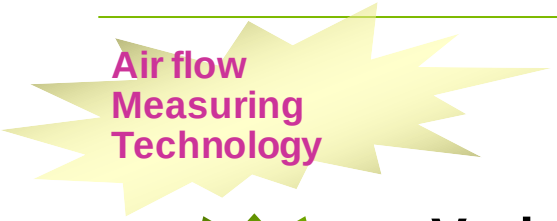
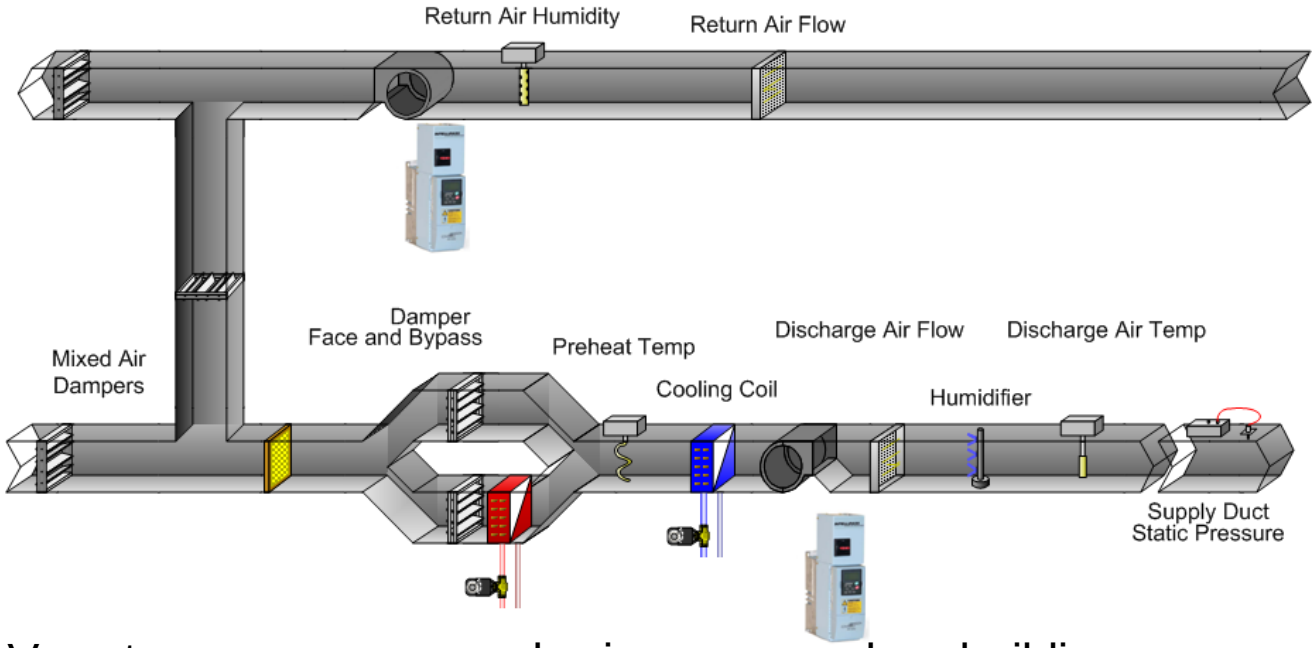


Variable air volume (VAV) Air Handling System
What Makes VAV Box Performance Better

Yong Zhao
Johnson Controls Australia

Johnson Controls

Variable air volume (VAV) Air Handling System



VAV systems are vary popular in many modern buildings

- VAV systems contain many zones with diverse airflow needs
- VAV systems have “bad” zones
- VAV systems are dynamic
- VAV systems have minimum airflow zones

Variable air volume (VAV) Terminal Unit

Consider the relationship between damper position and airflow

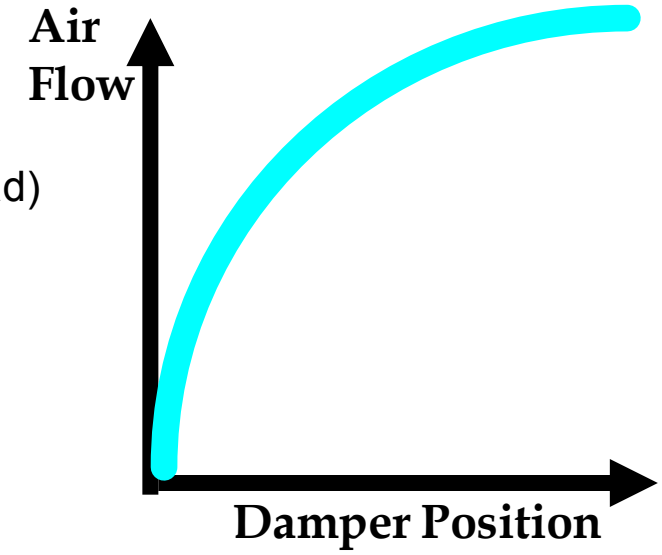
- System is sensitive as damper starts to open, so large proportional band is needed
- When damper is almost open, system is not very sensitive, so a small proportional band is needed

Consider the “optimal” proportional band for a mixed air control loop

- It will vary by a factor of ten between summer and winter
- Good commissioning is critical

Conventional PI control resulted in

- Systems tuned for “worst case” (typically low load) conditions and unresponsive at other times
- Comfort problems
- High energy (fan consumption) cost



Variable air volume (VAV) Terminal Unit

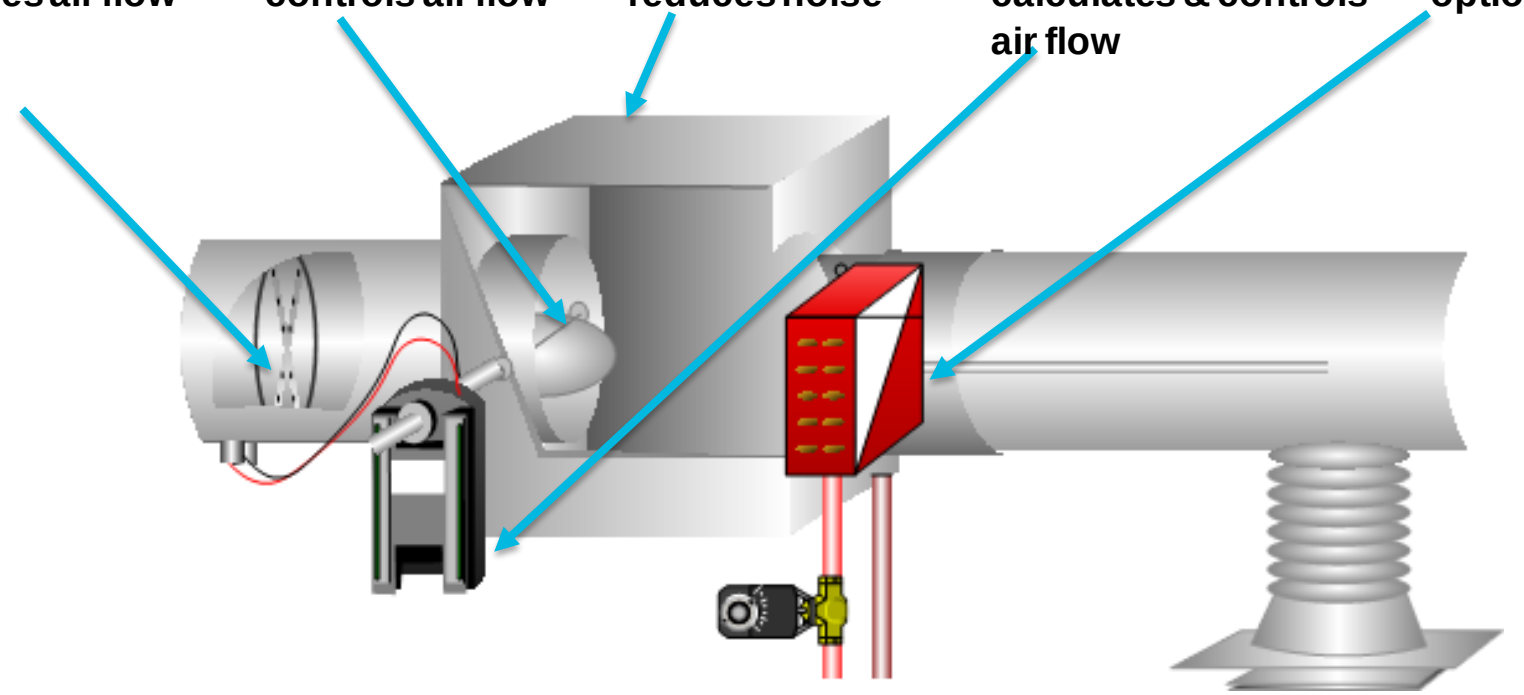
1
Velocity Sensor
measures air flow

2
Flow Damper
controls air flow

3
Mixing Box
reduces noise

4
VAV Brain
calculates & controls air flow

5
Reheat
option



Variable air volume (VAV) Terminal Unit

What makes VAV box performance better

1. Air flow measuring – Velocity sensor
   - more accurate to measure the air flow = better control (less hunting) = less temperature variation = less energy consumption
   - not easy to maintain accuracy when flow rate is lower
2. Air flow controlling – Flow damper
   - Pressure drop across the VAV box
     - Less the pressure drop = less fan energy consumption
3. Noise level – Mixing box
   - Lower dB rating = quieter the box = more comfortable
4. Controller

Air Flow Measuring – Velocity sensor

Flow measurement is the key factor in VAV controls

1. Based on **ASHRAE 2001** **Fundamentals, Chapter 14.15 Measurement and Instruments** (table 4)
   - Pitot tube is a Standard instrument for measuring duct velocities
   - It can measure air velocity in the duct from 0.9 to 50 m/s with micro manometer
   - The accuracy is 1-5% and falls off at low end of range
2. Large turn down ratio (Vmax/Vmin) can save energy but how to measure low velocity accurately when Vmin is very small.
   - Using expansive measuring instrument, such as ultrasonic sensor
   - Using amplify velocity pressure signal to increase accuracy
     - Check Patented FlowStar™ airflow sensor (Patent #5,481,925)

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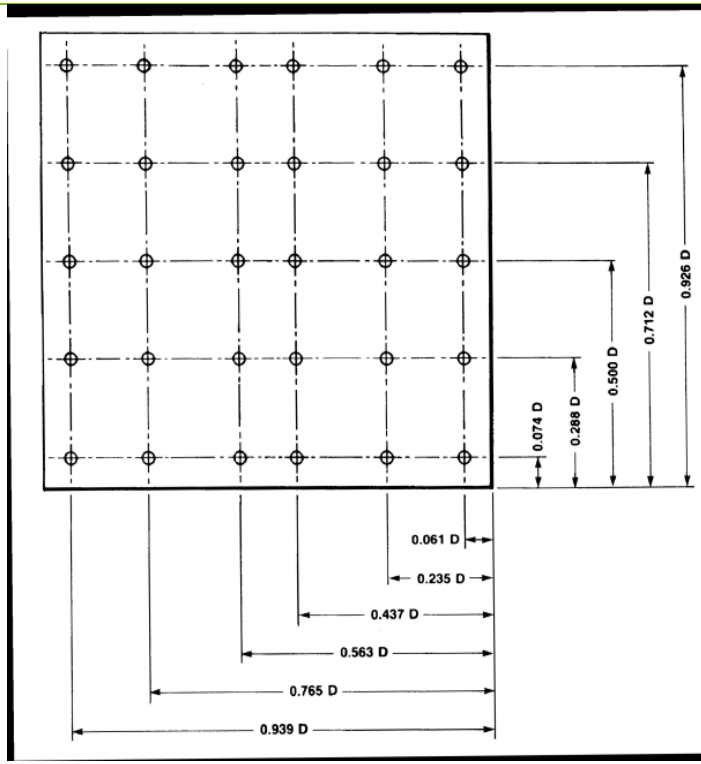
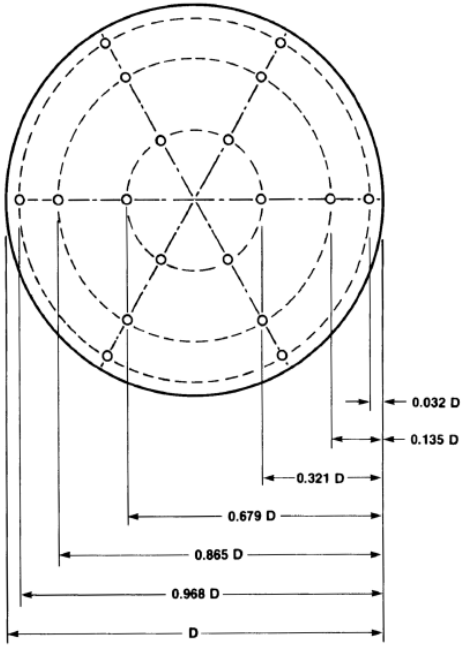
Air Flow Measuring – Velocity sensor

ASHRAE 2001 Fundamentals

Chapter 14.17 -Measuring Flow in Ducts

- Velocity in a duct is seldom uniform, a traverse is usually made to determine average velocity
- Point velocities are determined by the log-Tchebycheff rule (ISO Standard 3966) or, if care is taken, by the equal area method.
- Figure 6 shows suggested sensor locations for traversing round and rectangular ducts
- For a rectangular duct traverse, a minimum of 25 points should be measured.





Log-Tchebycheff rule for rectangular ducts

No. of Points for Traverse Lines	Position Relative to Inner Wall
5	0.074, 0.288, 0.500, 0.712, 0.926
6	0.061, 0.235, 0.437, 0.563, 0.765, 0.939
7	0.053, 0.203, 0.366, 0.500, 0.634,0.797, 0.947

Log-linear rule for circular ducts

No. of Measuring Points per Diameter	Position Relative to Inner Wall
6	0.032, 0.135, 0.321, 0.679, 0.865, 0.968
8	0.021, 0.117, 0.184, 0.345, 0.655, 0.816, 0.883, 0.981
10	0.019, 0.077, 0.153, 0.217, 0.361, 0.639, 0.783, 0.847, 0.923, 0.981

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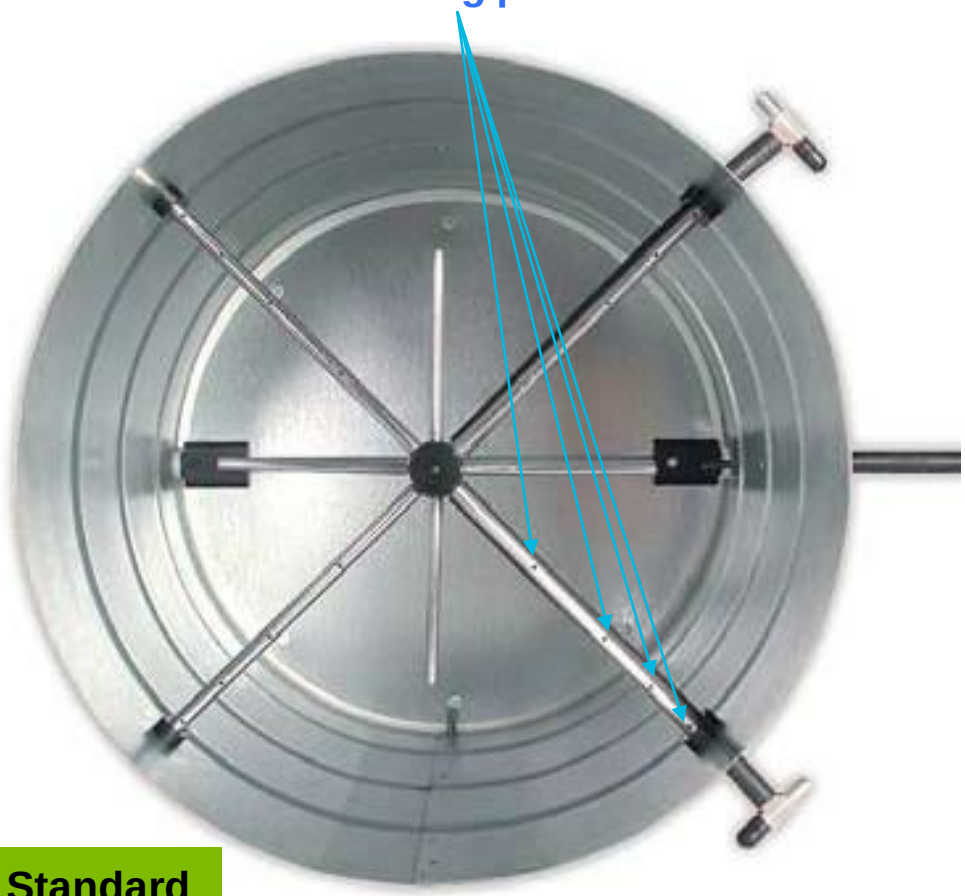
Air Flow Measuring – Velocity sensor

Example VAV box

2 sensing points

16 sensing points



ASHREA Standard vs. Non-ASHREA Standard

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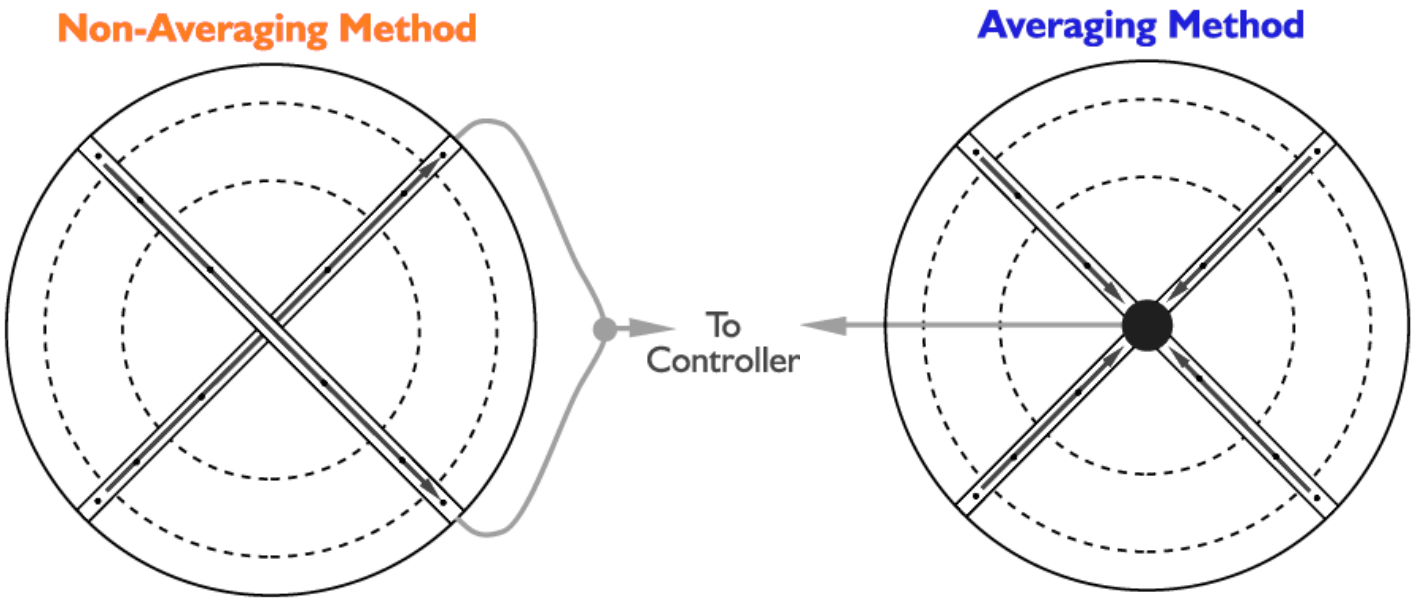
Air Flow Measuring – Velocity sensor

Example VAV box



- Reading will skewed by Stratification of the velocity profile

- Accurate reading, even there is a higher velocity on one side of the sensor

Averaging vs. Non-Averaging Method

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Example of VAV Box selection

- Maximum inlet velocity less than 8 m/s

	PRIMARY AIRFLOW			NOM	VAV Inlet Velocity /Cooling	
	MAX [l/s]	Turn Down	MIN [l/s]	SIZE	@ Max [m/s]	@ Min [m/s]
Example 1	395	30%	119	10	7.98	2.39
Example 2	395	50%	198	10	7.98	3.99
Example 1	420	30%	126	12	5.86	1.76
Example 2	420	60%	252	12	5.86	3.52

- The turn down ratio (minimum air flow) has to be increased to compensate stable control at low flow rate

Air Flow Measuring – Velocity sensor

Amplified Velocity Pressure

- Compensate for VAV Controller Limitations
- Prevent need to undersize VAV unit
- Minimum suggested Velocity is 3.56m/s
- Improved Temperature Control
- Meet IAQ Airflow Requirements
- Use Properly Sized Terminals

Amplified Velocity Pressure

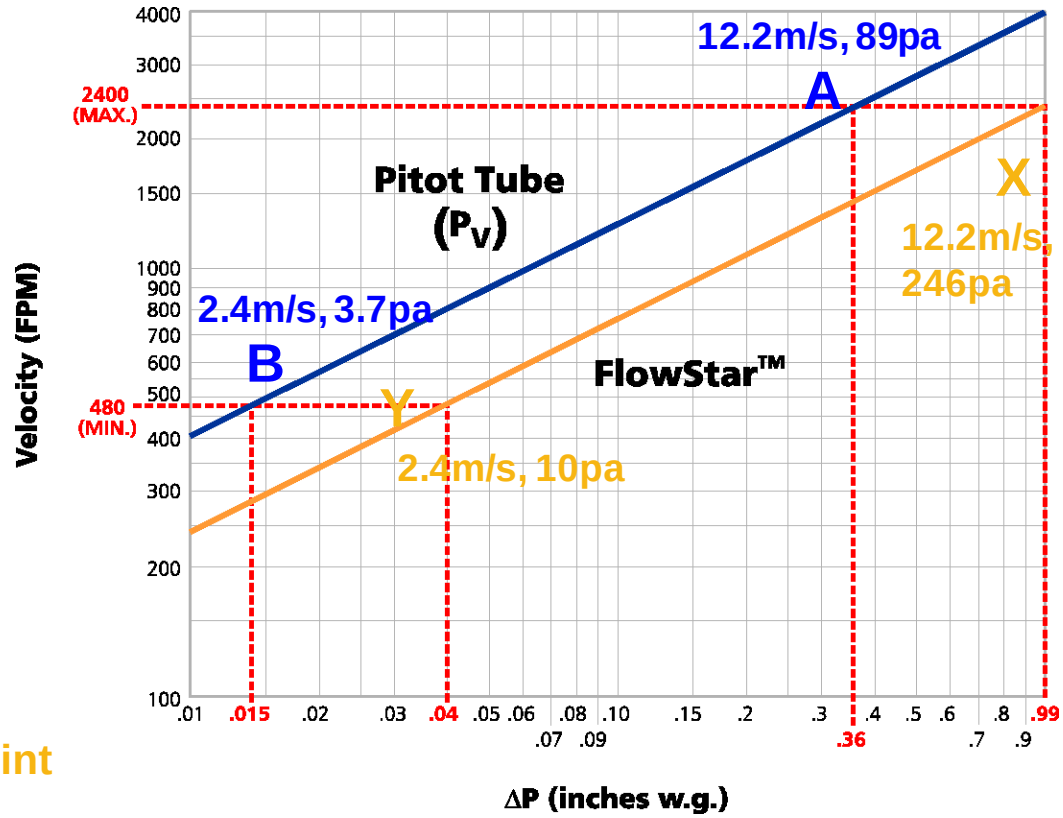
Line AB using pitot tube
- **A:**12.2m/s, 89pa
- **B:** 2.4m/s, 3.7pa

Line XY using FlowStarTM
- **X:** 12.2m/s 246pa
- **Y:** 2.4 m/s 10pa

Flowstar pressure gain
- Increase from 89 to 246pa
- Increase from 3.7 to 10pa

Increase Control Range
- **Increase from 3.7 to 10pa**

Decrease minimum controllable setpoint
- **Increase from 89 to 246pa**



Air Flow Measuring – Velocity sensor

Amplified Velocity Pressure

Size 8 example	Velocity	Velocity Pressure		Yield increase
		Pitot /Pv	FlowStar /dP	
	m/s	Pa	Pa	
Vmax	15.3	139.5	373.6	268%
Design	12.2	89.7	246.6	275%
Vmin	2.44	3.7	10.0	266%

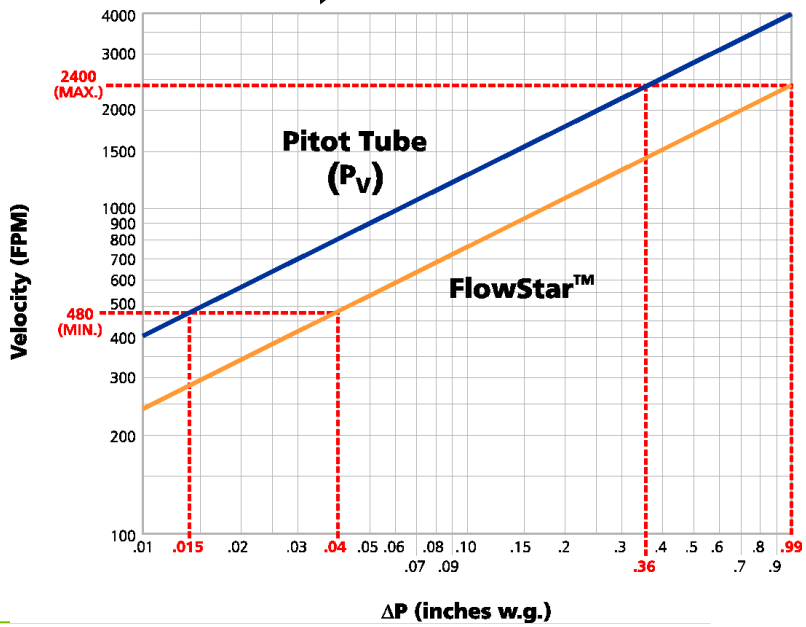
Yields 230 to 290% amplification

Increased *Range* of Control

- Pitot Tube: 3.7 to 90 Pa
- FlowStar: 10 to 246 pa

Decreased *Minimum* Controllable Setpoint

- Example. Size 8:
- Pitot Tube:44 l/s @3.7 Pa
- FlowStar:29 l/s @3.7 Pa



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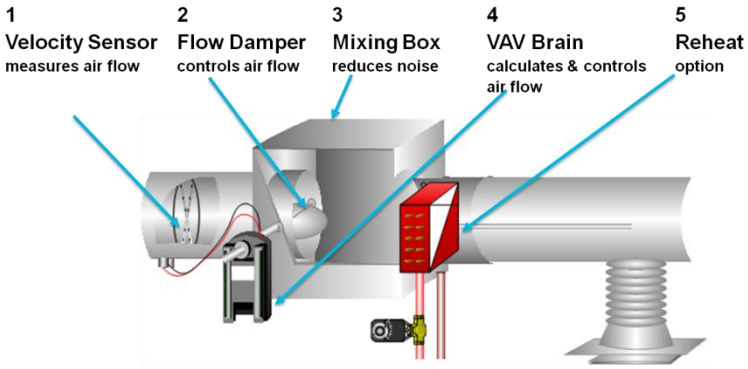
Air Flow Controlling – Flow damper

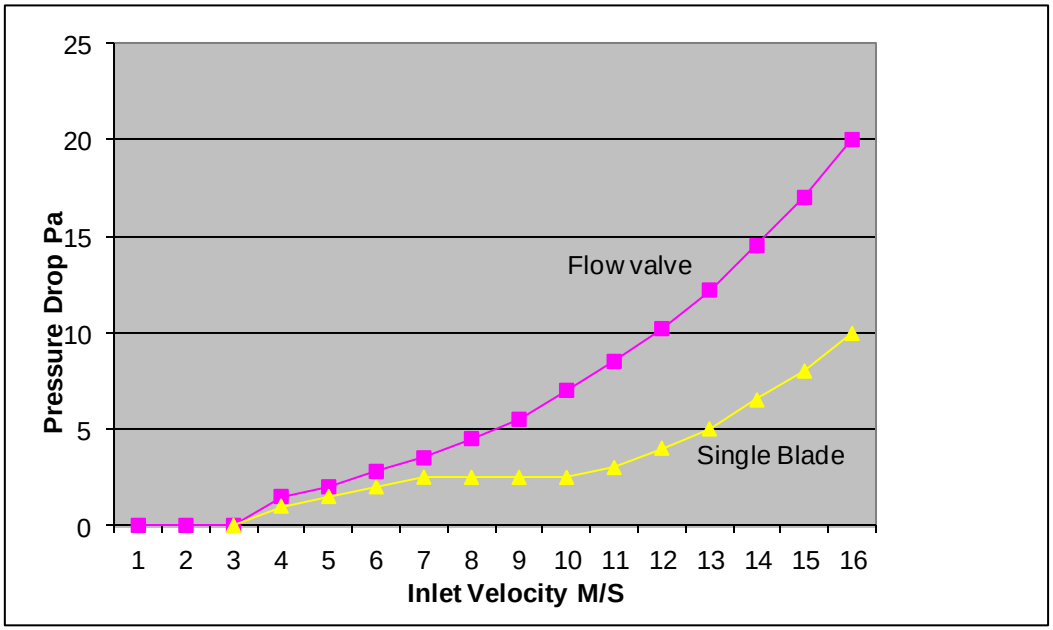


1. **ASHRAE 2001 Fundamentals, Chapter 15.7 Fundamentals of Control Damper**
   - Automatic dampers are used in air-conditioning and ventilation to control airflow
     A. Multi-blade dampers are used to control flow through large openings typical of those in air handlers
     B. Single-blade dampers are typically used for flow control at the zone
2. Multi-blade damper requires smaller actuator (toque) than single-blade damper to control/modulate air flow
3. Control accuracy
   - No difference in control accuracy between multi-blade or single blade damper
   - 5% accuracy from minimum flow rate to maximum flow rate as standard requirement

Air Flow Controlling – Flow damper

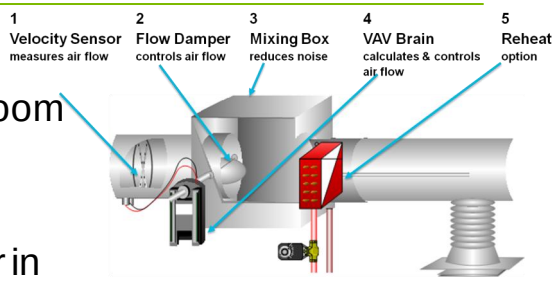
4. Energy consumption

- Damper leakage, particularly where tight shutoff is necessary to reduce significantly
- Less pressure drop, less fan energy consumption
  - Example of VAV Boxes comparison



Noise Level – Mixing Box

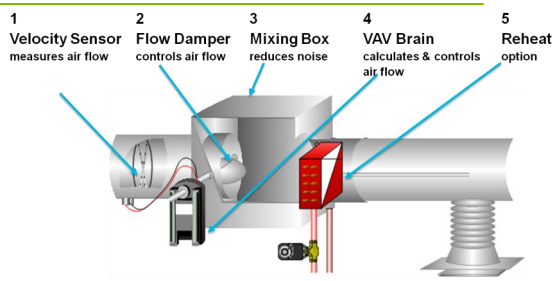
1. Noise will occur when damper is throttling/controlling air flow
   - Discharge sound power is more significant to the noise level in the room
2. Mixing box is critical to reduce noise level
   - Poor quality designed mixing box will require an extra acoustic barrier in downstream of VAV box to reduce noise level

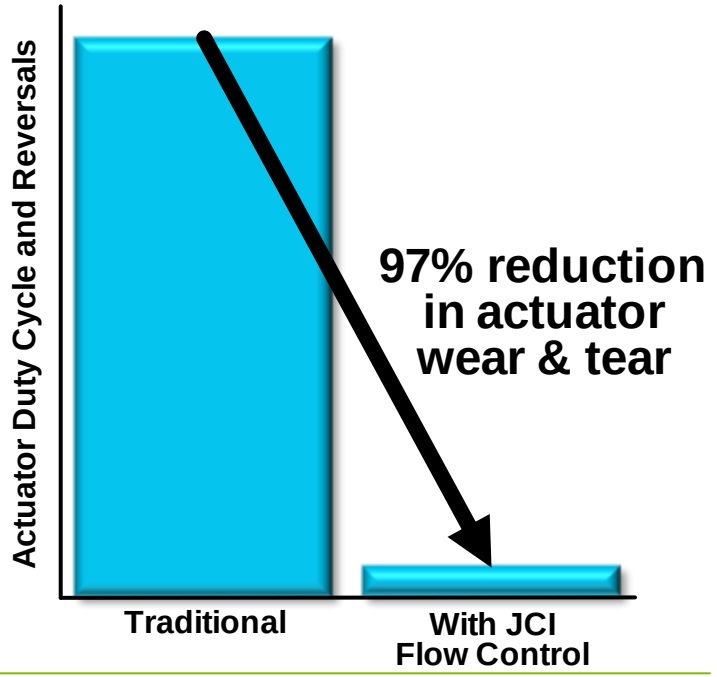


Size	Air Flow	Flow Valve							Single-Blade							Multi -Blade						
		125	250	500	1K	2K	4K	Ave	125	250	500	1K	2K	4K	Ave	125	250	500	1K	2K	4K	Ave
	L/S	2	3	4	5	6	7		2	3	4	5	6	7		2	3	4	5	6	7	
		Discharge Sound power																				
8	350	53	54	51	50	53	50	99%	57	55	52	48	43	40	94%	62	59	56	54	54	53	107%
10	500	55	55	53	52	54	52	99%	57	55	52	49	43	40	91%	63	62	61	58	57	57	110%
12	700	57	57	55	53	56	54	101%	56	55	54	49	45	42	91%	65	61	61	58	57	56	109%
14	1,000	59	60	57	56	58	57	101%	58	56	55	50	46	42	89%	70	64	62	63	61	60	110%
16	1,250	60	61	59	57	59	59	101%	60	55	54	49	46	42	88%	74	66	65	63	61	59	111%
		Radiated Sound power																				
8	350	51	45	37	32	30	26	94%	57	46	40	33	30	27	99%	61	47	42	36	34	33	107%
10	500	52	46	38	33	31	27	93%	54	45	40	34	29	29	94%	66	53	46	39	36	36	113%
12	700	53	48	40	34	32	28	93%	52	47	43	36	32	29	94%	65	55	46	43	41	39	114%
14	1,000	55	50	42	35	33	30	91%	52	47	42	38	34	30	90%	68	59	50	48	46	46	118%
16	1,250	56	51	43	36	34	31	92%	52	47	41	36	31	30	87%	70	62	53	50	48	47	121%

Air Flow Controlling – Controller

1. Flow control algorithm provides fast, accurate control and extends actuator life
   - Integral actuator is ninety times more precise than a traditional actuator
   - (US Patents 5768121 and 5875109)
2. Precision damper actuator provides accurate control
   - (US Patent 6198243)
3. Finite State Machine eliminate simultaneous heating and cooling to reduce energy
   - (*US Patents 6006142 and 6219590*
   - Finite State Machine now incorporated into ASHRAE Fundamentals Handbook





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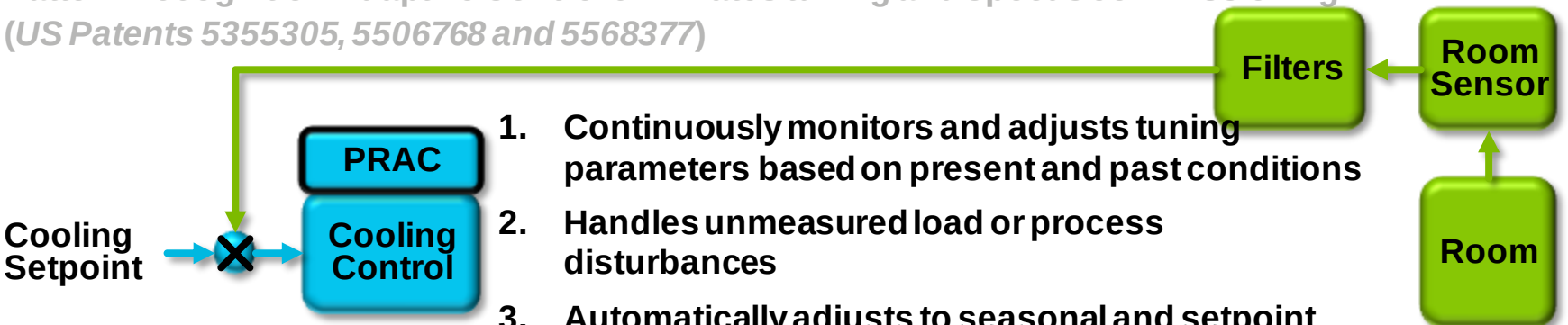
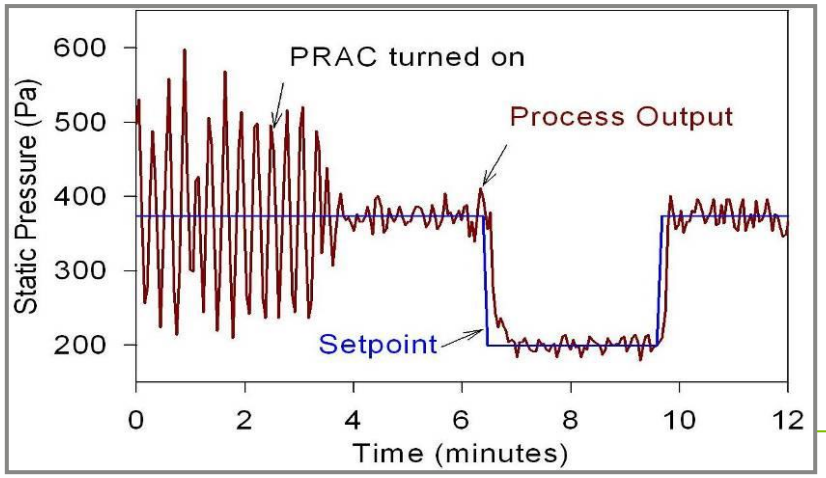
Air Flow Controlling – Controller

Pattern Recognition Adaptive Control eliminates tuning and speeds commissioning
(*US Patents 5355305, 5506768 and 5568377*)



1. Continuously monitors and adjusts tuning parameters based on present and past conditions
2. Handles unmeasured load or process disturbances
3. Automatically adjusts to seasonal and setpoint changes
4. Places a Variable Dead-band around the setpoint based on noise level sampled
5. Reduces actuator hunting



Energy savings
Better quality control
Extended actuator life
Control stability during setpoint change
Eliminates tuning
Speeds commissioning

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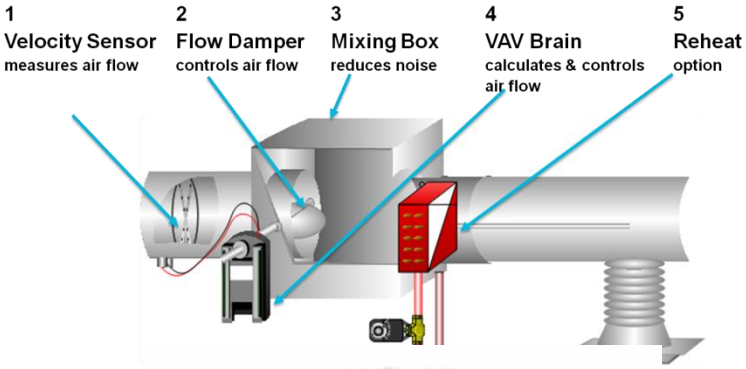
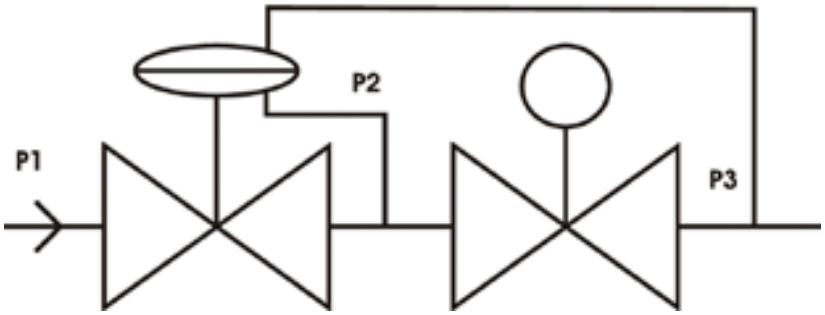
Heating Water Coil Controlling – PICV

Pressure Independent Control Valve

- adjusts the flow rate in case of partial load
- the differential pressure regulator corrects any differential pressure variation
- allows precise modulating control.
- guarantee a suitable flow rate and avoiding too high energy consumption.

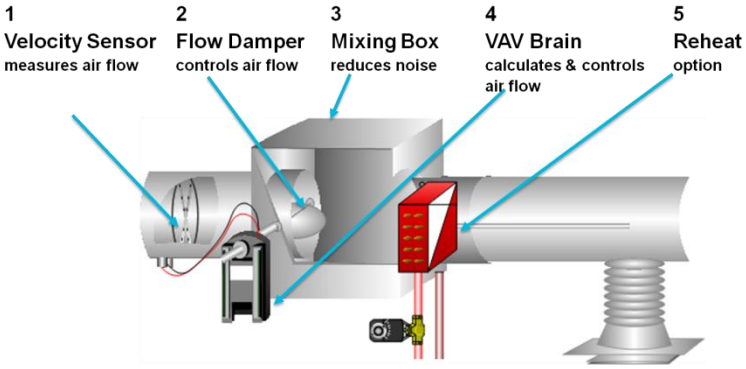
a considerable reduction in temperature variations and adjustment movements and to the extension of the life of the moving devices





Conclusion

- The sensing point of velocity sensor is critical to measure air flow accurately
- Amplified Velocity Pressure is the solution to measure low air flow rate when high turn-down ratio required
- Single-blade has advantage of lower pressure drop and lower noise level
- Fast_Accurate_Stable air flow controller can deliver both comfortable and energy efficient VAV system
- PICV for hot water coil is another solution to deliver both comfortable and energy efficient VAV system



- **Factory calibrated VAV box with Generic Bacnet MS/TP controller for any BMS system**
- **Control system can deliver both comfortable and energy efficient solution ONLY when the mechanical equipment allows to**

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