



Industrial Fan Systems

Virtual INPLT Training & Assessment

Session 6



Fan Virtual INPLT Facilitator



Ron Wroblewski, PE,
Productive Energy Solutions, LLC
Madison, Wisconsin

ron@productiveenergy.com
(608) 232-1861

Acknowledgments

- William (Bill) Hunter, PE, Airclean Systems, Seattle WA
- Eddie Radd, CFW Fans, Cape Town, SA
- William (Bill) W.T. Corey, Corey Consultancy, Surrey England
- US Department of Energy , Advanced Manufacturing Office
- Oak Ridge National Laboratory
- United Nations Industrial Development Organization
- Air Movement and Control, AMCA international
- Many industrial clients – both in the US and internationally

Agenda – Session 6

- Welcome and Introductions
 - Safety and Housekeeping
 - Agenda for Fan System Virtual INPLT (8 weeks)
 - Today's Content:
 - Psychrometrics and density in fan systems
 - System effect in fan systems
- MEASUR Tool
- Demonstration
- Kahoot Quiz Game
 - Q&A



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 MUTE 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



Fan system Virtual INPLT Agenda

- **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**

Session 6 Learning Objectives

Class participants will:

1. Review fluid properties as they relate to fan systems
2. Analyze psychrometric charts
3. Apply psychrometric principles to determine gas density
4. Understand how MEASUR handles gas temperature and density
5. Examine causes and implications of system effect
6. Analyze system effect using AMCA approach

Psychrometrics and density for fan systems

Density Calculations in MEASUR

- MEASUR has tools for estimating air density
- Based on ASHRAE methodology
- Gas density should be considered for all fan applications:
 - Air at standard conditions
 - Air at non-standard conditions
 - Air that contains water vapor
 - Gas that is not air

Calculating Air Density Overview

- Standard air density value
- Dry air density calculations use Perfect Gas Law
- Moist air density calculations:
 - use MEASUR or other psychrometric software
- Psychrometric chart overview and use

Standard Air Density

- Sea level barometric pressure
101 325 Pa
29.92 in Hg
- Standard air temperature
21 °C
70 F

Given these conditions, air density is
1.2 kg/m³
0.075 lb/ft³

Dry Air Density

$$\rho = \frac{P}{R_o T}$$

Where:

Units in SI

P = Absolute pressure in Pa

R_o = Individual gas constant,
equal to 287.10 J/kg-K for air

T = Absolute temperature, in Kelvin

Dry Air Density Calculation

Gas Constant

$$R_o = \frac{R_u}{M}$$

Where:

Units in SI

R_o = Individual gas constant

R_u = Universal gas constant,
equal to 8 314.3 J/kg-mol-K

M = Apparent molecule weight of gas, in kg-mol

Dry Air Density Calculation (cont.)

Gas Constant

Example: The molecular weight of air is 28.96 kg-mol. To calculate R_o for air in SI units:

$$R_o = \frac{8\,314.3}{28.96}$$
$$R_o = 287.10 J / kg - K$$

Dry Air Density Calculation (cont.)

Determine Absolute Temperature

$$T = t + 273.15$$

Where:

T = Temperature in kelvins

t = Temperature in degrees celsius

Dry Air Density Calculation Example

Based on standard air:

$$\rho = \frac{101\,325}{287.10 \times (21 + 273.1)}$$
$$\rho = 1.200 \text{ kg} / \text{m}^3$$

Where

Units in SI

101 325 pa = Standard barometric pressure

21°C = Standard temperature

Moist Air Calculations Use:

- Dry bulb and wet bulb temperatures,
- Dry bulb temperature and relative humidity, or
- Dry bulb temperature and humidity ratio

Other Thermodynamic Parameters Overview

Parameters for moist air density calculations can be obtained from psychrometric charts:

- Parameters for moist air density calculations
- Skeleton psychrometric chart
- Normal temperature psychrometric chart
- High temperature psychrometric chart

Parameters for Moist Air Density Calculations

- Old-school version pictured on the right
- More modern versions are digital electronic instruments to measure temperature and humidity



Dry Air Density Calculation

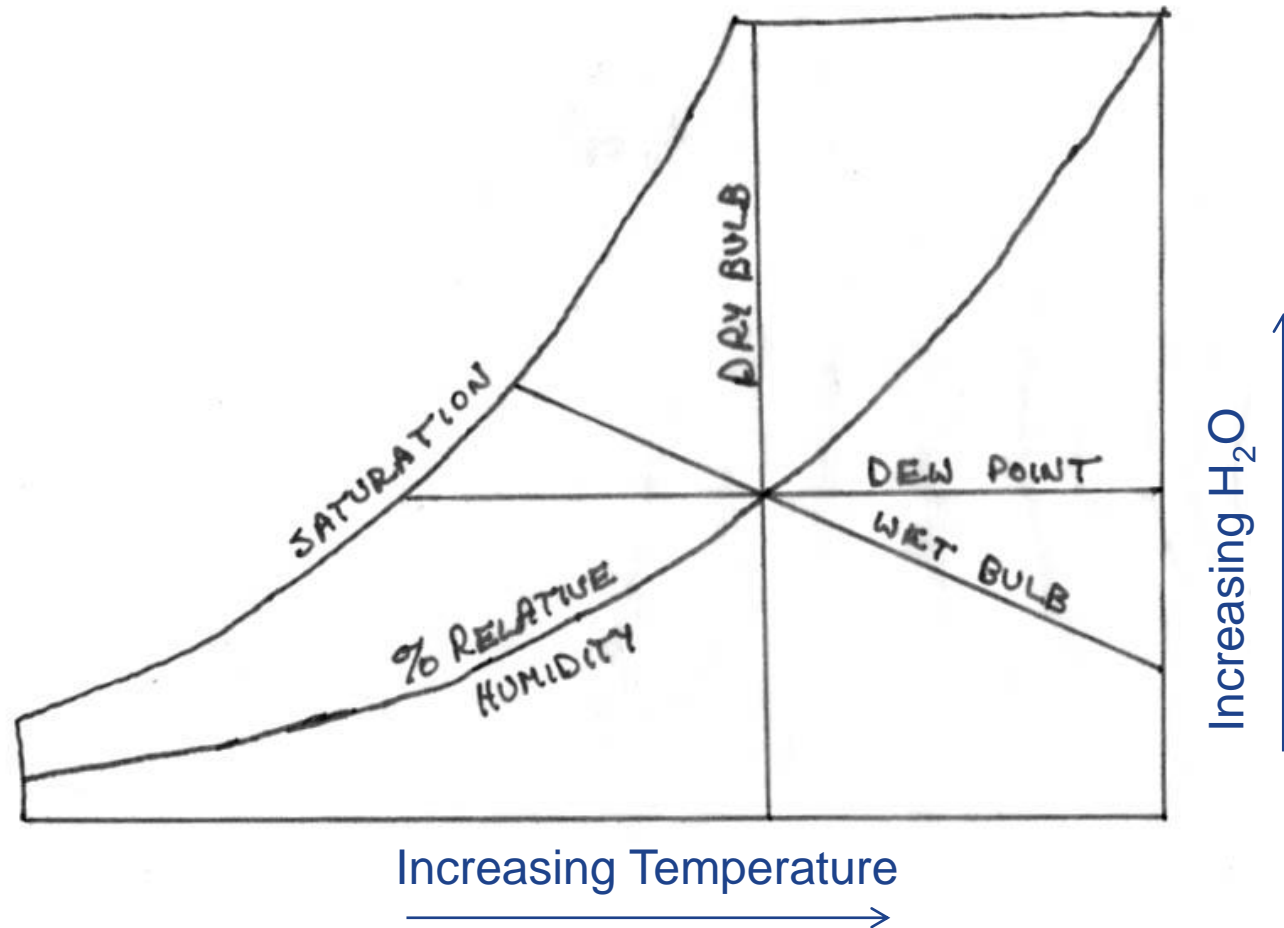
- If the air is dry the following can be used.

$$\rho = 0.075 \times \left(\frac{460 + 70}{460 + t} \right) \times \left(\frac{P_{bar} + P}{29.92 \times 13.6} \right)$$

- Where:

- Units in I-P
- ρ = Gas density lbm/ft³
- P_{bar} = Local barometric pressure in **inches w.g.**
(multiply in. Hg x 13.59 to get barometric into inches water)
- P = Local pressure inches w.g. (within the duct)
- t = Air temperature °F

Skeleton Psychrometric Chart

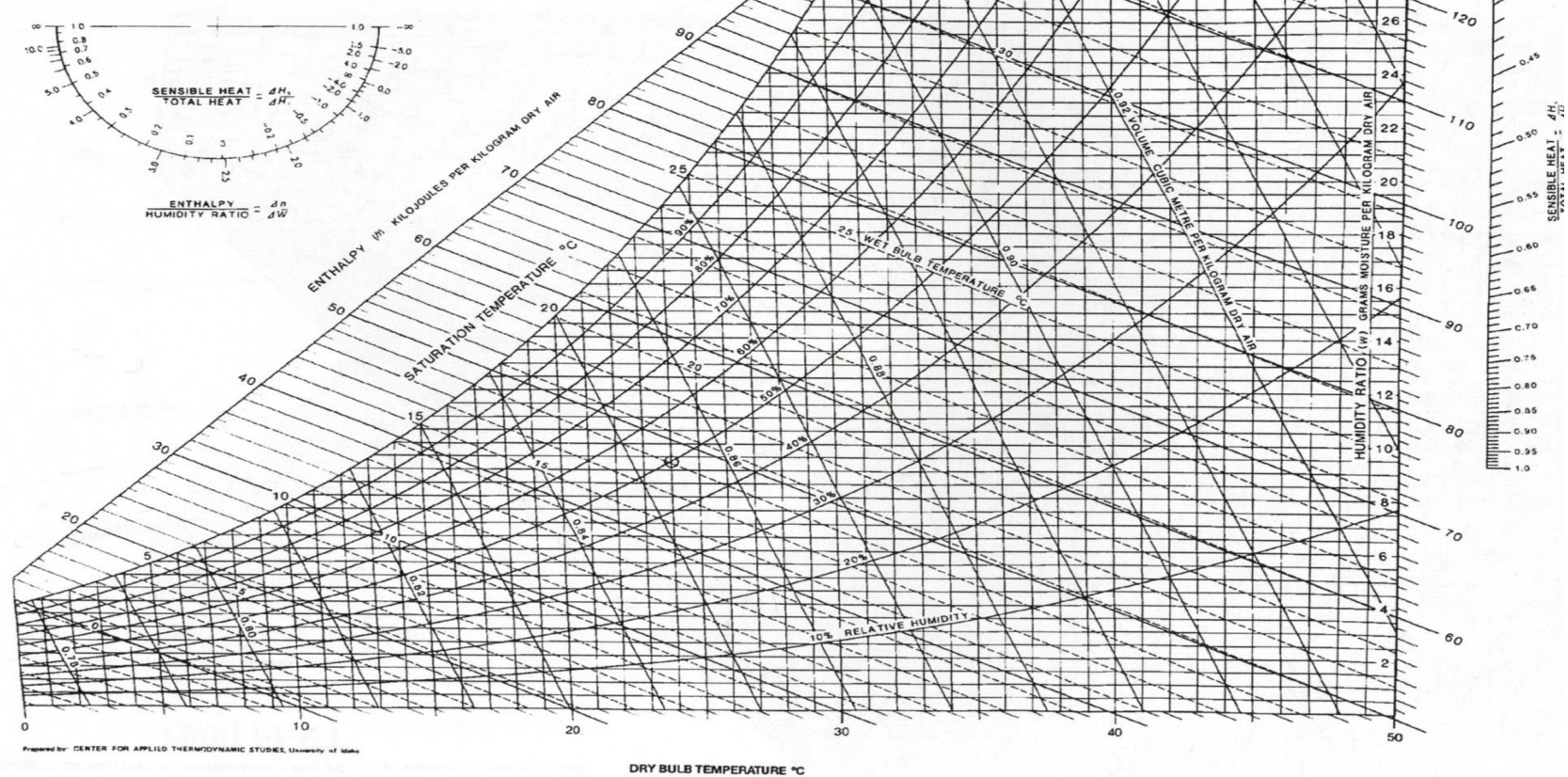


Normal Temperature Psychrometric Chart

ASHRAE PSYCHROMETRIC CHART NO. 1
NORMAL TEMPERATURE SEA LEVEL
BAROMETRIC PRESSURE 101.325 kPa.



COPYRIGHT 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.



Psychrometric chart No. 1 S-I.

Density Shortcuts

- Neglecting moisture (water vapor) at 21 °C or less: error less than 1%.
- Use standard density between 10 °C and 30 °C: error less than 3%.

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: Units SI (*I-P*)

ρ_c = the new density, kg/m³ (*lb/ft³*)

ρ = the original density, kg/m³ (*lb/ft³*)

T_c = the new temperature, Kelvins (*Rankine*)

T = the original temperature, Kelvins (*Rankine*)

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

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

Flue Gas Density

Adjust table values below for actual temperature and pressure:

Fuel	Flue Gas Density	
	lbm/ft ³	kg/m ³
COAL	0.078	1.25
OIL	0.075	1.20
NATURAL GAS	0.0725	1.16
BAGASSE	0.070	1.12
BLAST FURNACE GAS	0.076	1.22
LIGNITE	0.073	1.17
WOOD	0.070	1.12

The above densities at 70°F and 29.92 in. Hg (21 °C and 101 325 Pa) are based on average fuel analyses and moisture contents

Using the Psychrometric Chart

Instructions: Determine the relative humidity and dew point temperature, given a wet bulb temperature of 22 °C and a dry bulb temperature of 29 °C:

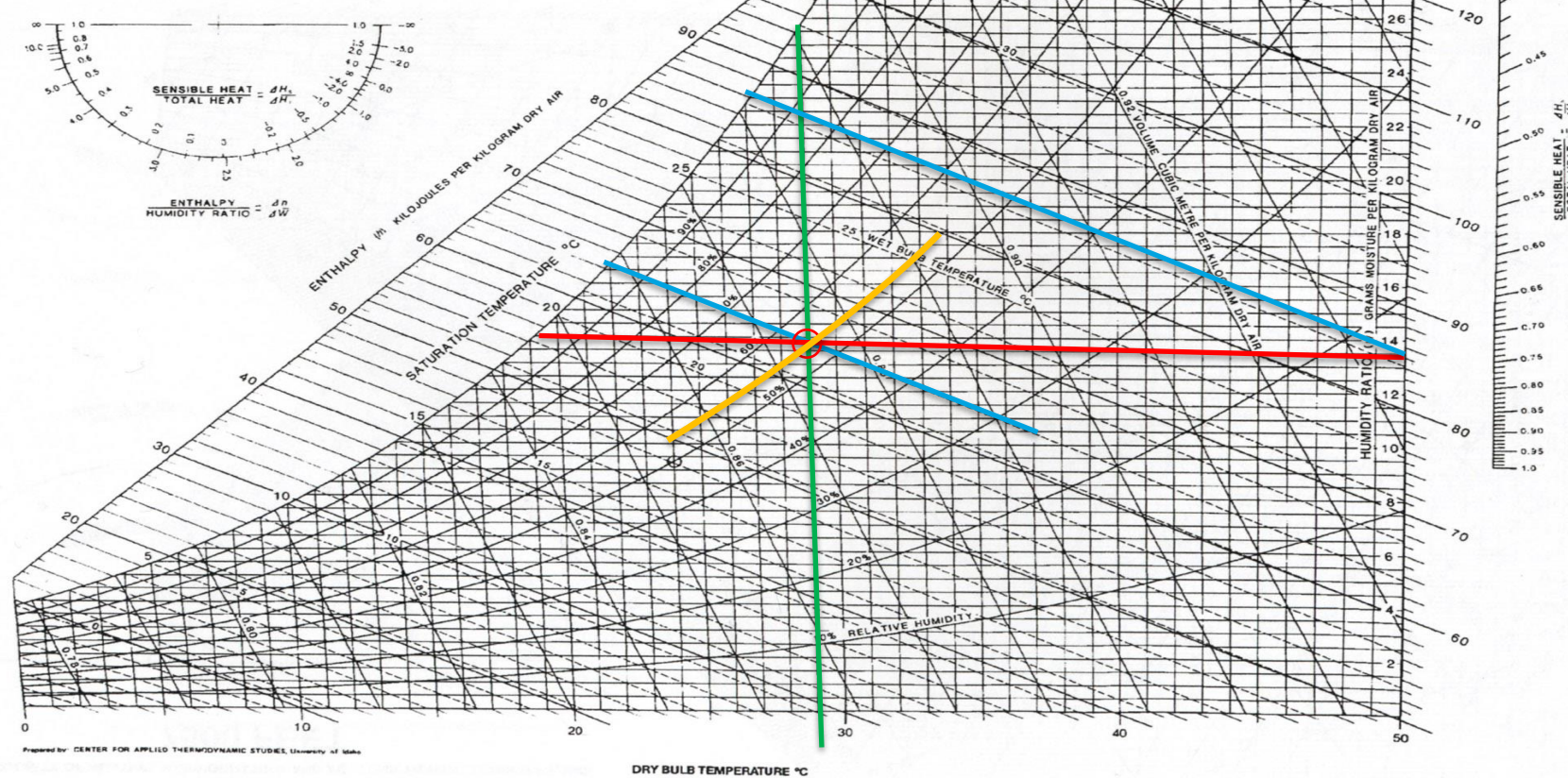
1. What is the relative humidity?
2. What is the dew point temperature?
3. If the mixture is heated to 50° C, what is the new wet bulb?

Normal Temperature Psychrometric Chart

ASHRAE PSYCHROMETRIC CHART NO. 1
NORMAL TEMPERATURE SEA LEVEL
BAROMETRIC PRESSURE 101.325 kPa.



COPYRIGHT 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.



- DB
- WB
- DP
- RH

Psychrometric chart No. 1 S-I.

Using MEASUR to Estimate Gas Density

Instructions: Please use MEASUR to determine the density of air in the following conditions

Parameter	Metric
Wet Bulb	43.3 °C
Dry Bulb	76.7 °C
Barometric	101 325 Pa
Density	kg/m ³
Dew Point	°C

Using MEASUR to Estimate Gas Density

Instructions: Please use MEASUR to determine the density of air in the following conditions

Parameter	Metric
Dew Point	37.8 °C
Dry Bulb	65.5 °C
Wet Bulb	°C
Barometric	101 325 Pa
Density	kg/m ³

FSAT Air Density Exceptions, (continued)

- Relative humidity cannot be used as input above 212 °F.
 - The concept of RH breaks down above 212°, because water can develop a vapor pressure higher than atmosphere pressure.
 - FSAT calculations for temperatures above 212° should be treated with care. A manual method can also be used to calculate density.

- NOTE: The dry bulb temperature must always be higher than the wet bulb temperature.

System Effect in Fan systems

System Effect Definition

- The most common causes of deficient fan/system performance are improper fan inlet duct design, and fan outlet duct design
- The System Effect Factor (SEF):
a value that accounts for the effect of conditions adversely influencing fan performance

No System Effect

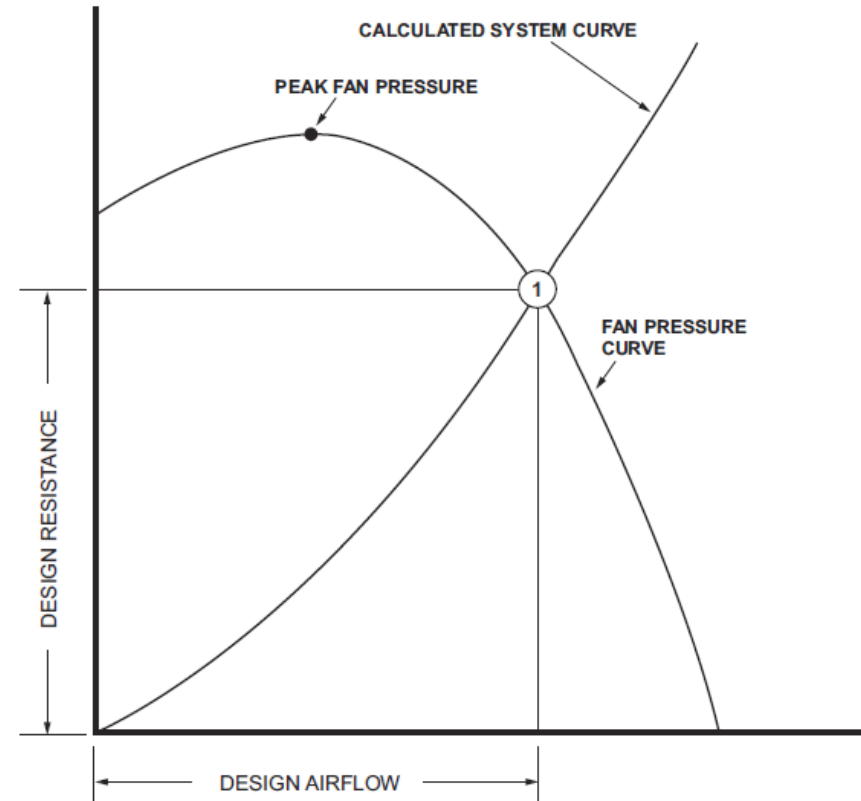
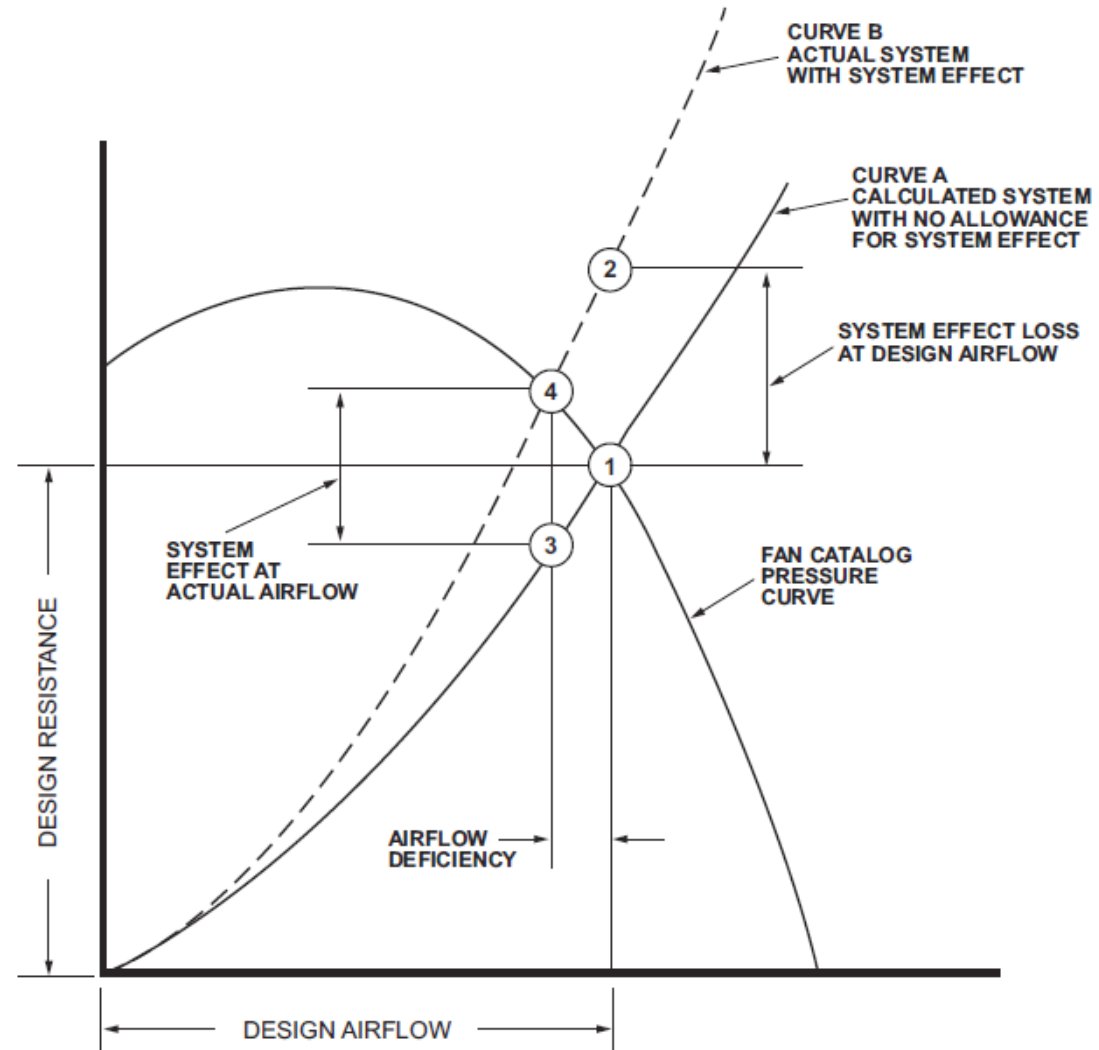


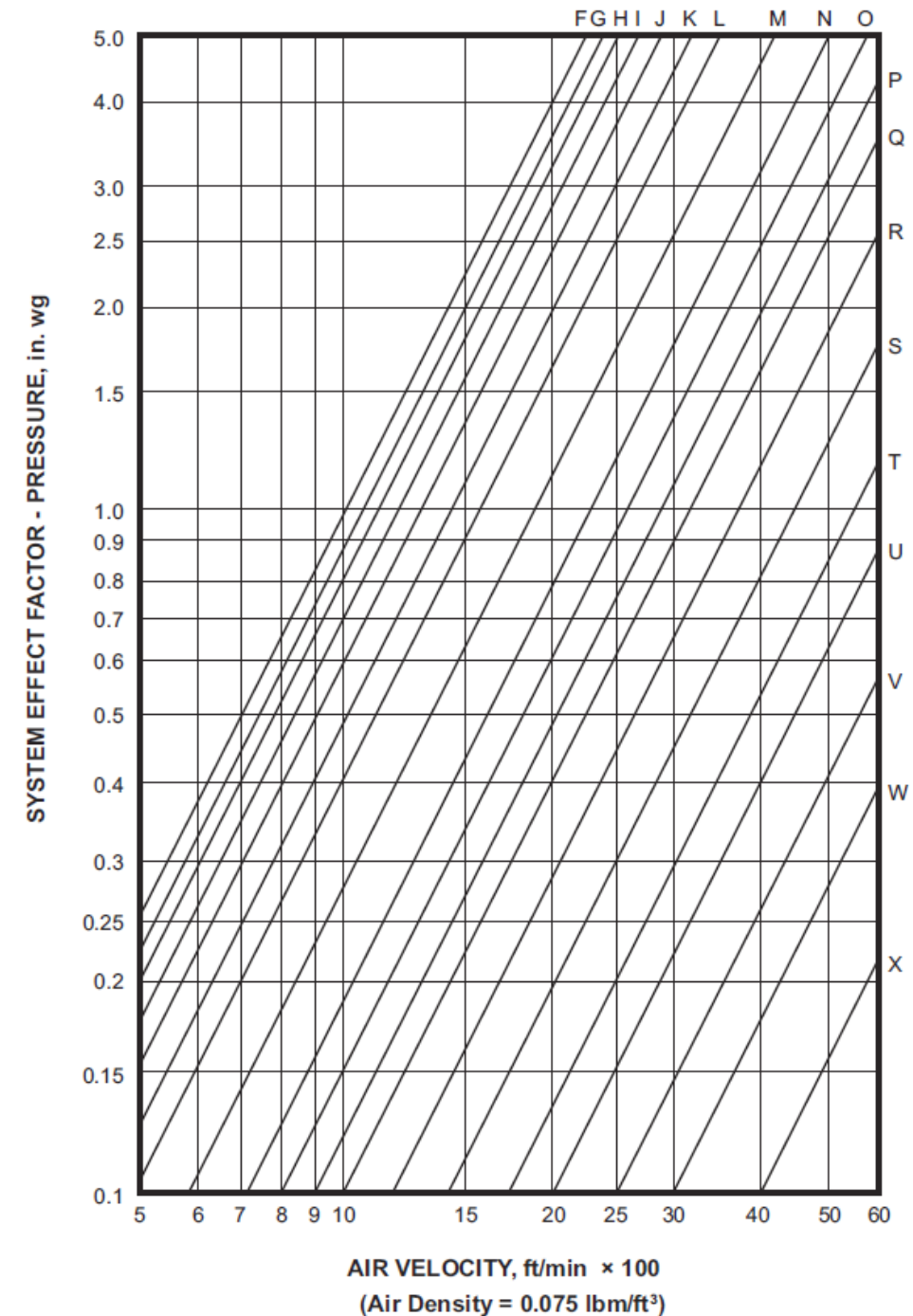
Figure 6.5 - Fan/System Curve at Design Point

Deficient Flow



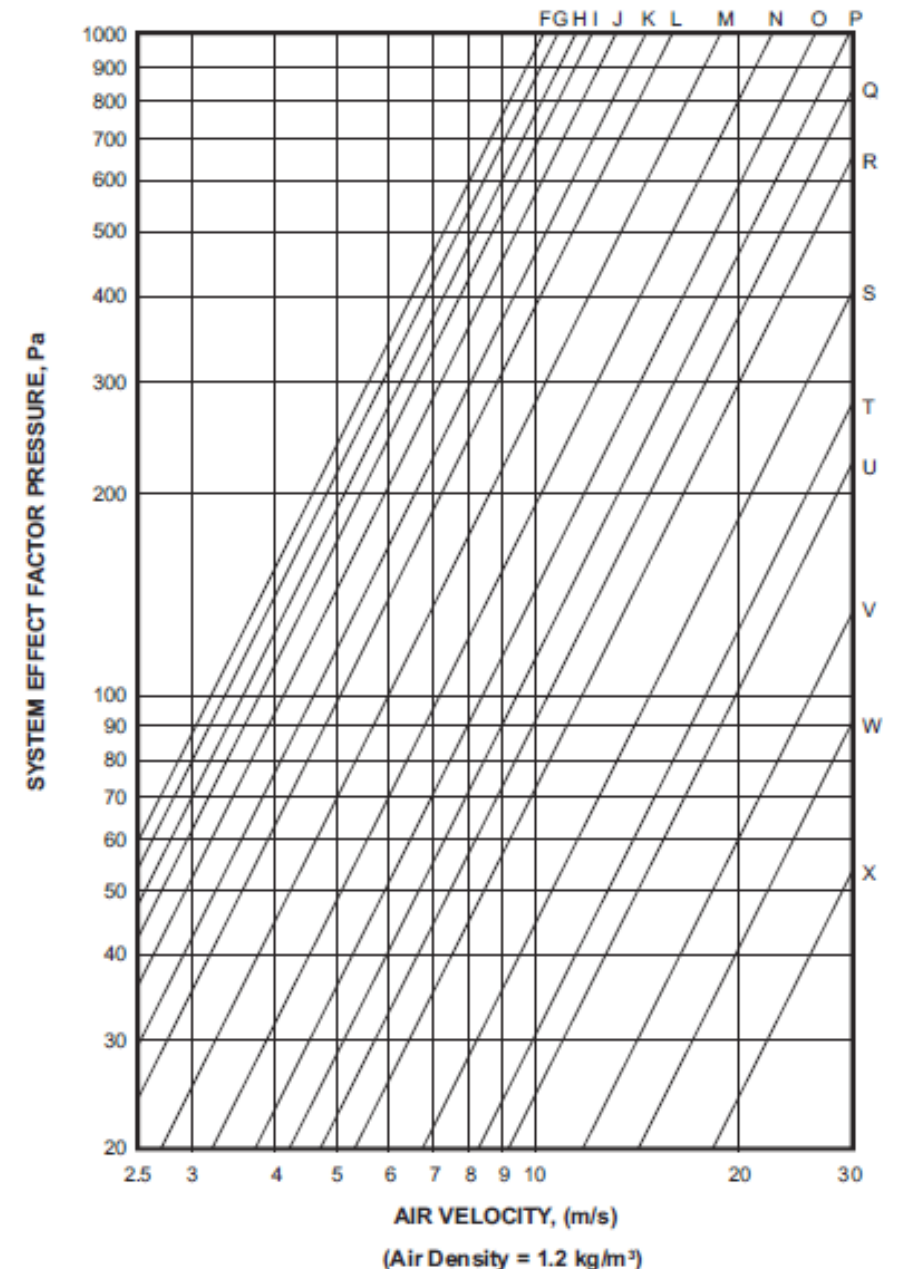
System Effect Factor (SEF) Chart

- The system effect is heavily dependent upon the velocity pressure
- Higher velocity means higher SEF
- This version of the AMCA approach assigns different letter values to the situations depending on the severity of the impact.
- Letter X would indicate a low impact
- Letter F would indicate a higher impact



System Effect Factor (SEF) Chart

- The system effect is heavily dependent upon the velocity pressure
- Higher velocity means higher SEF
- This version of the AMCA approach assigns different letter values to the situations depending on the severity of the impact.
- Letter X would indicate a low impact
- Letter F would indicate a higher impact



Adjusting SEF For Density

$$SEF_2 = SEF_1 \left(\frac{d_2}{d_1} \right)$$

Where:

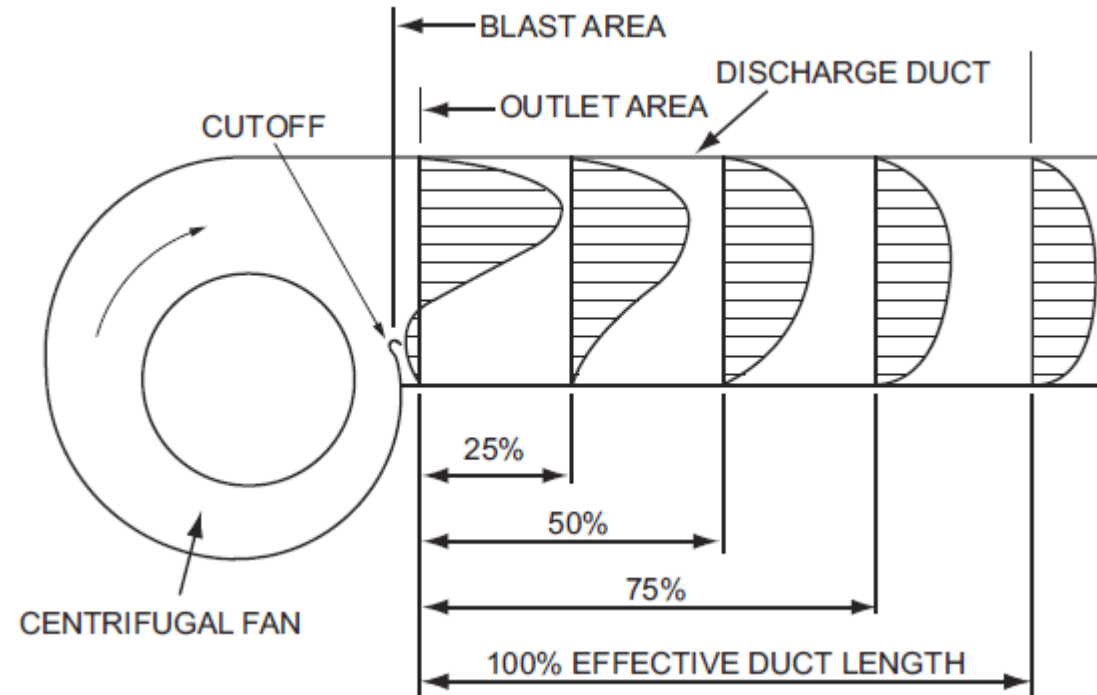
SEF_2 = SEF at actual density

SEF_1 = SEF at standard density

d_2 = actual density

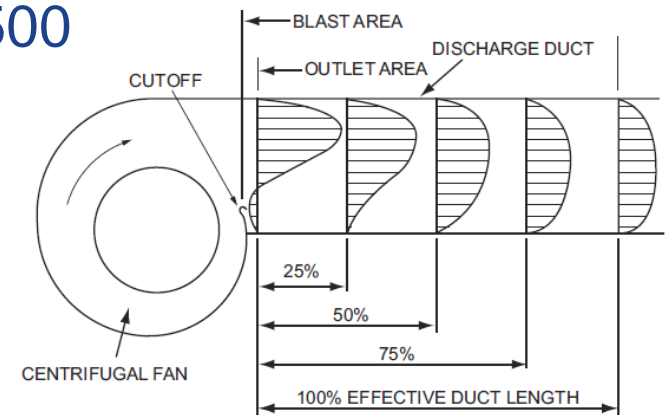
d_1 = standard density

Effective Duct Length

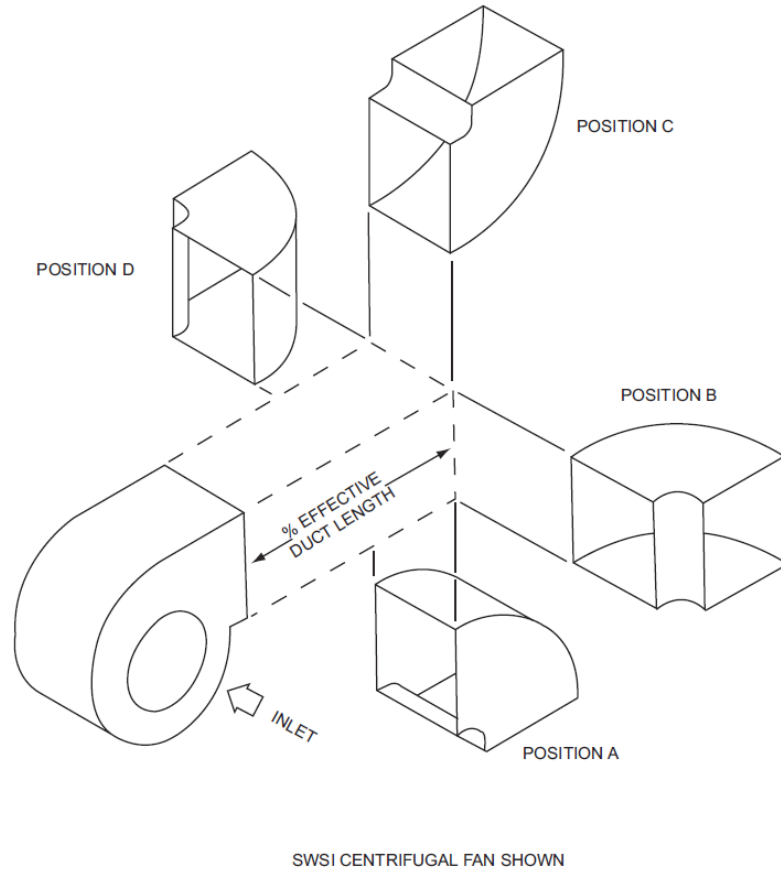


Calculating 100% Effective Duct Length

- To calculate 100% duct length, assume a minimum of 2½ duct diameters for 12.7 m/s (2500 fpm) or less. Add 1 duct diameter for each additional 5.08 m/s (1000 fpm).
- **EXAMPLE:** 25.4 m/s (5000 fpm) = 5 equivalent duct diameters
 1. Start with base of 2-1/2D
 2. Find velocity in excess of 2500 fpm: $5000 - 2500 = 2500$
 3. Add 1 D for each 1000 fpm in excess of 2500, so $2500/1000 = 2\text{-}1/2$ diameters
 4. Total of base and diameters for velocity above 2500:
 $2\text{-}1/2D + 2\text{-}1/2D = 5 D$



System effect on the fan outlet



<i>Blast Area</i> <i>Outlet Area</i>	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

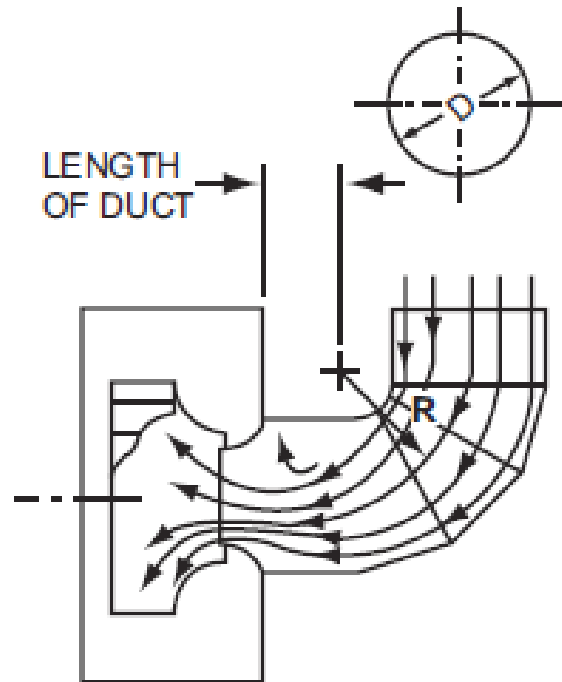


Figure 9.3A - Non-Uniform Airflow Into a Fan Inlet Induced by a 90°, 3-Piece Section Elbow-- No Turning Vanes

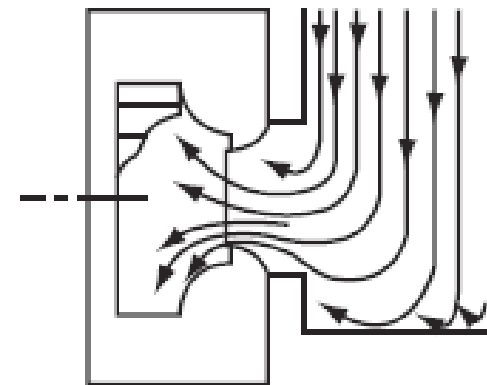
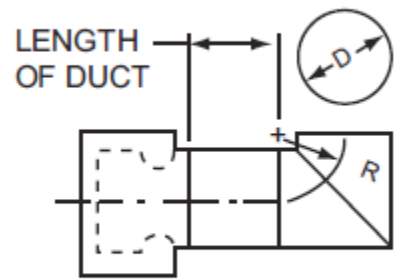


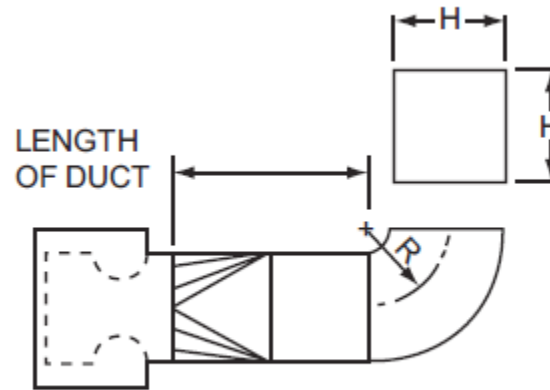
Figure 9.3B - Non-Uniform Airflow Induced Into Fan Inlet by a Rectangular Inlet Duct

System effect at fan Inlet



SYSTEM EFFECT CURVES			
R/D	NO DUCT	2D DUCT	5D DUCT
—	N	P	R-S

Figure 9.4A - Two Piece Mitered 90° Round Section Elbow - Not Vaned



SYSTEM EFFECT CURVES			
R/D	NO DUCT	2D DUCT	5D DUCT
0.5	O	Q	S
0.75	P	R	S-T
1.0	R	S-T	U-V
1.0	S	T-U	V

Figure 9.5A - Square Elbow with Inlet Transition - No Turning Vanes

Equivalent Diameter for Rectangular Ducts

- For ducts with REASONABLE aspect ratio (i.e. aspect ratio 4 : 1 or less)
- Calculate duct area
- Calculate the diameter of a circle with the same area:

$$D_{eq} = \sqrt{\frac{4 \times a \times b}{\pi}}$$

- A and b are the length and width of the rectangular duct

Example: No Outlet Duct

Calculate Effective Duct Length:

- Fan Flow 50.8 m³/s 107,600 cfm
- Fan Outlet Area 2 m² 21.52 ft²
- Fan Blast Area 1.4 m² 15.09 ft²
- Duct Velocity 50.8 / 2 = 25.4 m/s 5000 fpm

$$100\% \text{ Effective Duct} = 2.5 + \frac{(25.4 - 12.7)}{5.08}$$

$$100\% \text{ Effective Duct} = 2.5 + 2.5$$

$$100\% \text{ Effective Duct} = 5$$

$$5 \text{ Diameters} = 5 \times 5.25 = 26 \text{ ft}$$

Example: No Outlet Duct

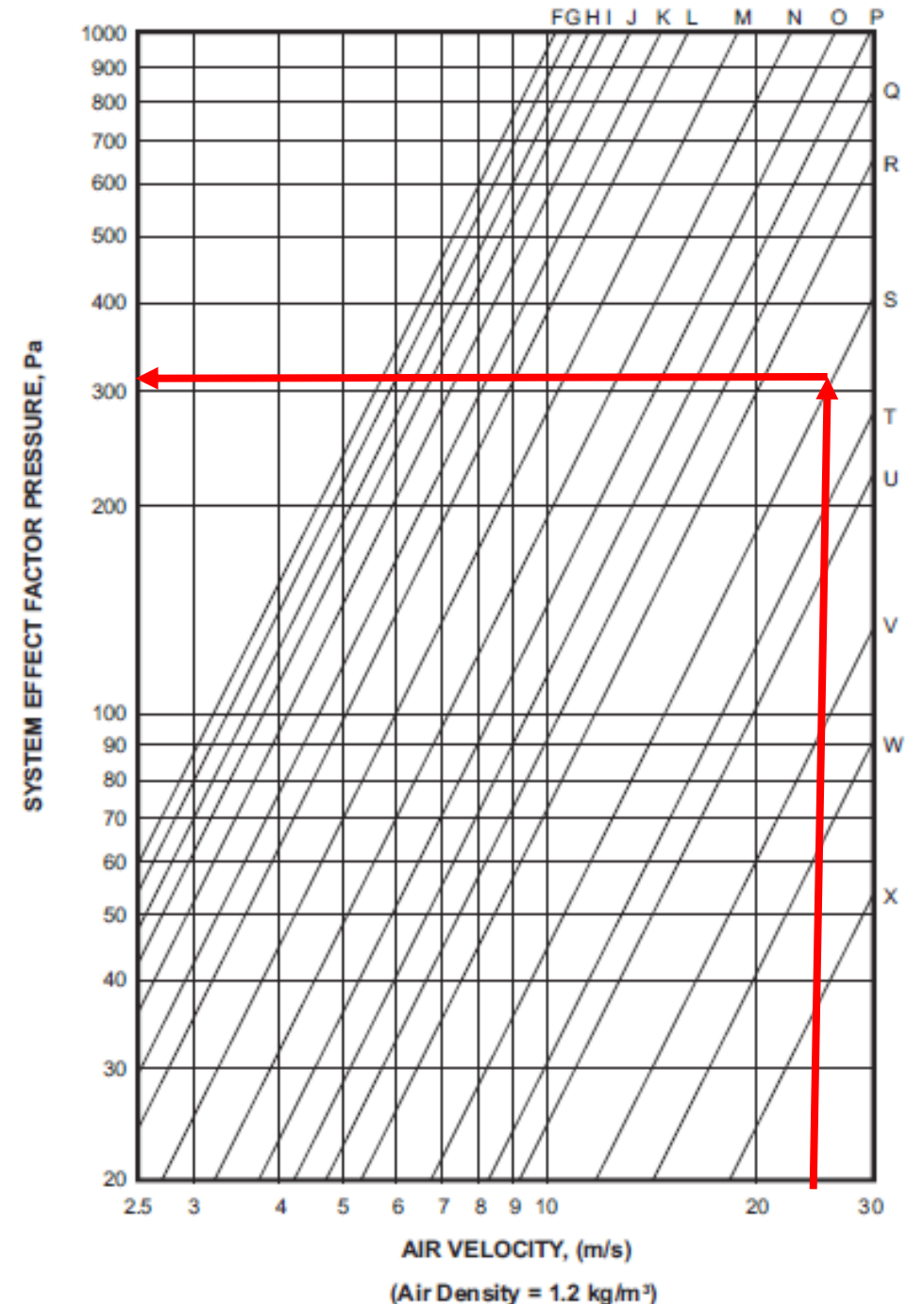
Figure 8.3 AMCA 201

	No Duct	12% Effective Duct	25% Effective Duct	50% Effective Duct	100% Effective Duct
Pressure Recovery	0%	50%	80%	90%	100%
$\frac{\text{Blast Area}}{\text{Outlet Area}}$	System Effect Curve				
0.4	P	R-S	U	W	—
0.5	P	R-S	U	W	—
0.6	R-S	S-T	U-V	W-X	—
0.7	S	U	W-X	—	—
0.8	T-U	V-W	X	—	—
0.9	V-W	W-X	—	—	—
1.0	—	—	—	—	—

Determine *SEF* by using Figure 7.1

Example – No Outlet duct

- Discharge velocity = 25.4 m/s = 5,000 fpm
- Curve “S”
- SEF = 310 Pa or 1.25 Inches w.g.
- Correct for density if required



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"*



Homework #6

For your top candidate fan, based on the local barometric pressure and the dry bulb, wet bulb, and pressure at each measurement plane use MEASUR to calculate the density at each plane:

Plane	DB Temperature	WB Temperature	Barometric pressure	Local pressure	density
1 Fan inlet					
2 Fan outlet					
3 Traverse					
4 Upstream of fan					
5 Downstream of fan					

Homework #6 b

For your top candidate fan(s), collect the necessary information to estimate an instances of system effect at the fan inlet or outlet, (or system effect in any fan in your facility)

Plane	Elbows or turns	Diameters from fan	velocity	Duct size	density
1 Fan inlet					
2 Fan outlet					

Thank You all for attending today's webinar.

See you all on next Thursday –

If you have specific questions, please stay online and we will try and answer them.

**Alternately, you can email questions to me at
ron@productiveenergy.com**