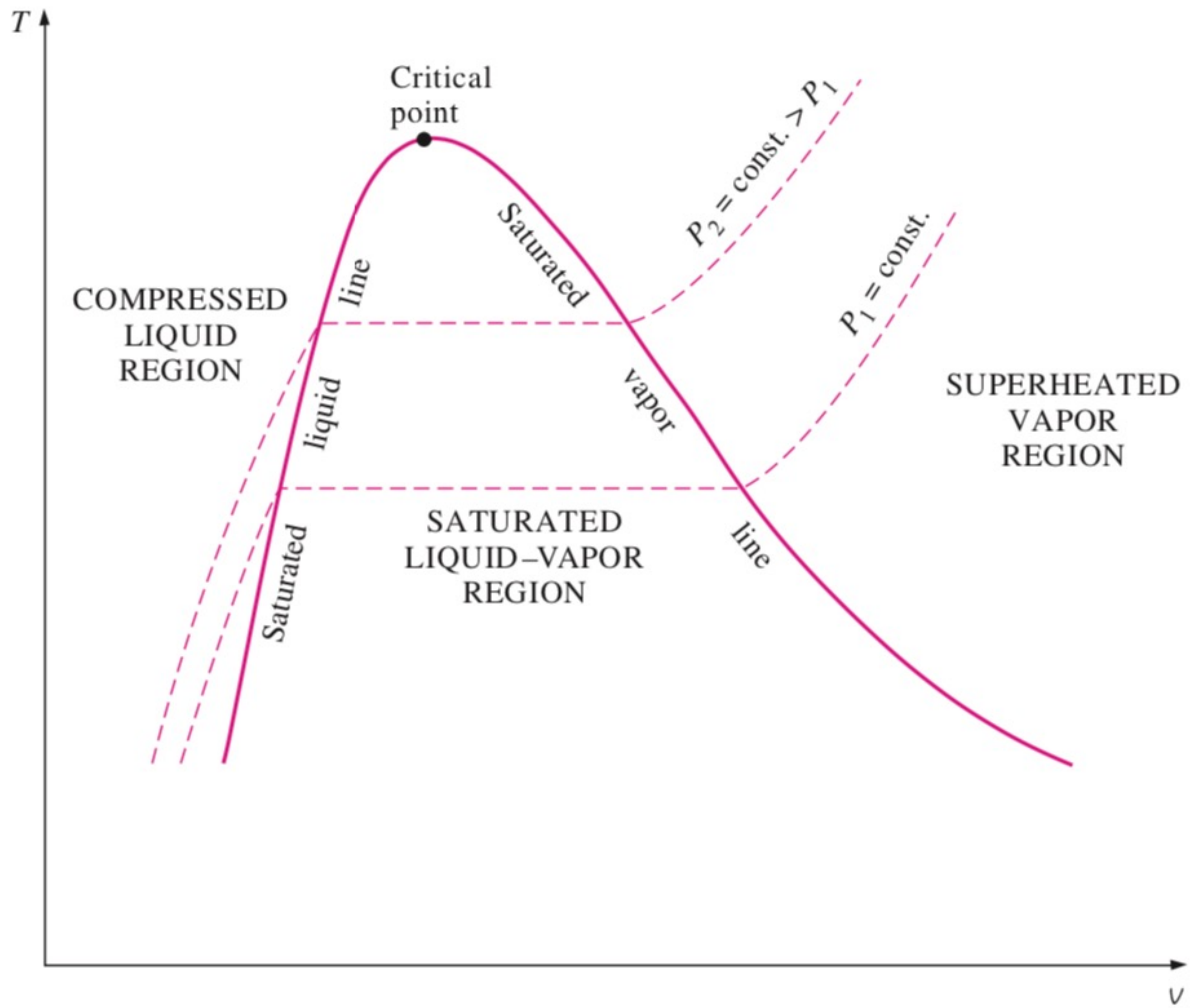
Properties of Pure Substances

- How do we define the critical point?



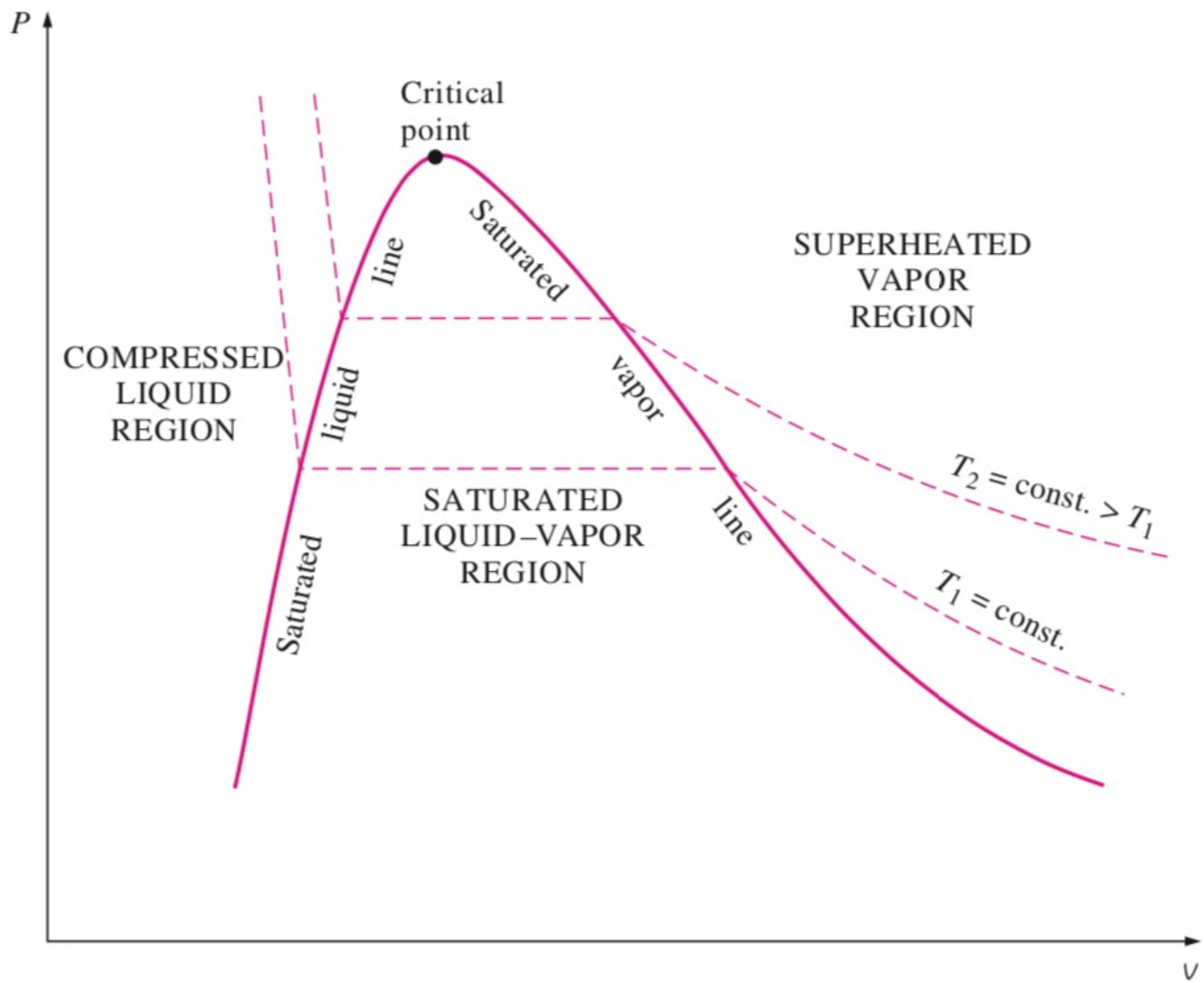
Properties of Pure Substances

- We can put all these lines and form a saturation dome



Properties of Pure Substances

- We can put all these lines and form a saturation curve



Properties of Pure Substances

- Let’s calculate some properties for a saturated liquid and vapor

v_f : Specific volume of saturated liquid

v_g : Specific volume of saturated vapor

v_{fg} : Different between v_f and v_g = $v_g - v_f$

Properties of Pure Substances

- Where do find them in the Handbook?

1.8 **2017 ASHRAE Handbook—Fundamentals**

Table 3 Thermodynamic Properties of Water at Saturation (*Continued*)

Temp., °F t	Absolute Pressure p_{ws}, psia	Specific Volume, ft³/lb$_w$ Sat. Solid v_i/v_f	Evap. v_{ig}/v_{fg}	Sat. Vapor v_g	Specific Enthalpy, Btu/lb$_w$ Sat. Solid h_i/h_f	Evap. h_{ig}/h_{fg}	Sat. Vapor h_g	Specific Entropy, Btu/lb$_w$·°F Sat. Solid s_i/s_f	Evap. s_{ig}/s_{fg}	Sat. Vapor s_g	Temp., °F t
–12	0.009700	0.01741	27490	27490	–164.46	1220.32	1055.86	–0.3365	2.7259	2.3895	–12
–11	0.010249	0.01741	26073	26073	–164.00	1220.30	1056.30	–0.3355	2.7198	2.3844	–11
–10	0.010827	0.01741	24736	24736	–163.54	1220.28	1056.74	–0.3344	2.7137	2.3793	–10
–9	0.011435	0.01741	23473	23473	–163.08	1220.26	1057.18	–0.3334	2.7077	2.3743	–9
–8	0.012075	0.01741	22279	22279	–162.62	1220.24	1057.63	–0.3324	2.7016	2.3692	–8
–7	0.012747	0.01742	21151	21152	–162.15	1220.22	1058.07	–0.3314	2.6956	2.3642	–7
–6	0.013453	0.01742	20086	20086	–161.69	1220.20	1058.51	–0.3303	2.6896	2.3593	–6
–5	0.014194	0.01742	19078	19078	–161.23	1220.17	1058.95	–0.3293	2.6837	2.3543	–5
–4	0.014974	0.01742	18125	18125	–160.76	1220.15	1059.39	–0.3283	2.6777	2.3494	–4
–3	0.015792	0.01742	17223	17223	–160.29	1220.12	1059.83	–0.3273	2.6718	2.3445	–3
–2	0.016651	0.01742	16370	16370	–159.83	1220.10	1060.27	–0.3263	2.6659	2.3396	–2
–1	0.017553	0.01742	15563	15563	–159.36	1220.07	1060.71	–0.3252	2.6600	2.3348	–1
0	0.018499	0.01743	14799	14799	–158.89	1220.04	1061.15	–0.3242	2.6542	2.3300	0
1	0.019492	0.01743	14076	14076	–158.42	1220.01	1061.59	–0.3232	2.6483	2.3251	1
2	0.020533	0.01743	13391	13391	–157.95	1219.98	1062.03	–0.3222	2.6425	2.3204	2
3	0.021625	0.01743	12742	12742	–157.48	1219.95	1062.47	–0.3212	2.6368	2.3156	3
4	0.022770	0.01743	12127	12127	–157.00	1219.92	1062.91	–0.3201	2.6310	2.3109	4
5	0.023971	0.01743	11545	11545	–156.53	1219.88	1063.35	–0.3191	2.6253	2.3062	5
6	0.025229	0.01743	10992	10992	–156.05	1219.85	1063.79	–0.3181	2.6196	2.3015	6
7	0.026547	0.01744	10469	10469	–155.58	1219.81	1064.23	–0.3171	2.6139	2.2968	7
8	0.027929	0.01744	9972	9972	–155.10	1219.77	1064.67	–0.3160	2.6082	2.2921	8
9	0.029375	0.01744	9501	9501	–154.62	1219.74	1065.11	–0.3150	2.6025	2.2875	9
10	0.030890	0.01744	9055	9055	–154.15	1219.70	1065.55	–0.3140	2.5969	2.2829	10
11	0.032476	0.01744	8631	8631	–153.67	1219.66	1065.99	–0.3130	2.5913	2.2783	11
12	0.034136	0.01744	8228	8228	–153.18	1219.61	1066.43	–0.3120	2.5857	2.2738	12
13	0.035874	0.01744	7846	7846	–152.70	1219.57	1066.87	–0.3109	2.5802	2.2692	13
14	0.037692	0.01745	7484	7484	–152.22	1219.53	1067.31	–0.3099	2.5746	2.2647	14
15	0.039593	0.01745	7139	7139	–151.74	1219.48	1067.75	–0.3089	2.5691	2.2602	15
16	0.041582	0.01745	6812	6812	–151.25	1219.44	1068.19	–0.3079	2.5636	2.2557	16
17	0.043662	0.01745	6501	6501	–150.77	1219.39	1068.63	–0.3069	2.5581	2.2513	17
18	0.045837	0.01745	6205	6205	–150.28	1219.34	1069.06	–0.3058	2.5527	2.2468	18
19	0.048109	0.01745	5925	5925	–149.79	1219.29	1069.50	–0.3048	2.5473	2.2424	19

Properties of Pure Substances

- Where do find them in the Handbook?

Refrigerant 718 (Water/Steam) Properties of Saturated Liquid and Saturated Vapor

Temp.,* °F	Pressure, psia	Density, lb/ft³ Liquid	Volume, ft³/lb Vapor	Enthalpy, Btu/lb Liquid	Enthalpy, Btu/lb Vapor	Entropy, Btu/lb·°F Liquid	Entropy, Btu/lb·°F Vapor	Specific Heat c_p, Btu/lb·°F Liquid	Specific Heat c_p, Btu/lb·°F Vapor	c_p/c_v Vapor	Vel. of Sound, ft/s Liquid	Vel. of Sound, ft/s Vapor	Viscosity, lb_m/ft·h Liquid	Viscosity, lb_m/ft·h Vapor	Thermal Cond., Btu/h·ft·°F Liquid	Thermal Cond., Btu/h·ft·°F Vapor	Surface Tension, dyne/cm	Temp.,* °F
32.02[a]	0.089	62.42	3299.7	0.00	1075.92	0.0000	2.1882	1.0086	0.4504	1.3285	4601	1342	4.333	0.0223	0.3244	0.00987	75.65	32.02
40	0.122	62.42	2443.3	8.04	1079.42	0.0162	2.1604	1.0055	0.4514	1.3282	4670	1352	3.738	0.0226	0.3293	0.01001	75.02	40
50	0.178	62.41	1702.8	18.08	1083.79	0.0361	2.1271	1.0028	0.4528	1.3278	4748	1365	3.159	0.0229	0.3353	0.01019	74.22	50
60	0.256	62.36	1206.0	28.10	1088.15	0.0556	2.0954	1.0010	0.4543	1.3275	4815	1378	2.712	0.0232	0.3413	0.01038	73.40	60
70	0.363	62.30	867.11	38.10	1092.50	0.0746	2.0653	0.9999	0.4558	1.3273	4874	1391	2.359	0.0236	0.3471	0.01058	72.57	70
80	0.507	62.21	632.38	48.10	1096.83	0.0933	2.0366	0.9993	0.4574	1.3272	4924	1403	2.074	0.0240	0.3527	0.01079	71.71	80
90	0.699	62.11	467.40	58.09	1101.15	0.1117	2.0093	0.9990	0.4591	1.3271	4967	1416	1.841	0.0244	0.3579	0.01101	70.84	90
100	0.951	61.99	349.84	68.08	1105.44	0.1297	1.9832	0.9989	0.4609	1.3272	5003	1428	1.648	0.0248	0.3628	0.01124	69.96	100
110	1.277	61.86	264.97	78.07	1109.71	0.1474	1.9583	0.9991	0.4628	1.3273	5033	1440	1.486	0.0252	0.3672	0.01148	69.05	110
120	1.695	61.71	202.95	88.06	1113.95	0.1648	1.9346	0.9993	0.4648	1.3276	5056	1452	1.348	0.0256	0.3713	0.01172	68.13	120
130	2.226	61.55	157.09	98.06	1118.17	0.1819	1.9118	0.9997	0.4671	1.3280	5075	1463	1.230	0.0260	0.3750	0.01198	67.19	130
140	2.893	61.38	122.82	108.06	1122.35	0.1987	1.8901	1.0003	0.4696	1.3285	5088	1475	1.128	0.0265	0.3783	0.01225	66.24	140
150	3.723	61.19	96.930	118.07	1126.49	0.2152	1.8693	1.0009	0.4723	1.3291	5097	1486	1.040	0.0269	0.3813	0.01253	65.27	150
160	4.747	61.00	77.184	128.08	1130.59	0.2315	1.8493	1.0016	0.4753	1.3299	5101	1497	0.962	0.0273	0.3839	0.01282	64.28	160
170	6.000	60.79	61.980	138.11	1134.65	0.2476	1.8302	1.0025	0.4787	1.3309	5101	1508	0.894	0.0278	0.3862	0.01312	63.28	170
180	7.520	60.58	50.169	148.14	1138.65	0.2634	1.8118	1.0035	0.4824	1.3320	5098	1518	0.834	0.0282	0.3881	0.01343	62.26	180
190	9.350	60.35	40.916	158.19	1142.60	0.2789	1.7942	1.0046	0.4865	1.3333	5090	1528	0.780	0.0287	0.3898	0.01375	61.23	190
200	11.538	60.12	33.609	168.24	1146.48	0.2943	1.7772	1.0059	0.4911	1.3348	5080	1538	0.732	0.0291	0.3912	0.01409	60.19	200
210	14.136	59.88	27.794	178.31	1150.30	0.3094	1.7609	1.0073	0.4961	1.3366	5066	1547	0.690	0.0296	0.3924	0.01444	59.13	210
211.95[b]	14.696	59.83	26.802	180.28	1151.04	0.3124	1.7578	1.0076	0.4971	1.3369	5063	1549	0.682	0.0297	0.3926	0.01451	58.92	211.95
220	17.201	59.63	23.133	188.40	1154.05	0.3244	1.7451	1.0088	0.5016	1.3386	5049	1557	0.651	0.0300	0.3934	0.01480	58.05	220
230	20.795	59.37	19.371	198.51	1157.72	0.3391	1.7299	1.0106	0.5077	1.3408	5029	1565	0.616	0.0305	0.3941	0.01517	56.96	230
240	24.986	59.10	16.314	208.63	1161.31	0.3537	1.7153	1.0125	0.5145	1.3434	5007	1574	0.585	0.0310	0.3947	0.01556	55.86	240
250	29.844	58.82	13.815	218.78	1164.81	0.3680	1.7011	1.0147	0.5218	1.3464	4981	1582	0.556	0.0314	0.3951	0.01596	54.74	250
260	35.447	58.53	11.759	228.95	1168.21	0.3823	1.6874	1.0170	0.5299	1.3496	4953	1590	0.530	0.0319	0.3953	0.01638	53.62	260
270	41.878	58.24	10.058	239.14	1171.52	0.3963	1.6741	1.0196	0.5387	1.3533	4923	1597	0.506	0.0324	0.3953	0.01680	52.47	270
280	49.222	57.94	8.6431	249.37	1174.71	0.4102	1.6612	1.0224	0.5483	1.3574	4890	1604	0.484	0.0328	0.3952	0.01725	51.32	280
290	57.574	57.63	7.4600	259.62	1177.79	0.4239	1.6487	1.0254	0.5586	1.3620	4855	1611	0.464	0.0333	0.3949	0.01770	50.16	290
300	67.029	57.31	6.4658	269.91	1180.75	0.4375	1.6365	1.0287	0.5698	1.3671	4817	1617	0.445	0.0338	0.3944	0.01817	48.98	300

Properties of Pure Substances

- Where do find them?

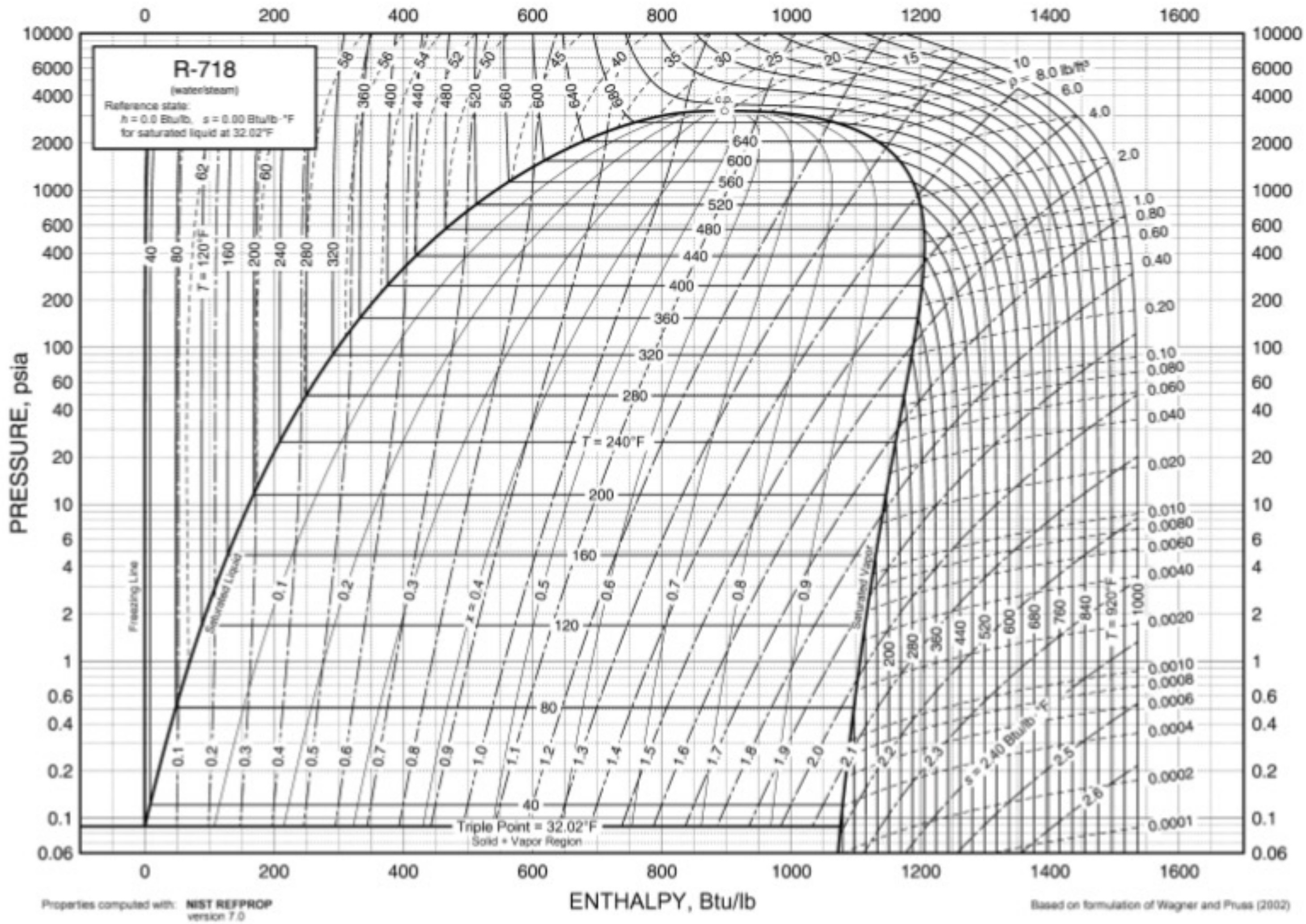
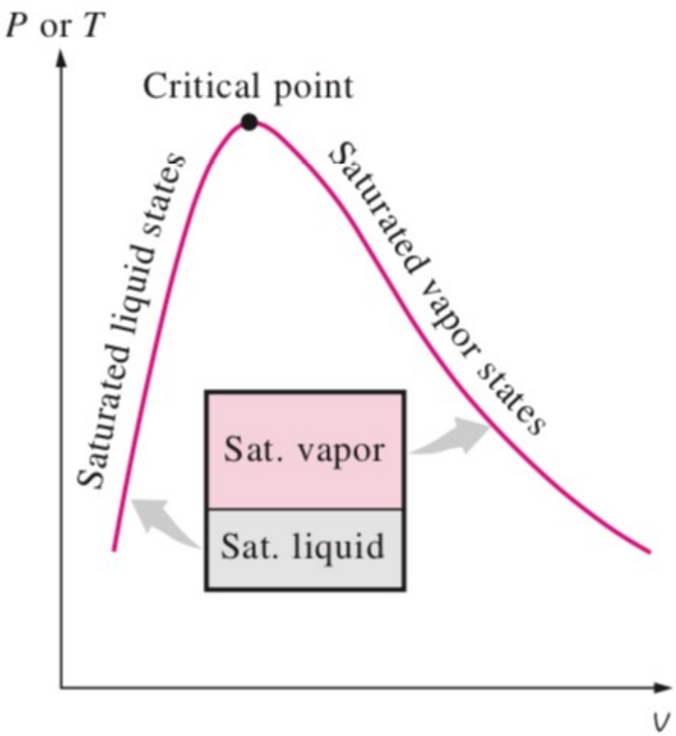


Fig. 20 Pressure-Enthalpy Diagram for Refrigerant 718 (Water/Steam)

Properties of Pure Substances

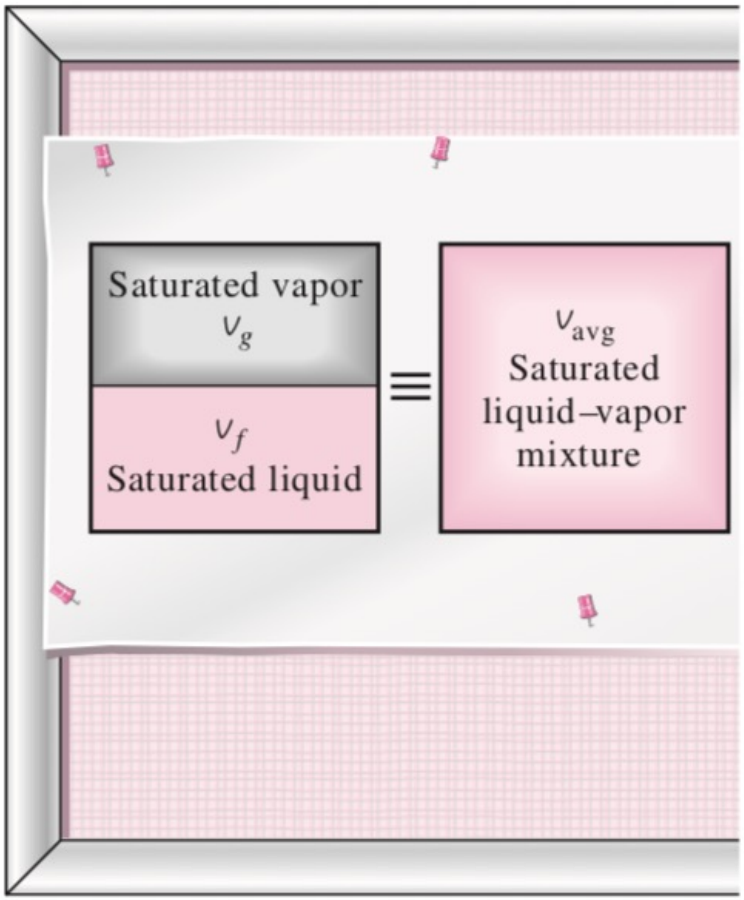
- Quality (x) is the ratio of the mass of vapor to the total mass of the mixture:



$$x = \frac{m_{vapor}}{m_{total}} \qquad x = \frac{m_g}{m_t}$$

$$m_{total} = m_{liquid} + m_{vpor} = m_f + m_g$$

Properties of Pure Substances

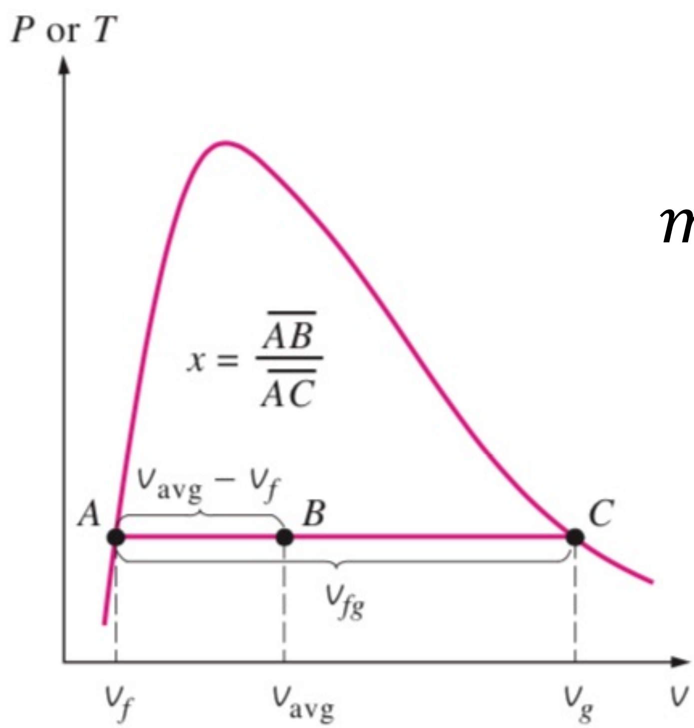


$$V_{avg} = V_f + V_g$$

$$V_{avg} = m v_{avg}$$

$$m_t V_{avg} = m_f v_f + m_g v_g$$

Properties of Pure Substances



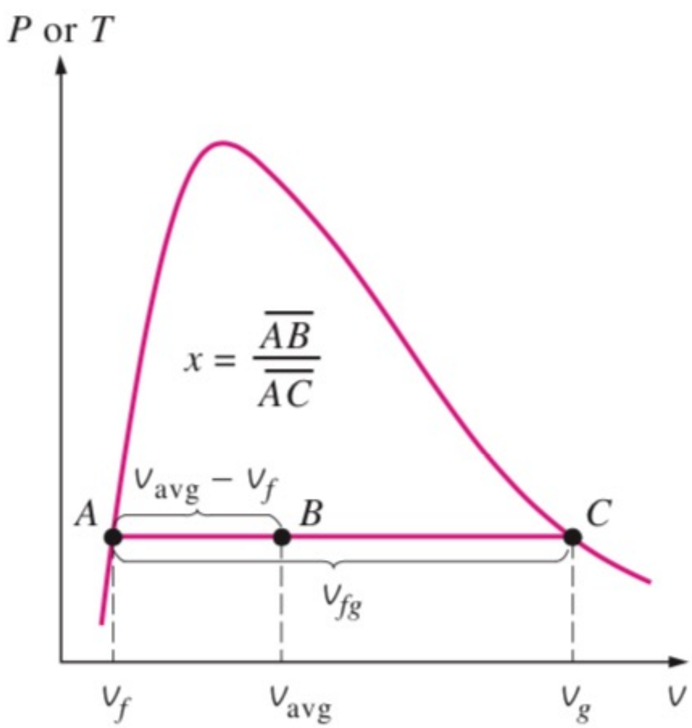
$$m_t v_{avg} = (m_t - m_f)v_f + m_g v_g$$

$$m_t v_{avg} = (m_t/m_t - m_g/m_t)v_f + m_g/m_t v_g$$

$$v_{avg} = (1 - x)v_f + x v_g$$

$$x = \frac{v_{avg} - v_f}{v_{fg}}$$

Properties of Pure Substances



$$v_{avg} = (1 - x)v_f + xv_g$$

$$h_{avg} = (1 - x)h + xh_g$$

Properties of Pure Substances

The Built Environment Research Group

advancing energy, environmental, and sustainability
research within the built environment
at Illinois Institute of Technology

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CAE 208/MMAE 320: Thermodynamics (Fall 2022)

CAE 208/MMAE 320 covers basic principles of thermodynamics applied to engineering systems using pure substances and mixtures as working fluids as well as covering direct application of the laws of thermodynamics to analysis of closed and open systems, mass and energy flow.

Course Syllabus

- Syllabus

Lecture Notes

- Lecture 01: Course overview and introduction
- Lecture 02: Basic concepts of thermodynamics (I)
- Lecture 03: Basic concepts of thermodynamics (II)
- Lecture 04: Basic concepts of thermodynamics (III)
- Lecture 05: Energy and energy analysis (I)
- Lecture 06: Energy and energy analysis (II)
- Lecture 07: Energy and energy analysis (III)
- Lecture 08: No Class
- Lecture 09: Properties of pure substances (I)
- Lecture 10: Properties of pure substances (II)
- Lecture 11: Properties of pure substances (III)
- Lecture 12: Properties of pure substances (IV)
- Lecture 13: Energy analysis of closed systems (I)
- Lecture 14: Energy analysis of closed systems (II)

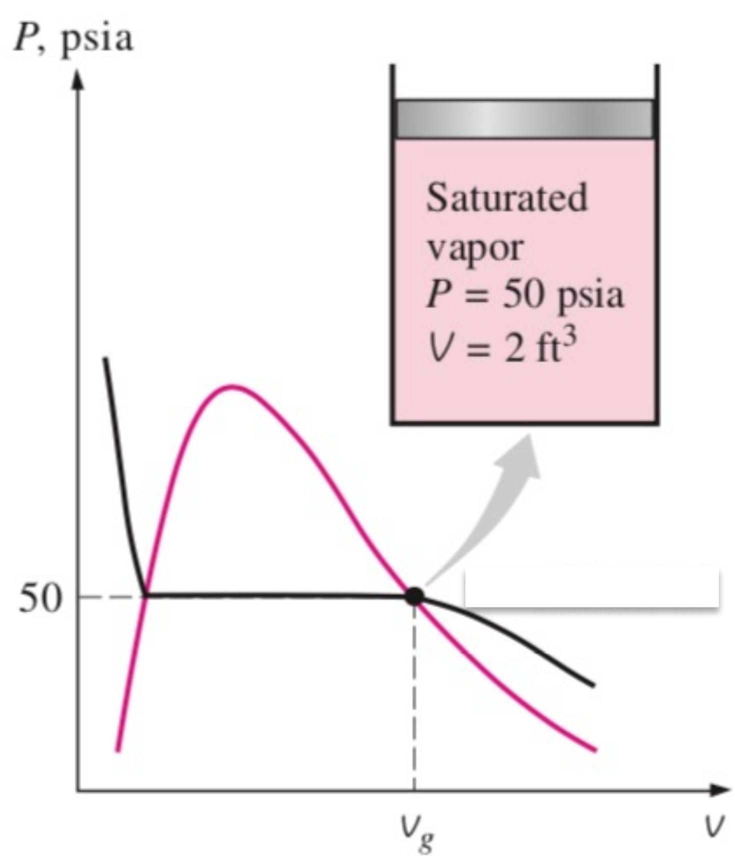
http://built-envi.com/courses/cae-208-thermodynamics-fall-2022/

CLASS ACTIVITY

(From Thermodynamics By Cengel)

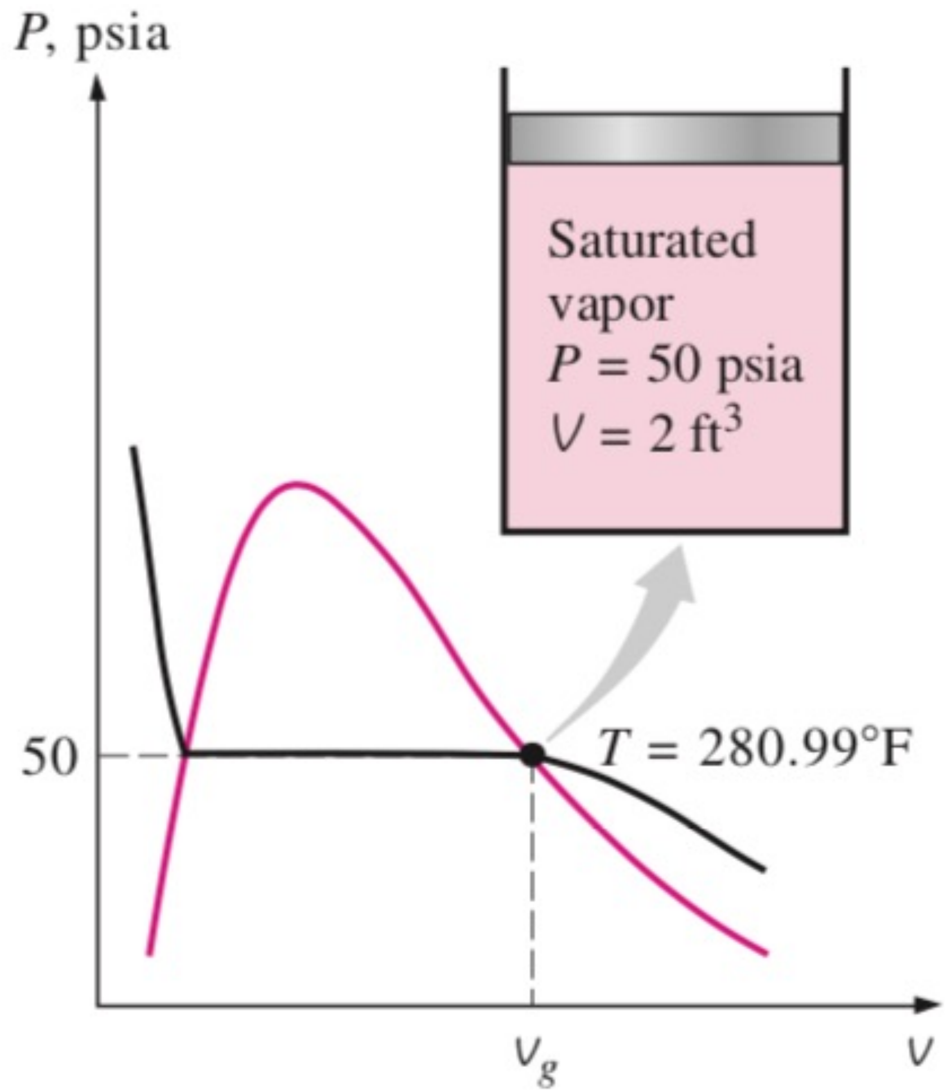
Class Activity

- **Question:** A piston-cylinder device contains 2 ft^3 of saturated water vapor at 50 psia pressure. Determine the temperature and the mass of vapor inside of the cylinder?



Class Activity

- **Solution:**



Class Activity

- **Solution:**

Thermophysical Properties of Refrigerants 30.43

Refrigerant 718 (Water/Steam) Properties of Saturated Liquid and Saturated Vapor

Temp.,* °F	Pressure, psia	Density, lb/ft³ Liquid	Volume, ft³/lb Vapor	Enthalpy, Btu/lb Liquid	Enthalpy, Btu/lb Vapor	Entropy, Btu/lb·°F Liquid	Entropy, Btu/lb·°F Vapor	Specific Heat c_p, Btu/lb·°F Liquid	Specific Heat c_p, Btu/lb·°F Vapor	c_p/c_v Vapor	Vel. of Sound, ft/s Liquid	Vel. of Sound, ft/s Vapor	Viscosity, lb_m/ft·h Liquid	Viscosity, lb_m/ft·h Vapor	Thermal Cond., Btu/h·ft·°F Liquid	Thermal Cond., Btu/h·ft·°F Vapor	Surface Tension, dyne/cm	Temp.,* °F
250	29.844	58.82	13.815	218.78	1164.81	0.3680	1.7011	1.0147	0.5218	1.3464	4981	1582	0.556	0.0314	0.3951	0.01596	54.74	250
260	35.447	58.53	11.759	228.95	1168.21	0.3823	1.6874	1.0170	0.5299	1.3496	4953	1590	0.530	0.0319	0.3953	0.01638	53.62	260
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300	67.029	57.31	6.4658	269.91	1180.75	0.4375	1.6365	1.0287	0.5698	1.3671	4817	1617	0.445	0.0338	0.3944	0.01817	48.98	300
310	77.691	56.99	5.6263	280.23	1183.58	0.4510	1.6246	1.0323	0.5818	1.3727	4777	1623	0.428	0.0342	0.3939	0.01866	47.79	310
320	89.667	56.65	4.9142	290.60	1186.28	0.4643	1.6131	1.0362	0.5947	1.3790	4735	1628	0.412	0.0347	0.3931	0.01916	46.59	320

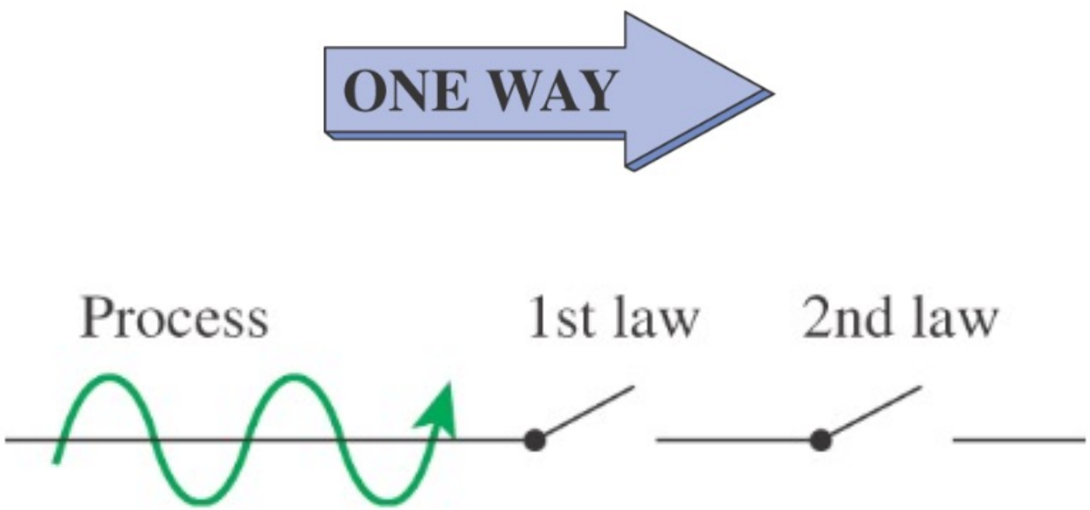
$$v_g(at\ p = 50\ psia) = 8.51\,\frac{ft^3}{lb}$$

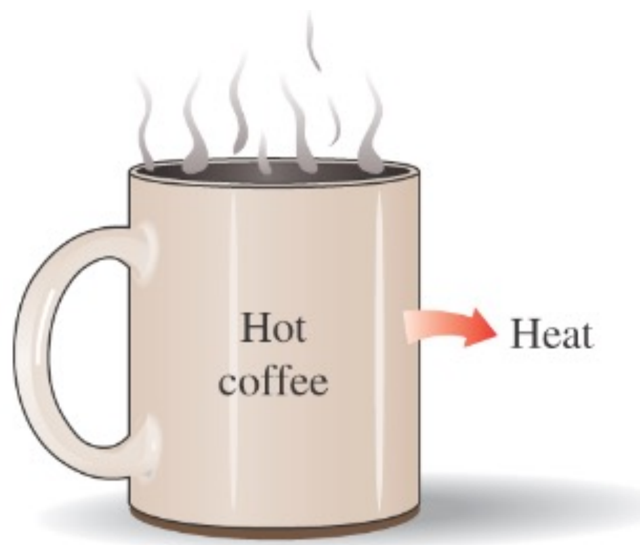
$$m = \frac{V}{v_g} = \frac{2}{8.51} = 0.23\ lbm$$

RECAP OF 208/MMAE 320: REFRIGERATION CYCLE

Refrigeration Cycle

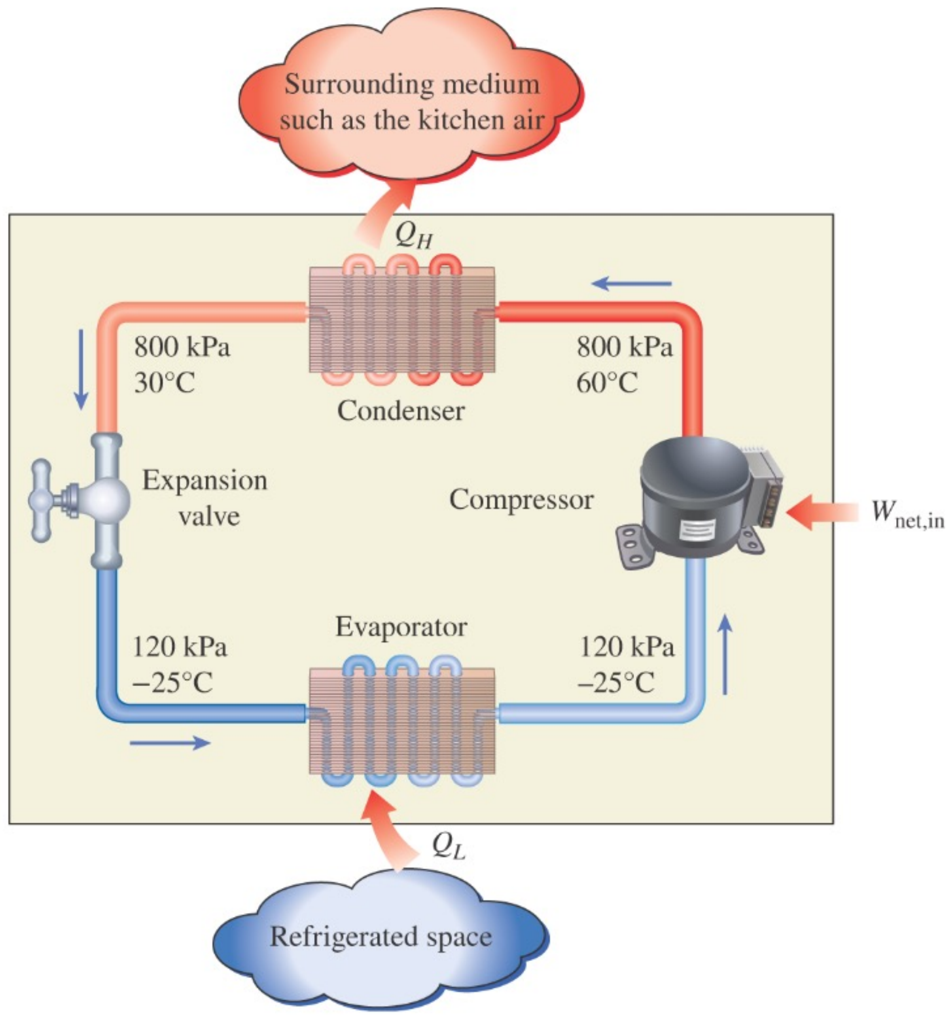
- The first law places no restriction on the direction of a process but satisfying the first law does not ensure that the process can actually occur
- A process cannot occur unless it satisfies both the first and the second laws of thermodynamics
- The second law also asserts that energy has quality as well as quantity





Refrigeration Cycle

- The most frequently used refrigeration cycle is the vapor-compression refrigeration cycle



Refrigeration Cycle

- The efficiency of a refrigerator is expressed in terms of the coefficient of performance (COP)
- The objective of a refrigerator is to remove heat (Q_L) from the refrigerated space

$$COP_R = \frac{Desired\ output}{Require\ input} = \frac{Q_L}{W_{net,in}}$$

$$COP_R = \frac{Q_L}{Q_H - Q_L} = \frac{1}{\frac{Q_H}{Q_L} - 1}$$

- Can the value of COP_R be greater than unity?

Refrigeration Cycle

- ***Heat Pumps:*** The objective of a heat pump is to supply heat Q_H into the warmer space

$$COP_{HP} = \frac{Desired\ output}{Require\ input} = \frac{Q_H}{W_{net,in}}$$

$$COP_{HP} = \frac{Desired\ output}{Require\ input} = \frac{Q_H}{Q_H - Q_L}$$

$$COP_{HP} = COP_R + 1$$