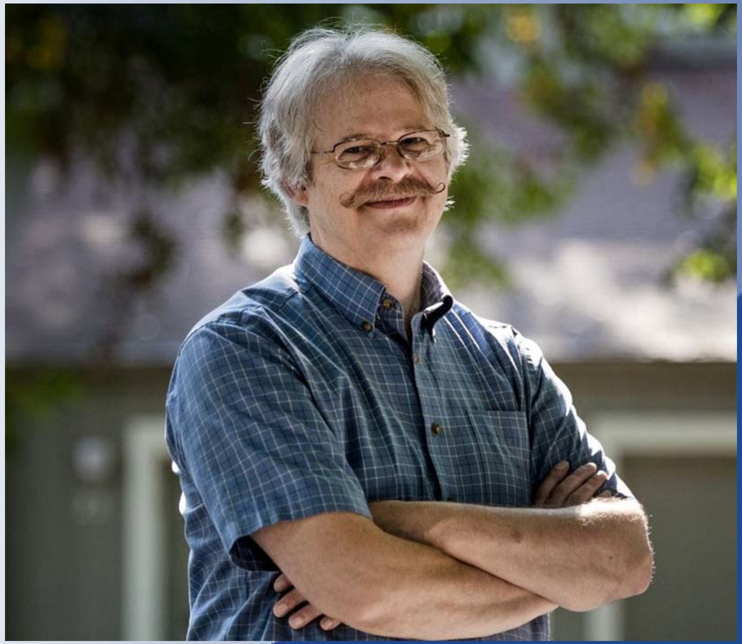
Better Plants
U.S. DEPARTMENT OF ENERGY

Industrial Fan Systems
Virtual INPLT Training & Assessment

Session 8

U.S. DEPARTMENT OF ENERGY

Fan Virtual INPLT Facilitator



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Acknowledgments

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- William (Bill) W.T. Corey
- US Department of Energy , Advanced Manufacturing Office
- Oak Ridge National Laboratory
- United Nations Industrial Development Organization
- Air Movement and Control Association, AMCA International
- Many industrial clients – both in the US and internationally

Agenda – Session Eight

- Welcome and Introductions
- Safety and Housekeeping
- Agenda for Fan System Virtual INPLT (8 weeks)
- Today's Content:

  Industrial Fan Systems Fundamentals
    - Review of key points

  Presentations from participants
    - Summary of fans
    - Potential Fan System Optimization Projects

  Industrial Fan Systems Fundamentals
    - More details about heat recovery in fan systems
- Q&A

Better Buildings is an initiative of the U.S. Department of Energy

Safety and Housekeeping

- Safety Moment
  - Fans can be dangerous, and caution should be used around fan systems
  - Accidents can be life-threatening
- You are welcome to ask questions at any time during the webinar
- When you are not asking a question, please <u>MUTE</u> your mic and this will provide the best sound quality for all participants
- We will be recording all these webinars and by staying on-line and attending the meeting you are giving your consent to be recorded
  - A link to the recorded webinars will be provided, afterwards

Review of Sessions 1-7

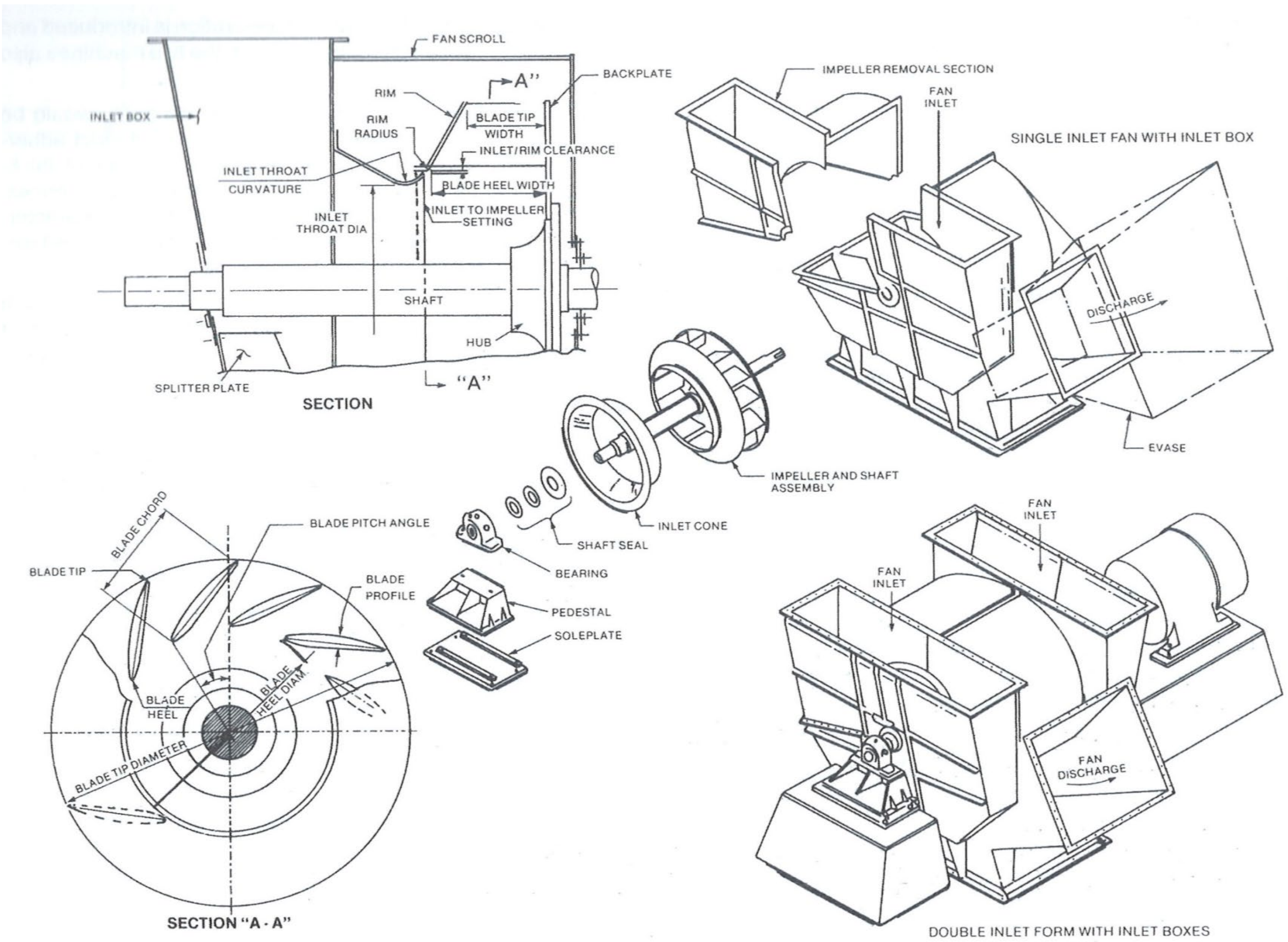
- Week 1 – Industrial Fan Systems Fundamentals and Introduction to MEASUR
- Week 2 – Fan and system curves, Fan types
- Week 3 – Fan affinity laws, Fan system controls
- Week 4 – Creating a fan performance measurement plan & selecting measurement planes
- Week 5 – Pressure considerations, Sizing ducts and estimating losses, Optimization techniques
- Week 6 – Psychrometrics and air density for fan systems, System effect in fan systems
- Week 7 – Fan system optimization strategies, Fan system evaluation with MEASUR
- Week 8 – Industrial Fan System VINPLT Wrap-up Presentations

Optimization Benefits

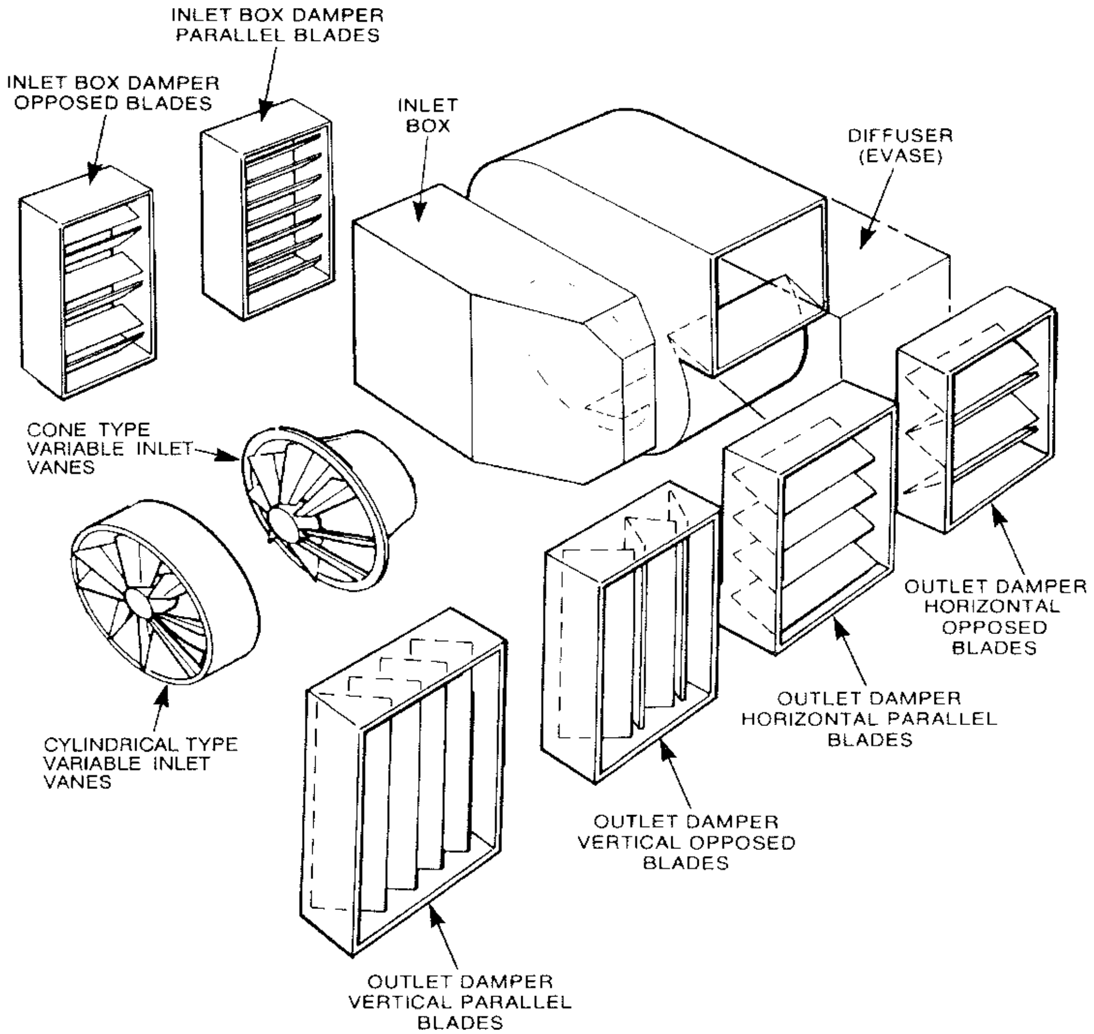
- Financial
- Corporate
- Production
- Maintenance
- Safety
- Environmental
- Societal

Time Magazine April 5, 2004

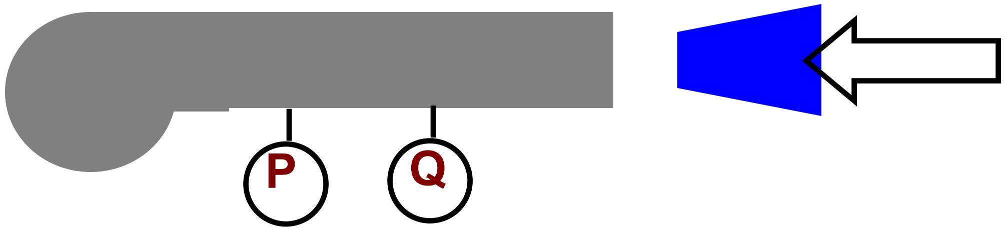
Centrifugal Fans



Fan Accessories and Dampers

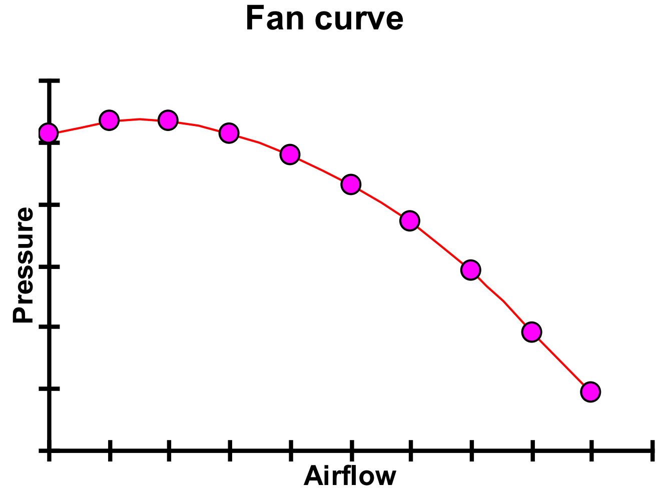


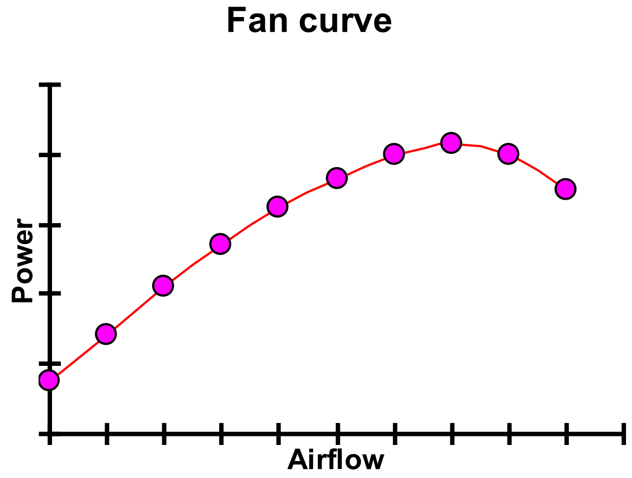
Fan Curve Development



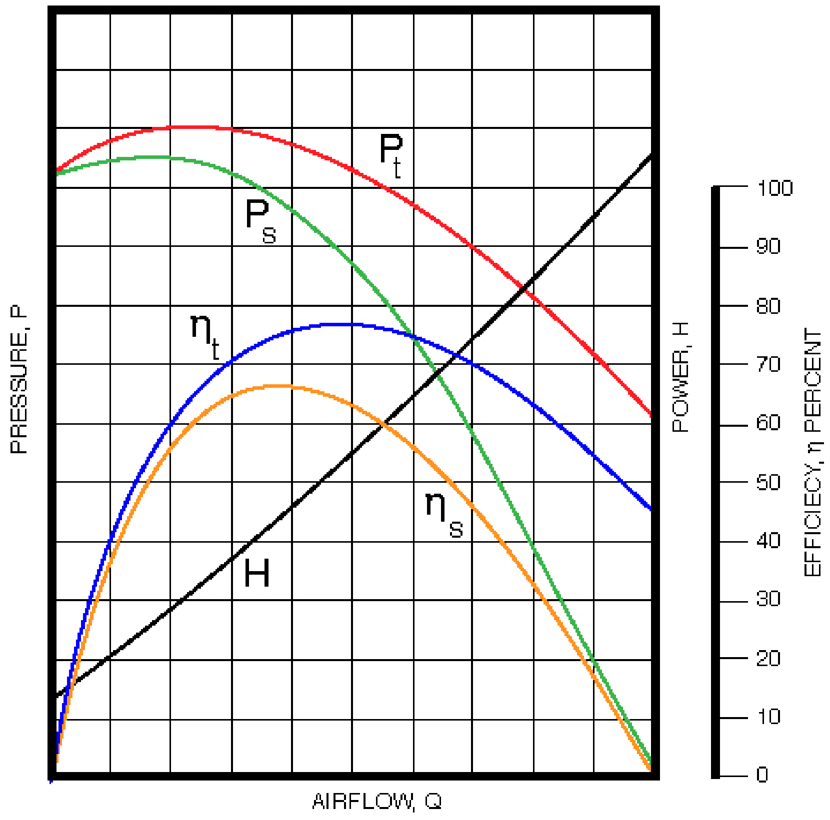
1. Measure: flow, pressure, and power
2. Plot Data
3. Choke off Flow

Repeat Steps 1-3 until shut-off point is reached.





Fan Performance Curve with Efficiency



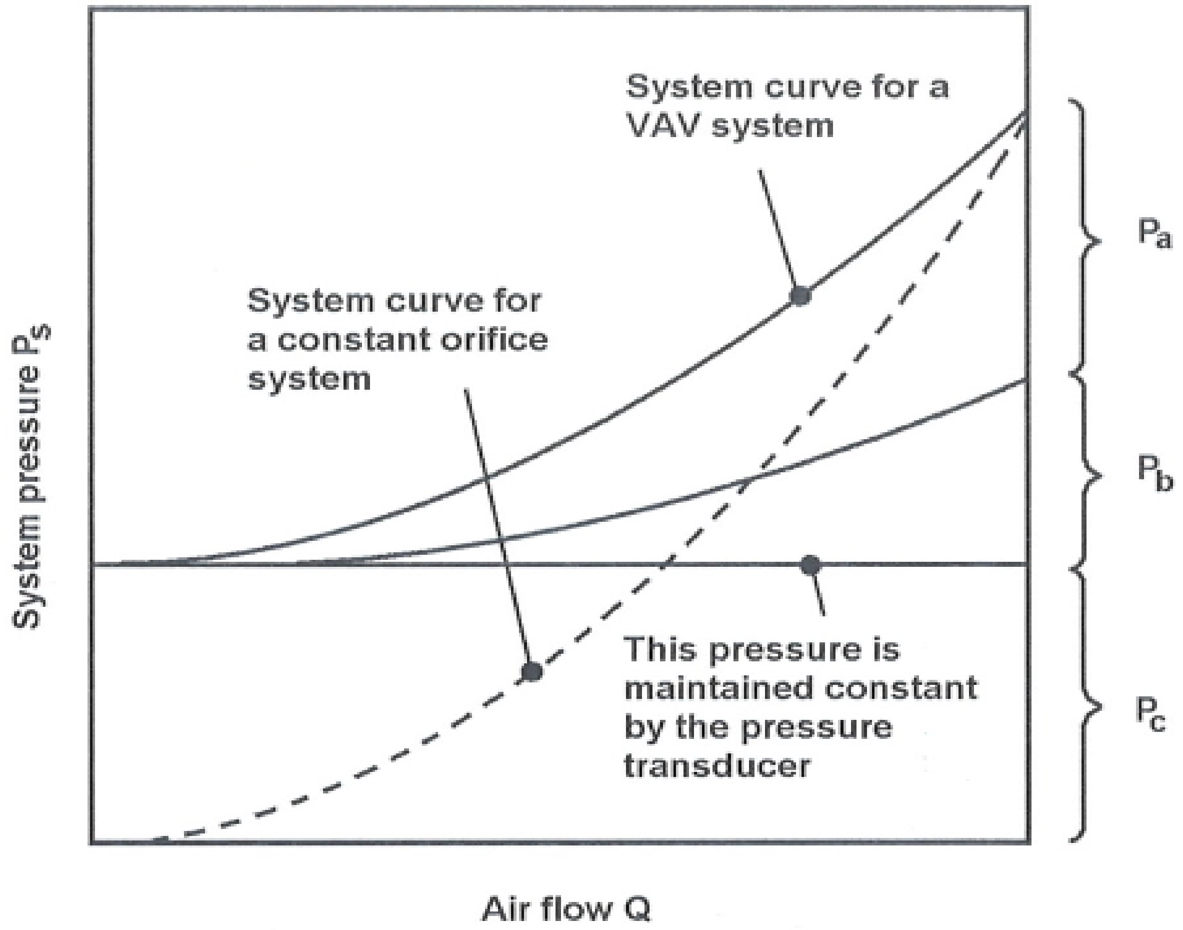
SIZE 30 FAN AT N RPM

OPERATION AT
STANDARD DENSITY

VAV System Typical Characteristic Curve

Note: newer digital VAV systems have a very tiny differential pressure requirement across the VAV

Sometimes process systems have a fixed pressure requirement.

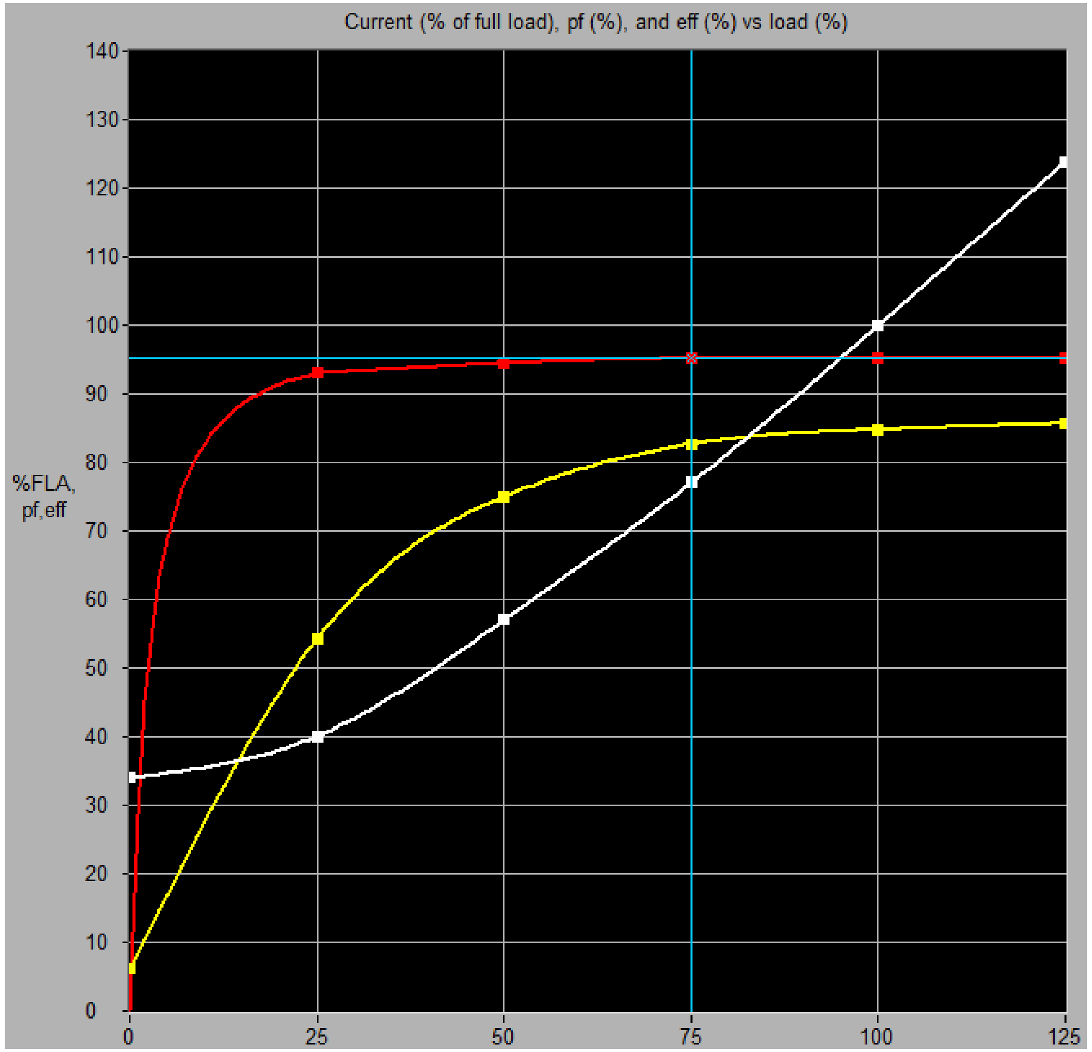


Motor characteristic curves

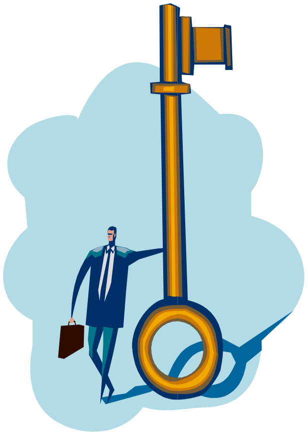
Red = Efficiency
Yellow = Power Factor
White = %FLA

- MEASUR uses this type of motor data to accurately estimate power factor (and thus power) from the measured amps and volts
- Caution: if capacitors are wired in at the motor, use a power meter and enter the kW in MEASUR instead of amps and volts

These curves are for a 1200 rpm 200 hp 460-volt AC induction motor



Key Points / Action Items



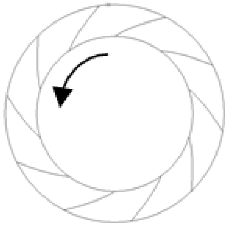
1. Remember to include the non-energy benefits when you are putting together the business plan to justify a fan system optimization project

2. Use a power meter, if possible, when measuring the energy draw of a fan system. If no power meter is available, check carefully for the presence of capacitors

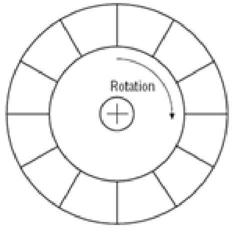
3. Remember that the Fan System Optimization Checklist is meant as a tool to prioritize potential projects

Centrifugal Fan Types Summary

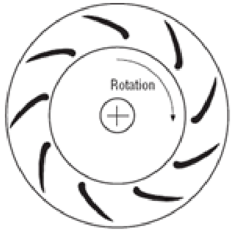
– Backward Curved (BCC)



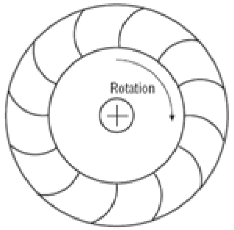
Radial Bladed (RBC)



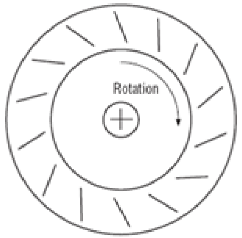
– Backward Aerofoil (BAC)



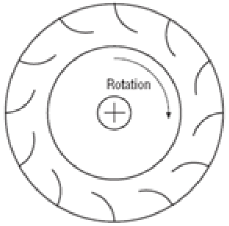
Forward Curved(FCC)



– Backward Inclined (BIC)



Radial Tipped (RT)

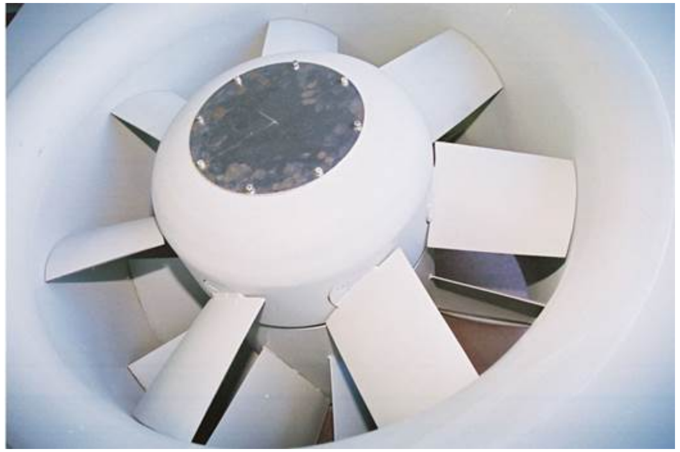


Axial Fan Types - Summary

Propeller

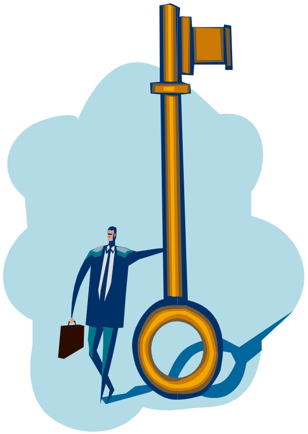
Vane
Axial

(Includes guide vanes)



Tube
Axial
(no guide vanes)

Key Points / Action Items



1. *The fan curve and system curve together can be used as a “road map” for navigating through a fan upgrade project, or for diagnosing system flow and pressure issues*

2. *Beware of selecting fans with their operating point too close to the surge point*

3. *Using the correct type of fan for the application is the first step towards a reliable and efficient system*

Simplified Affinity Laws – density change

Changes in density when Kp can be neglected

$$\left(\frac{Q_c}{Q}\right)=\cancel{\left(\frac{D_c}{D}\right)^3}\cancel{\left(\frac{N_c}{N}\right)}\cancel{\left(\frac{K_p}{K_{Pc}}\right)}$$

$$\left(\frac{P_{tc}}{P_t}\right)=\cancel{\left(\frac{D_c}{D}\right)^2}\cancel{\left(\frac{N_c}{N}\right)^2}\cancel{\left(\frac{K_p}{K_{Pc}}\right)}\left(\frac{\rho_c}{\rho}\right)$$

$$\left(\frac{H_c}{H}\right)=\cancel{\left(\frac{D_c}{D}\right)^5}\cancel{\left(\frac{N_c}{N}\right)^3}\cancel{\left(\frac{K_p}{K_{Pc}}\right)}\left(\frac{\rho_c}{\rho}\right)$$

OR

$Q_c = Q$

$P_{tc} = P_t \times (\rho_c/\rho)$

$P_{sc} = P_s \times (\rho_c/\rho)$

$P_{vc} = P_v \times (\rho_c/\rho)$

$H_c = H \times (\rho_c/\rho)$

Simplified Affinity Laws – speed change

Changes in Fan speed when Kp can be neglected

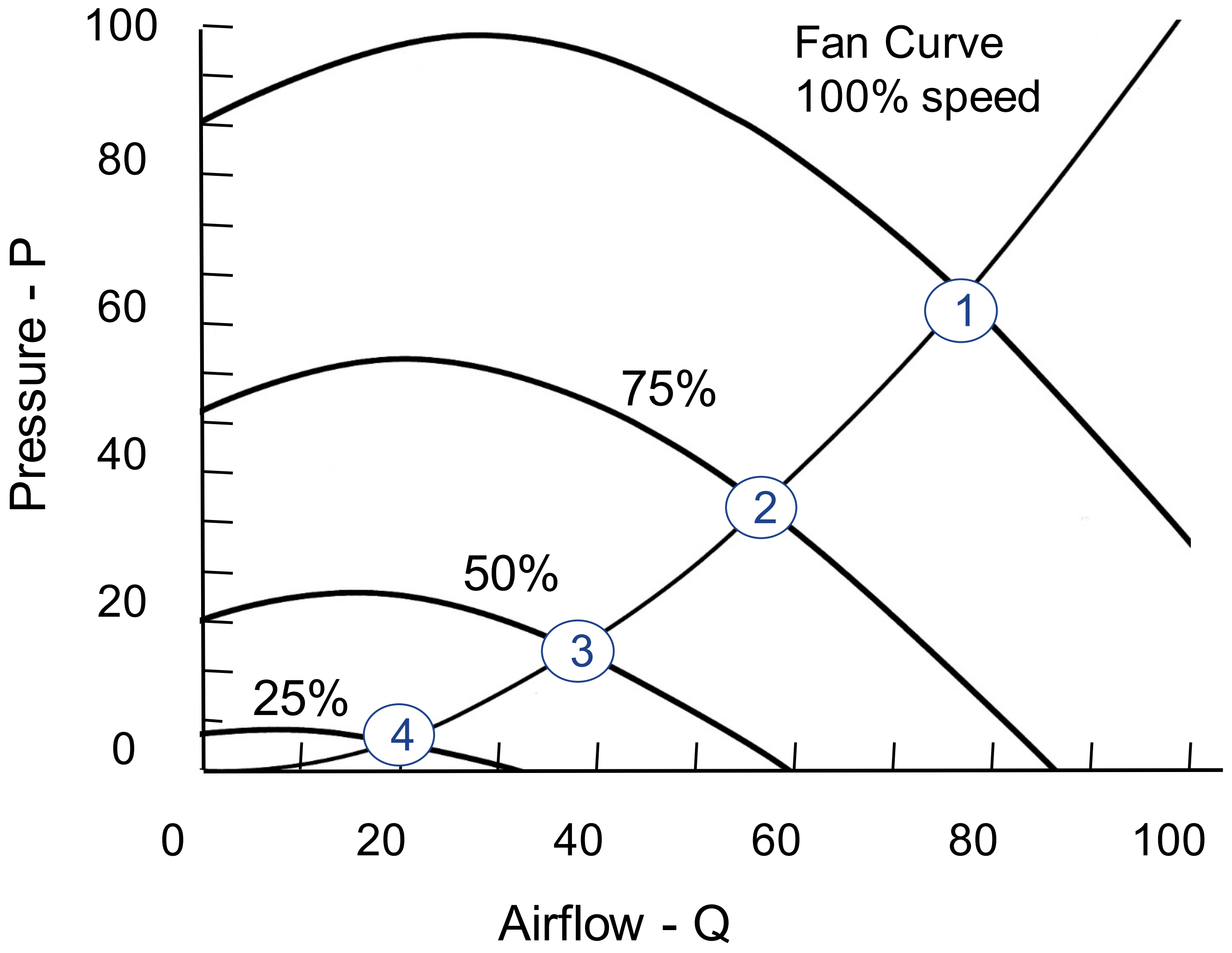
$$Q_c = Q \times \left(\frac{N_c}{N}\right)$$

$$P_c = P \times \left(\frac{N_c}{N}\right)^2$$

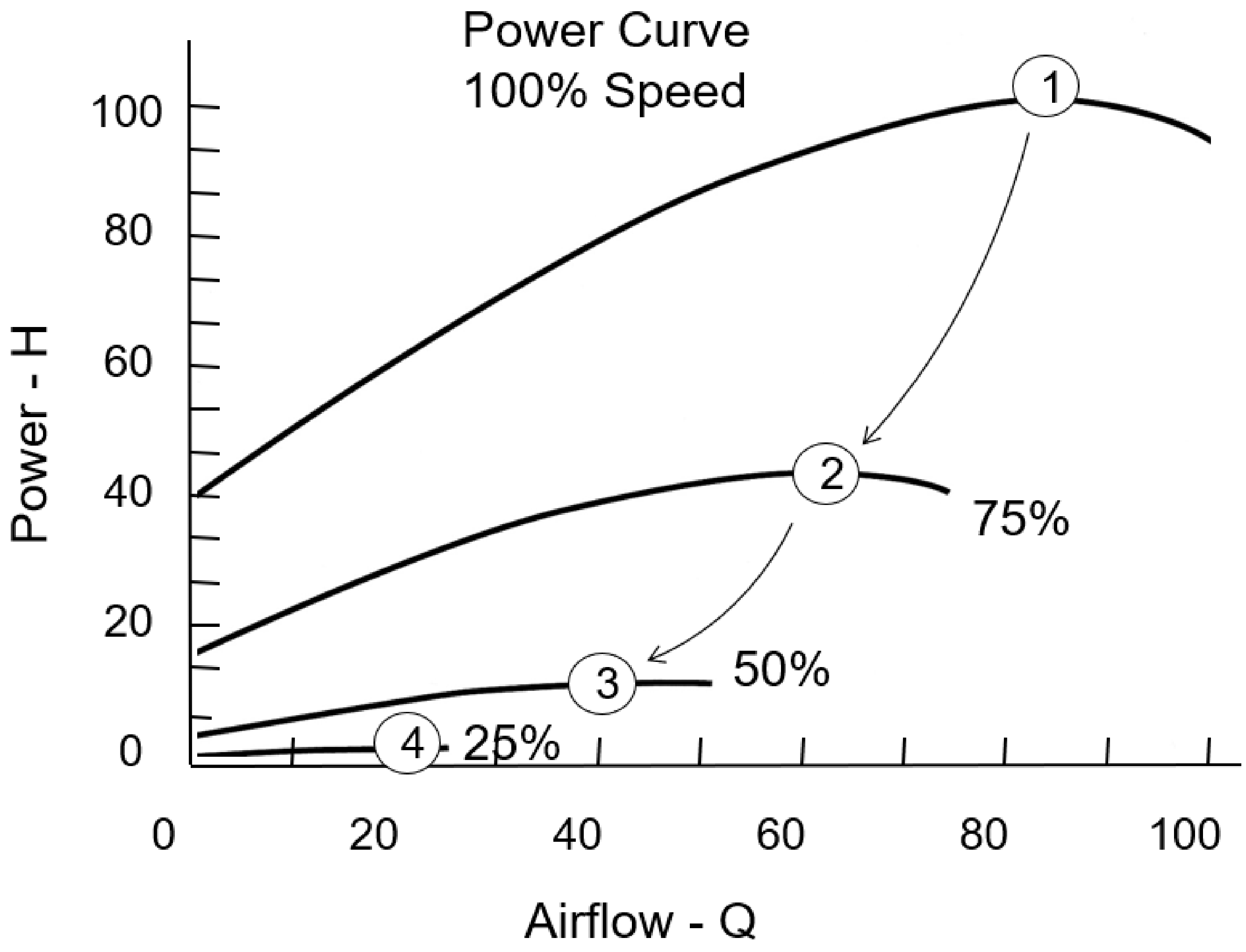
$$H_c = H \times \left(\frac{N_c}{N}\right)^3$$

$$H_c = \frac{P_c \times Q_c}{6356 \times \eta}$$

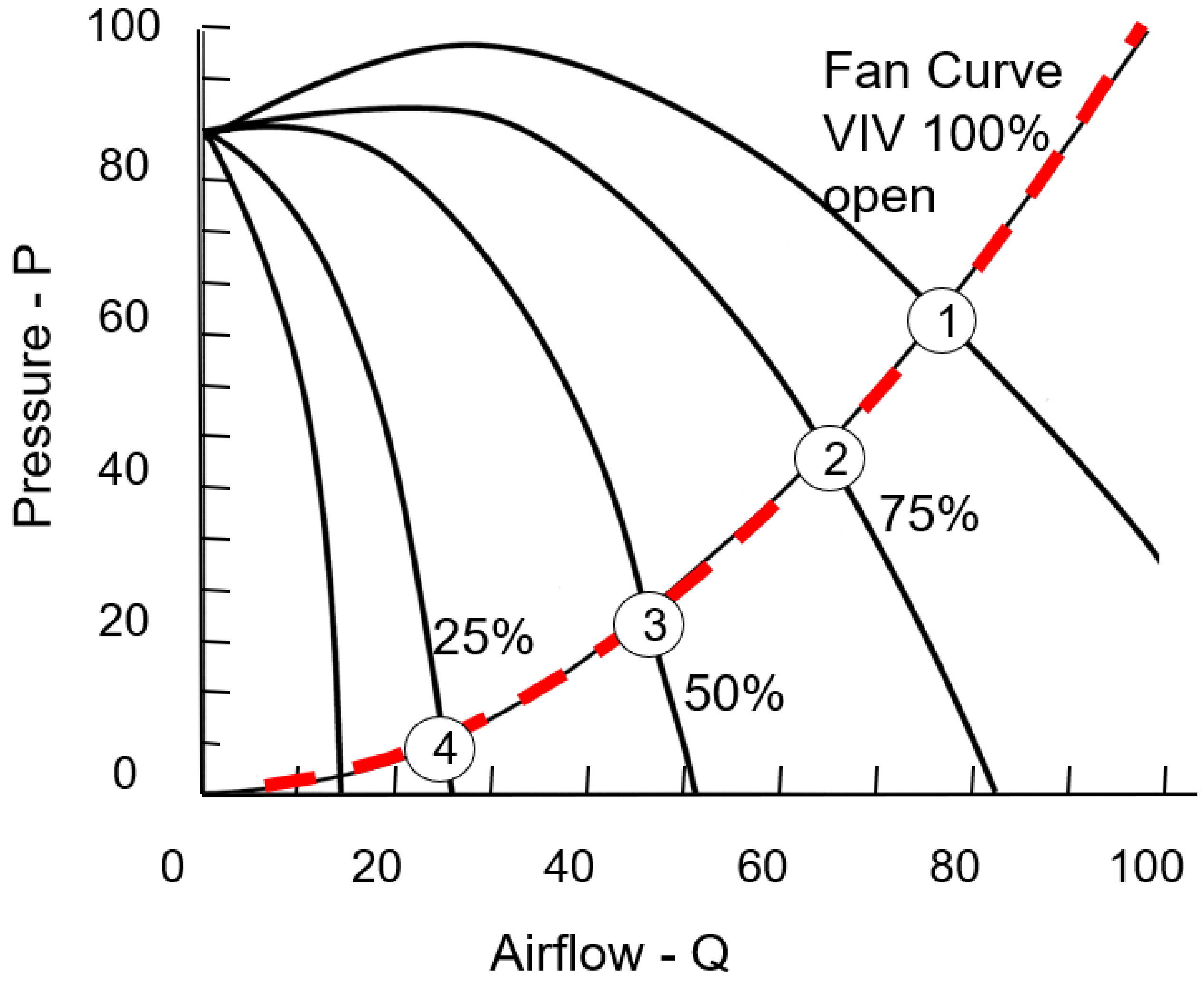
Fan Performance Curve with Variable Speed Drive



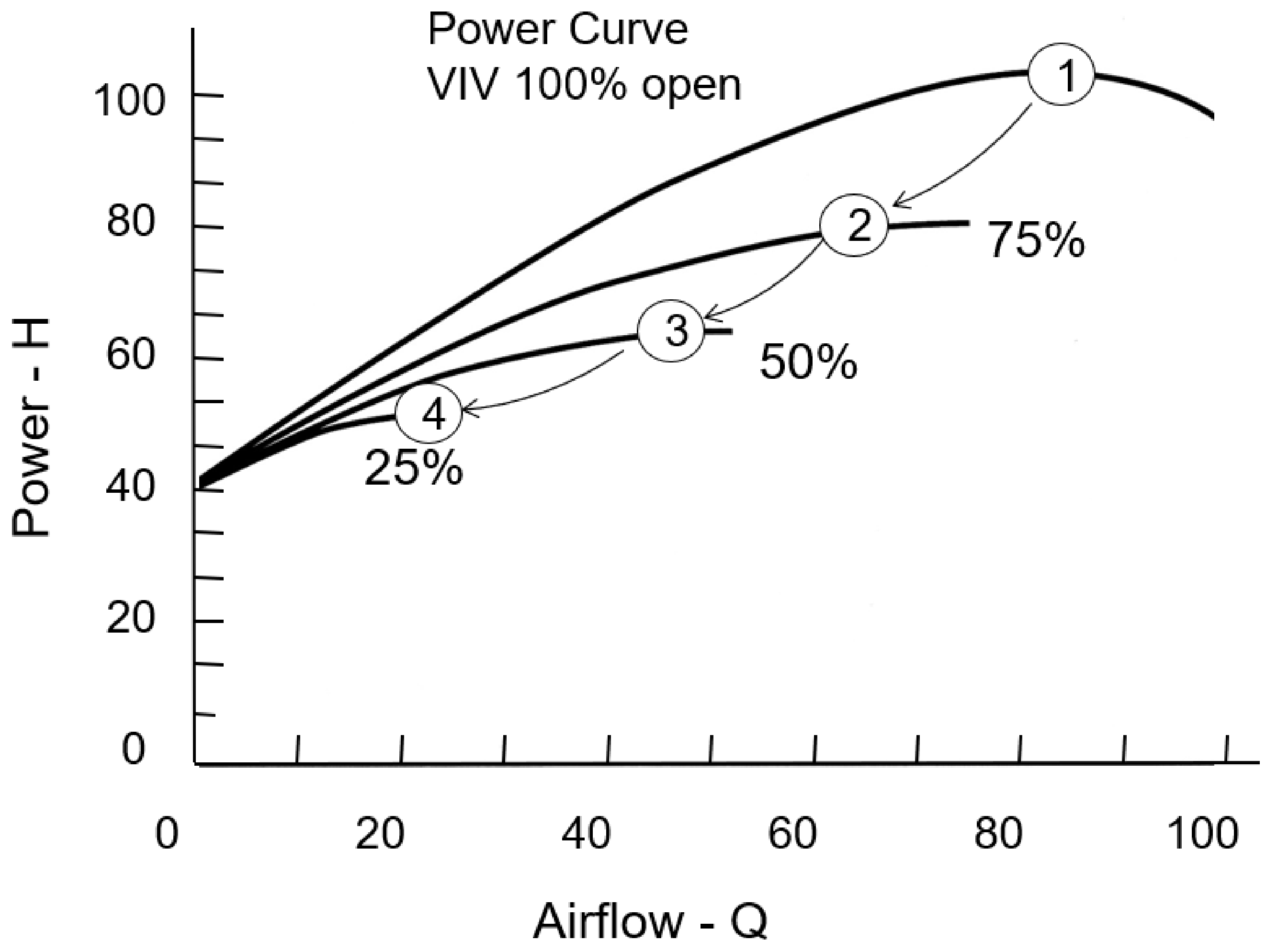
Fan Power Curve with Variable Speed Drive



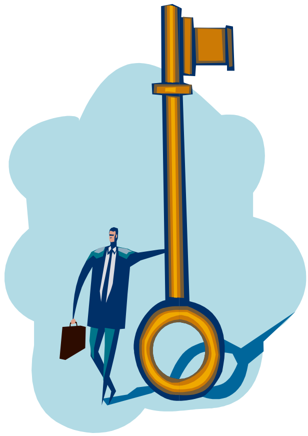
Fan Performance Curve with Variable Inlet Vanes



Varying Power Curves for Variable Inlet Vanes



Key Points / Action Items



1. When changing the rotational speed of a fan:
   - The change in flow is directly proportional to the speed change
   - The change in pressure is proportional to the square of the speed change,
   - The change in power is proportional to the cube of the speed change
2. Normally slowing down the fan is more efficient than using a damper to control the flow
3. Variable Inlet Vanes are generally the most efficient form of damper control, since they impart a pre-swirl
4. Avoid using a VFD for constant flow application.
5. Especially avoid using a VFD for applications with high constant pressure requirements

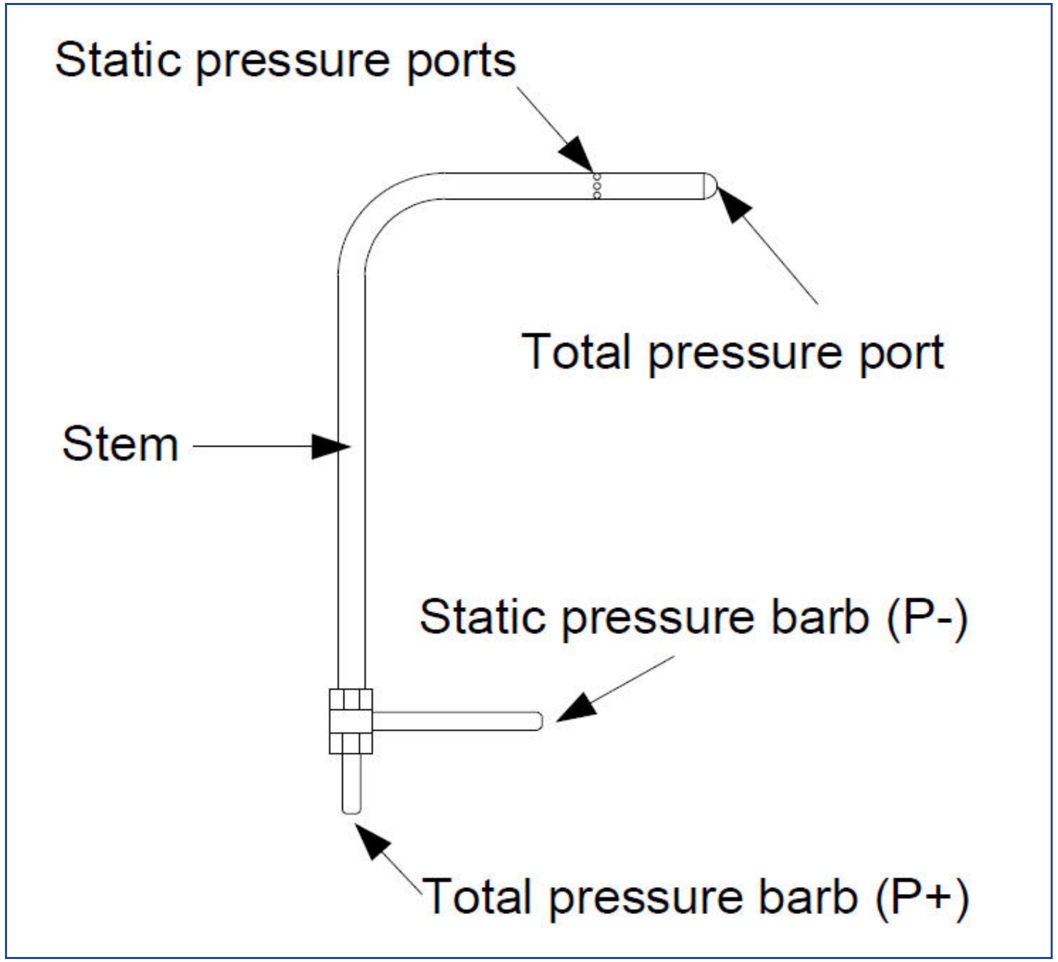
Fan System Performance Measurement Tools

Fan performance is measured with the goal of definitively establishing what the fan is doing. This goal includes completely defining the performance of the fan as it relates to flow, pressure and power.

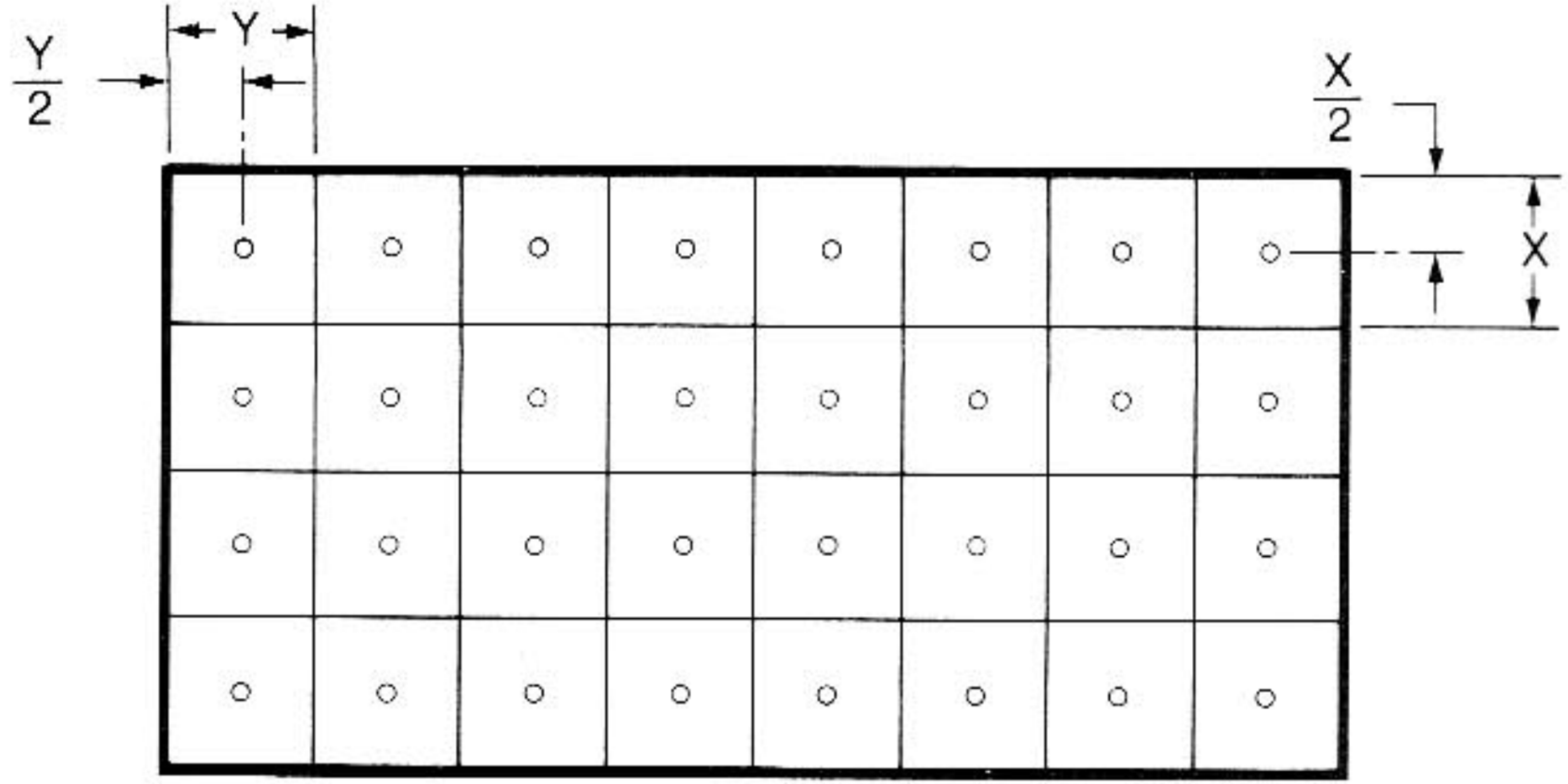
Instrumentation includes:

- Manometers
- Barometers
- Tachometers
- Thermocouple
- Power meter

Pitôt Static for Connection to Manometer

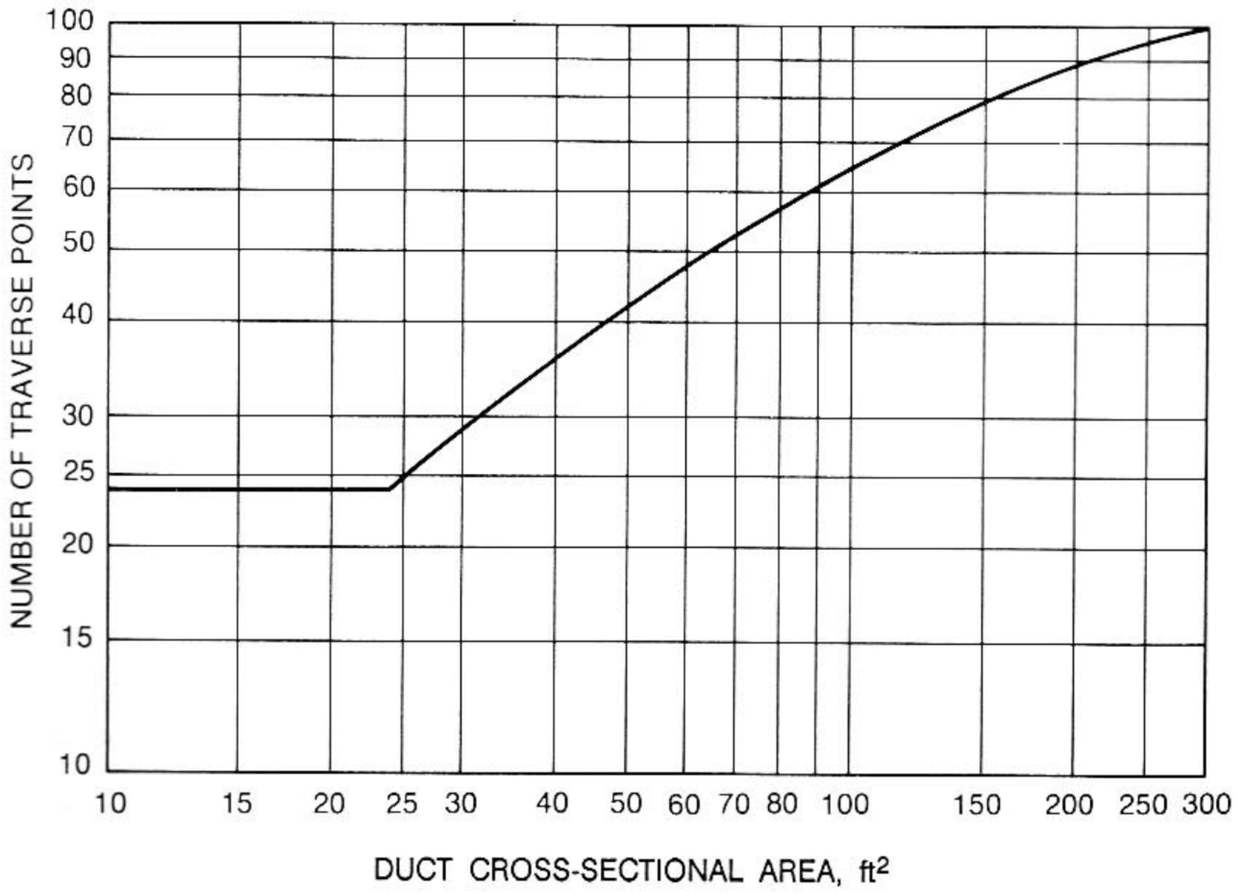


Measurement Grids – AMCA 203



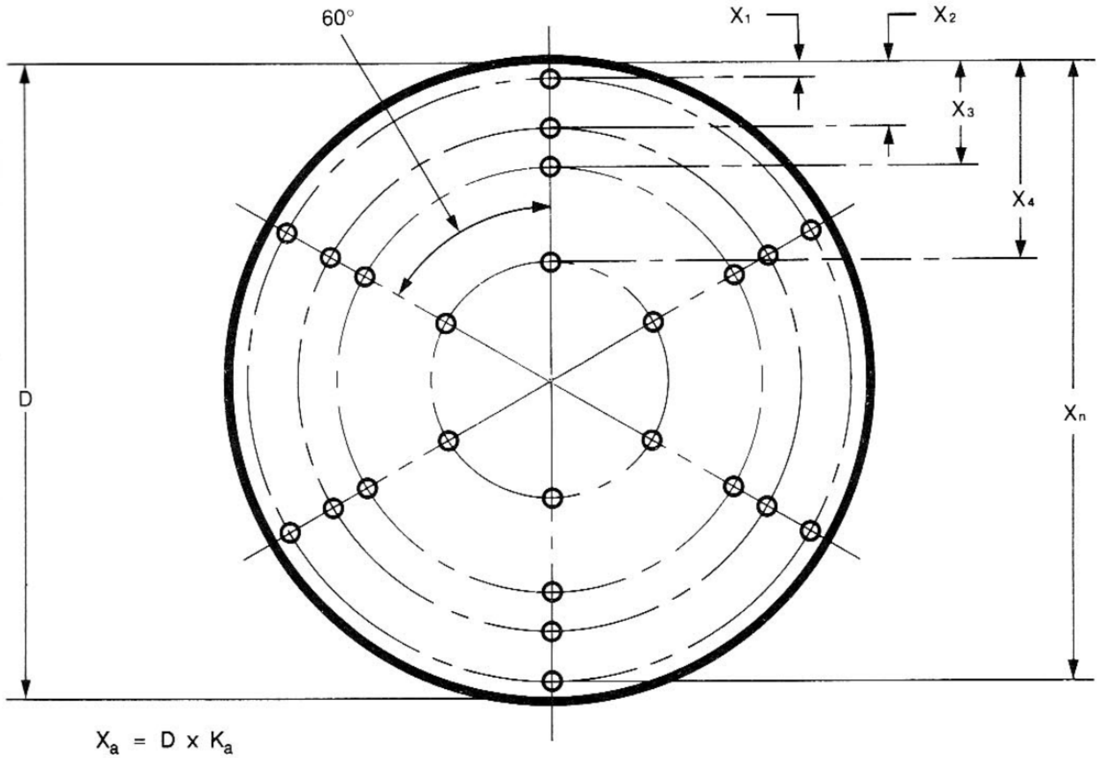
DISTRIBUTION OF TRAVERSE POINTS FOR RECTANGULAR DUCT

Measurement Grids – AMCA 203



RECOMMENDED MINIMUM NUMBER OF TRAVERSE POINTS FOR RECTANGULAR DUCTS

Measurement Grids – AMCA 203



$X_a = D \times K_a$

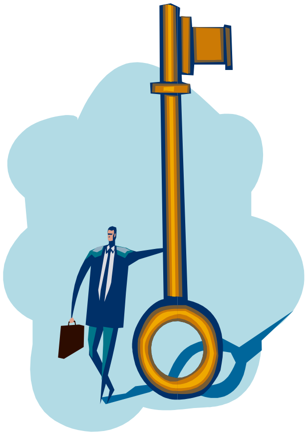
where D is the inside diameter of the duct and K_a is the factor corresponding to the duct size and the traverse point location as indicated in the table below.

INSIDE DIAMETER OF DUCT	NUMBER OF TRAVERSE POINTS IN EACH OF 3 DIAMETERS	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9	K_{10}	K_{11}	K_{12}	K_{13}	K_{14}	K_{15}	K_{16}
LESS THAN 8 ft	8	.021	.117	.184	.345	.655	.816	.883	.979	—	—	—	—	—	—	—	—
8 ft THRU 12 ft	12	.014	.075	.114	.183	.241	.374	.626	.759	.817	.886	.925	.986	—	—	—	—
GREATER THAN 12 ft	16	.010	.055	.082	.128	.166	.225	.276	.391	.609	.724	.775	.834	.872	.918	.945	.990

Flow Traverse Plane Criteria

1. Uniform velocity distribution
2. Flow stream at right angles to plane
3. Regular duct cross section (i.e. rectangle or circle)
4. Uniform cross section at plane (not diverging or converging)
5. If in a converging or diverging section, the plane is at the tip of the pitot tube.
6. In a section of duct unaffected by leakage
7. If at the fan discharge, then a 100% effective duct length is needed
8. If at inlet, ½ duct diameter upstream of inlet
9. If in inlet box, then 12” downstream of inlet damper trailing edge

Key Points / Action Items



1. Proper selection of measurement planes is critical when setting up an in-situ fan performance test

2. Ideally, the traverse plane should be located in a section of duct that is at least a few diameters downstream of elbows or other flow impediments, and relatively near the fan inlet if possible.

3. Avoid putting the flow traverse plane on the outlet of the fan, if possible

4. For dusty airstreams use an S-type pitot tube and make sure you apply the correction factor

5. Work with a mentor to gain experience in conducting a fan test – somethings are not possible to learn from a book or a webinar – they require hands-on training.

Fan System Pressure Considerations

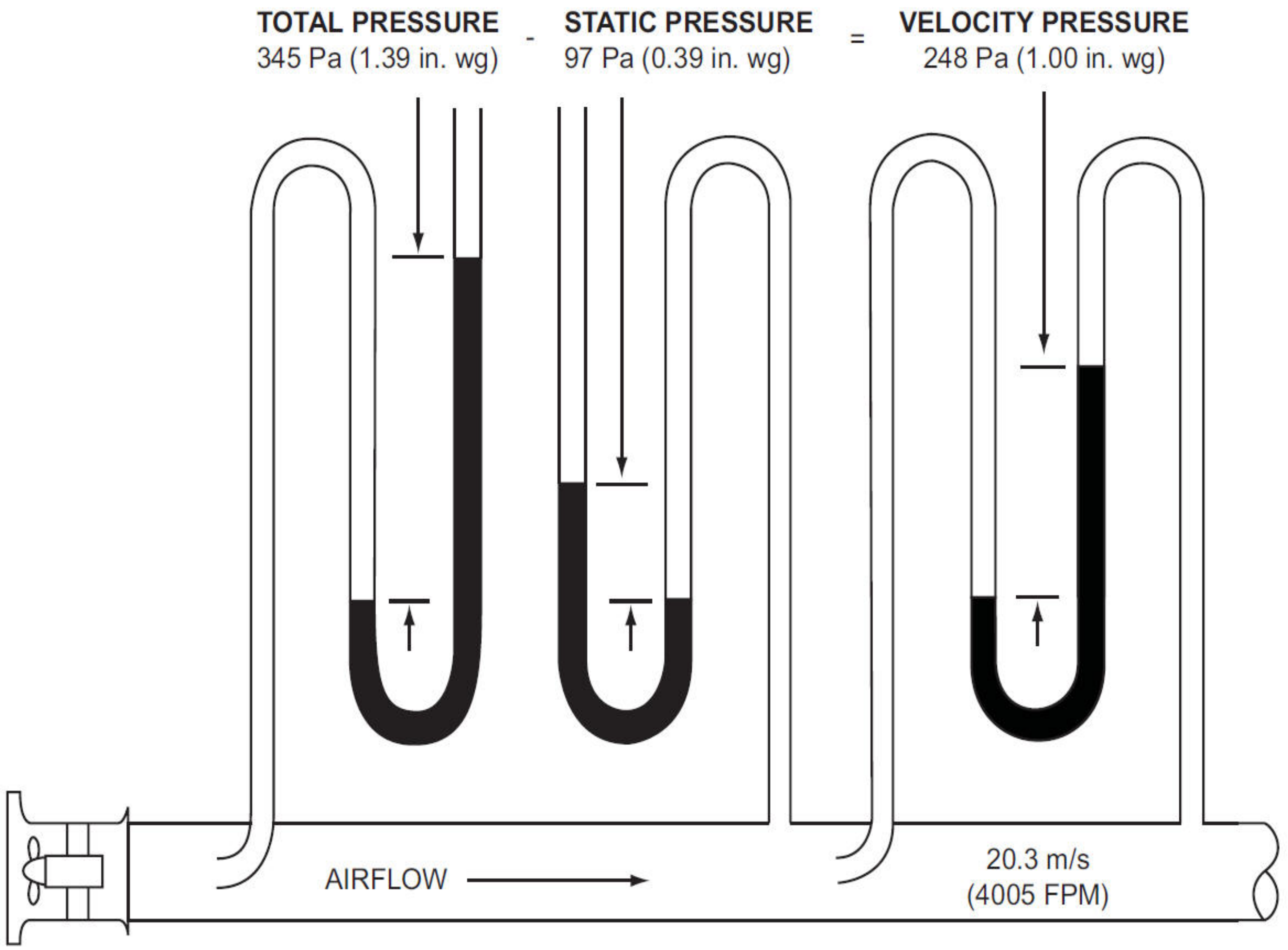
Bernoulli's equation determines the relationship between the static pressure (P_s), velocity pressure (P_v) and total pressure (P_t).

$$P_t = P_s + P_v$$

The fan static pressure is defined in AMCA measurement protocols as the outlet static pressure minus the inlet static pressure minus the inlet velocity pressure:

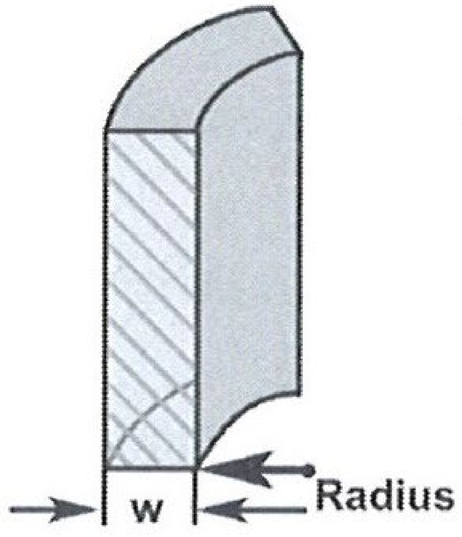
$$P_s = P_{s2} - P_{s1} - P_{v1}$$

System Pressure Illustration- Positive Pressure

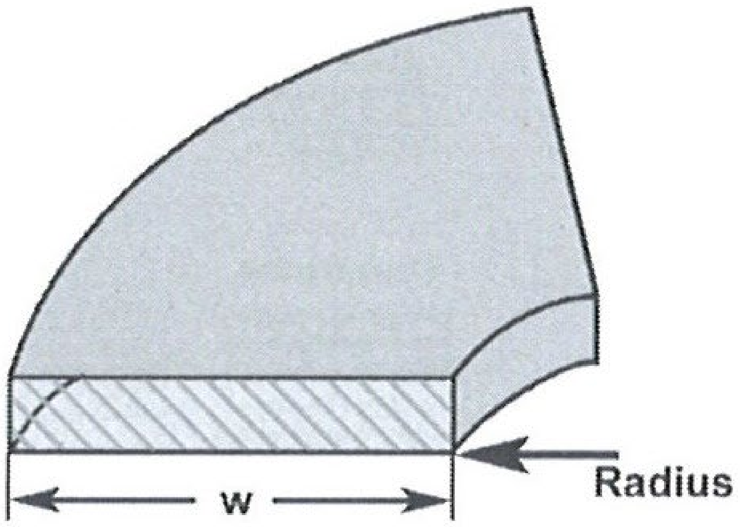


345= 97 + 248

Easy and Hard Bends



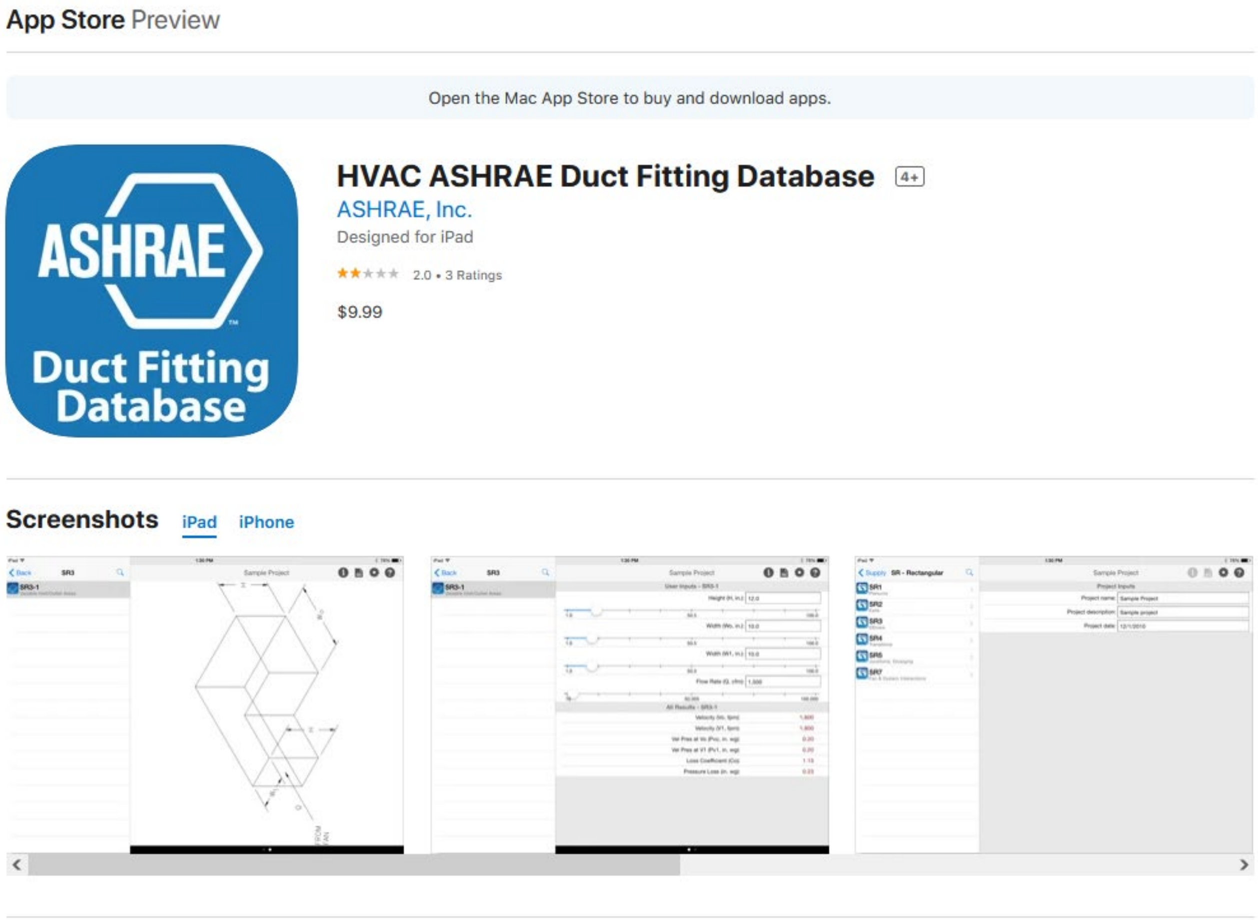
Easy



Hard

ASHRAE Duct fitting database ap

- $9.99 Ap Works on Iphone, Ipad
- Separate version for computer $147



Key Points / Action Items

1. "follow" a particle of air through the duct system and examine the trade off between static pressure and velocity pressure.

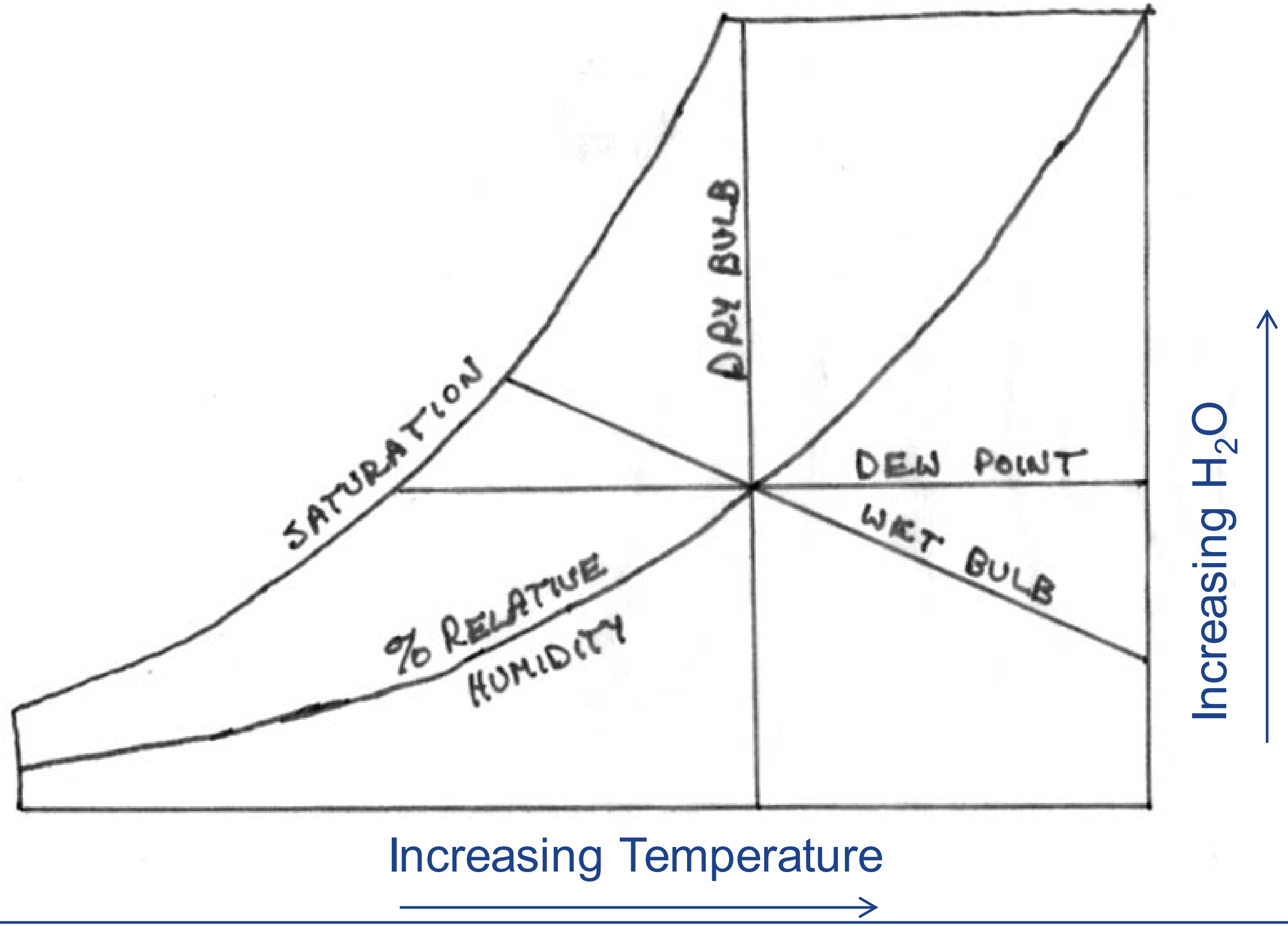
2. Remember that as the velocity goes up due to a duct constriction, the velocity pressure goes up also, so there is a corresponding decrease in the static pressure

3. When materials are conveyed through the fan system, ensure that velocities are high enough to keep particles entrained, but not excessive to incur additional losses

4. Use easy bends and gradual transitions in ductwork

5. Use ASHRAE duct fitting ap to estimate duct losses

Skeleton Psychrometric Chart



Density Shortcuts: Adjust Known Density

If the density of a mix of gasses is known at a given temperature and pressure you can adjust the density for a new temperature and pressure according to the perfect gas laws

$$\rho_c = \rho \times \frac{T}{T_c} \times \frac{P}{P_c}$$

Where:

ρ_c = the new density, in kg/m^3 (lb/ft^3)

ρ = the original density, in kg/m^3

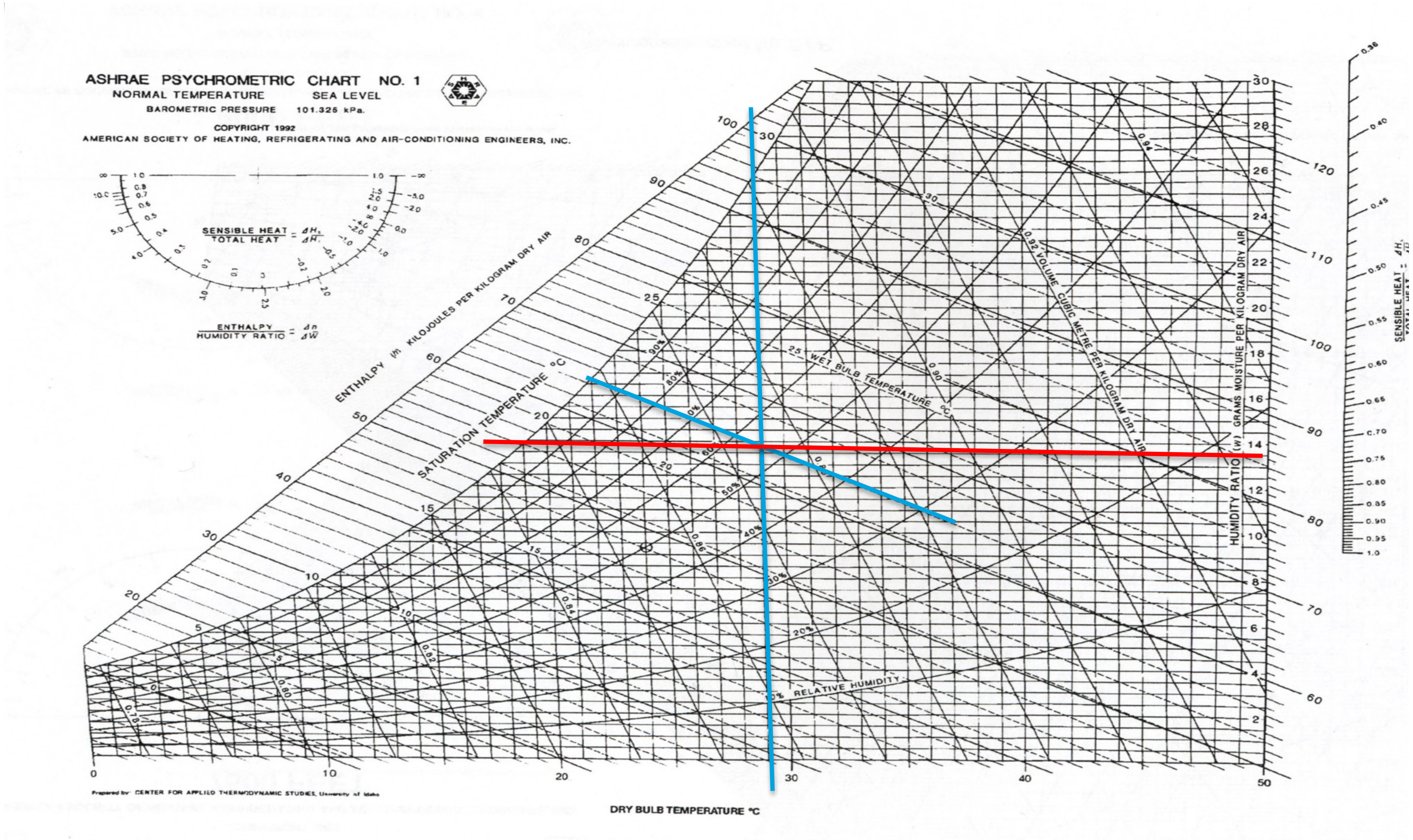
T_c = the new temperature, in kelvins (Rankine)

T = the original temperature, in kelvins

P_c = the new absolute pressure, in Pa (in. Hg)

P = the original absolute pressure, in Pa (in. Hg)

Normal Temperature Psychrometric Chart



Psychrometric chart No. 1 S-I.

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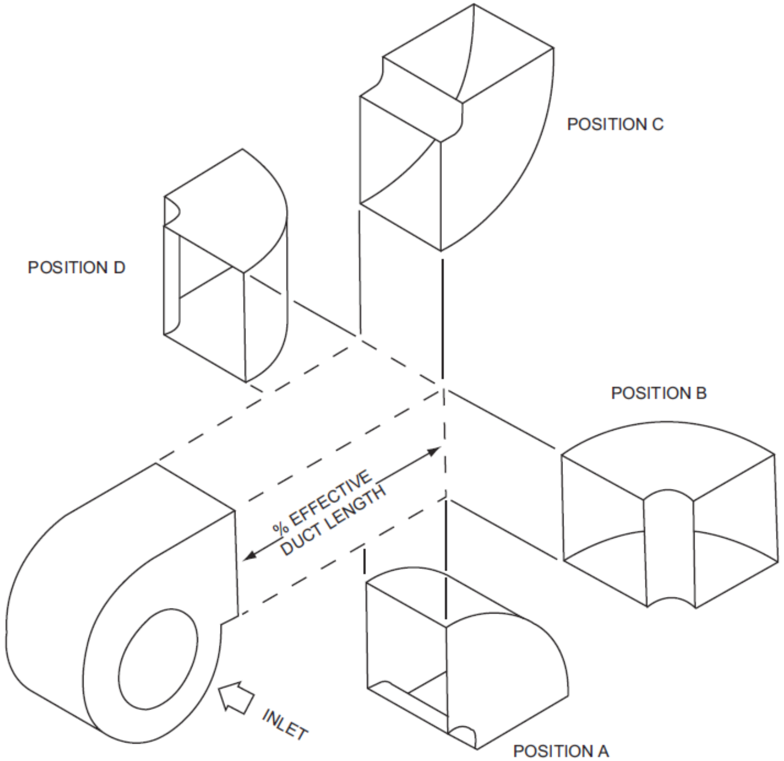
System effect on the fan outlet



SWSI CENTRIFUGAL FAN SHOWN

Blast Area / Outlet Area	Outlet Elbow Position	No Outlet Duct	12% Effective Duct	25% Effective Duct	50% Effective Duct	100% Effective Duct
0.4	A	N	O	P-Q	S	*NO System Effect Factor*
	B	M-N	N	O-P	R-S	
	C	L-M	M	N	Q	
	D	L-M	M	N	Q	
0.5	A	O-P	P-Q	R	T	
	B	N-O	O-P	Q	S-T	
	C	M-N	N	O-P	R-S	
	D	M-N	N	O-P	R-S	
0.6	A	Q	Q-R	S	U	
	B	P	Q	R	T	
	C	N-O	O	Q	S	
	D	N-O	O	Q	S	
0.7	A	R-S	S	T	V	
	B	Q-R	R-S	S-T	U-V	
	C	P	Q	R-S	T	
	D	P	Q	R-S	T	
0.8	A	S	S-T	T-U	W	
	B	R-S	S	T	V	
	C	Q-R	R	S	U-V	
	D	Q-R	R	S	U-V	
0.9	A	T	T-U	U-V	W	
	B	S	S-T	T-U	W	
	C	R	S	S-T	V	
	D	R	S	S-T	V	
1.0	A	T	T-U	U-V	W	
	B	S-T	T	U	W	
	C	R-S	S	T	V	
	D	R-S	S	T	V	

SYSTEM EFFECT CURVES FOR SWSI FANS

System Effect at Fan inlet

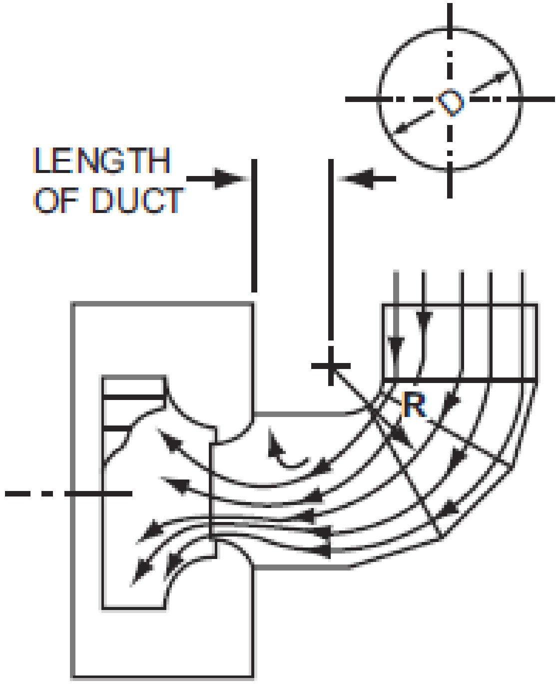


Figure 9.3A - Non-Uniform Airflow Into a Fan Inlet Induced by a 90°, 3-Piece Section Elbow--No Turning Vanes

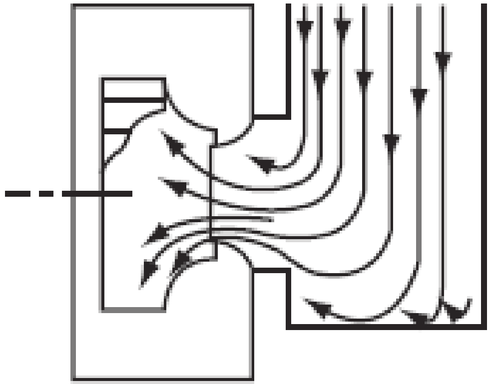


Figure 9.3B - Non-Uniform Airflow Induced Into Fan Inlet by a Rectangular Inlet Duct

Key Points / Action Items

1. *The density will vary at the various measurement planes because the temperature and the local pressure will vary among the planes*

2. *Density is an important factor in the analysis of the in-situ performance test data. It is important to pay attention to calculating it as accurately as possible.*

3. *Weight of dust is not included in the density calculations covered in today's course*

4. *Abrupt turns at the inlet or outlet of the fan, the lack of an outlet duct, and other factors can prevent the fan from achieving its laboratory tested performance because of the phenomena called "system effect"*

Polling Question 1 & 2

Polling Question

1) Do you think there might be heat recovery opportunities at your facility?
   A. Yes, I think there might be
   B. Not certain, but possibly might be
   C. Probably not
2) Which of the following would you be most interested in learning more about?
   A. Air to air – Fixed plate
   B. Air to air - Heat wheel
   C. Air to air - Heat pipe
   D. Air to water or air to steam for power generation

Heat recovery in fan systems

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Heat Recovery Strategies

In many fan systems, the thermal energy being carried by the fluid far exceeds the electrical energy driving the fan motor. In all too many cases the energy is dumped to atmosphere or discarded.

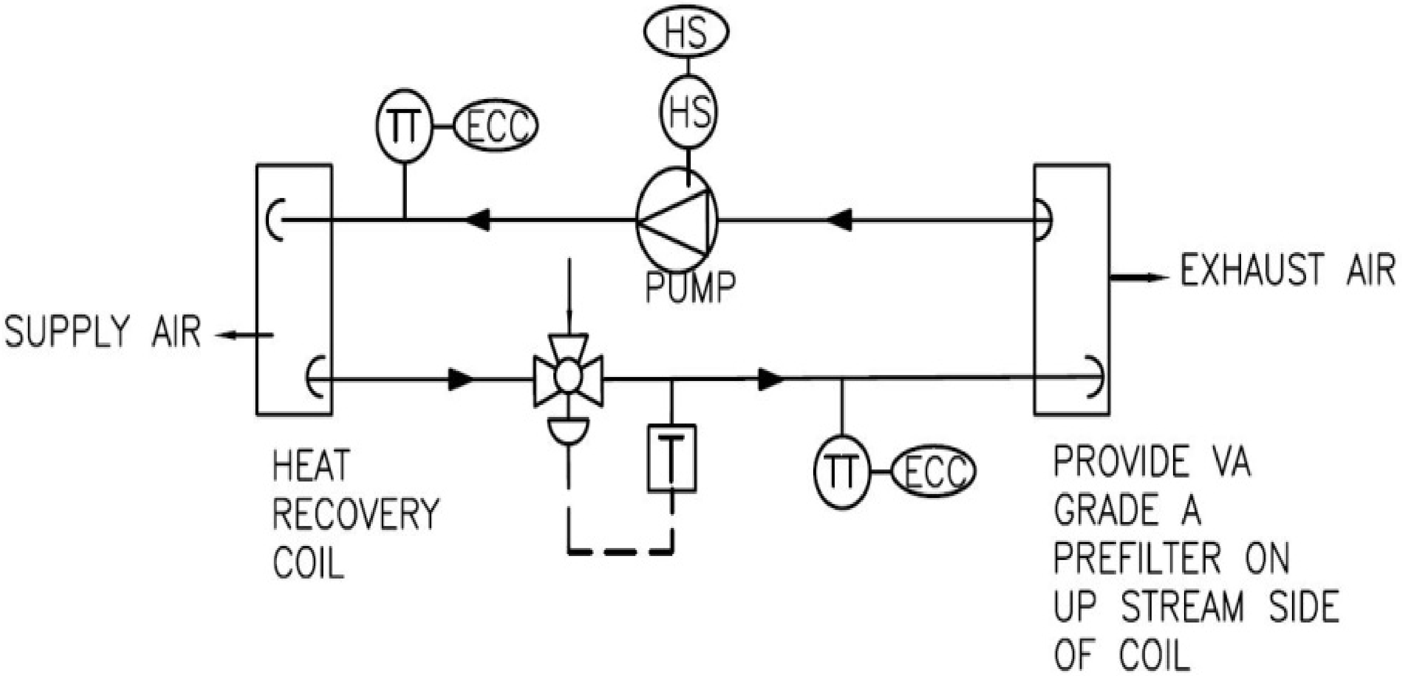
- Glycol Run-Around System
- Air-to-Air
  - Flat plate
  - Heat Pipes
  - Heat Wheel
- Air to Water
- Water to Air

Heat exchanger effectiveness

Effectiveness

- The effectiveness of a heat exchanger is a measure of the amount of heat recovered vs the theoretical maximum amount of heat that could be recovered
- Effectiveness can range from 0% to 100%
- “Real world” heat exchanger effectiveness usually 40 – 80%
- Used as a measure of sensible heat transfer

Glycol Run- Around System



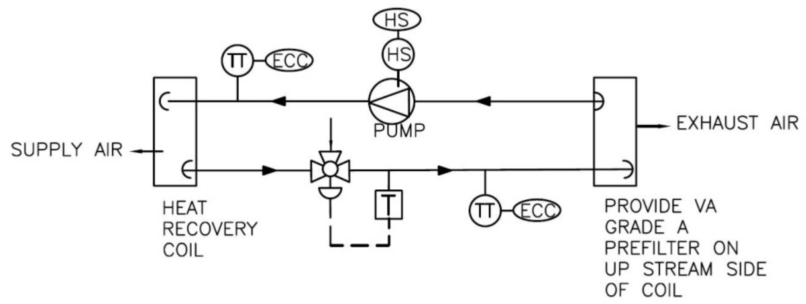
Glycol Run- Around System

Advantages

- Exhaust and intake need not be right next to each other
- Glycol means system can operate below freezing

Disadvantages

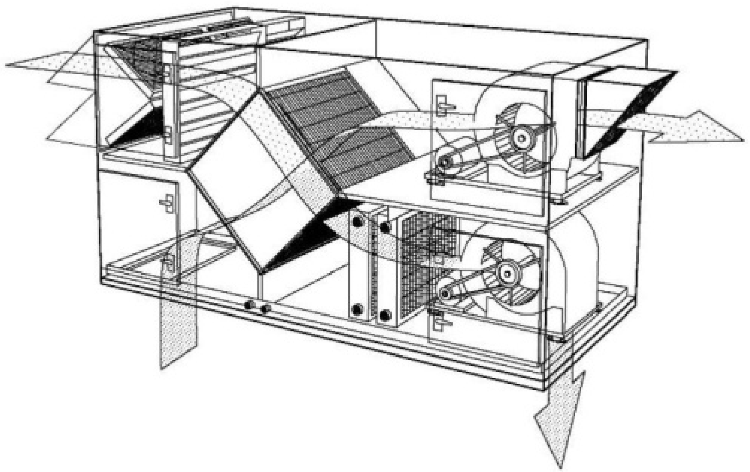
- Two-stage heat exchange diminishes effectiveness
- Parasitic power loss in pump
- Piping can be expensive
- Possible leaks
- Low effectiveness – 40-60%



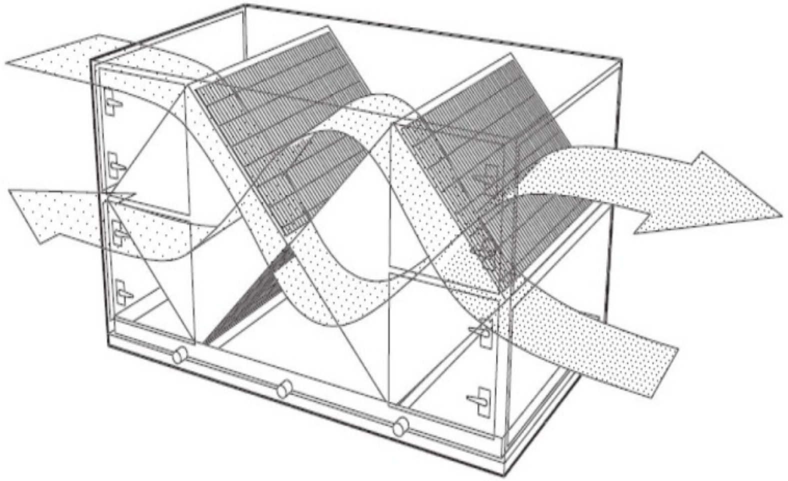
Best Application:

Where there is a physical separation and a large temperature difference between exhaust and intake gas streams

Air-to-Air – Flat plate



Make-up Air Unit



Double Pass Arrangement

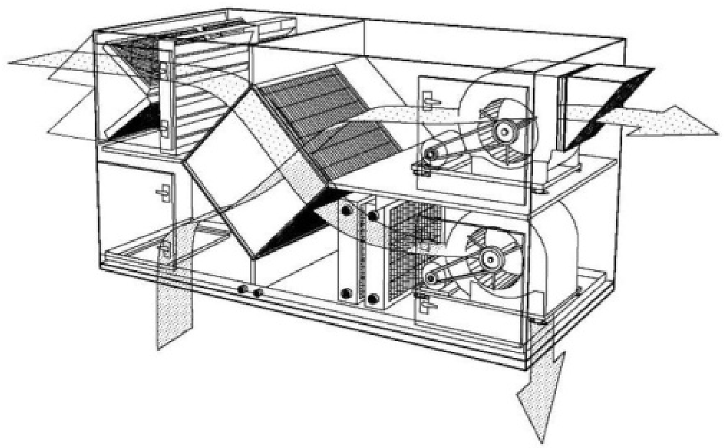
Air to air - Flat Plate

Advantages

- One stage heat transfer
- Simple construction
- No moving parts other than fan
- low pressure loss
- Up to 80% effectiveness w/two-stage

Disadvantages

- Exhaust and intake gas streams must be in reasonably close proximity



Best Applications:

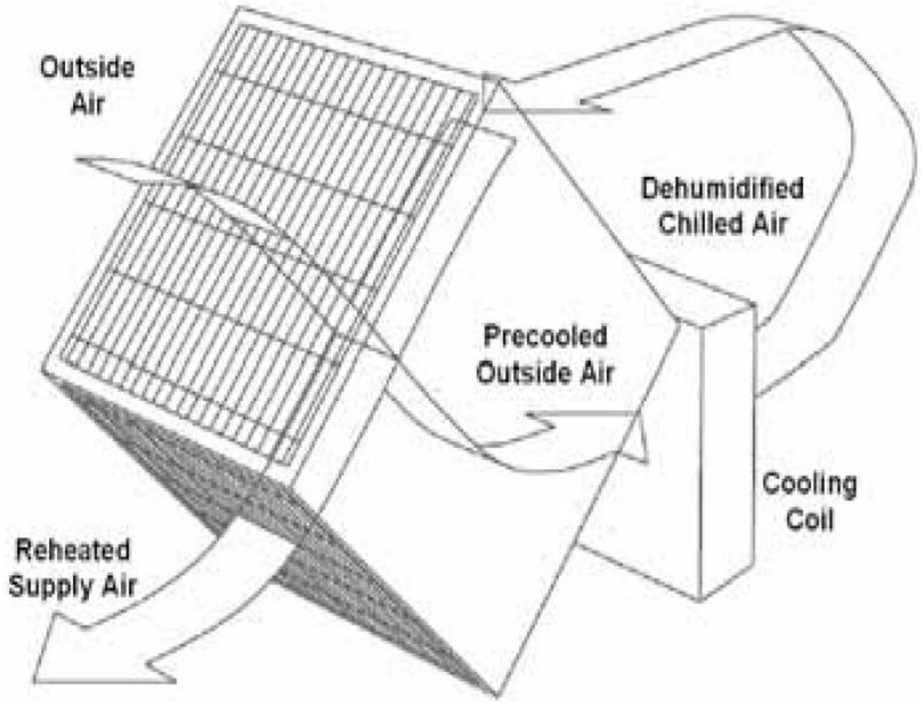
Clean air applications (relatively)

Supercharging a dehumidifier

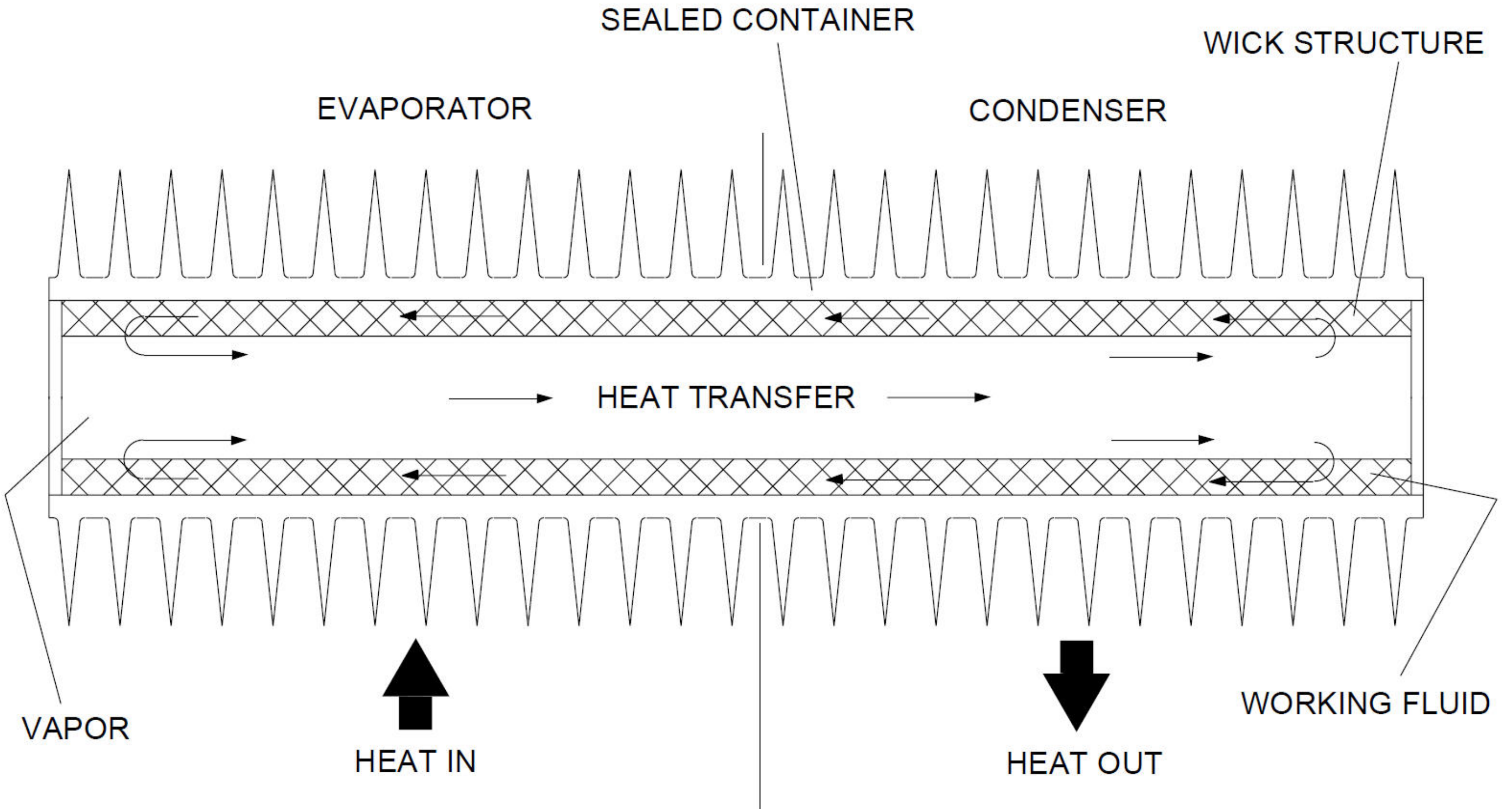
New construction

Industrial flat plate heat exchanger

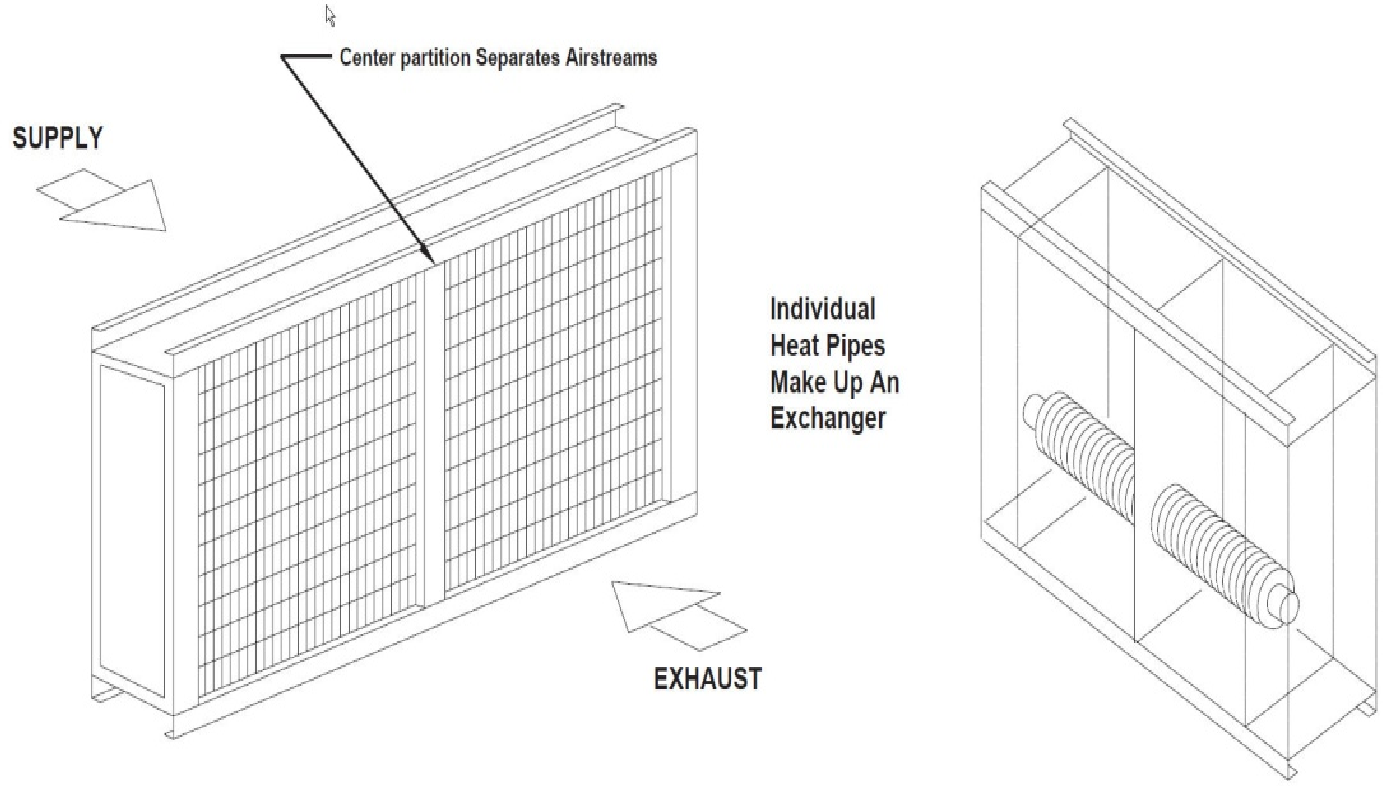
Using Air-to-Air HX to Super-Charge a Dehumidifier



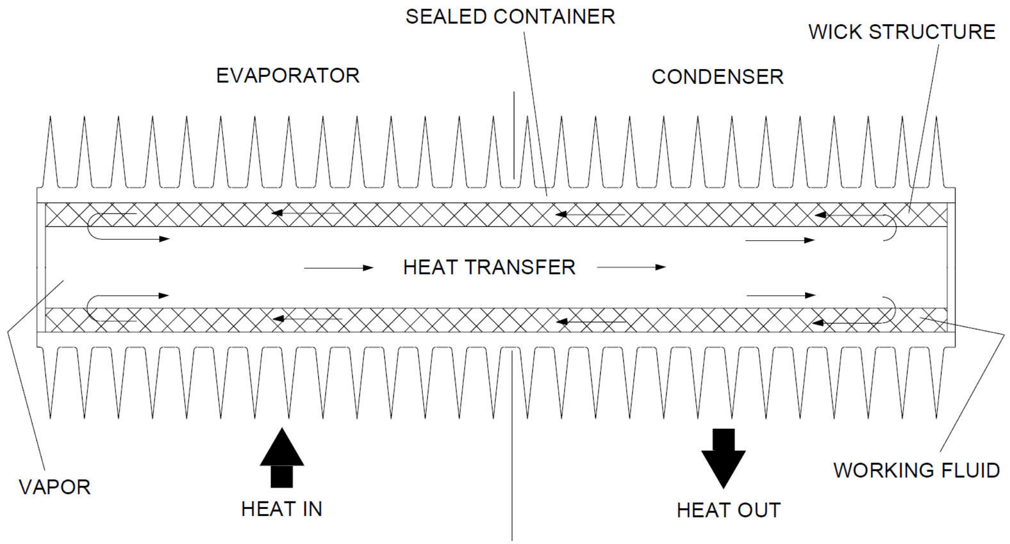
Heat Pipe Inner Workings



Heat Pipes in Side-by-Side Heat Recovery Arrangement



Heat Pipes



Advantages

- Low pressure loss
- Few moving parts, no pump

Disadvantages

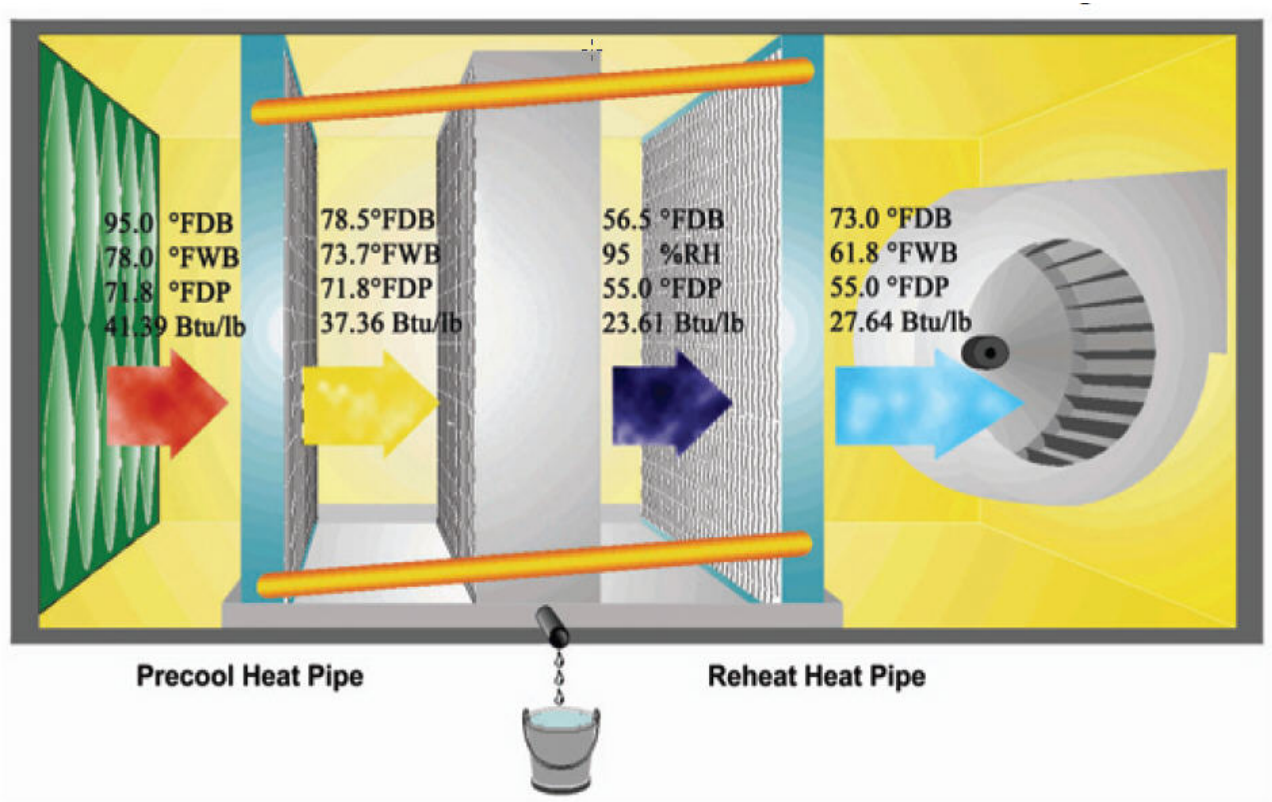
- Exhaust and intake gas streams must be in reasonably close proximity
- Gas should be pretty clean
- Frost can form in cold climates unless care is taken to avoid it

Best Applications:

Clean air applications (relatively)

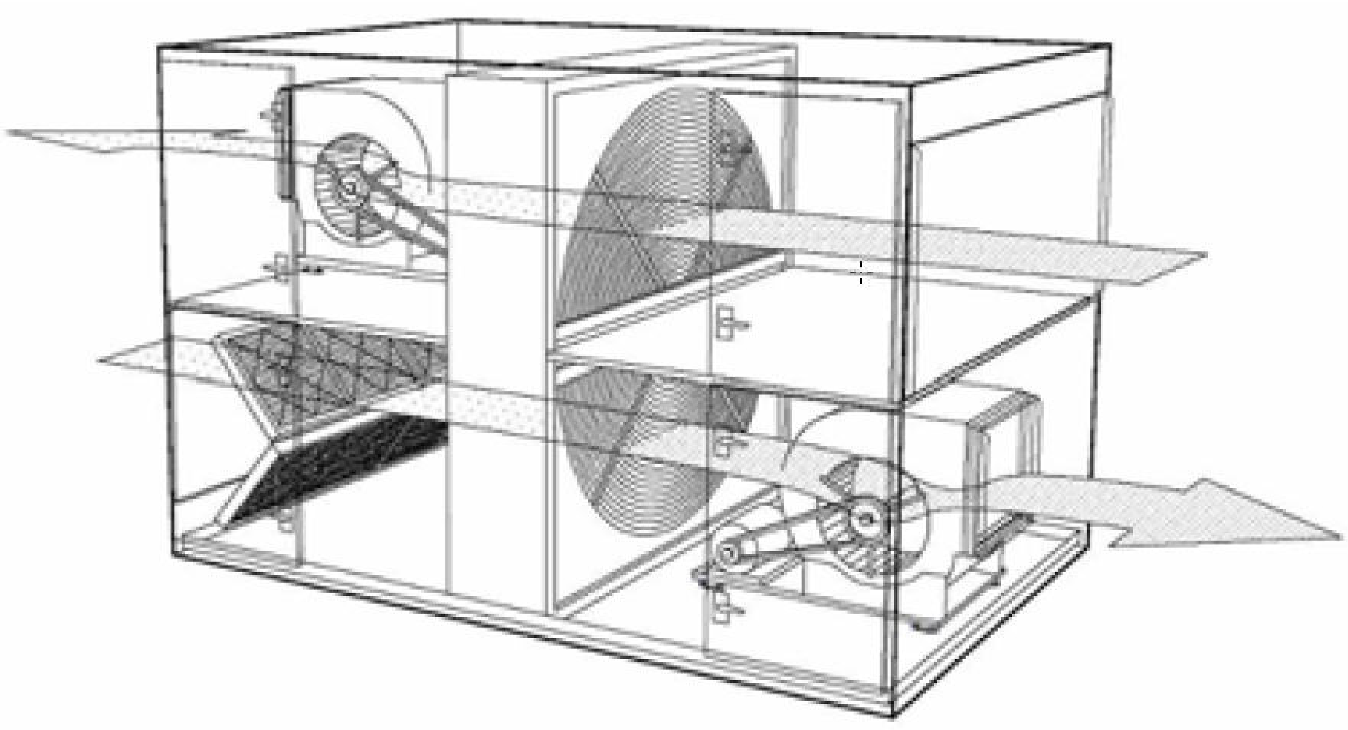
Supercharging a dehumidifier

Heat Pipes used to supercharge dehumidification



Heat Wheel Make-Up Air Heat Recovery Unit

- Wheel can be made of porous material to recover latent heat
- Wheels made of
  - Fibrous paperboard
  - Silica gel
- Large silica gel wheels can be very heavy



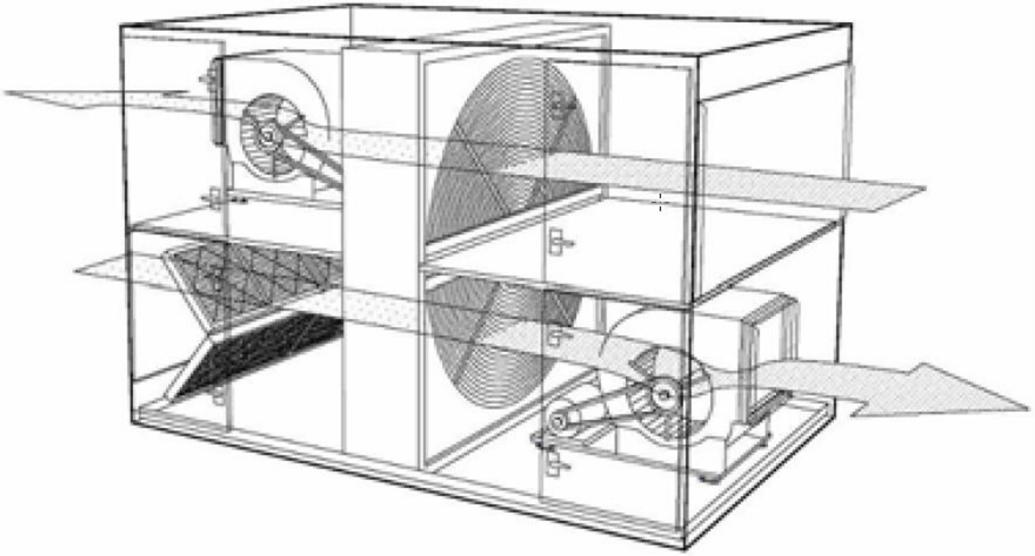
Heat Wheel

Advantages

- Can capture latent heat
- High effectiveness

Disadvantages

- Exhaust and intake gas streams must be in reasonably close proximity
- Gas should be clean
- Possible to re-introduce chemical or biological contaminants in exhaust
- Silica gel wheels can be extremely heavy in larger sizes



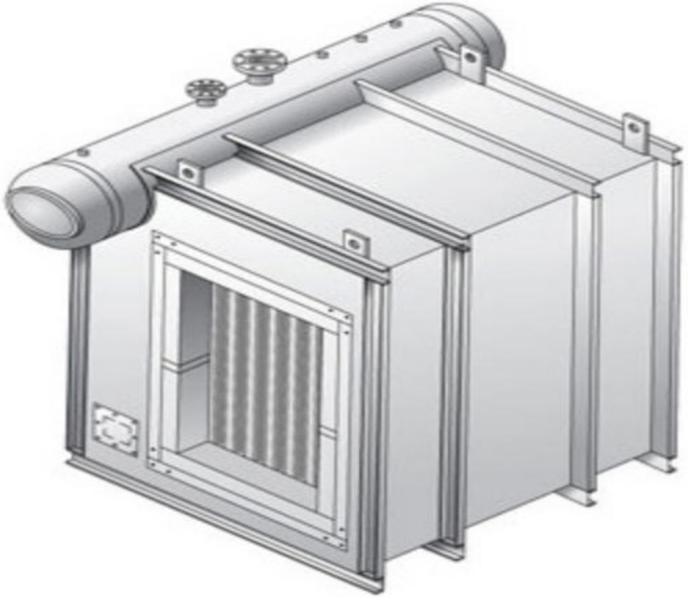
Best Applications:

HVAC Clean air applications (relatively)

New construction

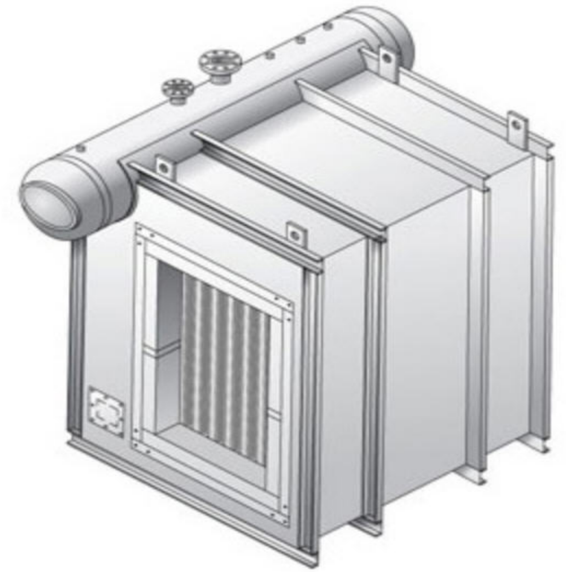
Air to Water

Flue Gas Heat Recovery Tube Bundle



Heat Recovery Steam Generator

Heat Recovery Steam Generator



Advantages

- If the gas stream is hot enough you can generate steam
- Steam can be used drive a turbine and generate electricity

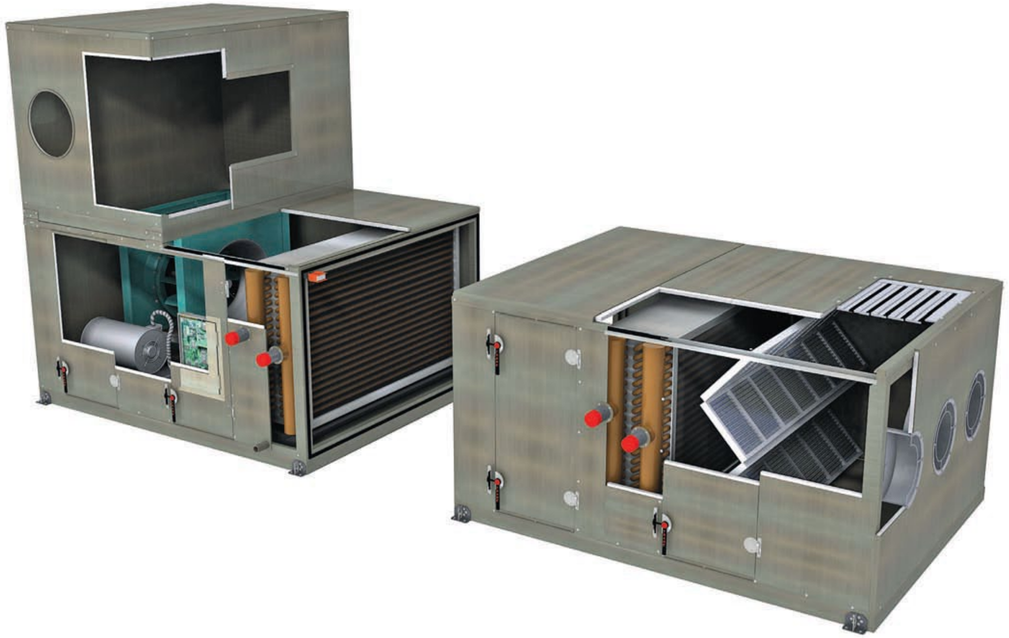
Disadvantages

- Avoid condensation in the gas stream
- May need corrosion resistant material

Best Applications:

High temperature flue gas recovery

Water to Air



- Easiest heat recovery is when there is hot water already available from a process, such as water-cooled ductwork, furnace jacket water, etc.

Calculating heat availability

$$\overset{\circ}{Q} = M \cdot Cp \cdot \Delta T$$

M = mass flow rate

Cp = specific heat

ΔT = temperature difference

In SI units, for air:

$$\textbf{kJ} = \textbf{4387} \times \textbf{m}^3\textbf{/s} \times \Delta T_C$$

- Can also use the difference in the enthalpy from MEASUR Psychrometric calculator