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Application Note 016 - CFM Monitoring and Control

Overview of Setup for CFM Monitoring and Control with BAS

To design and configure a BAS site for CFM control (each of the following steps are described in greater detail later in this Application Note):

1. Select an appropriate differential pressure transducer.
2. Calculate a BAS Constant (BASk) factor for the selected transducer.
3. Determine a CFM Constant (CFMk) factor for each VAV/VariZone box size and model.
4. Enter the BASk factor in the BAS system configuration using System / Site Configure / VAV/VariZone Settings
5. For each Zone with CFM control:
    a. Select Zone / Configure and then Sensors.
    b. Configure the Sensor Scaling at the appropriate Analog Input as CFM Sensor.
    c. Select the input range as 0-5 VDC (always select 0-5 VDC).
    d. Select Ok and then Actuators.
    e. Select the Pressure Independent option.
    f. Enter the CFM Constant.
    g. Enter the CFM Offset (in either Volts or Bits).
    h. Select the CFM Min and Max values nearest to the design Min and Max.
    i. Select Ok and then Ok again to save the Zone configuration.
    j. If necessary, each Zone's CFM Constant may be adjusted slightly up or down so that the CFM reading matches the CFM measurements from the system air balance. Any adjustments more than +/-10% from the design CFM Constant should be investigated.

Selecting a Differential Pressure Transducer Range

First check each Zone to locate the worst case zone with the highest primary air velocity/velocity pressure. The velocity pressure can be found using a chart provided by the VAV box manufacturer to locate the velocity pressure that corresponds to the maximum design CFM for that Zone. Typically the maximum velocity pressure will not exceed 1" wc and rarely exceeds 1.5" wc. The low end of the range for the selected transducer should always be 0" wc.

All sensors at the site must be the same range and output (see Calculating a BAS Constant Factor below). To provide the maximum possible CFM resolution, select a transducer with the lowest possible pressure range that can still read the worst case velocity pressure. A transducer with a 0-1" wc range will provide a signal with 1.4 times the resolution of a 0-2" wc transducer.

Selecting a Differential Pressure Transducer Output

The transducer output is often determined by a combination of the manufacturer, supplier, availability, and cost. The output will affect the resolution, so if the output is optional select an output that provides the best possible resolution. The outputs below are listed in order from highest to lowest resolution.

1. 0-5 VDC / 0-10 VDC (best resolution)
2. 0.5-4.5 VDC / 1-5 VDC / 2-10 VDC (around 10% loss of resolution compared to 0-5 VDC)
3. 4-20 mA (around 20% loss of resolution compared to 0-5 VDC)

Calculating a BAS Constant Factor (BASk)

The BASk factor defines the sensor range and output for the system and is used by the system, along with the CFMk factor, to convert the reading from the pressure transducer to a CFM value. There is only a single BASk factor that can be configured at each site, so all pressure transducers must use a combination of pressure range and output that results in the same BASk factor.

The BAS system default setting for the BASk factor is 746. This value is based on use of a pressure transducer with a range of 0-1” wc and an output of 4-20 mA. If using any other range and/or output, the new BASk factor must be calculated and configured in the system.

The smaller the BASk factor the better the resolution of the CFM readings. Lower transducer pressure ranges provide lower BASk factors and better resolution. Higher voltage output spans also provide lower BASk factors and better resolution.

The BASk factor can be calculated using a worksheet found in the EZ Dealer Excel workbook or by using the formula below:

$$\text{BASk} = 1400 \times \sqrt{\frac{\text{VPmax}}{\text{Vspan}}}$$

VPmax is the maximum velocity pressure (in “ wc) that can be read by the transducer.
Vspan is the total span (in VDC) of the transducer’s output.

Vspan values for various typical transducers:

Output	Vspan (VDC)
0-5 VDC	5
0-10 VDC	5
0.5-4.5 VDC	4
1-5 VDC	4
2-10 VDC	4
4-20 mA	3.52

Determining a Zone's CFM Constant Factor (CFMk)

The CFMk factor is an industry standard term and is used to convert a velocity pressure reading into a CFM value. It is defined by the VAV box size and differential pressure signal multiplier. The CFMk factor is always equal to the CFM that will cause the factory installed flow ring/velocity pressure pickup to generate a velocity pressure of 1" wc.

Most VAV box manufacturers will improve sensitivity of CFM readings by designing the flow ring/velocity pressure pickup so that it amplifies the velocity pressure reading. This multiplier is specific to each manufacturer and box model and if needed should be available from the manufacturer. It will typically range from about 1.2 to 4.0. If the differential pressure reading is provided by a standard pitot tube, there is no amplification and the multiplier is 1.0.

The CFMk factor can be determined one of three ways:

1. If available, always use the CFMk factor provided by the VAV box and/or air flow pick-up tube manufacturer.
2. If a CFM chart is available for the VAV box, use the chart to find the CFM equal to a differential pressure output of 1.0" wc. CFMk is the same as the CFM when at 1.0" wc.
3. Calculate the CFMk factor using a worksheet found in the EZ Dealer Excel workbook or by using the formula below. This method should not be used unless the flow ring/velocity pressure pickup multiplier is known. If the multiplier is unknown and this is the only option, use a value of 1.6 for the multiplier to calculate an initial CFMk and then adjust the CFMk as necessary to match the air balance results.

$$\text{CFMk} = \frac{4005 \times A}{\text{Mult}}$$

A is the area in square feet of the cross section of the primary duct at the location of the flow ring/pressure pickup tubes.
Mult is differential pressure signal multiplier built into the flow ring/pressure pickup tube.

CFM Calculations

Once the BASk and CFMk factors have been determined and entered into the system, BAS calculates Zone CFM readings using the following formula:

$$\text{BAS CFM} = \frac{\text{BASk} \times \text{CFMk} \times \sqrt{\text{AIr} - \text{OFS}}}{10{,}000}$$

AIr is the unscaled (raw) input for the analog input defined as a CFM sensor for the Zone and will be between 0-255.
OFS is the CFM sensor offset, in Bits, previously entered in the Zone configuration.

The CFM can also be manually calculated using the following standard formula:

$$\text{CFM} = \frac{4005 \times \sqrt{\text{VP}} \times A}{\text{Mult}}$$

VP is the velocity pressure reading (in " wc) from the flow ring/pressure pickup tube.
A is the area in square feet of the cross section of the primary duct.
Mult is differential pressure signal multiplier built into the flow ring/pressure pickup tube.

Factors Affecting the Accuracy of CFM Monitoring and Control

The accuracy of control and resolution of CFM readings are affected by both the range and the output of the pressure transducer being used, and by the design of the HVAC system. Use the criteria described previously to select a transducer with the range and output that provides the best CFM control. A chart is also attached at the end of this Application Note with data showing the resolution of various pressure transducer range and output combinations to help in transducer selection.

The selection of the appropriate VAV box for each Zone is typically done by a design engineer without input from the control system installer. Most engineers will select a VAV box at least one or two sizes bigger than is needed for the design maximum CFM for the Zone. This causes the box to operate near the low end of the box's capacity.

The nature of velocity pressure (also commonly referred to as differential pressure) is that it takes a much larger change in CFM to make the same change in velocity pressure at the low end of the box capacity than at the high end. For example, a typical pressure transducer with a range of 0-1" wc and a 0-5 VDC output has a resolution of 0.00392" wc. For a typical 10" round VAV box, it takes a change of 12 CFM to generate a change in velocity pressure of 0.00392" wc at the low end of its operating range. This same box at the upper end of its operating range will only require a change of 1 CFM to generate the same 0.00392" wc change in velocity pressure.

In this example the control of CFM is 12 times more accurate and sensitive when operating near the high end of the box's capacity than when at the low end. See the charts at the end of this Application Note for additional details on velocity pressure vs CFM. Whenever possible, the control system installer should encourage the design engineer to select the smallest size box that can provide the maximum design CFM for that Zone.

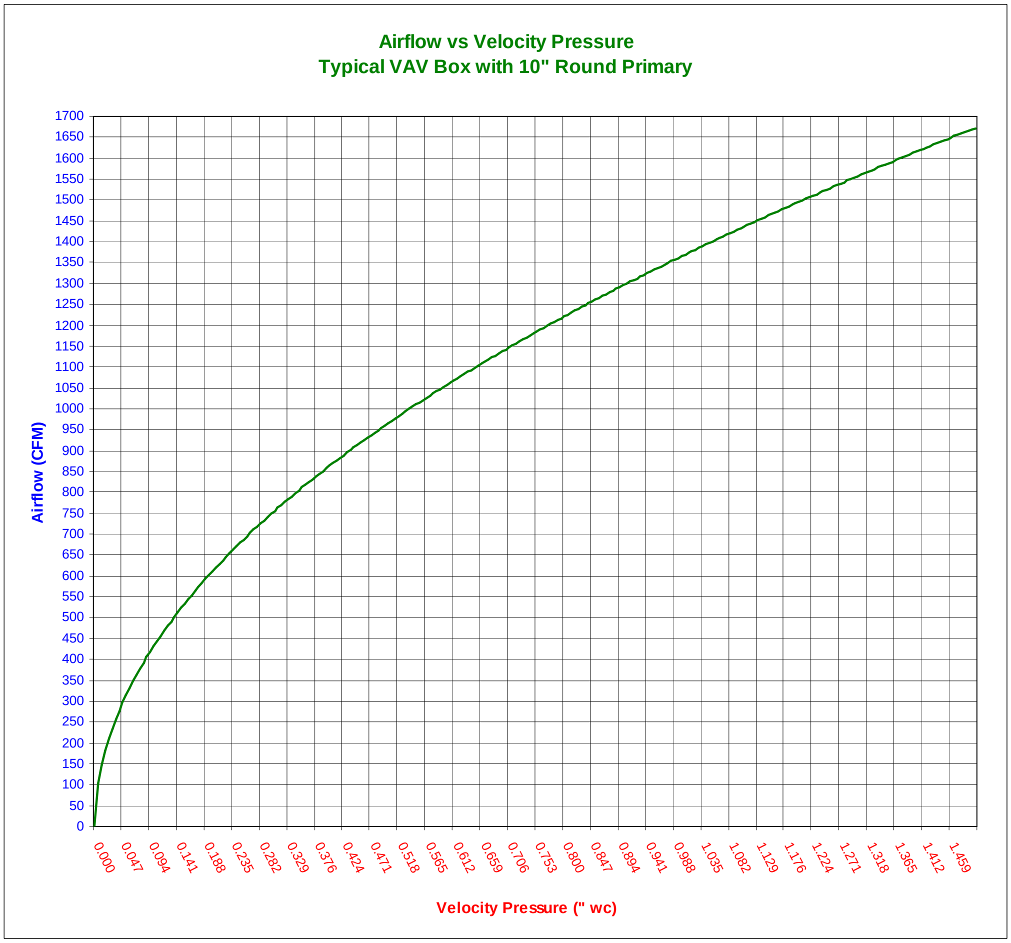
Optimum Operating Range for CFM Control of a VAV Box

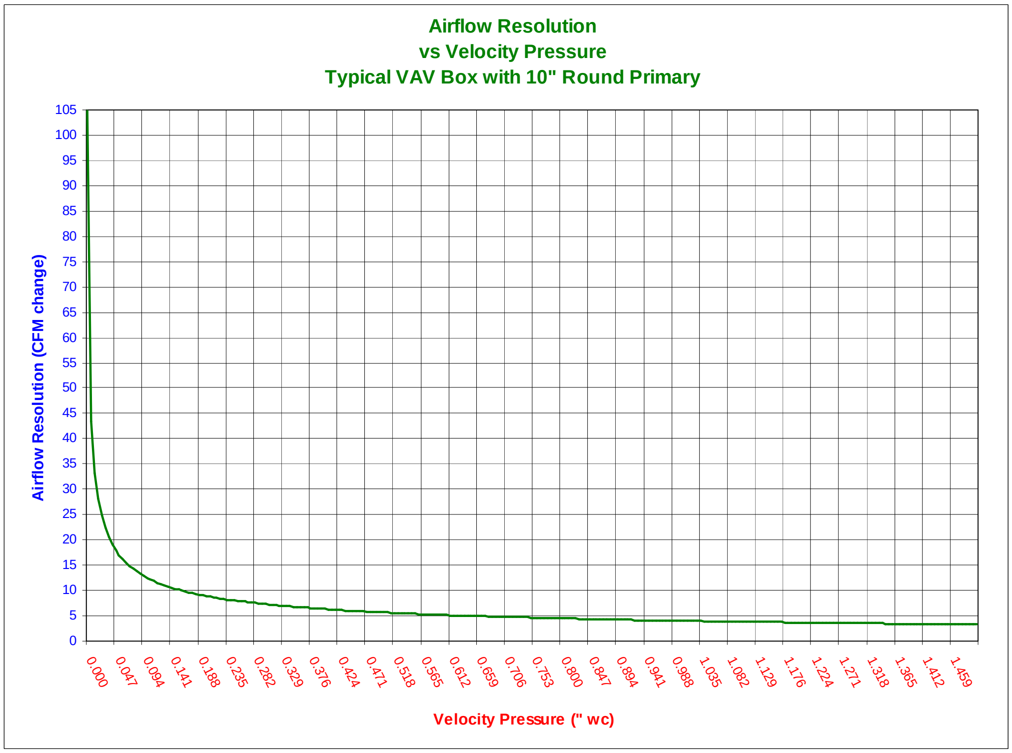
These two charts plot velocity pressure vs total airflow and velocity pressure vs airflow resolution. This example is based on a VAV box with a 10" round primary and a CFMk factor of 1365, but is valid for any VAV box size. The box has a maximum airflow capacity of 1670 CFM with a corresponding velocity pressure of 1.5" wc.

The first chart shows that when airflow is below about 300 CFM (velocity pressure of 0.049" wc), or 18% of rated capacity, an increasingly large change in CFM is required to the produce a measurable change in velocity pressure. The next chart also shows that below this same point the resolution, or smallest change that it is possible to see, becomes very large. The charts also show that the highest resolution and control of CFM is at or above about 835 CFM (velocity pressure of 0.373" wc), or 50% of rated capacity.

Therefore, as these two charts show:

1. The most accurate control of CFM is achieved when a VAV box is operating between 50-100% of its rated capacity.
2. Less accurate but still acceptable control of CFM can be achieved when a VAV box is operating between 18-50% of its rated capacity.
3. Accurate control is very difficult when a VAV box is operating below 18% of its rated capacity and CFM readings are meaningless below 10% of its rated capacity (velocity pressure of 0.015" wc).


Airflow vs Velocity Pressure
Typical VAV Box with 10" Round Primary
Airflow (CFM)
Velocity Pressure (" wc)


Airflow Resolution
vs Velocity Pressure
Typical VAV Box with 10" Round Primary
Airflow Resolution (CFM change)
Velocity Pressure (" wc)

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Comparison of Resolution of CFM Readings using Various Static Pressure Transducer Ranges and Outputs

			0 -> 5 VDC Output			0.5 -> 4.5 VDC Output			1 -> 5 VDC Output			4 -> 20 mA Output		
Pressure Sensor Definition		**Output Min (VDC)**	0	0	0	0.5	0.5	0.5	1	1	1	0.88	0.88	0.88
		Output Max (VDC)	5	5	5	4.5	4.5	4.5	5	5	5	4.4	4.4	4.4
		Press Max (" wc)	1	1.5	2	1	1.5	2	1	1.5	2	1	1.5	2
		BAS-k	626	767	886	700	857	990	700	857	990	746	914	1056
		Offset Volts	0	0	0	0.5	0.5	0.5	1	1	1	0.88	0.88	0.88
		Offset Bits	0	0	0	26	26	26	51	51	51	45	45	45
		# of Steps	256	256	256	205	205	205	205	205	205	180	180	180
Typical 6" Primary - CFM-k=	**491**	**Lo Limit CFM**	31	38	44	34	42	49	34	42	49	37	45	52
		Resolution at Lo Limit CFM	12	15	18	15	18	20	15	18	20	15	18	21
		Minimum Position / 20% CFM	98	121	139	98	120	139	98	120	`	98	120	139
		Resolution at 20% CFM	5	5	7	6	8	8	6	8	8	7	9	9
		Mid-Range CFM	348	426	492	348	426	492	348	426	492	347	426	492
		Resolution at Mid-Range CFM	2	2	2	2	2	2	2	2	2	1	3	3
		Hi Limit CFM	491	601	695	491	601	694	491	601	694	490	600	694
		Resolution at Hi Limit CFM	1	1	2	1	1	1	1	1	1	1	1	2
Typical 8" Primary - CFM-k=	**875**	**Lo Limit CFM**	55	67	78	61	75	87	61	75	87	65	80	92
		Resolution at Lo Limit CFM	22	28	32	26	31	36	26	31	36	27	33	39
		Minimum Position / 20% CFM	175	215	248	175	215	248	175	215	`	175	215	248
		Resolution at 20% CFM	9	10	12	11	12	15	11	12	15	12	14	17
		Mid-Range CFM	620	759	877	620	759	877	620	759	877	619	759	877
		Resolution at Mid-Range CFM	3	3	3	3	4	4	3	4	4	3	5	5
		Hi Limit CFM	875	1072	1238	875	1071	1237	875	1071	1237	873	1070	1236
		Resolution at Hi Limit CFM	2	2	2	2	3	3	2	3	3	2	3	3
Typical 10" Primary - CFM-k=	**1365**	**Lo Limit CFM**	85	105	121	96	117	135	96	117	135	102	125	144
		Resolution at Lo Limit CFM	36	43	50	39	48	56	39	48	56	42	51	60
		Minimum Position / 20% CFM	273	335	387	274	335	387	274	335	387	273	335	387
		Resolution at 20% CFM	13	16	18	16	20	23	16	20	23	19	22	26
		Mid-Range CFM	967	1184	1368	967	1184	1368	967	1184	1368	966	1184	1367
		Resolution at Mid-Range CFM	4	4	5	4	5	7	4	5	7	5	7	7
		Hi Limit CFM	1365	1672	1931	1365	1671	1930	1365	1671	1930	1362	1669	1929
		Resolution at Hi Limit CFM	3	3	4	4	4	5	4	4	5	3	4	6
Typical 12" Primary - CFM-k=	**1950**	**Lo Limit CFM**	122	150	173	137	167	193	137	167	193	145	178	206
		Resolution at Lo Limit CFM	51	62	71	56	69	80	56	69	80	61	74	85
		Minimum Position / 20% CFM	391	479	553	391	479	553	391	479	553	390	478	553
		Resolution at 20% CFM	18	22	26	23	28	33	23	28	33	27	32	37
		Mid-Range CFM	1381	1692	1955	1382	1692	1954	1382	1692	1954	1380	1691	1954
		Resolution at Mid-Range CFM	5	6	8	7	8	9	7	8	9	8	10	11
		Hi Limit CFM	1949	2388	2759	1950	2387	2757	1950	2387	2757	1946	2385	2755
		Resolution at Hi Limit CFM	4	4	5	5	6	6	5	6	6	5	7	8
Typical 14" Primary - CFM-k=	**2676**	**Lo Limit CFM**	168	205	237	187	229	265	187	229	265	200	245	283
		Resolution at Lo Limit CFM	69	85	98	78	95	110	78	95	110	82	101	117
		Minimum Position / 20% CFM	536	657	759	536	657	759	536	657	759	536	656	758
		Resolution at 20% CFM	26	31	36	32	39	45	32	39	45	36	44	51
		Mid-Range CFM	1895	2322	2682	1896	2322	2682	1896	2322	2682	1894	2320	2681
		Resolution at Mid-Range CFM	7	9	10	9	12	13	9	12	13	11	13	15
		Hi Limit CFM	2675	3278	3786	2675	3276	3784	2675	3276	3784	2671	3272	3781
		Resolution at Hi Limit CFM	5	7	7	6	9	9	6	9	9	8	9	11
Typical 16" Primary - CFM-k=	**3495**	**Lo Limit CFM**	219	268	310	245	300	346	245	300	346	261	319	369
		Resolution at Lo Limit CFM	90	111	128	101	124	143	101	124	143	108	133	153
		Minimum Position / 20% CFM	700	858	991	701	858	991	701	858	991	700	857	990
		Resolution at 20% CFM	34	41	47	41	50	58	41	50	58	47	58	67
		Mid-Range CFM	2475	3033	3503	2477	3032	3503	2477	3032	3503	2473	3031	3501
		Resolution at Mid-Range CFM	9	12	13	12	14	17	12	14	17	13	17	19
		Hi Limit CFM	3494	4281	4945	3494	4278	4942	3494	4278	4942	3488	4274	4938
		Resolution at Hi Limit CFM	7	9	10	8	10	12	8	10	12	9	12	14

Description for each parameter shown above

Output Min (VDC)	The output of the pressure transducer when the differential pressure is at 0" wc.
Output Max (VDC)	The output of the pressure transducer when the differential pressure is at maximum.
Press Max (" wc)	The maximum differential pressure input of the pressure transducer (" wc).
BAS-k	A calculated value that defines the pressure transducer input and voltage output range.
Offset Volts	The pressure transducer output at 0 CFM (always the same value as Output Min).
Offset Bits	The unscaled / raw value of the analog input that corresponds to the Offset Volts value.
# of Steps	The maximum # of steps (or bits of resolution) for the output range of the pressure transducer.
Lo Limit CFM	The lowest possible CFM value that can be read for the sensor range/output combination.
Resolution at Lo Limit CFM	The smallest change in CFM that can be seen at Lo Limit CFM.
Minimum Position / 20% CFM	Typical Minimum CFM configuration - 20% of Hi Limit CFM.
Resolution at 20% CFM	The smallest change in CFM that can be seen at 20% CFM.
Mid-Range CFM	Middle of CFM control range - normal operating CFM.
Resolution at Mid-Range CFM	The smallest change in CFM that can be seen at Mid-Range CFM.
Hi Limit CFM	The highest possible CFM value that can be read for the sensor range/output combination.
Resolution at Hi Limit CFM	The smallest change in CFM that can be seen at Hi Limit CFM.

Typical VAV Box CFM Airflow Chart

This airflow chart is for VAV boxes manufactured by Enviro-Tec, but is typical for CFM vs velocity pressure found on VAV boxes from most manufacturers.

Note that the chart does not include CFM values for velocity pressures below 0.015" wc, or about 10% of the rated CFM capacity of the box.