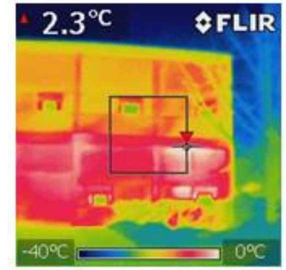
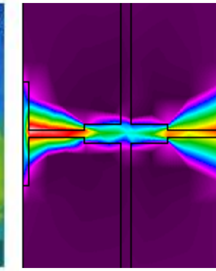
CAE 331/513
Building Science
Fall 2018



October 18, 2018
Finishing HVAC systems

Air and water: pressures and flows

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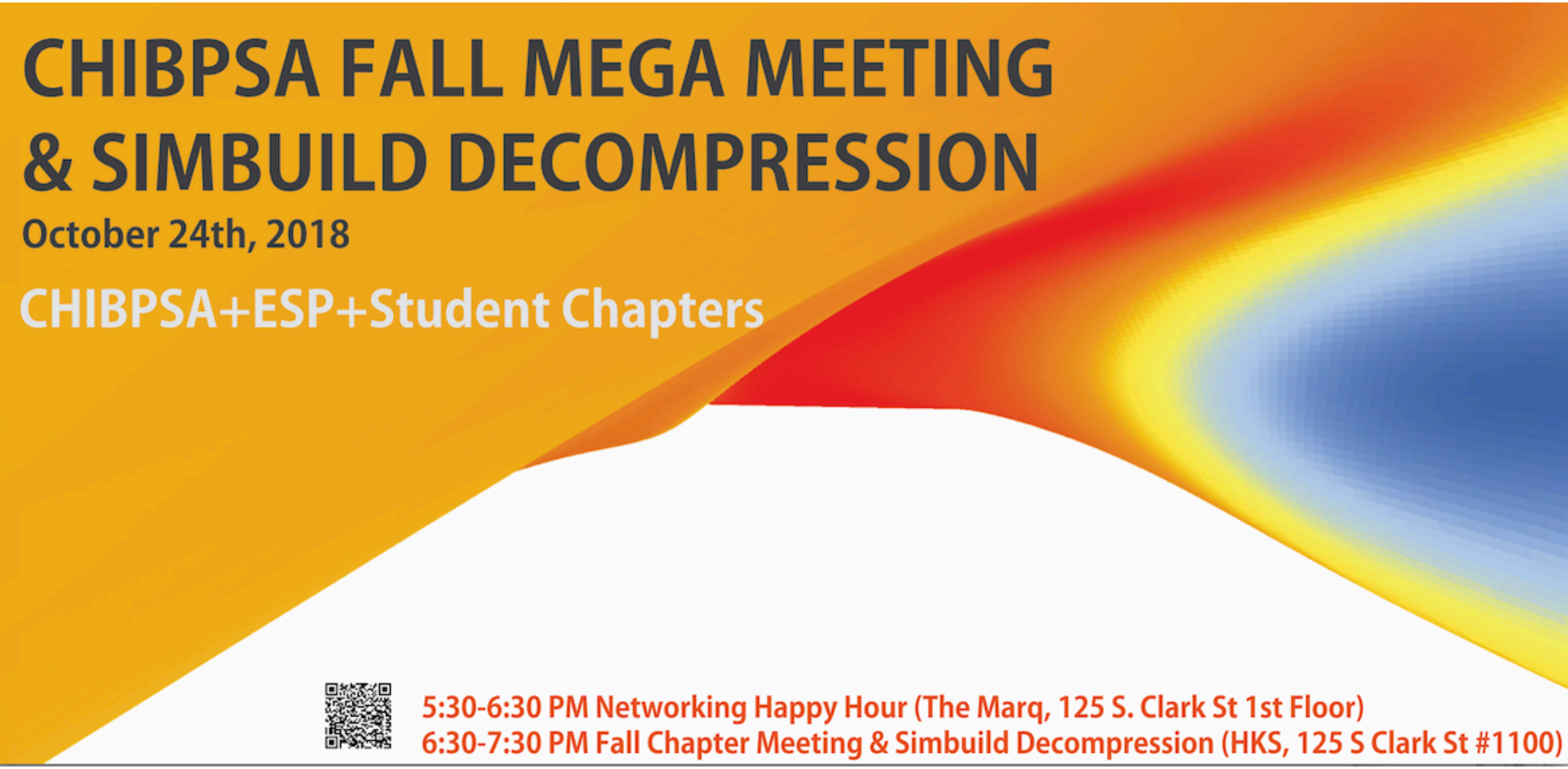
Dr. Brent Stephens, Ph.D.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
brent@iit.edu

Chicago IBPSA meeting: October 24, 2018



Register here:
https://www.eventbrite.com/e/chibpsa-fall-mega-meeting-simbuild-decompression-tickets-51294676759

ASHRAE Scholarships

Apply Today! | Selection Process | Scholarships, Criteria and Deadlines

Tips for Applicants | Scholarship Recipients | Scholarship Presentations

https://www.ashrae.org/communities/student-zone/scholarships-and-grants/scholarship-program

Graduate student projects: Topics due today

Last name	First name	Project topic
Attablayo	Gracelyn	
Diego Maristany	Alvaro	
Fernandez-Aceytuno	Clara	
Kang	Insung	
Kansara	Nupoor Nileshkumar	
Khairnar	Piyush	ETFE façade (in Kaplan Center)
Kodihalli Thathaiah	Aakash Babu	
Lopez Lopez	Miguel Angel	
Ma	Lijian	
Reyes Martinez	Laura	Thermal comfort differences in genders
Riley	Christopher	
Saggu	Gurmandeep Kaur	
Zeng	Yicheng	
Abromitis	Kari	
Diaz Alvarez	Inigo	
Diego Rodriguez	Patricia	
Kang	Liwen	
Martin Mallo	Jesus	
Mitkees	Lobna	Thermal comfort in Crown Hall
Vara Vaquero	Fernando	

Last time and this time

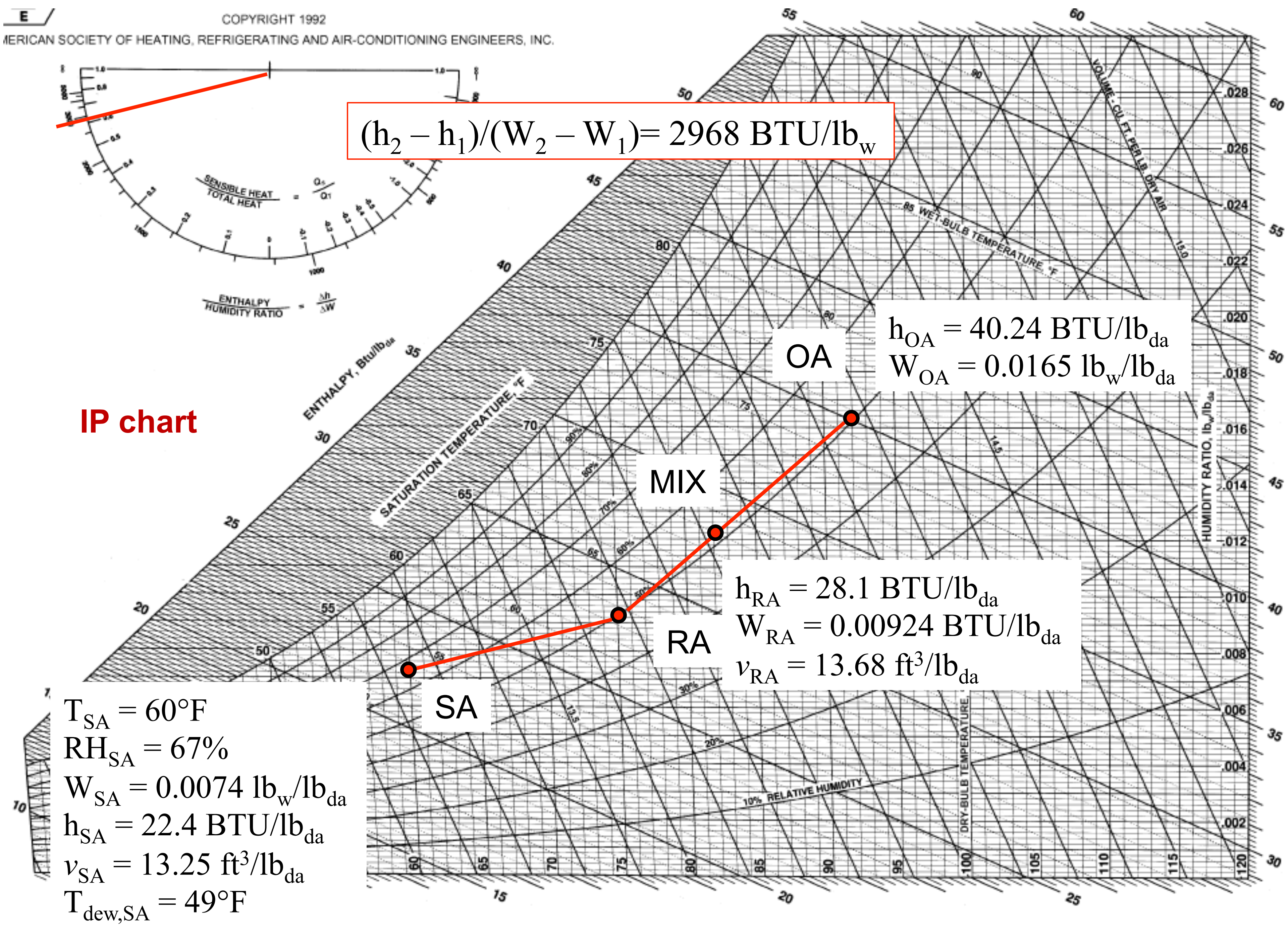
Last time:
- Continued psychrometric process example problems

Today:
- HW 4 due
- Finish example problem from Tuesday
- Finish HVAC systems
  - Big central systems
  - Economizers
  - Heat/energy recovery systems
  - District energy systems
  - Heat pumps
  - Air and water: pressure and flows

Example 8: Single-zone space conditioning (IP)

- Assume the restaurant from the previous example is to be served by an air handling unit that mixes outdoor air with recirculated air, then passes the air over a cooling coil to the space. Outside air conditions are 92°F dry bulb and 77°F wet bulb temperatures. The rate of exhaust from the restaurant is 4500 CFM.

- Determine the following:
  a) The mass flow rate of recirculated air
  b) The thermodynamic state of the moist air entering the cooling coil
  c) The refrigeration capacity required


COPYRIGHT 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
(h2 – h1)/(W2 – W1)= 2968 BTU/lbw
IP chart
ENTHALPY, Btu/lbda
SATURATION TEMPERATURE, °F
85 WET-BULB TEMPERATURE, °F
VOLUME, CU.FT. PER LB. DRY AIR
HUMIDITY RATIO, lbw/lbda
DRY-BULB TEMPERATURE, °F
10% RELATIVE HUMIDITY
OA
hOA = 40.24 BTU/lbda
WOA = 0.0165 lbw/lbda
MIX
RA
hRA = 28.1 BTU/lbda
WRA = 0.00924 BTU/lbda
vRA = 13.68 ft3/lbda
SA
TSA = 60°F
RHSA = 67%
WSA = 0.0074 lbw/lbda
hSA = 22.4 BTU/lbda
vSA = 13.25 ft3/lbda
Tdew,SA = 49°F

FINISHING HVAC SYSTEMS

Typical large central commercial systems

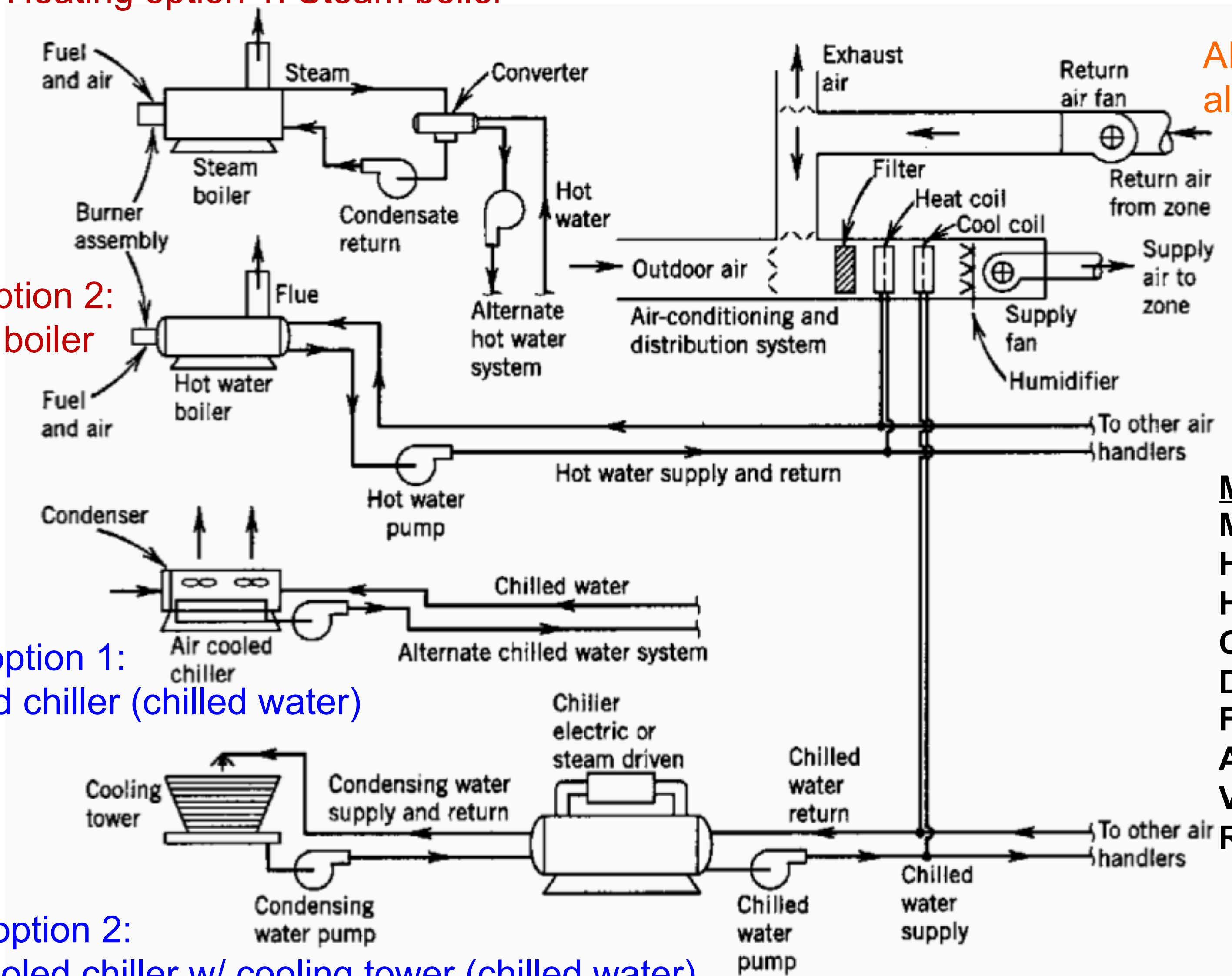
Heating option 1: Steam boiler

AHU serves all rooms

Heating option 2: Hot water boiler

Cooling option 1: Air cooled chiller (chilled water)

Cooling option 2: Water cooled chiller w/ cooling tower (chilled water)

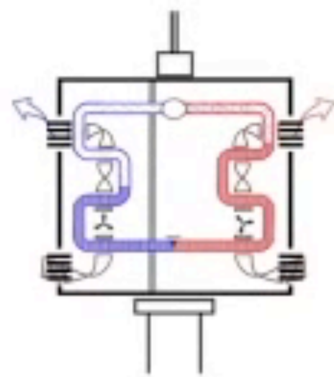


Main processes:
Mixing
Heating
Humidification
Cooling
Dehumidification
Filtration
Air distribution
Ventilation
Recirculation

Typical large central commercial systems

Air Conditioning for Big Buildings

by: Michael Ermann and Clark Coots

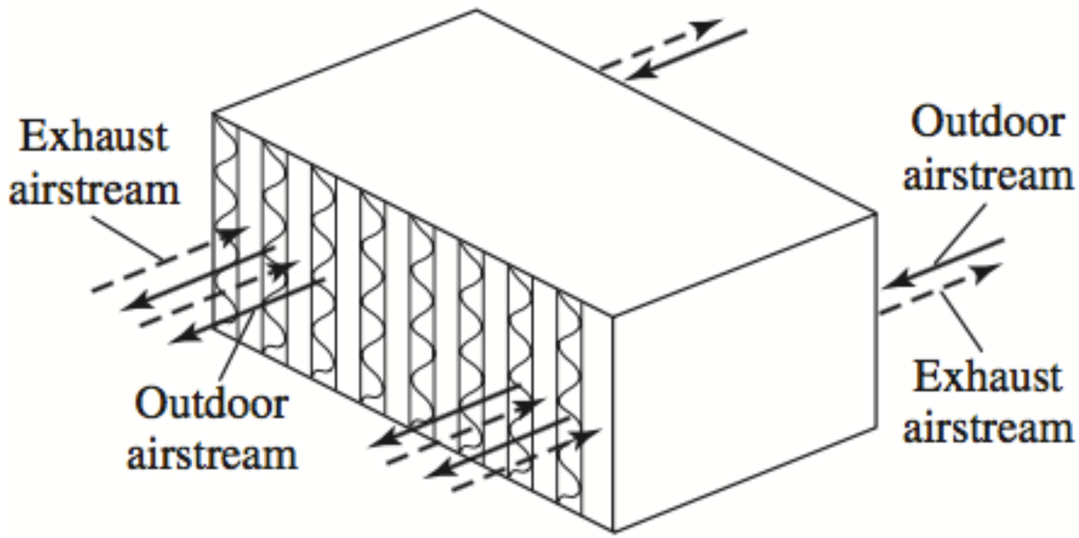


https://www.youtube.com/watch?v=j1nYipLAv0U

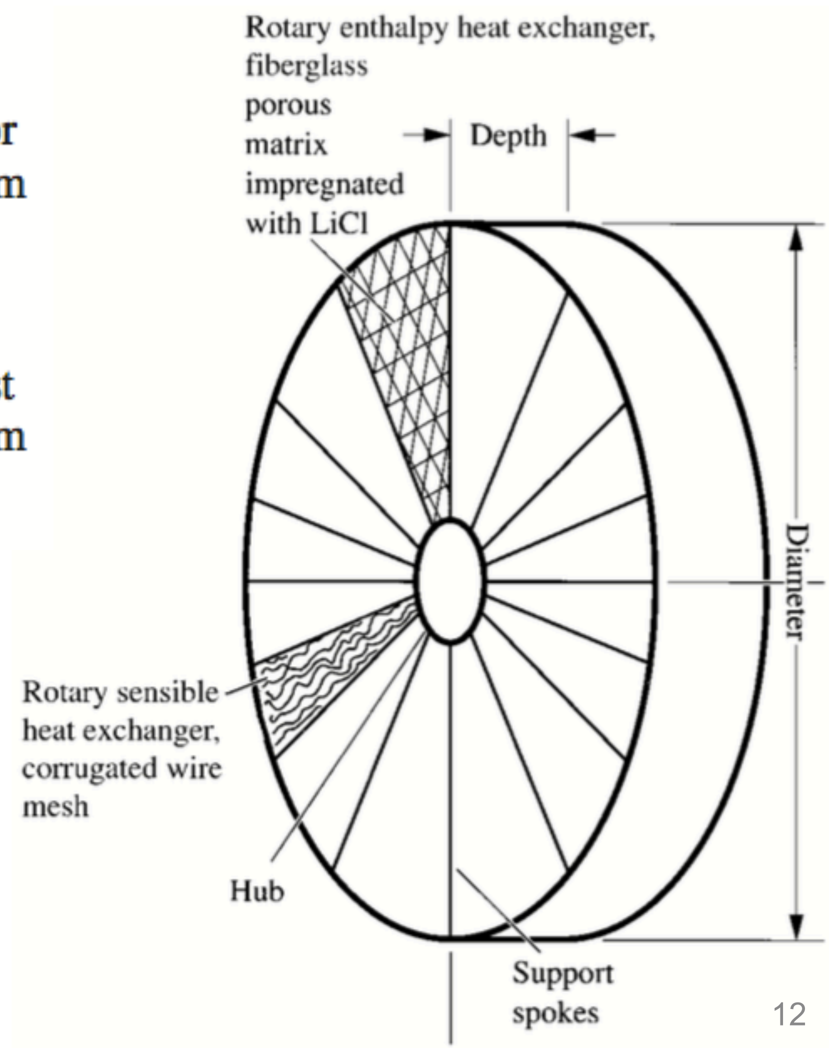
HEAT/ENERGY RECOVERY SYSTEMS

Heat/energy recovery systems

Air to air heat recovery



Rotary/enthalpy wheel

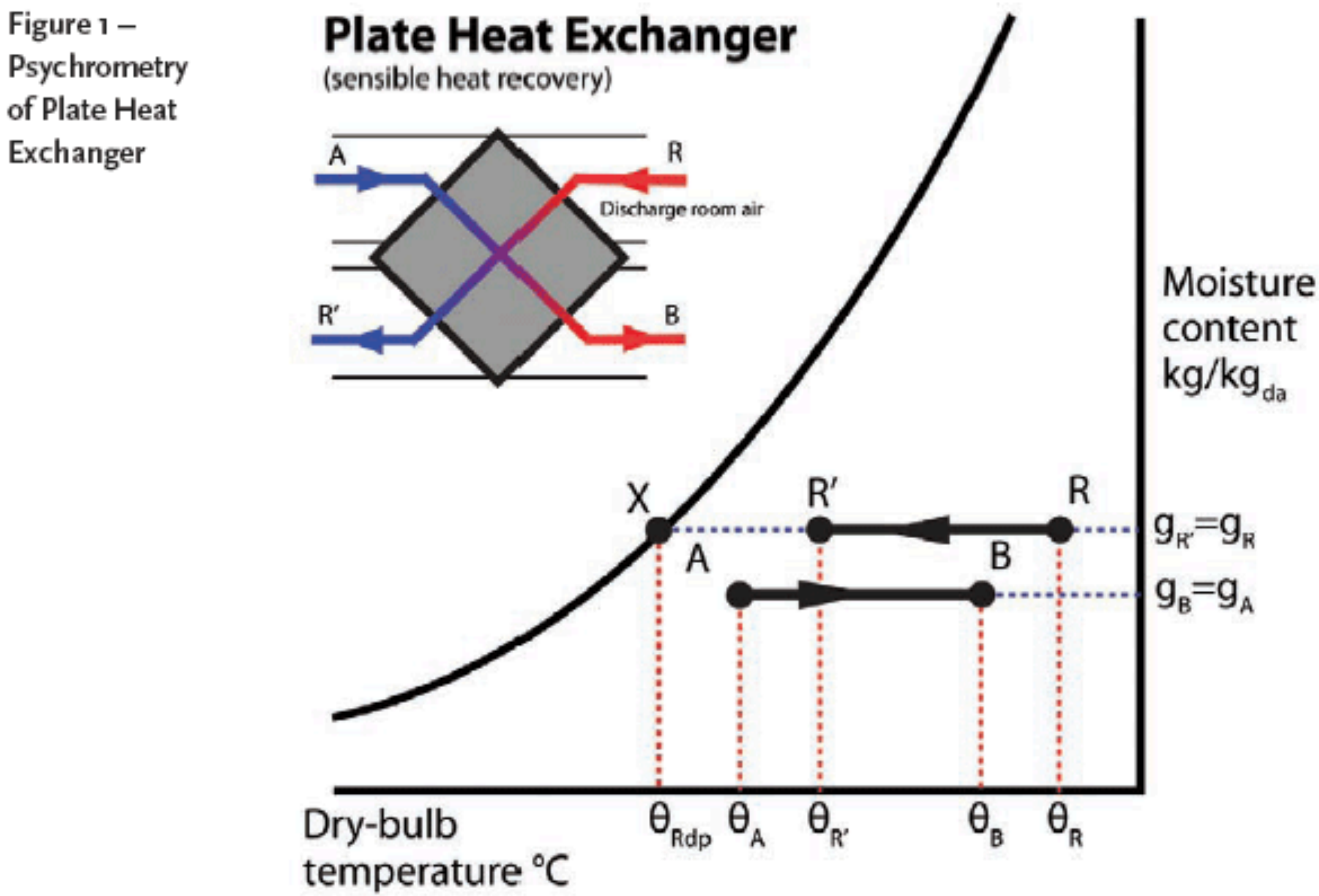


Heat/energy recovery systems

https://www.youtube.com/watch?v=QOSelUK6dpQ

Heat/energy recovery systems

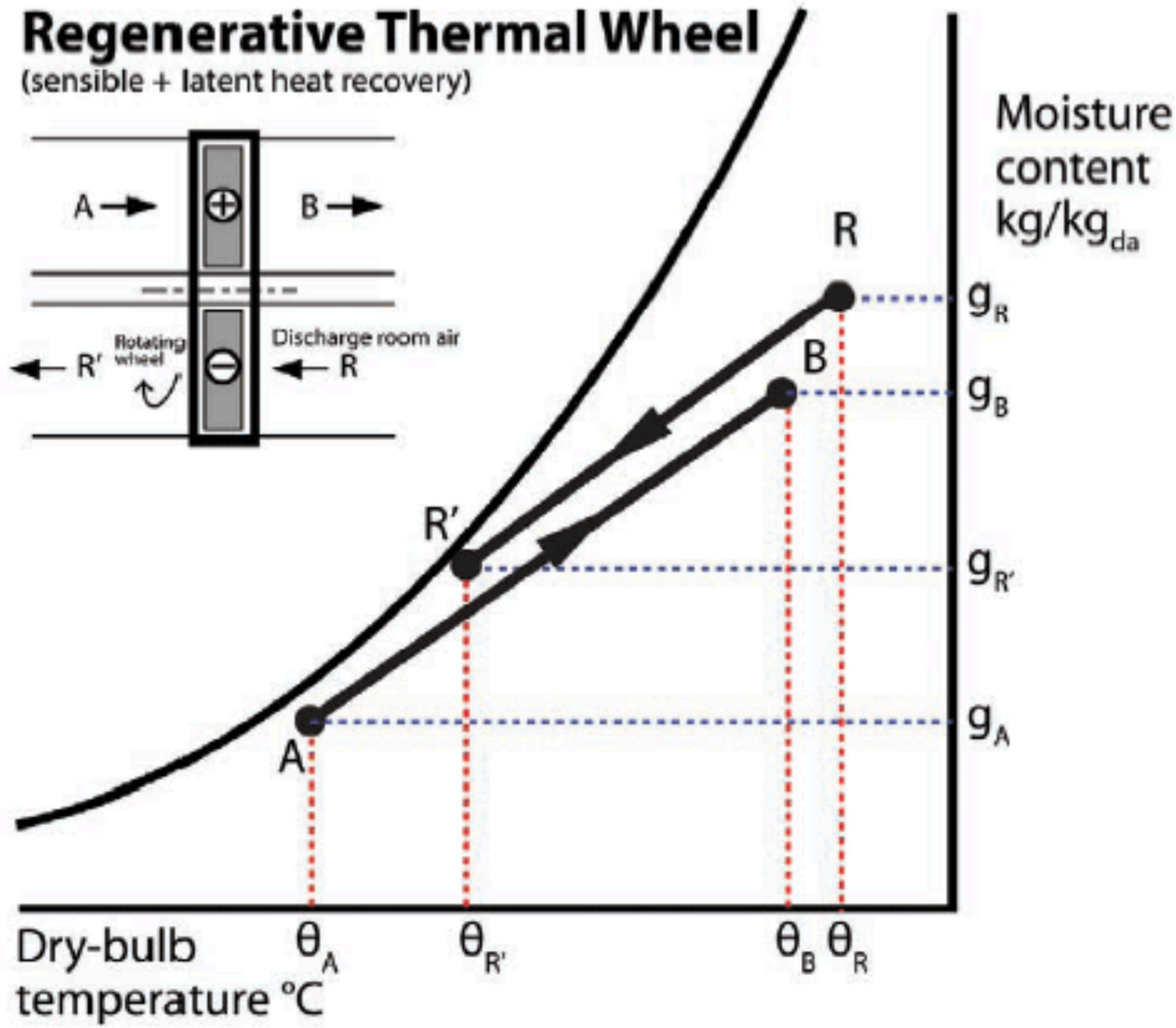
Plate heat exchanger or thermal wheel



https://www.cibsejournal.com/cpd/modules/2009-12/

Energy recovery systems

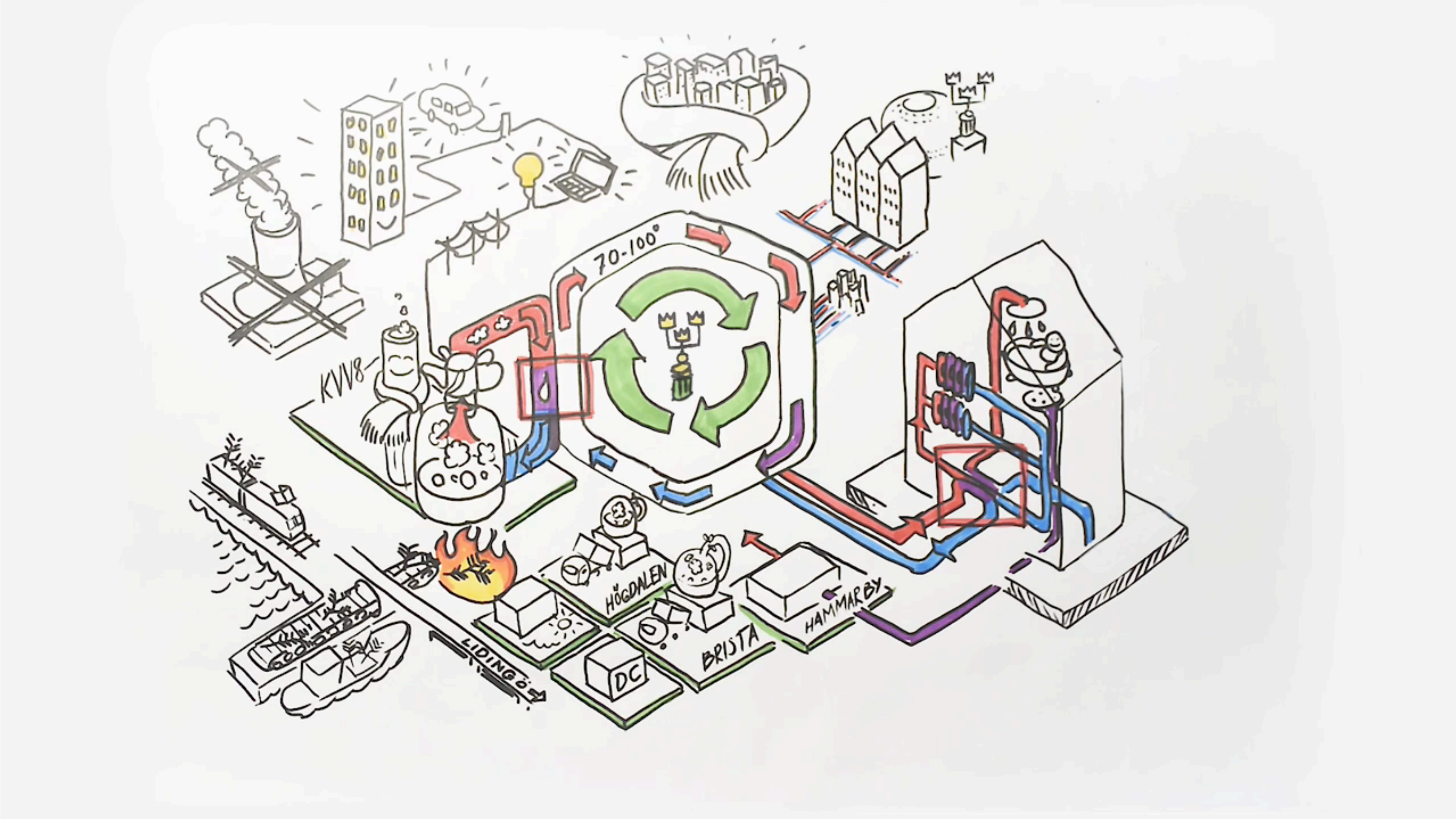
Enthalpy wheel (sensible + latent)



https://www.cibsejournal.com/cpd/modules/2009-12/

DISTRICT ENERGY SYSTEMS

District heating and combined heat and power



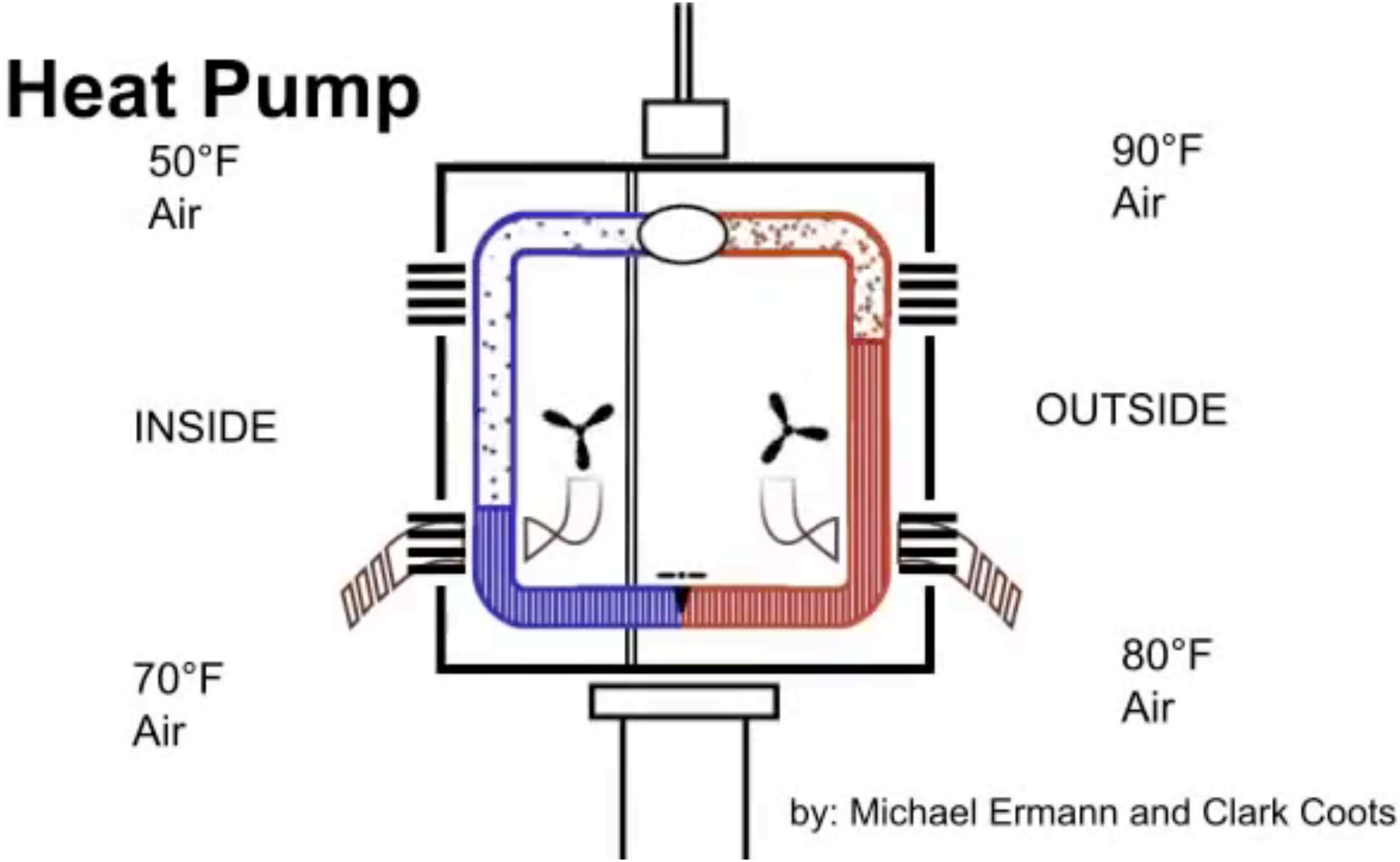
https://www.youtube.com/watch?v=MhJVsSkxg7s

District cooling

https://www.youtube.com/watch?v=7IZ3PBr7dO4

HEAT PUMPS

Air- and ground-source heat pumps

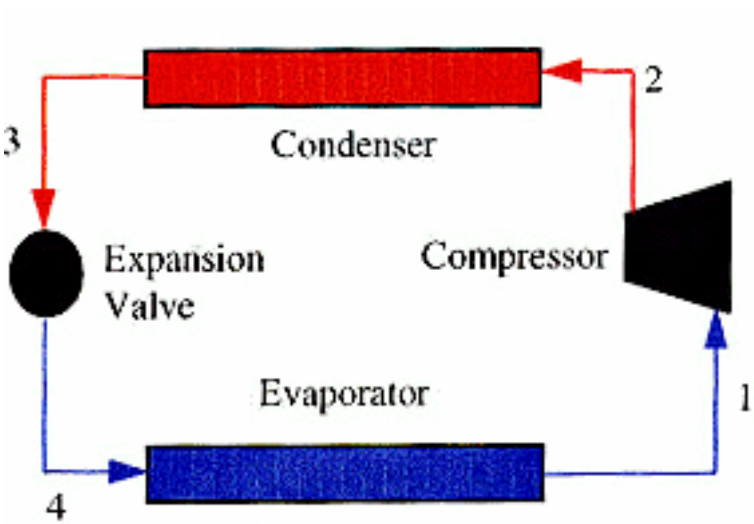


https://www.youtube.com/watch?v=NyNeh7wPQQk

Air-source heat pumps

Cooling

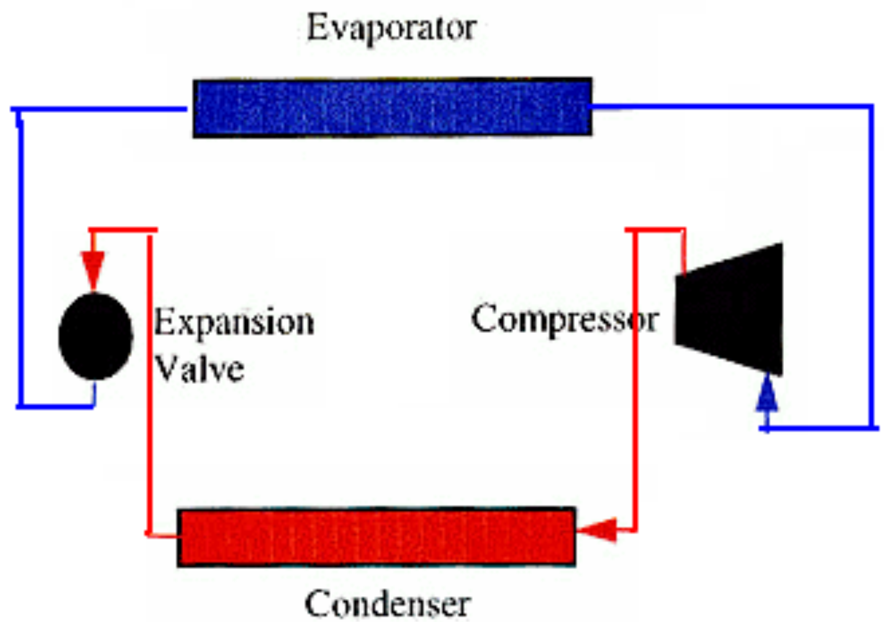
Outside 95°F



Inside 75°F

Heating

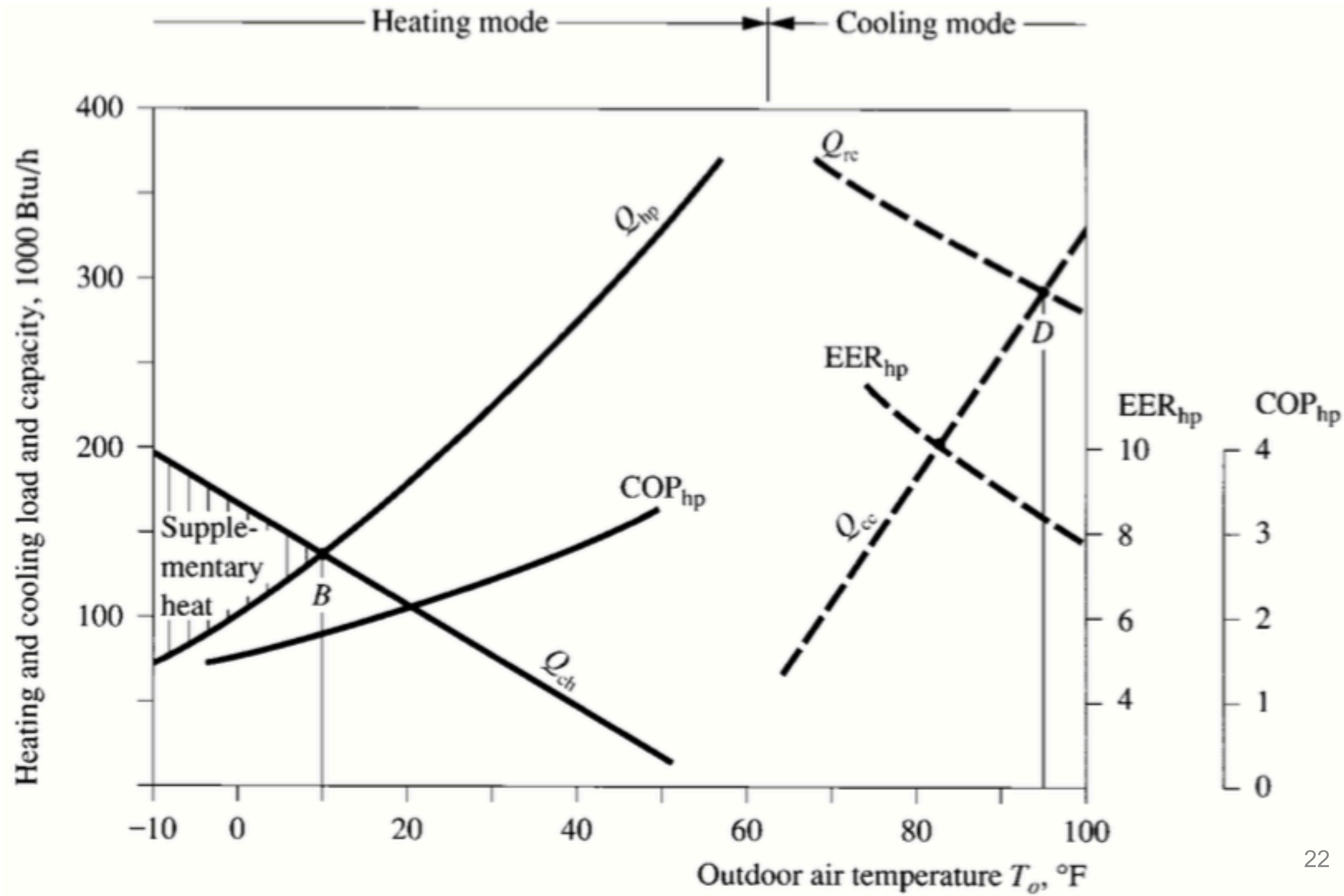
Outside 45°F



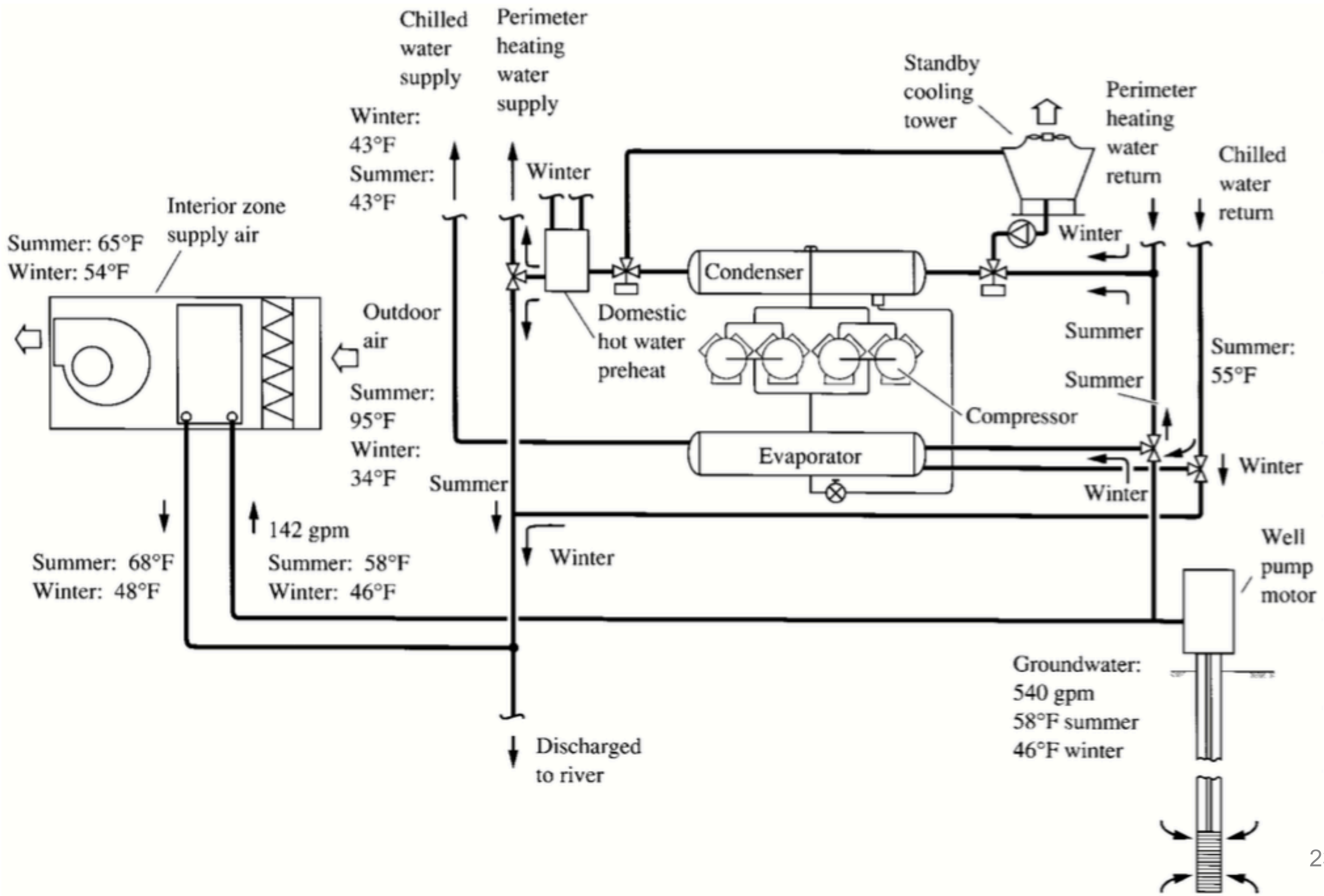
Inside 75°F

Heat pumps are basically air-conditioners run in reverse

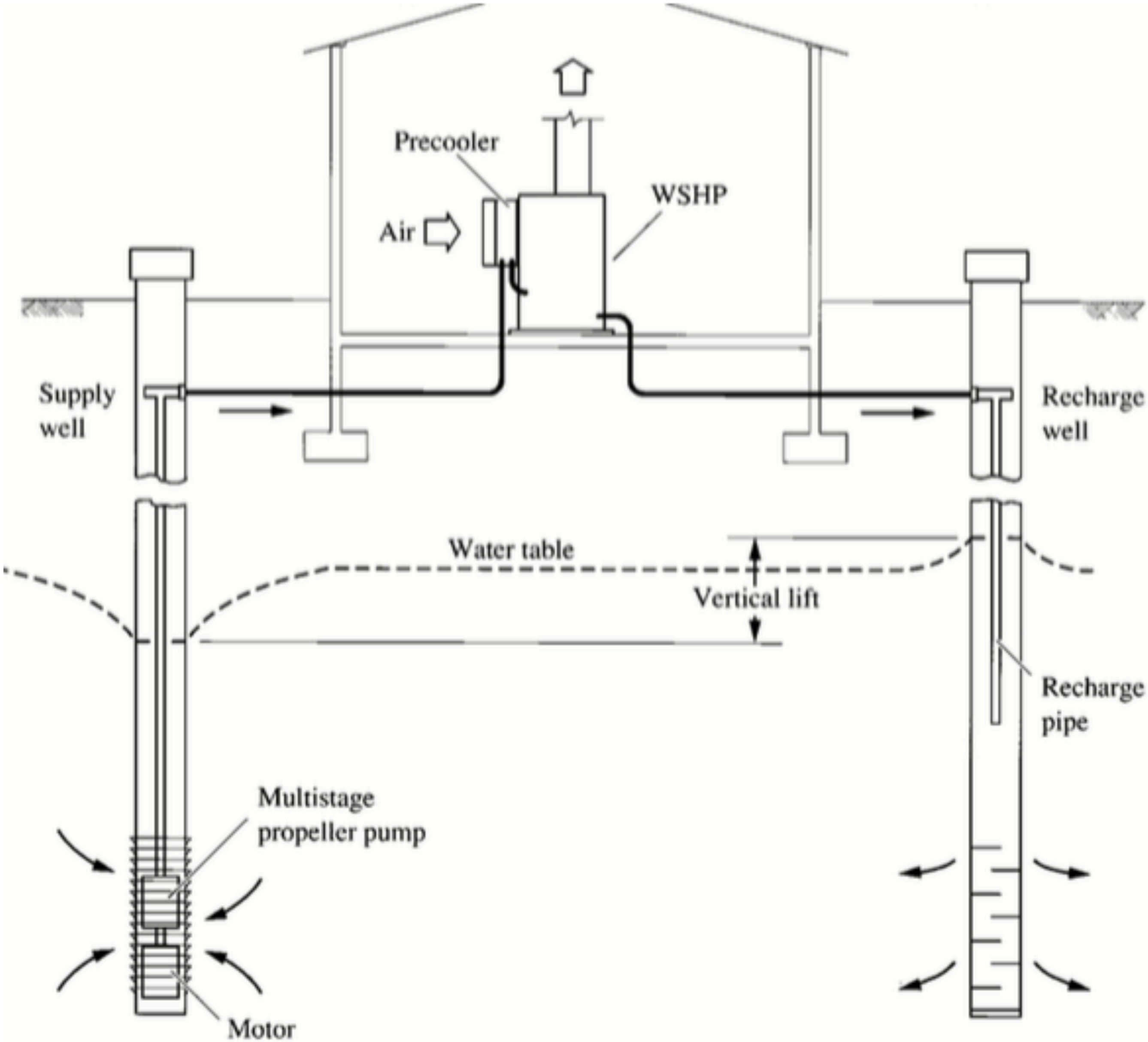
Air-source heat pumps



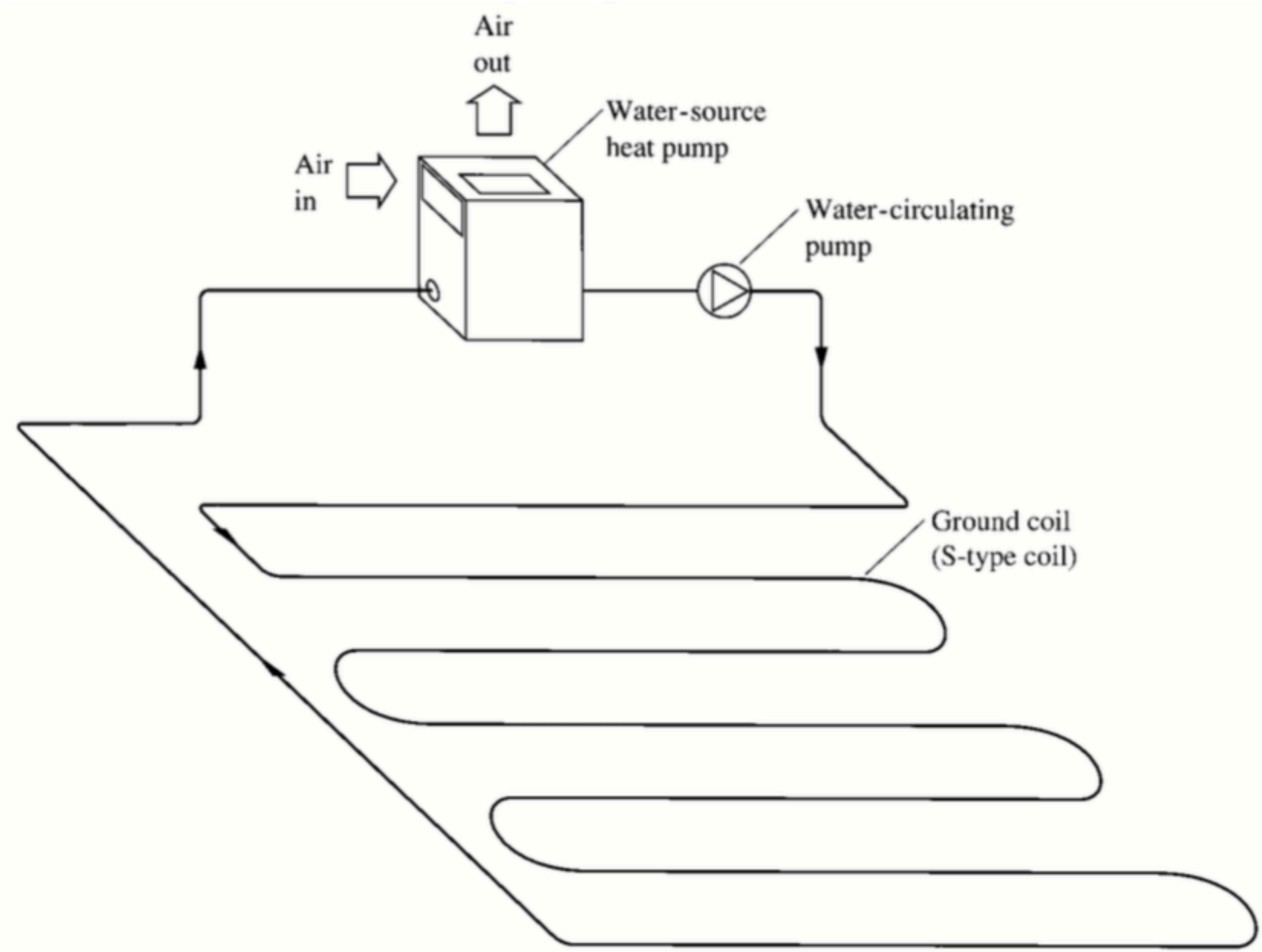
Ground-source heat pumps



Ground-source heat pumps



Ground-source heat pumps

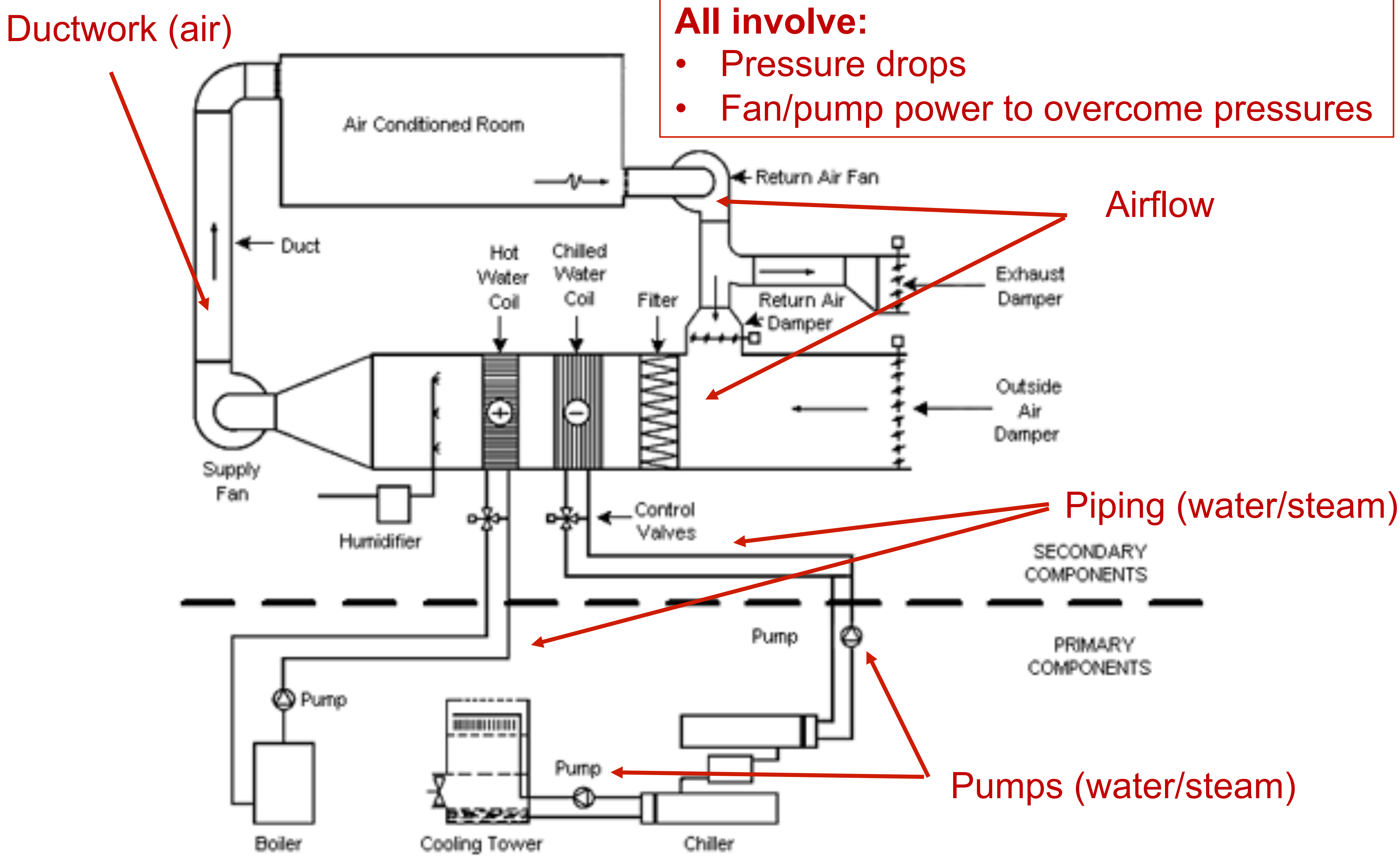


AIR AND WATER DISTRIBUTION SYSTEMS

Fluid flows and fan/pump power

Air and water distribution systems

All involve:
- Pressure drops
- Fan/pump power to overcome pressures



Air and water distribution systems

- We use **fans** to move air around buildings
- We use **pumps** to move water/steam around buildings
- There are a few principles we need to understand to characterize **fan/pump energy and performance**

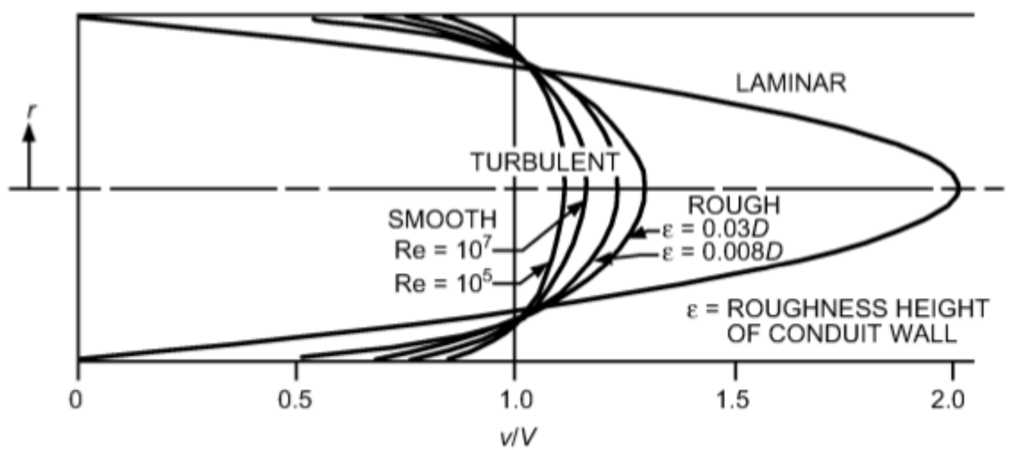


Fig. 4 Velocity Profiles of Flow in Pipes

$$\text{Re} = \frac{\rho v L}{\mu}$$

Air and water distribution systems

Ducts

Pipes

Fluid flows in buildings: Overcoming pressure losses

- We use liquids and gases to deliver/extract heating or cooling energy in building mechanical systems
  - Water, refrigerants, and air
- We often need to understand fluid motion, pressure losses, and pressure rises by pumps and fans in order to correctly size systems and predict their performance
- We can use the Bernoulli equation to describe fluid flows in HVAC systems

$$\mathrm{p}_1 + \frac{1}{2}\rho_1 v_1^2 + \rho_1 g h_1 = \mathrm{p}_2 + \frac{1}{2}\rho_2 v_2^2 + \rho_2 g h_2 + p_{friction}$$

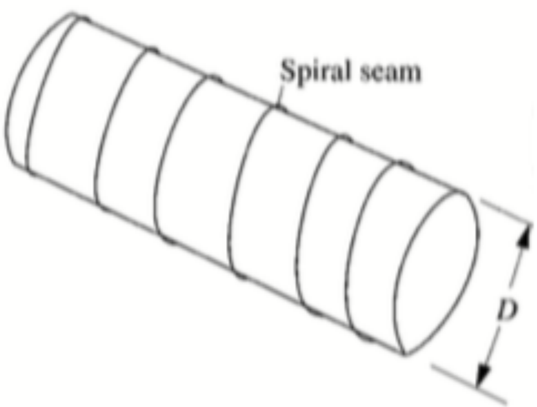
Static pressure | Velocity pressure | Pressure head | Friction losses

If friction and head are negligible, we can relate velocity to pressure:

$$v = \sqrt{\frac{2\Delta \mathrm{P}}{\rho}}$$

Pressure losses

- We often need to find the pressure drop in pipes and ducts
  - Most flows in HVAC systems are turbulent



$$\Delta p_{friction} = f\left(\frac{L}{D_h}\right)\left(\frac{1}{2}\rho v^2\right) = K\left(\frac{1}{2}\rho v^2\right)$$

$$D_h = \frac{4A}{P} = \text{hydraulic diameter}$$

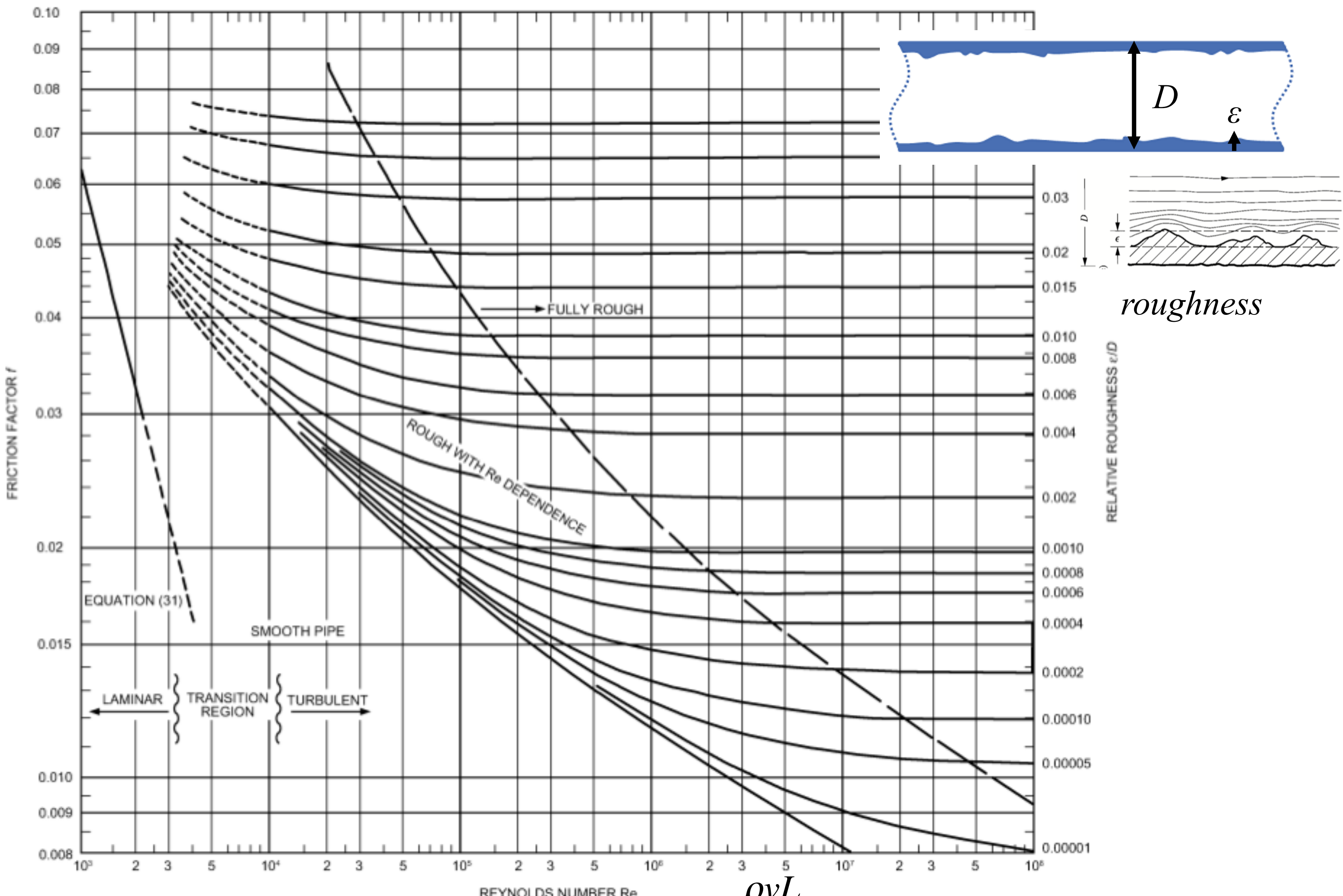
f = friction factor (-)
L = length (m)
D_h = hydraulic diameter (m)
ρ = fluid density (kg/m^3)
v = fluid velocity (m/s)

$$K = f\left(\frac{L}{D_h}\right)$$ In a straight pipe

$$K = f\left(\frac{L}{D_h} + \sum_{fittings} K_f\right)$$ In a straight pipe with fittings

Friction factor, f

f

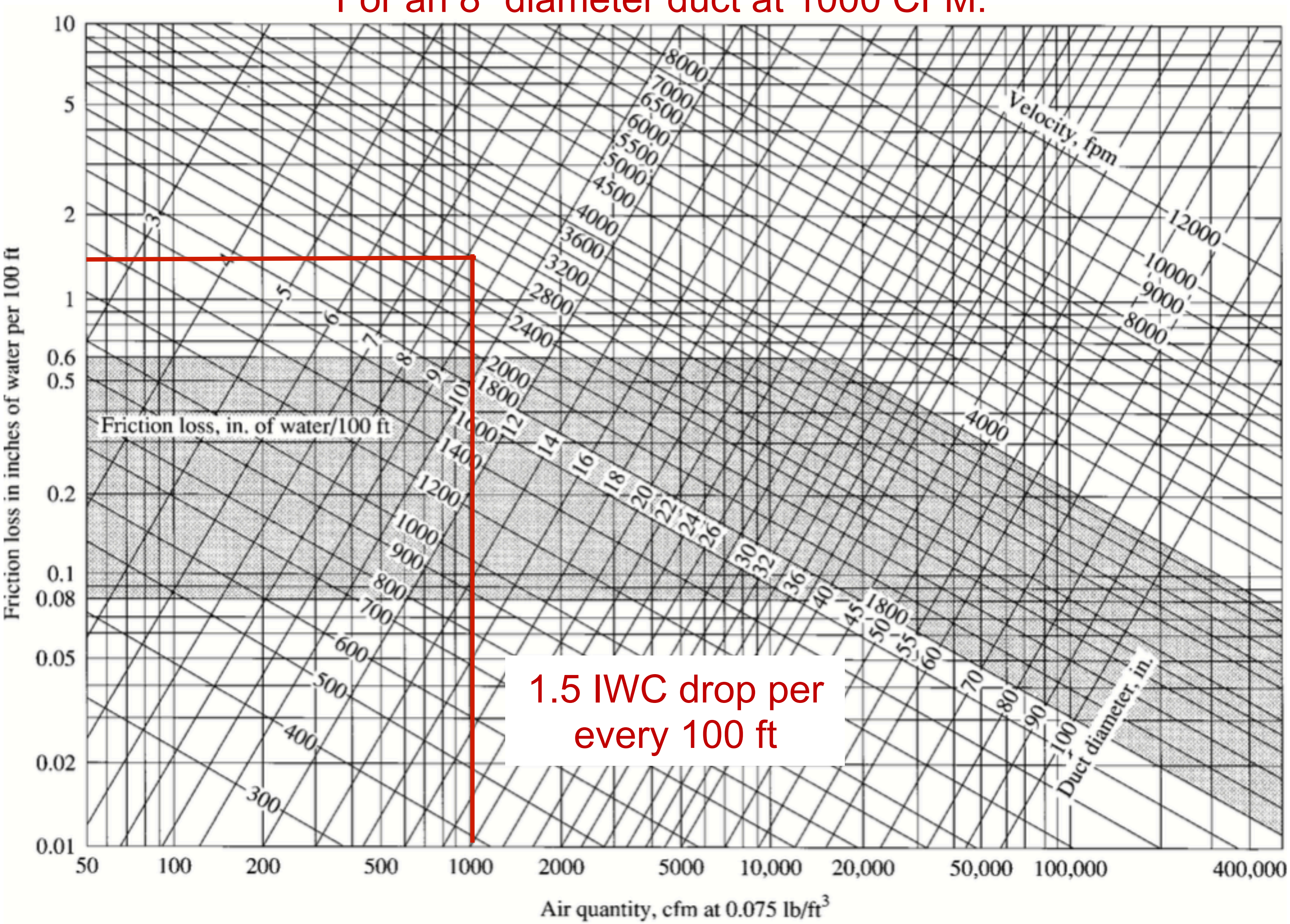


roughness

$$\mathrm{Re} = \frac{\rho v L}{\mu} \qquad (L = D_h)$$

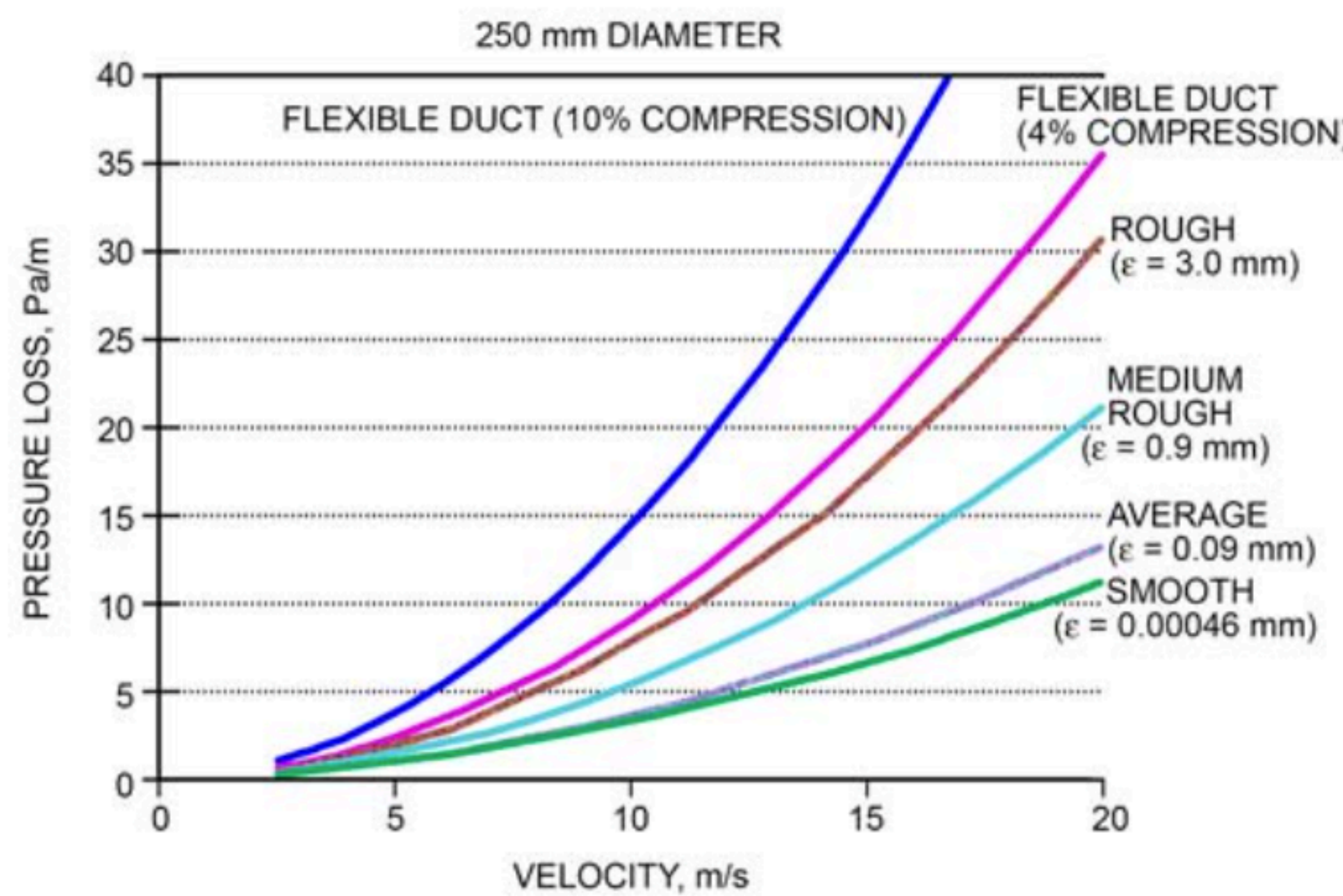
Duct friction charts (IP units)

For an 8” diameter duct at 1000 CFM:



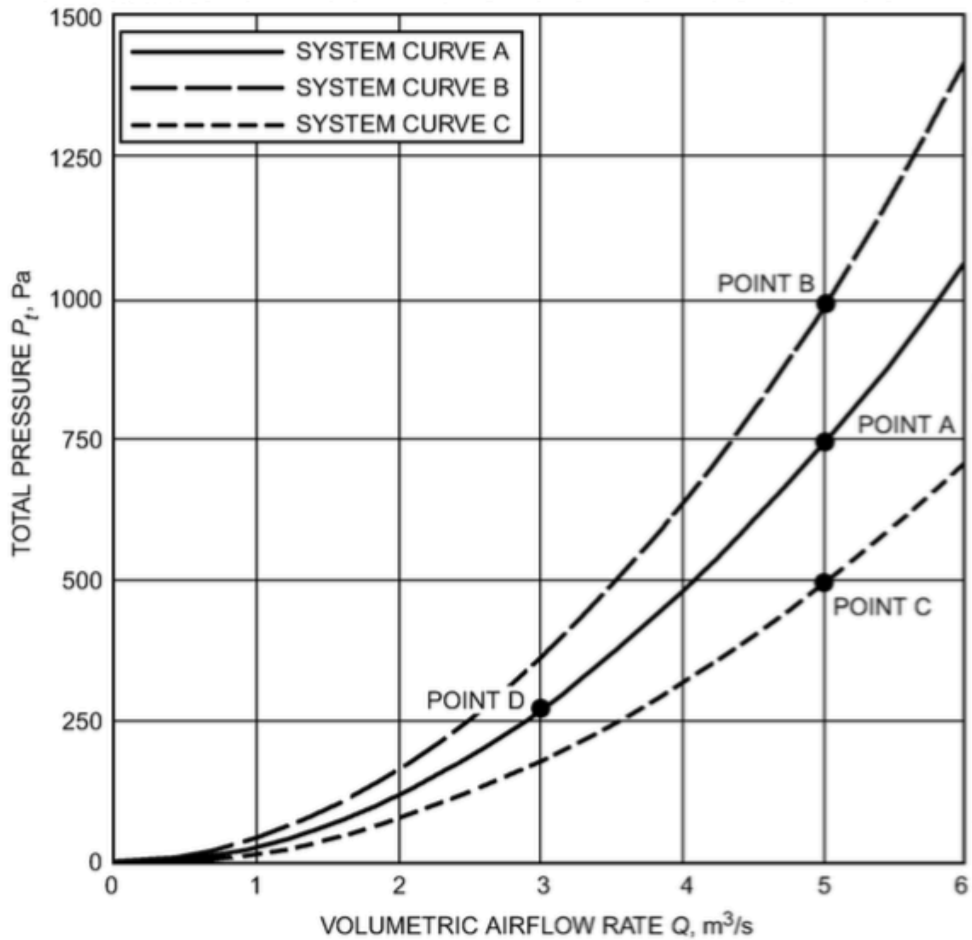
1.5 IWC drop per every 100 ft

Duct friction plots



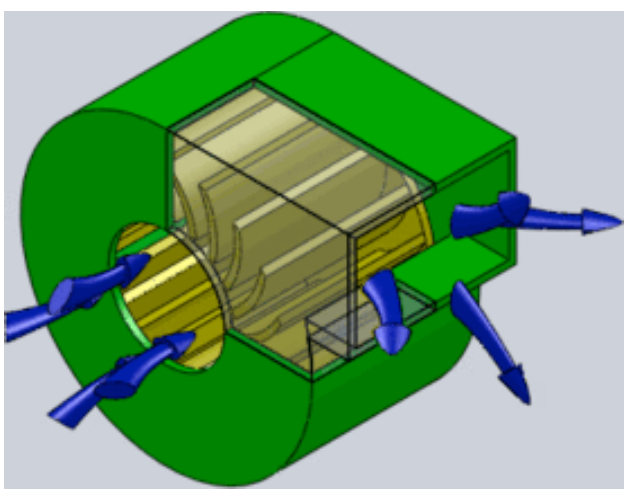
System curves

We characterize distribution systems (e.g., pipes or ducts) with a <u>system curve</u>

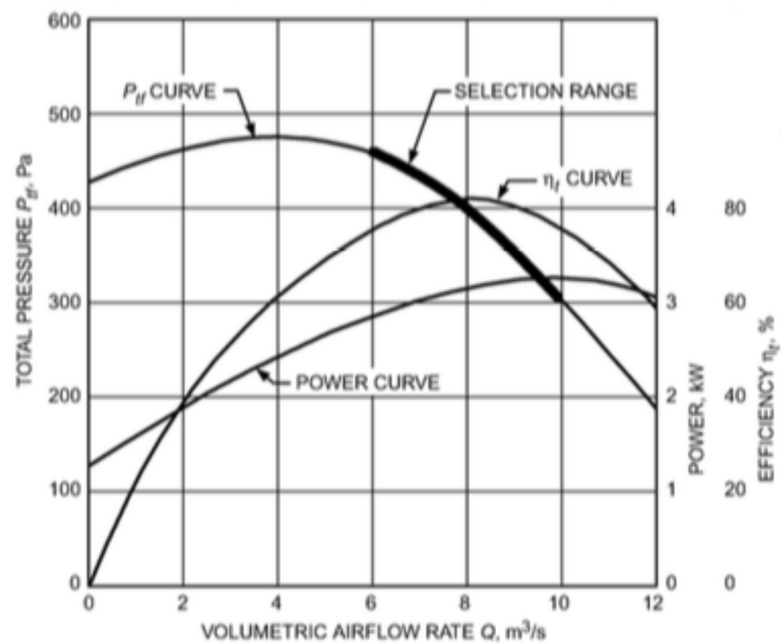


Fan/pump curves

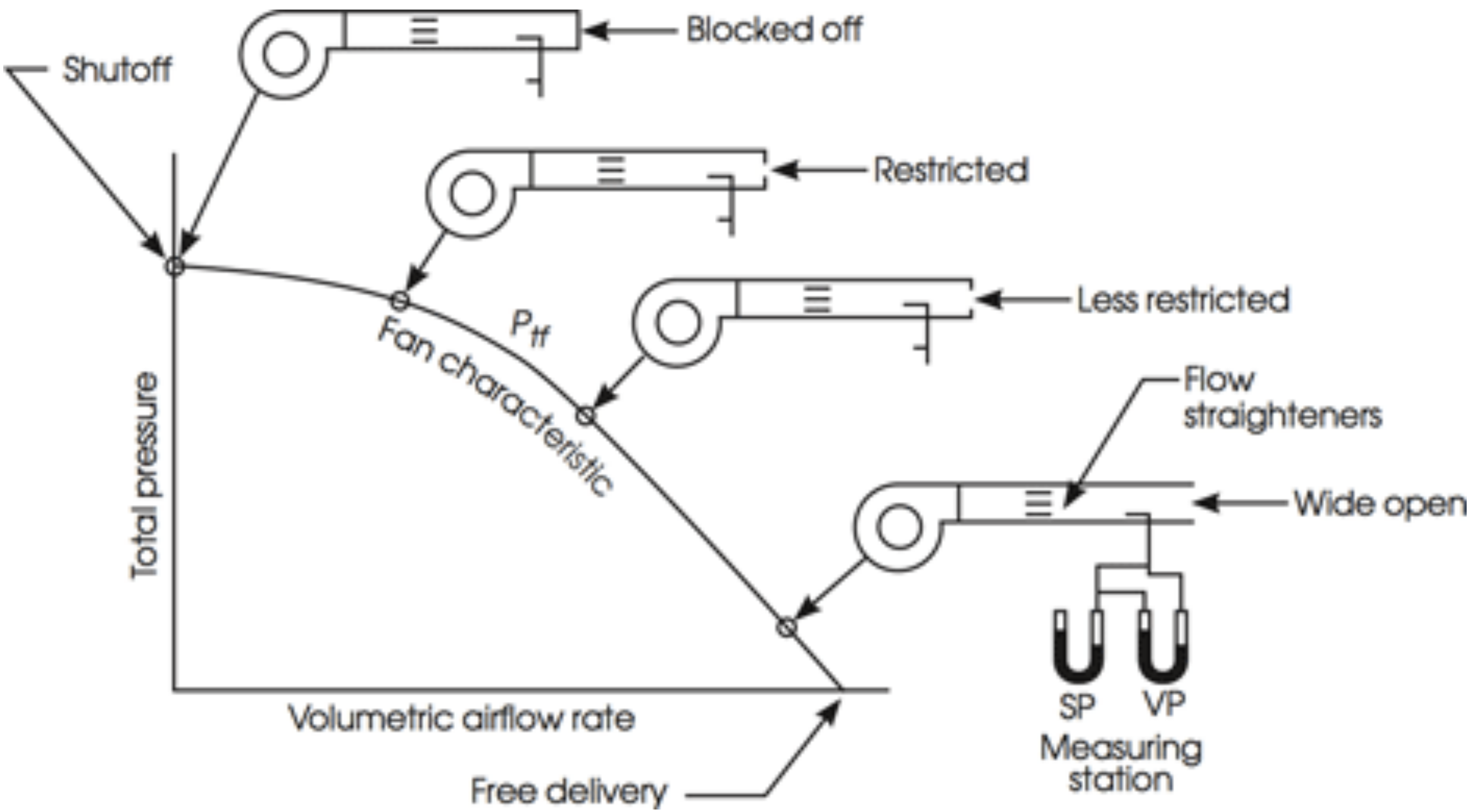
- Fans (and pumps) are used to overcome pressure drops in air and water distribution systems
- Their size and power draw are functions of the magnitude of pressure rise required
- We characterize performance by **<u>fan</u>** <u>or</u> **<u>pump performance curves</u>**



"Fan curve"



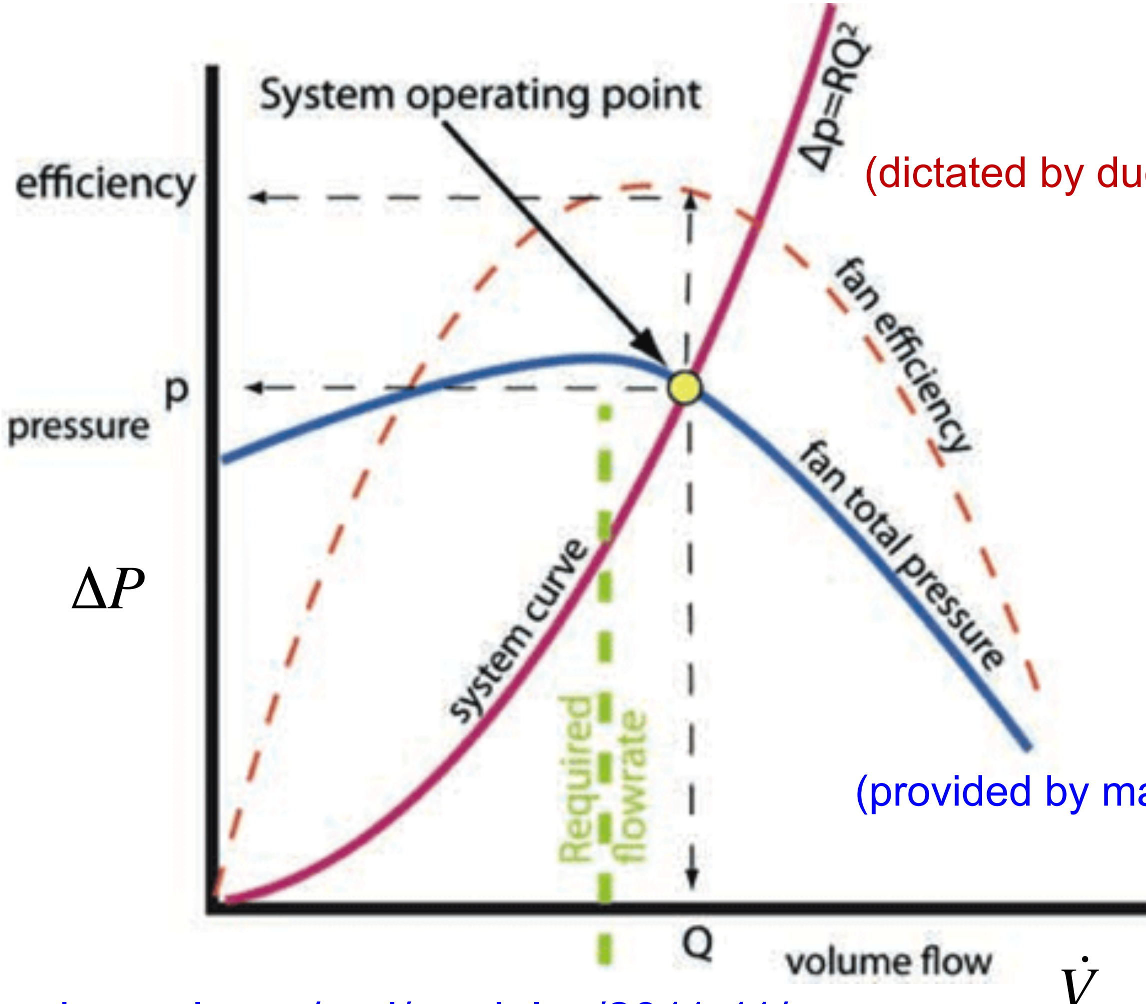
Fan/pump curves



https://www.cibsejournal.com/cpd/modules/2011-11/

Intersection of fan curves and system curves

We then characterize the performance of a fan (or pump) with the <u>intersection</u> of its fan (or pump) curve and system curve



(dictated by duct system)

And we calculate fan (or pump) power draw by:

$$\boxed{W_{fan} = \frac{\Delta P \cdot \dot{V}}{\eta_{fan}}}$$

(provided by manufacturer)

https://www.cibsejournal.com/cpd/modules/2011-11/

What are typical fan efficiencies?

Common ranges from 30 to 80% depending on the fan type

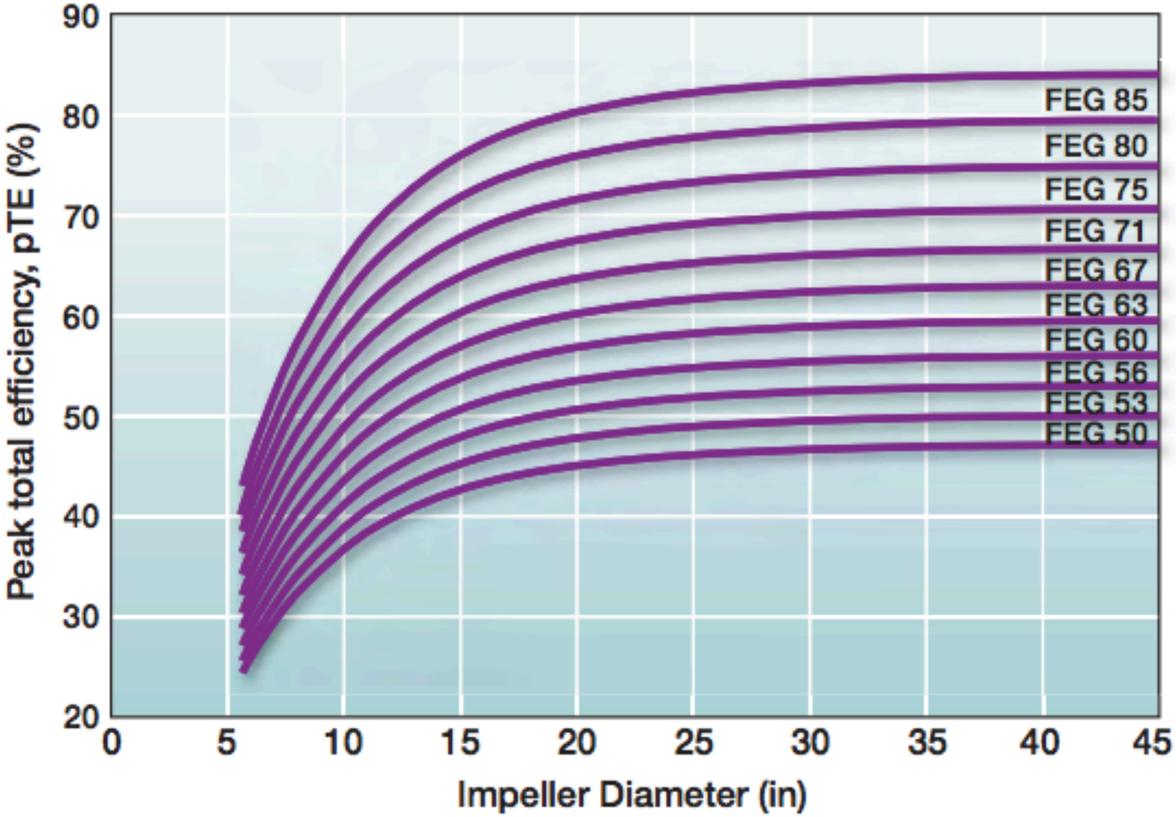
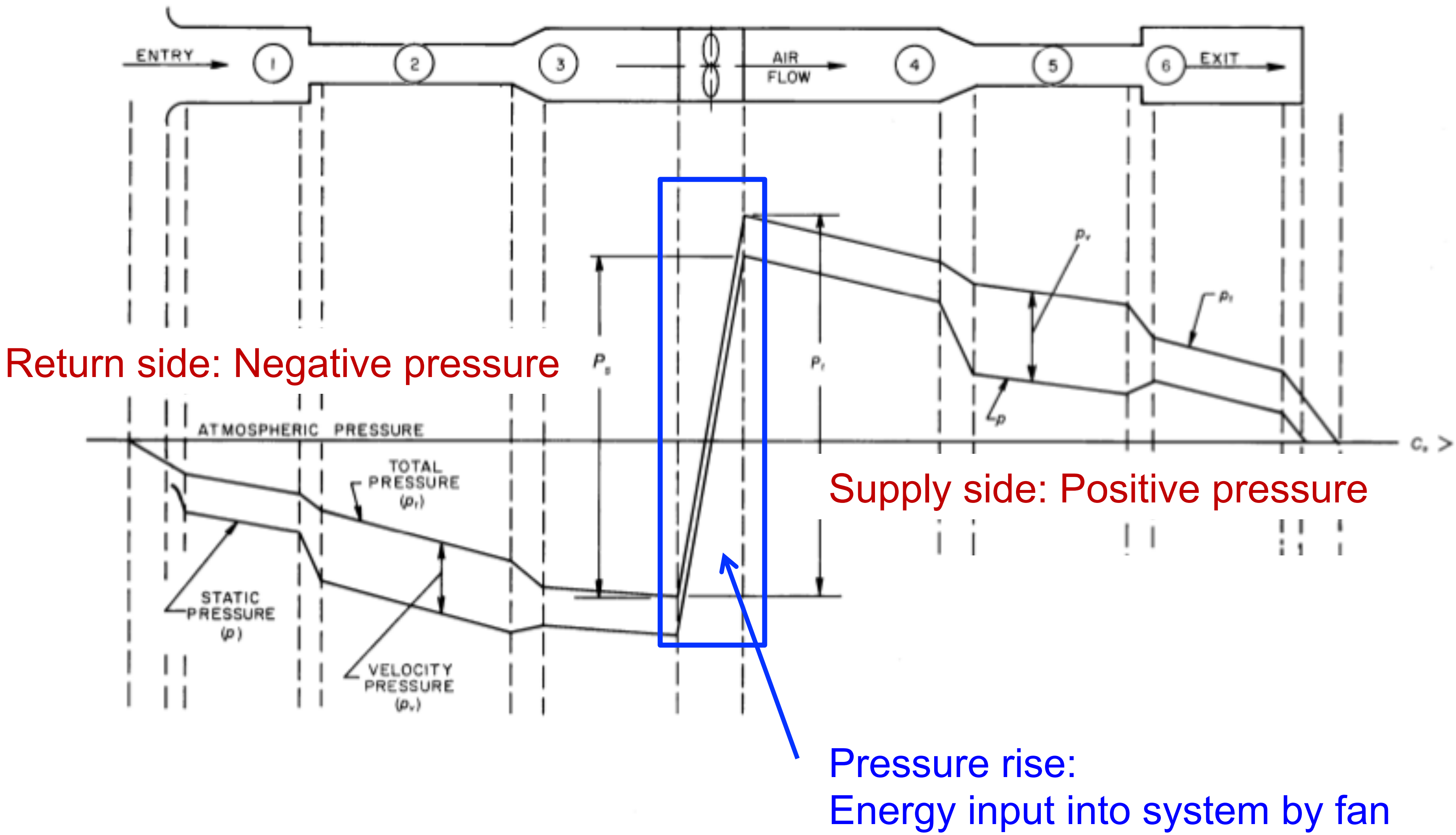


Figure 2. Fan Efficiency Grade curves are used to classify fans by their energy efficiency.

https://www.amca.org/UserFiles/file/AMCA_Spring2010RoleOfFE.pdf

Pressure losses and rises in HVAC systems



Investigation of HVAC system in this room