# 11 Exhaust Fan Application Primer

## 11.1 Summary

This primer describes how to set up an Aircuity system to enable safe control of dilution levels with laboratory exhaust fans based on active sensing of contaminants in the fan plenum or fan inlets. A signal is sent by the Aircuity system to the lab's building control system to enable higher exit fan velocities when the Aircuity system detects a contaminant level above a given threshold in the exhaust plenum. Demand based control can result in significant energy savings due to the fact that exhaust air often accounts for 20% or more of a critical facility's HVAC energy costs even though it is usually clean for the majority of the time. What's more, when air change rates are varied in labs a tremendous amount of excess total airflow (and therefore fan energy cost) can be avoided by allowing the flow through the fans to vary as long as minimum exit velocities are maintained to address dilution requirements. Here, the exhaust flow will be based on the greater of the building's ventilation demand or the exhaust flow necessary to satisfy dilution requirements.

Overall system setup and logic required to vary exhaust stack velocity based on dilution demand, in conjunction with lab exhaust ventilation demand and along with design considerations for each component of the system, will be addressed.

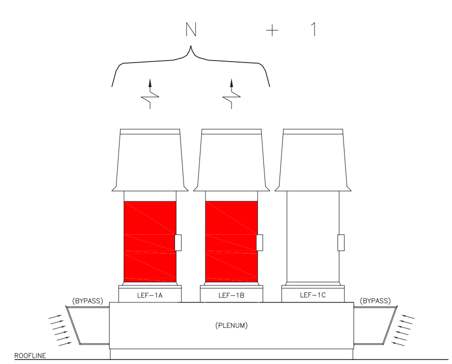
Exhaust fan systems are designed to provide dilution to the compounds intended for use in the facility and, independent of whether or not demand based control of the fan(s) is applied, it is quite common that the design process results in a list of compounds for which a quantity usage protocol needs to be applied. This is due to the fact that despite the high levels of dilution provided, either the toxicity or odor levels of certain compounds necessitate such restrictions. The demand based control of an exhaust fan(s) via the active sensing provided by the Aircuity system is intended to work in conjunction with these compound quantity usage restrictions.

## 11.2 Background

Laboratory exhaust fans are often operated at constant volume or are controlled in multiple manifolded arrays where the fans are turned on or off in a staged fashion with one to "N" fans operating based on the total exhaust fan requirements. With either of these approaches a bypass damper is usually provided as part of the exhaust plenum that functions to help control static pressure in the plenum by introducing a controllable amount of roof air into the exhaust plenum to make up for a reduction in exhaust air from the building. The fans are typically operated at a fixed flow rate in order to provide 3,000 fpm or some other exit velocity to mitigate re-entrainment of the exhaust plume from the fans. Often times a consultant will do a wind tunnel or a theoretical exhaust fan system dispersion analysis to determine stack heights, placements of fans and minimum exit fan velocities to achieve a minimum level of dilution from the fume hood interior to an air inlet that typically yields a dilution ratio of about 3,000:1. Here, the dilution ratio is the amount by which the exhaust stack effluent is diluted with respect to critical locations, such as air intakes or other critical locations or receptors around a building.

Although this is an effective approach to prevent re-entrainment, these fans can use a considerable amount of energy in order to achieve the high exit velocities necessary to maintain the desired levels of dilution. Although fan staging does serve to reduce the energy use versus running all fans constantly, it still is a wasteful approach versus varying the volume of each fan based on the building exhaust requirements. This is because the bypass damper introduces additional air that must be exhausted that requires additional fan energy. Additionally, fan operation to deliver high exit velocities requires additional fan power over that required to exhaust air at a lower velocity. This coupled with the non-linear or exponential nature of fan power consumption vs. fan flow also contributes to excessive energy consumption.

The drive to keep the physical height of exhaust stacks as short as possible for aesthetic reasons has given rise to the use of systems operating with higher exit or volume veloci-




**N+1 Redundancy**

A form of system resilience where **N** number of components have at least **1** backup which may be used in the event of a failure

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ties in order to achieve the same plume height characteristics of conventional taller stack systems. This is usually accomplished using entrained exhaust fan systems which have been popular for many years due to their compact design and their ability to provide added dilution. However, depending on the design requirements, operation at these higher discharge velocities poses an added impact on energy usage in addition to that required to move the bypass air volume.

## 11.3 Exhaust Contaminant Monitoring with VAV Exhaust Fan Control

One approach to save energy with laboratory exhaust fans is to realize that there are periods of time during which the fan exit velocities can be reduced and the use of bypass air can at least temporarily be eliminated to save energy. One such opportunity is when the level of contaminants in the exhaust stream being exhausted is below a given threshold level. When this air is "clean" and relatively free of contaminants, a high exhaust velocity is not needed since the level of required dilution can be reduced because what we are diluting is already at a low level. Dispersion analysis consultants have reviewed this application and have determined that using demand based control to reduce the dilution level from a ratio of about 3,000:1 to a ratio of about 750:1 is prudent and acceptable from an industrial hygiene and re-entrainment standpoint for most lab applications, based on the chemicals that the Aircuity system does and does not sense. For purposes of comparison, an "as manufactured" test of a fume hood's containment also requires about a 3,000:1 dilution ratio to minimize researcher exposures. On the other hand the dilution ratio required for an "as installed" test of a fume hood's containment typically is about 750:1.

**Note:** For purposes of comparison, an "as manufactured" test of a fume hood's containment also requires about a 3,000 to 1 dilution ratio to minimize researcher exposures. On the other hand the dilution ratio required for an "as installed" test of a fume hood's containment typically is about 750 to 1.

One reason dispersion analysis consultants are supportive of this application, even though the Aircuity system cannot sense all chemicals, relates to how dilution requirements are determined and the resulting protocols that are created when some compounds are used. The evaluation process ranks the required dilution of likely hazardous agents used in laboratories based on the expected vapor release that would result if a one liter container were to be spilled onto the interior work surface of a fume hood. Here, a one liter volume is usually chosen for such analysis, given the fact that the finite size of a standard fume hood will limit the surface area of a spill to roughly the same value even if more than one liter were to be spilled. In practice, for the vast majority of the hundreds of chemicals that may appear in a lab inventory, the reality is that even 750 to 1 dilution from the exhaust system is more than sufficient. This is the case for all but about 71 extreme compounds that have low TLVs or odor thresholds and are typically reviewed and considered by these consultants (see Figure 11-1 for a list of these compounds). On the other hand, it is interesting to note that for a subset of about 54% of these extreme compounds, even a 3,000:1 dilution level is not adequate and that, for these compounds, an individual usage protocol should be established which prescribes usage quantity limitations below 1 liter based on the hazard level and other properties of the material (such as the vapor pressure of the substance for example). These restrictions are established by working with a dispersion analysis consultant and will vary with the design of each exhaust system.

It should be noted that the list of 71 compounds in Figure 11-1 is not meant to be an all inclusive list. There may be other compounds which are not on this list, for which dilution requirements may need to be evaluated. This is beyond the scope of this primer, and is a topic for which a dispersion analysis expert should be consulted for recommendations. This list (Figure 11-1) has been organized starting with the compounds requiring the most amount of dilution (or usage restriction) to those requiring the least (but typically at least 3,000:1 dilution from the fan system). For example, a liter spill of Arsine would require the most amount of dilution, versus a liter spill of Acetic Acid. In reality, a substance like Arsine is so extremely toxic that an exhaust system would normally not be able to provide enough dilution for this compound at any practical flow level, so it is categorized as a parameter which would only be used with a quantity limit protocol applied (indeed a very restrictive one). For compounds at the top of this list quantity usage would be limited to milliliters, rather than liters, given the extreme nature of these compounds. This would be the case whether demand based control is applied or not. This list groups the first 38 of the 71 compounds (from Arsine to Butylamine) as typically requiring a quantity use limitation protocol because, 3,000:1 dilution is not sufficient for these compounds.

The balance of the list of Figure 11-1 comprises compounds which can usually be properly diluted at 3,000:1 dilution levels when there is a 1 liter spill, from Bromine to Acetic Acid. However, a third category of compounds has been identified from this based on those which cannot be detected by the Aircuity system where a quantity usage limitation would have to be prescribed if demand based control were applied. This would limit the usage volume of these compounds to some value less than one liter, based on what can safely be diluted to prevent concentrations from reaching TLV levels or odor threshold levels at the receptor points (such as air intakes) when the exhaust fan system provides only 750:1 dilution. For example, sulfur dioxide is one of the compounds included within this third list. Because this compound is not detected by the Aircuity system, the exhaust system would operate at 750:1 dilution in the event of a spill of this compound and, therefore, the usage quantity of this compound would have to be limited to ensure the TLV of this chemical is not exceeded when the exhaust fan is delivering 750:1 dilution.

| Compound | CAS# | Compound | CAS# | Compund | CAS# |
|---|---|---|---|---|---|
| ✓ Arsine | 7784-42-1 | Tungston Hexafluoride | 7783-82-6 | Sulfur Dioxide | 7803-62-5 |
| ✓ Methyl Mercaptan | 74-93-1 | ✓ Dimethylhydrazine (1,1-) | 57-14-7 | ✓ Nitric Oxide | 10102-43-9 |
| ✓ Ethyl Mercaptan | 75-08-1 | ✓ Isopropylamine | 75-31-0 | Boron Trifluoride | 7637-07-2 |
| ✓ Ethyl Acrylate | 140-88-5 | ✓ Cresol (all isomers) | 1319-77-3 | Germane Tetrahydride | 7782-65-2 |
| ✓ Hydrogen Sulfide | 7783-06-4 | Diborane | 19287-45-7 | ✓ Hydrazine | 302-01-2 |
| ✓ Nickel Carbonyl (as Ni) | 13463-39-3 | ✓ Phosphine | 7803-51-2 | ✓ Methyl Methracrylate | 80-62-6 |
| Perchloromethyl Mercaptan | 594-42-3 | ✓ Nitrogen Dioxide | 10102-44-0 | ✓ Ethylene Oxide | 75-21-8 |
| Sulfur Pentafluoride | 5714-22-7 | ✓ Ethylamine | 75-04-7 | Dibromo-3-chloropropane (1,2-) | 96-12-8 |
| Chromyl Chloride | 14977-61-8 | ✓ Carbon Disulfide | 75-15-0 | ✓ Propyl Acetate (-n) | 109-60-4 |
| Chlorine Triflouride | 7790-91-2 | ✓ Methyl Hydrazine | 60-34-4 | ✓ Triethylamine | 121-44-8 |
| ✓ Butyl Mercaptan | 109-79-5 | Bromine Pentafluoride | 7789-30-2 | Tributyl Phosphate | 126-73-8 |
| Osmium Tetroxide | 20816-12-0 | ✓ Tetramethyl Lead (as Pb) | 75-74-1 | ✓ Xylidine | 1300-73-8 |
| Picric Acid | 88-89-1 | ✓ Butadiene | 106-99-0 | Hydrogen Chloride | 7647-01-0 |
| ✓ Pentaborane | 19624-22-7 | ✓ Butylamine | 109-73-9 | ✓ Phosphorus Trichloride | 7719-12-2 |
| Chlorine | 7782-50-5 | ✓ Bromine | 7726-95-6 | Iron Pentacarbonyl | 13463-40-6 |
| ✓ Acetaldehyde | 75-07-0 | ✓ Dimethylamine | 124-40-3 | Fluroxene | 406-90-6 |
| ✓ Hydrogen Selenide | 7783-07-5 | ✓ Ethyl Ether | 60-29-7 | ✓ Chloroprene (Beta-) | 126-99-8 |
| Chloromethyl Ether (bis-) | 542-88-1 | ✓ Acrolein | 107-02-8 | ✓ Methylamine | 74-89-5 |
| Hydrogen Fluoride | 7664-39-3 | ✓ Morpholine | 110-91-8 | ✓ Cumene (Isopropyl Benzene) | 98-82-8 |
| ✓ Isopropyl Ether | 108-20-3 | ✓ Diisopropylamine | 108-18-9 | Dichloropropane (-1,2) | 78-87-5 |
| ✓ Methyl Isocyanate | 624-83-9 | Tetranitromethane | 509-14-8 | ✓ Allyl Chloride | 107-05-01 |
| ✓ Diethylamine | 109-89-7 | ✓ Mesityl Oxide | 141-79-7 | ✓ Methyl (n-amyl) Ketone | 110-43-0 |
| Phosgene | 75-44-5 | Flourine | 7782-41-4 | ✓ Acetic Acid | 64-19-7 |
| Amyl Acetate (sec-) | 626-38-0 | Hydrogen Bromide | 10035-10-6 | | |

✓ Detected by the Aircuity System

Typically requires a quantity limitation protocol even at 3000:1 dilution

Typically can be properly diluted at 3000:1 dilution

3000:1 dilution is typically sufficient, but would require quantity limitation protocol because not detected by the Aircuity System.

**Figure 11-1. Some Extreme Compounds Requiring Higher Dilution Levels from an Exhaust Fan System**

The Aircuity system detects the majority of the 71 chemicals that require at least a 3000:1 dilution. However, many of the compounds not sensed by the Aircuity system tend to be rarely used compounds that typically require more than 3000:1 dilution, and therefore have a usage limitation protocol. Therefore, to achieve the same level of safety provided by a fixed high exhaust velocity system may require limiting the quantities used of a few more compounds than already require limits based on the current fixed 3,000:1 dilution approach. For example, a detailed review of chemicals used in a university lab building project that was considered typical found only one compound of the above 71 chemicals that was being used that could not be detected. However, this compound (Osmium Tetroxide) was already in the list of chemicals with required usage limits. Additionally, the quantity that was to be used was just 1% of the safety limit based on a 750:1 dilution resulting from the Aircuity system not sensing it. As a result, 100% of the chemicals on the list of potentially used chemicals were either sensed or had usage quantities that were below applicable safety limits and no additional usage quantity restrictions. A review of this list of compounds and their associated usage protocols is considered to be a required step when determining the appropriateness of an exhaust fan control application in every lab facility.

### 11.3.1 Comparing Ventilation Demand Against Dilution Requirements to Determine Fan Setpoint

When working with variable volume lab control systems, the total exhaust volume from labs (the ventilation exhaust) is determined by a combination of fume hood, thermal, and air change rate demands from the individual lab spaces; when Lab DCV is applied, the flow requirements can vary by a factor of 6:1 or more. With traditional constant volume exhaust fan systems, as the ventilation exhaust levels decrease, more bypass air is brought into the fan system in order to maintain plenum static pressure and the design stack exit velocity necessary to achieve a minimum dilution requirement. Again, in the past, dilution requirements have been set based on worst case conditions, leading to dilution levels of 3000:1 or greater. Often times, the fan needs to be set to even higher flows than are necessary to achieve design dilution levels (3,000:1 for example) as a result of the peak ventilation flow from the lab spaces. This maximum flow condition dictated by the variable volume controls of the labs is usually a very short lived condition. For example, such ventilation levels may be required occasionally during peak fume hood usage. Depending on the circumstances and frequency of these conditions the design may assume some level of diversity to help reduce the constant volume fan's setpoint. However, in most cases, even with systems which are designed to provide constant dilution levels, it is far more energy efficient to vary the fan speed as the ventilation demand exceeds the fan dilution requirements, rather than to maintain the higher fan CFM on a constant basis.

This variable volume exhaust flow control approach (which often additionally includes a diversity factor) is accomplished by way of a high select function, as shown in Figure 11-2. Here, the dilution command is determined based on the stack velocity necessary to achieve the desired plume height and level of dilution (determined by a wind tunnel study for example), and it is compared against the building ventilation command to create the exhaust fan setpoint.

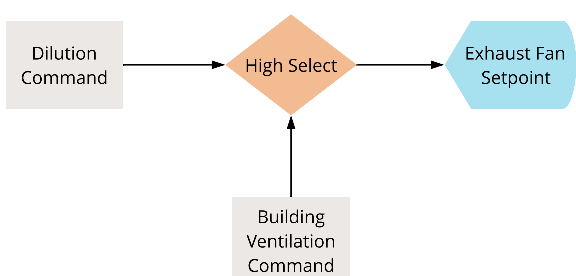


**Figure 11-2. Exhaust Fan Setpoint Based on Higher of Flow Requirements for Diltution or Building Ventilation**

Figure 11-3 helps to illustrate the VAV concept further, but at two different dilution levels which are triggered using exhaust contaminant monitoring via the Aircuity system.

To help explain the concept further, consider a laboratory exhaust fan system as shown in Figure 11-3 below. The fan system features three individual fans in an N+1 arrangement, each powered by a motor with variable frequency drives (VFDs). All three fans are mounted to a common plenum which also features dual bypass inlets dampers on opposite ends.

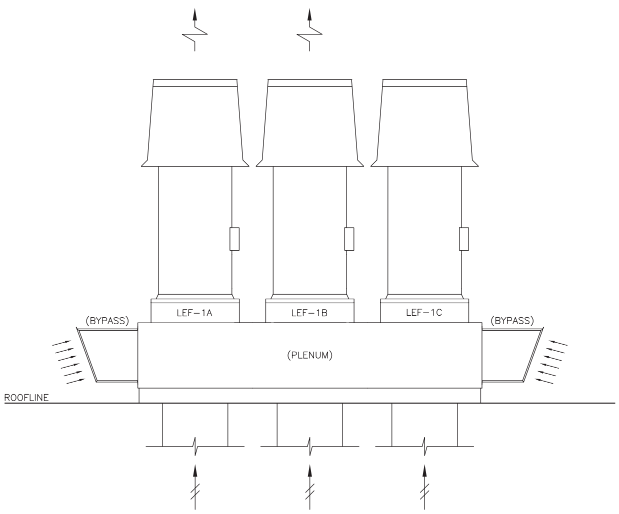


**Figure 11-3. Typical High Plume Dilution Exhaust Fan System Consisting of Three Exhaust Fans**

In this example, the fan system was originally sized to exhaust a total of 100,000 CFM at -4.15" w.c. TSP, and a dilution ratio of 3,000:1. Therefore, since the fan system was originally configured in an N+1 arrangement, only two fans would operate at any given time, providing 50,000 CFM of exhaust air each in order to maintain the dilution ratio of 3,000:1.

A reduction in the dilution ratio form 3,000:1 down to 750:1 would essentially result in a reduction of airflow from each fan from 50,000 CFM to 12,500 CFM. This reduction alone would result in a considerable amount of energy savings! There is, however, a finite limit to how much you are allowed to reduce an exhaust fan system's volumetric flowrate. Figure 11-4 below shows a fan curve from a product selection software package. From this fan curve, it may be observed how there is both a maximum, as well as a minimum fan speed which you may safely operate the fan system between.

It's important to note that the exhaust fan flow reduction shown in Figure 11-3 can only be achieved if exhaust contaminant monitoring is combined with an effective lab DCV solution (also provided via the Aircuity system), which is used to safely turn-down lab air change rates and therefore ventilation flows.

In this particular example, with a VFD, the fan system may be lowered all the way down to 313 RPM before reaching the 20 Hz lower physical limit of the VFD.

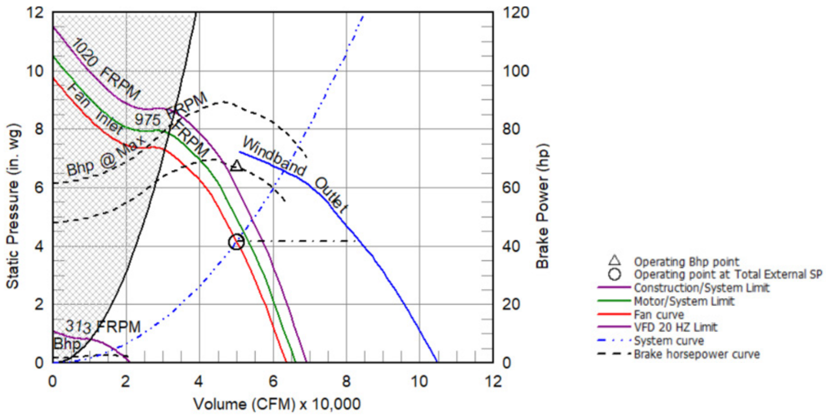


**Figure 11-4. Fan System Curve Showing Upper and Lower RPM Limits for each Exhaust Fan**

Using fan Affinity Laws, it is possible to correlate the proposed reduction in airflow to an estimated reduction in electrical energy consumption. When a fan's wheel or impeller diameter is held constant, the fan affinity laws state that:

Flow is directly proportional to shaft speed:

$$\frac{CFM_1}{CFM_2} = \frac{RPM_1}{RPM_2} \quad \textbf{(Equation A)}$$

Pressure or head is proportional to the square of the shaft speed:

$$\frac{SP_1}{SP_2} = \left(\frac{RPM_1}{RPM_2}\right)^2 \quad \textbf{(Equation B)}$$

And power is proportional to the cube of shaft speed:

$$\frac{HP_1}{HP_2} = \left(\frac{RPM_1}{RPM_2}\right)^3 \quad \textbf{(Equation C)}$$

With these equations we may quickly determine how, for this fan system, it would not be possible to reduce the airflow all the way down to 12,500 CFM for each fan. Doing so would result in both fans in the system operating at a speed of approximately 235 RPM— which, per the manufacturer's published data, is below the minimum allowable fan speed. Rearranging Equation A above to solve for $CFM_2$, we may set $RPM_2$ to be equal to the lower RPM limit of the fans (313 RPM) while using the originally specified airflow value of 50,000 CFM for $CFM_1$ and the originally specified fan speed of 939 RPM for $RPM_1$:

$$CFM_2 = \left(\frac{CFM_1 x RPM_2}{RPM_1}\right) \quad \text{or...} \quad CFM_2 = \left(\frac{50{,}000 x 313}{939}\right) = 16{,}650\ CFM$$

Knowing the physical limitations of the fan system, using the values mentioned in the example above, and the affinity laws, if we were to reduce the fan system's total airflow to 33,300 CFM, only operate two of the three fans, and assuming 24/7 operation, the estimated savings for this fan system may be computed to be:

| Initial Conditions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | EF-1a | EF-1b | EF-1c | Totals | Annual Energy Consumption (KWh) | Energy Cost ($/KWh) | Annual Electrical Cost | Annual Savings |
| CFM | 50,000 | 50000 | 0 | 100,000 | 873,722 | 0.11 | $96,109.46 | - |
| RPM | 939 | 939 | 0 | - | | | | |
| KW | 49.87 | 49.87 | 0 | 99.74 | | | | |

**Table 11-1. The Initial Design Conditions of the Exhaust Fan System as Shown in Figure 11-5**

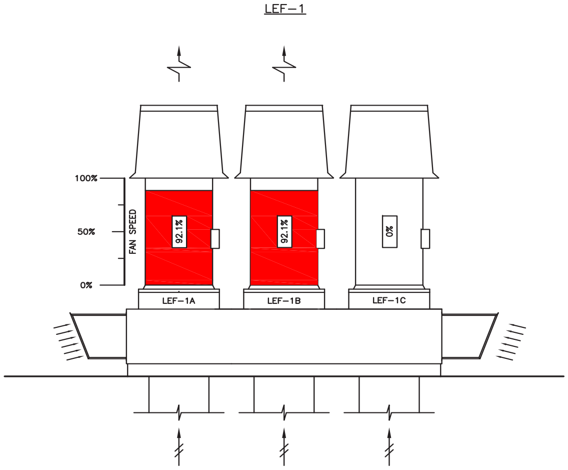


**Figure 11-5. Typical High Plume Dilution Exhaust Fan System Consisting of Three Exhaust Fans**

| After Airflow Reduction | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | EF-1a | EF-1b | EF-1c | Totals | Annual Energy Consumption (KWh) | Energy Cost ($/KWh) | Annual Electrical Cost | Annual Savings |
| CFM | 16,650 | 16,650 | 0 | 33,300 | | | | |
| RPM | 313 | 313 | 0 | - | 32,263 | 0.11 | $3,548.94 | **$92,560.52** |
| KW | 1.84 | 1.84 | 0 | 3.68 | | | | |

**Table 11-2. Estimated Annual Energy Usage/Savings for the Exhaust Fan System as Shown in Figure 11-6**

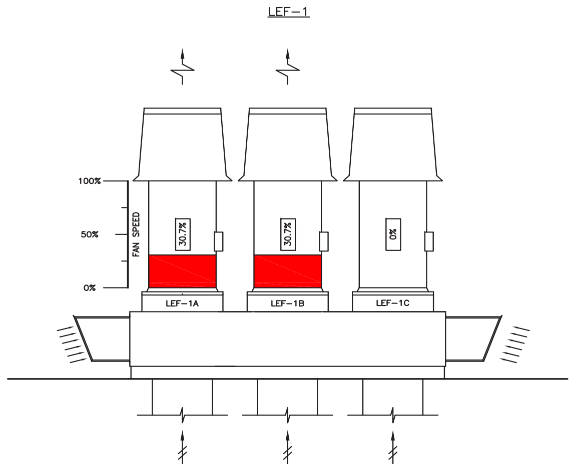


**Figure 11-6. The Exhaust Fan System as Shown in Figure 11-5 After a Reduction in the Flow**

Since we have reduced the airflow for each fan to their absolute minimum fan speeds there is no more energy savings to be had for this exhaust fan system by reducing fan speed. However, if the fan system had not 'bottomed out', to obtain an even greater reduction in electrical energy consumption, it may be possible on some fan systems to abandon the traditional N+1 operating sequence, and instead run all three fans at equal, even further reduced speeds. Since we have already established how, due to the Fan Affinity Laws, the power consumption of the fan system is proportional to the cube of the shaft speed, the overall reduction percentage of power consumption for the entire fan system would be even greater than previously discussed!

## 11.3.2 Contaminant Threshold for Triggering the Exhaust Fan to Provide a Higher Dilution Level/Discharge Velocity

For most exhaust fan demand based control applications, it is possible to use a pre-determined threshold value as the basis for indexing the fan system to a higher dilution level. This is the value of the differential contaminant signal provided by the Aircuity system to the BAS, configured in units of ppm (part per million) of TVOCs. The way in which this is determined relates to the exposure limit of the most toxic compound that the system will need to respond to as well as the minimum dilution that the exhaust fan system will provide. For example, in most cases, the minimum level of dilution that will be provided is 750:1 from the exhaust fan, and the two most extreme compounds that the system may have to respond to include Bromine (PEL = .1 ppm) and Acrolein (PEL = .1 ppm as well). Design considerations assume that the sensed contaminant level will therefore be diluted by a factor of 750 and that the threshold value to trigger higher dilution levels will conservatively prevent concentrations from reaching the lowest exposure limit (in this case 0.1 ppm). For this purpose a threshold value of 1 ppm of the contaminant signal is more than sufficient. Here, assuming 750:1 dilution, the source (concentration within the exhaust plenum) would be diluted to a value of 0.0013 ppm (1.3 ppb), which is far below the lowest exposure limit of compounds we need to respond to (in this case 0.1 ppm). This trigger value (1 ppm) should be sufficient for nearly any fan system unless for some reason the system has been designed to deliver a minimum dilution level that is far less than 750:1 or the Aircuity system is required to respond to a compound requiring high dilution and having a lower exposure limit than 0.1 ppm.

## 11.4 System Overview

Figure 11-4 is a high-level overview of the elements involved to provide demand based control of an exhaust fan system. Using continuously monitored air data, Aircuity provides a differential contaminant signal (based on exhaust and supply plenum contaminant measurements) and conveys it to the Building Automation System (BAS) in order to establish a dilution command. This dilution command sets the fan's minimum stack velocity and is high-selected with the building ventilation command (lab total exhaust signal from the lab ventilation controls) in order to establish a fan setpoint. This high-select function was summarized in Figure 11-2. (Note: when we refer to the fan's minimum stack velocity it's because the stack velocity will increase above the minimum as the ventilation flow exceeds the dilution setpoint.) To support this, the BAS is configured with two dilution command settings (a minimum and maximum dilution setting) which are chosen based on the magnitude of the contaminant signal. When the magnitude of the contaminant signal from the Aircuity system exceeds the pre-determined trigger setting (usually 1 ppm as isobutylene), the max dilution setpoint is used, otherwise the min dilution setpoint is applied. In turn, the fan system (which will often include more than one staged fan) will be commanded based on the higher of the building ventilation command and the dilution command.

**Note:** When we refer to the fan's minimum stack velocity it's because the stack velocity will increase above the minimum as the ventilation flow exceeds the dilution setpoint.

The BAS should also provide fan feedback information back to the Aircuity system, such as fan flow, power, and speed so that proper operation as well as energy savings may be continuously verified.

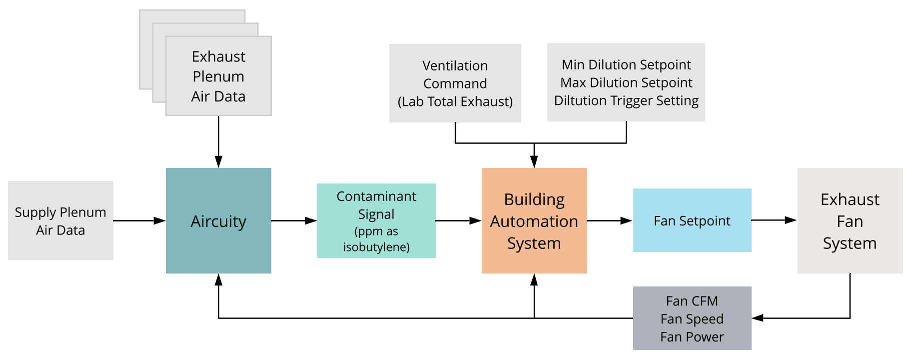


**Figure 11-7. The Building Automation System's Command Exhaust Fan Setpoint Based on the Higher of the Building Ventilation or Flow Requirement for Dilution**

## 11.5 Sequence of Operation

This section provides a general overview of the requirements for the Aircuity and Building Management System/Exhaust Fan System to implement this application. For more information, please review the sequence detailed in Appendix H of the Aircuity Guide Specification.

### 11.5.1 Aircuity System Sequence

The below sequence of operations is a suggestion by Aircuity only. Final sequence of operations shall always be verified and approved by the project's licensed Professional Engineer of record and shall always be deemed appropriate by the authority having jurisdiction.

1. A dedicated sensor suite will be used to just sense one to three exhaust fan plenum(s) and one supply plenum location. This will result in the exhaust plenum being sensed approximately every few minutes or less.

2. Using a combination PID & MOS TVOC sensor, the Aircuity system shall sense for contaminants in each of these locations:

   a. **Exhaust Fan Plenum** - Up to three locations (per SST) that are representative of the exhaust air prior to dilution by the exhaust fan system(s).

   b. **Supply Air Reference** - One sampled location (per SST) that is representative of the supply air provided to the spaces served by the exhaust fan system(s).

**3.** The Aircuity system shall create a differential contaminant signal for each sensed fan plenum location. This signal shall be composed of high selecting two differential TVOC signals; one using the Metal Oxide sensor and the other using the PID sensor. These signals shall be referenced to a suitable supply air plenum location for the supply fan serving the spaces within the building that the exhaust fan system is connected to. If more than one fan plenum location is being sensed for one independently controlled fan system, then the contaminant signals derived from each of the relevant fan plenum locations will be high selected via the Aircuity system to produce one differential contaminant signal representative of the worst case conditions sensed for that fan system.

**4.** The Aircuity system shall create a proportional ppm per Volt, hardwired analog output signal of either a 0–5 Vdc or a 0–10 Vdc from the high selected differential contaminant signal for use by the BAS for determination of when the exhaust fan plenum is no longer in a relatively clean state and a higher fan exit velocity is desired. Alternatively, a BACnet signal may be provided to the BAS system in lieu of the analog output signal. The BAS will use 1 ppm as a threshold value to trigger the fan to a higher velocity based on the contaminant signal. When this threshold is exceeded by either the analog output or BACnet signal, the BAS system will change the operation of the fans to increase the minimum exit velocity. The high and low exit velocity setpoints for the exhaust fan system shall be set with guidance from the project's exhaust fan dispersion analysis consultant. This consultation is not a part of the scope of the Aircuity system supplier, however the Aircuity system supplier will participate in meetings or calls with the consultant as needed.

**5.** If some sort of failure condition such as loss of network connectivity is detected by the system, the BACnet control and monitoring points shall be marked as "Unreliable" so the BAS system can detect this and command the high exit velocity setpoint as a failsafe command. Similarly, if an analog output signal is being provided to the BAS, upon detection of a failure by the Aircuity system, the ADR outputs will be driven to a failsafe level to command the high exit velocity setpoint of the exhaust fan system. These analog output signals shall be reverse acting to provide the high exit velocity setpoint upon a loss of power in the Aircuity system.

## 11.5.2 Building Automation System/Exhaust Fan System Control Sequence

The following represent comments that should be used only as guidance or to add to or modify the BAS sequence of operation for the exhaust fan system controls. These comments also do not constitute the entire sequence required for the exhaust fans which also needs to be tailored to the specific setup of the exhaust fan system and other aspects of that system.

**1.** The BAS shall operate the exhaust fan system at one of two dilution setpoints and high select the dilution setpoint with the lab total exhaust signal provided by the lab ventilation system. The control of which operating mode to use will be determined by the differential contaminant signal from the Aircuity system.

**2.** One of the dilution settings will be a high dilution setting that typically ensures 3000:1 dilution of contaminants from the fan system. The high dilution setting will be used when the differential contaminant signal from the Aircuity system exceeds a pre-determined value that will normally be set to 1 ppm calibrated to isobutylene. For this high dilution operating mode, an exhaust static pressure setpoint shall be maintained by a combination of fan staging (if more than one fan is involved) and control of a bypass damper connected to the exhaust fan plenum to provide roof air into the plenum to compensate for a reduction in exhaust flow from the building. Typically the bypass damper opening will be increased until the building exhaust volume decreases enough that one of the fans can be shut down with a corresponding reduction in the opening of the bypass damper. If the building exhaust volume subsequently increases then one of the fans that was shut down will be restarted and the bypass damper opened to provide control of the exhaust system static pressure.

**3.** The second dilution setting will be a low setting that typically ensures 750:1 dilution of contaminants from the fan system. This setting will be used when the differential contaminant signal from the Aircuity system is less than the pre-determined value used to switch to high dilution (typically 1 ppm). These high and low minimum dilution values or exhaust fan flow setpoints will be determined by an analysis from the project's exhaust dispersion consultant.

- For this low dilution operating mode an exhaust static pressure setpoint shall be maintained by a combination of fan staging (if more than one fan is involved) and control of the speed of the fans to match the exhaust flow to the exhaust flow from the building. All the fans that are running will be operated at the same speed for maximum energy savings. Typically the fan speed of the exhaust fans will be decreased when the building exhaust volume decreases.

- When the fan speeds drop enough that the speed corresponding to the minimum exit velocity (dilution) threshold is reached, then a subsequent drop in building exhaust flow will cause one of the fans to be shut down with a corresponding increase in the speed of the remaining fans.

  - If the building exhaust volume subsequently increases then one of the fans that was shut down will be restarted. At that point all fans will operate at the same speed to maintain the exhaust system static pressure setpoint.

  - If the minimum number of fans (typically one) is operating at their minimum exit velocities and a further decrease in building exhaust flow occurs, then at that point the plenum bypass damper may need to open to vary its opening to maintain control of the static pressure setpoint.

**4.** When the differential contaminant signal from the Aircuity system exceeds a threshold value determined with help from the project's exhaust fan dispersion consultant (typically 1 ppm as isobutylene), the BAS will operate the exhaust system with the high exit velocity control approach. When the differential contaminant signal drops below this threshold value then the BAS will operate the exhaust system with the low exit velocity control approach.

**5.** It is recommended that when the BAS switches from the low dilution mode to the high dilution mode that this operating mode is continued for at least 15 minutes before it is allowed to drop back to the low exit velocity mode upon a drop in the differential contaminant signal.

## 11.6 Design Guidelines

Many design considerations must be taken into account to ensure proper system performance of this application.

### 11.6.1 Conditions that Diminish or Eliminate the Opportunity for Exhaust Fan Control Systems

The use of an Aircuity system for demand based exhaust fan control is intended only for systems where excessive concentrations of corrosive vapors are not expected or where sufficient dilution will reduce the sensed concentrations of any corrosive materials to low levels. This is important since Aircuity sensors were not designed to be resistant to corrosive vapors. Any exhaust plenums that are constructed with a high grade of stainless steel such as 316 or use special corrosion resistant coatings should be evaluated as to the application of corrosives. Generally speaking, life science type laboratories should be excellent candidates, but organic chemistry labs will probably need some inquiry as to the amount and intensity of use of corrosives. This concern is lessened the larger the exhaust plenum and if room exhaust is being mixed in with any fume hood exhaust. Likewise, the smaller the fan system the greater the concern of any one fume hood's corrosive contaminants significantly affecting the plenum concentrations. If there is any doubt about the suitability of the application, please contact Aircuity technical services.

Additionally for the above reasons as well as ensuring at least somewhat reasonable paybacks, this application should not be applied to dedicated hood exhaust fans, hood exhaust only (no general exhaust) manifolds of less than 10 hoods or exhaust fan systems of less than 10,000 CFM in size.

## 11.6.2 Dedicated System Configuration

To keep sampling times short, only four locations including one supply air reference location can be sensed with one dedicated sensor suite being used for this application. This means that a sensor suite will be dedicated to sensing one larger or perhaps at most two smaller manifolded exhaust fan plenums.

## 11.6.3 Sampling Time

Unlike other applications involving demand control, exhaust fan control requires a much shorter response time than the typical 15 minute sampling times of these other applications. This is because a spill of a volatile liquid inside a hood for example can increase the concentration levels in the exhaust duct and plenum much faster than a similar sized spill in a lab room due to the much higher air velocities and related evaporation rates inside a hood coupled with a more limited volume in the exhaust duct and plenum vs. a lab room. Although the short term exposure limits (STEL) on which the exhaust re-entrainment studies are based refer to the average exposure over an average 15 minute period, it is prudent to use a much shorter sampling time than 15 minutes.

As an application rule to be able to quickly monitor a major increase in exhaust plenum contaminants the exhaust plenum itself shall be sensed approximately every 3 minutes or less.

## 11.6.4 Supply Air Reference

One of the sensed locations must be at a location within the supply plenum that serves the spaces also supported by the exhaust fan system. To maintain separation and further minimize the potential of cross contamination of sensing the supply air, the supply air plenum monitoring probe (duct probe) should be located on its own Air Data Router (ADR) that should be connected to its own limb of the sensor suite with no other locations sensed on this limb. All the exhaust plenum locations should then be located on the second of the two limbs or backbone cable inlets of the sensor suite.

All contaminant control signals created per Sensor Suite shall be a differential signal referenced to this supply plenum monitoring location.

## 11.6.5 Exhaust Plenum Sampling Locations

Regarding placement of the Duct Probes for sensing the exhaust plenum, there should first be at least one sampling location per exhaust fan in the plenum. Typically it is highly recommended that these sampling probes be positioned to sense at the inlet of the fans to be able to get a good representation of the concentration of contaminants being exhausted by the fan. An exception to this is where access to the fan inlet is difficult and it is more convenient to sense the exhaust contaminants instead at the exit of a few specific exhaust risers that carry the building flow up to the exhaust fans. If a riser location is measured it needs to meet the above mentioned criteria of typically not less than 10,000 CFM, and exhausting at least 10 hoods if no general exhaust is mixed in as well.

One other consideration of sampling locations is to try to avoid being near the roof bypass damper inlet so the sensing of the fans or risers is not significantly affected when a high exit velocity is commanded and the roof bypass damper opens flooding a portion of the plenum with fresh air. If this is unavoidable, having the BAS go to the high exit velocity for a minimum period of time such as 15 minutes or by using increased amounts of hysteresis for the contaminant threshold can compensate for this potential issue.

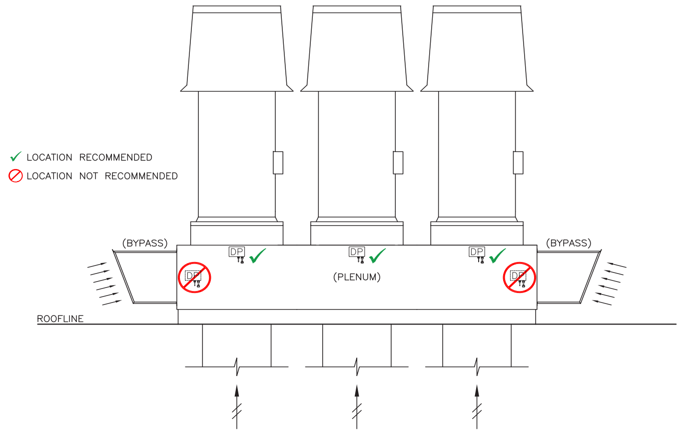


**Figure 11-8. Exhaust Fan System Probe Placement**

## 11.6.6 Initialization Value and Failsafe Response

Before the Aircuity system takes any samples, the system will output an initialization value. The purpose of this initialization value is to instruct the fan system to operate at a specified dilution ratio until valid samples have been taken (approximately three minutes from initial start-up). To comply with safety standards, it is recommended that an initialization value is chosen to command the exhaust fans to their high exit velocity conditions.

If a hard wired output signal is used from an Air Data Router, its failsafe condition should correspond to a high contaminant output. This output should also be reverse acting so a loss of power will drive the exhaust fans to their high exit velocity conditions. If BACnet signals are used for control, if these signals become "unreliable" then the BAS system should again drive the fan system to its high exit velocity condition.

## 11.6.7 Required Sensors (EFS-TVC-1&3)

In order to properly support the unique requirements associated with monitoring contaminants within an exhaust plenum, Aircuity has developed a special sensor offering (the EFS-TVC-1&3), which is intended specifically for the exhaust fan demand based control application. Although for the majority of the time the exhaust air will be clean for the systems intended for this application, the breadth and concentration levels of the compounds that the sensors will be exposed to are potentially much higher than that of other applications in which Aircuity is used to monitor TVOCs. To accommodate this potentially harsher environment, the EFS-TVC-1&3 provides TVOC measurements by combining a Metal Oxide Semiconductor (MOS) sensor with an enhanced Photoionization Detector (PID) sensor that includes active onboard sensor conditioning to ensure good sensor stability, even when exposed to high concentrations of adsorptive compounds. Further, the handling, test, and calibration process for these sensors have been tailored to fit the needs of this application.

## 11.6.8 Exhaust System Dispersion Analysis Consultant

To properly set the contaminant level trigger threshold as well as the range of exit velocities that are allowed it is recommended that an exhaust fan dispersion analysis consultant, sometimes known as a wind tunnel consultant, be hired by the customer. Often times these consultants are already on the design team or may have previously analyzed an existing building that is being retrofitted. Depending on whether the consultant is already on the design team, it is an existing building that was not analyzed, and the complexity of the site, the cost to do such a wind tunnel or perhaps a theoretical analysis could range from $5K up to $30K or more. Well known and experienced consultants in this field include CPP, RWDI, or Ambient Air. Of these three, CPP and RWDI are the most familiar with this approach, but all three are suitable consultants.