VAV Laboratory Room Airflow

The Lowdown on Turndown

Airflow Turndown

Airflow control ranges are normally expressed in terms of the required maximum and minimum attainable airflow rate. When this airflow rate is expressed as a simple ratio, it is commonly referred to as the *turndown ratio* or just *turndown*. For instance, if an air terminal and its associated control system provides fully modulated airflow control from 400 cfm up to 2000 cfm, the maximum-to-minimum airflow ratio can be expressed as 5-to-1 since the maximum airflow is 5 times the minimum airflow. Therefore, the turndown is stated as 5:1.

Turndown is commonly used as a convenient way to express the airflow control needed for specific types of applications without the necessity of having to refer to the specific maximum and minimum airflow rates involved. For instance, specifying that all VAV fume hood exhausts must be controlled over a 5-to-1 turndown ratio means the exhaust airflow must be modulated so that the minimum fume hood exhaust will be one fifth of the maximum exhaust. This minimum to maximum exhaust airflow relationship then applies to every fume hood even though different sizes of fume hoods have different airflow ranges.

Turndown Misconceptions

As simple as the concept of turndown may seem, it has led to considerable misunderstanding in the HVAC industry, and especially with regard to VAV laboratory ventilation applications. For instance, if a specific air terminal has a maximum airflow range from 3200 cfm down to 400 cfm, it would have a turndown ratio of 8-to-1. If another air terminal has the same maximum airflow of 3200 cfm but a minimum airflow of 200 cfm, its turndown ratio would be 16-to-1 or twice that of the 8-to-1 unit. A common but erroneous assumption is that the 16-to-1 unit provides twice the airflow range that the 8-to-1 unit can provide. Figure 1 shows a graphic comparison of these two turndown ratios. Note the small actual airflow difference between them.

![Figure 1. Comparison Between 16:1 and 8:1 Turndown Ratios.](image)

Higher turndown ratios have also been erroneously assumed to be indicative of better control performance. However, larger turndown ratios do not positively impact the main control performance factors such as accuracy, repeatability, low hysteresis, fast response, etc. Rather, the best control performance results when a control device has a range or turndown ratio that closely matches actual need. For example, precise control of temperature over a range from 65 to 75 degrees would more likely be attained from a controller having a range of 60 to 80 degrees as opposed to one with a much wider range such as 0 to 120 degrees. Consider a need to control shaft rotational speed at 1200 rpm. A controller with a range of 500 to 2000 rpm (a 4-to-1 turndown ratio) would most likely provide better control than one with a range of 200 to 5000 rpm (a 25-to-1 turndown ratio).
Thus, it is important not to equate higher turndown ratios with superior control performance. Rather, control devices should be compared on the basis of how closely their range or turndown ratio matches the application. In fact, the range or turndown ratio of a controller or control system should ideally be only slightly more than what the control application calls for. Turndown ratios greater than the actual need are generally undesirable.

**VAV Fume Hood Airflow**

Conventional fume hoods (in difference to low flow fume hoods) typically need a face velocity of approximately 100 feet per minute \(^1\) to provide fume containment. \(^2\) The maximum airflow through a fume hood will be the exhaust airflow rate necessary to provide the required face velocity at the maximum sash opening.

**VAV Fume Hood Maximum Exhaust Airflow**

In contrast to horizontal sliding sash fume hoods, fume hoods with vertical rising sashes provide a totally unobstructed face opening. As a result, vertical sash fume hoods require the highest exhaust airflow rate for a given fume hood width. Vertical rising sashes of bench type fume hoods generally have a maximum full open height of about 30 inches or 2.5 feet. When the sash is fully open, this results in 2.5 square feet of open sash area for each foot of sash width. The exhaust airflow needed to maintain an average face velocity of 100 fpm for each foot of sash width is:

\[
2.5 \text{ ft (Height)} \times 1 \text{ ft (Width)} \times 100 \text{ ft/min} = 250 \text{ cfm}
\]

Thus, a fume hood with a fully open vertical sash will have a maximum exhaust airflow of approximately 250 cfm for every foot of sash width.

**VAV Fume Hood Minimum Exhaust Airflow**

Even when the sash is fully closed, minimum fume hood exhaust airflow is needed to prevent a buildup of flammable or explosive fumes in the hood. The current versions of Standards NFPA 45 and ANSI/AIHA Z9.5 recommend that a minimum fume hood airflow of at least 25 cfm per square foot of work surface always be maintained whenever chemicals are present in the hood.

The typical bench type fume hood has a working depth of approximately 2 feet. Thus, the airflow necessary to maintain 25 cfm per square foot of internal work surface for each foot of internal width becomes:

\[
2 \text{ ft (Depth)} \times 1 \text{ ft (Width)} \times 25 \text{ cfm/ft}^2 = 50 \text{ cfm}
\]

Thus, a fume hood with a fully closed sash requires a minimum exhaust airflow of approximately 50 cfm for every foot of internal width. \(^3\)

**VAV Fume Hood Exhaust Airflow Turndown**

As indicated, the airflow through a vertical sash type fume hood will range from a maximum of about 250 cfm to a minimum of 50 cfm for each foot of sash width. The turndown ratio for maximum fume hood exhaust to minimum exhaust is about 5-to-1. Therefore, a VAV fume hood's exhaust air terminal and associated controls must provide a maximum turndown ratio of about 5-to-1. If the fume hood sash's full open height is less than 30 inches, the maximum exhaust required will be less and so will the required fume hood exhaust turndown ratio. If the internal work surface area is more than 2 square feet per ft. of sash width, the minimum exhaust will increase and thus decrease the required fume hood exhaust turndown ratio.

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1. American National Standard for Laboratory Ventilation ANSI/AIHA Z9.5, 3.3.1: “Design face velocities for laboratory chemical hoods in the range of 80–100 FPM (0.41−0.51m/s) will provide adequate face velocity for a majority of chemical hoods.” “This is the range recommended for a majority of laboratory chemical hoods.”

2. Safety professionals also point out that the face velocity required is also dependent upon other factors that affect fume hood containment such as room air currents, the fume hood’s airflow characteristics, the chemicals used and the type of experiments being conducted.

3. The internal work surface is a few inches wider than the sash opening width. This extra area (although small) should also be considered when determining a fume hood's minimum airflow. In addition, some fume hoods may have a working area deeper than 24 inches and if so, this should be considered when determining the minimum airflow.
VAV Laboratory Room Supply Air

VAV laboratory room supply air fulfills several functions:

- It provides makeup air for fume hood exhaust and the miscellaneous room exhausts.
- It maintains adequate room ventilation
- It maintains the room ambient temperature and humidity.

When a laboratory room has multiple fume hoods, the amount of makeup air needed for the fume hoods is often more than sufficient to maintain room ventilation and the required room ambient conditions. Thus, the maximum fume hood exhaust\(^4\) of a laboratory room is usually the determining factor regarding the maximum amount of room supply air that must be provided. Therefore, in laboratories with VAV fume hoods the supply air turndown requirements will quite often be close to the fume hood turndown requirements of 5-to-1.

Table 1 gives examples of 24 different VAV chemical laboratory rooms beginning with a single lab module\(^5\) type laboratory room with one small fume hood and progressing up to a triple sized lab modules with multiple large fume hoods. This table is a convenient reference for the airflow ranges likely to be needed for such laboratory rooms. The turndown ratios required for the supply makeup airflow are given in the far right hand column. Detailed descriptions of each of the table’s columns appear on the following page.

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4. When multiple VAV fume hoods are present, a VAV diversity (usage) factor is often used to establish a *maximum* fume hood exhaust airflow rate that is somewhat less than the theoretical maximum.

5. Research facilities are often comprised of single and double laboratory module rooms since the modular approach has been found to optimize laboratory usage.
<table>
<thead>
<tr>
<th>Room</th>
<th>Laboratory Room Size: (Length) (Width) (Height)</th>
<th>Floor Area</th>
<th>Room Volume</th>
<th>Excess Room Exhaust Airflow For Negative Pressure</th>
<th>VAV Fume Hoods in Room</th>
<th>Total Fume Hood Exhaust</th>
<th>Total Miscellaneous Room Exhaust</th>
<th>Room Minimum Air Changes Per Hour</th>
<th>Room Supply Airflow</th>
<th>Room Supply Turndown Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Length: 25 ft Width: 10 ft Height: 9 ft</td>
<td>250^12 cfm</td>
<td></td>
<td>1</td>
<td>1</td>
<td>150 750</td>
<td>200 cfm</td>
<td>(2 Bench Snorkels)</td>
<td>Min. Max.</td>
<td>Min. Max.</td>
</tr>
<tr>
<td>5</td>
<td>Length: 25 ft Width: 10 ft Height: 9 ft</td>
<td>250^12 cfm</td>
<td></td>
<td>5</td>
<td>5</td>
<td>750 3750</td>
<td>900 cfm</td>
<td>(6 Bench Snorkels)</td>
<td>Min. Max.</td>
<td>Min. Max.</td>
</tr>
<tr>
<td>7</td>
<td>Length: 25 ft Width: 10 ft Height: 9 ft</td>
<td>250^12 cfm</td>
<td></td>
<td>7</td>
<td>7</td>
<td>1200 6000</td>
<td>1350 cfm</td>
<td>(6 Bench Snorkels)</td>
<td>Min. Max.</td>
<td>Min. Max.</td>
</tr>
<tr>
<td>8</td>
<td>Length: 25 ft Width: 10 ft Height: 9 ft</td>
<td>250^12 cfm</td>
<td></td>
<td>8</td>
<td>8</td>
<td>1500 7500</td>
<td>1650 cfm</td>
<td>(6 Bench Snorkels)</td>
<td>Min. Max.</td>
<td>Min. Max.</td>
</tr>
</tbody>
</table>

**Legend:**
- Min. cfm: Minimum cfm
- Max. cfm: Maximum cfm

6. NFPA 45 and Standard ANSI/AIHA Z9.5 requires that VAV fume hoods maintain a minimum exhaust airflow of 25 cfm per square feet of internal hood work surface area.
7. Maximum exhaust airflow is based upon a vertical sash fume hood with an average face velocity of 100 fpm and a 30-inch maximum sash opening height.
8. Total Room Minimum airflow is the sum of the Total Fume Hood Minimum Exhaust plus the Constant Volume Room Exhaust.
9. Total Room Maximum Exhaust is the sum of the Total Fume Hood Maximum Exhaust plus the Constant Volume Room Exhaust.
10. Room Minimum Supply Airflow is the Total Room Exhaust minus the Excess Room Exhaust Airflow For Negative Pressure.
11. Room Maximum Supply Airflow is the Total Room Exhaust minus the Excess Room Exhaust Airflow For Negative Pressure.
12. The amount of Excess Room Exhaust Airflow For Negative Pressure is the approximate amount needed to maintain 0.010 inches of negative pressure for the size of room.
Laboratory Room Size
Table 1 covers three different sizes of laboratory rooms separated by the double line divisions of the table. Each group has eight identically sized laboratory rooms. Rooms 1 through 8 represent single module laboratory rooms that are 25 feet long, 10 feet wide, and 9 feet high. Rooms 9 through 16 represent double module laboratory rooms with twice the area of the single module rooms. Rooms 17 through 24 have three times the area of a single module room. The increased room sizes are needed to accommodate the increased number of fume hoods in these rooms. The volume of each room is given in order to determine the room’s ventilation rate in air changes per hour.

Excess Room Exhaust Airflow For Negative Pressure
Each of the three laboratory room sizes has excess exhaust air to maintain a negative static pressure relationship of approximately 0.010 inches w.c. with respect to the adjacent areas. Somewhat more excess room exhaust airflow is required for larger rooms since room leakage typically increases as the size increases. For additional information on room leakage areas and the exhaust offset required, see Siemens Technology Report No. 3, Volumetric Airflow Tracking Vs. Differential Pressure Sensing (149-977).

VAV Fume Hoods in Room
The size and quantity of fume hoods assumed to be in each room are indicated. Room 1 has one 4-foot wide fume hood while Room 24 has six 8-foot wide fume hoods. The varying quantities and sizes of fume hoods result in considerable variation in the room airflow requirements.

Total Fume Hood Exhaust
Each fume hood is assumed to be a VAV fume hood with one vertical rising sash. This results in the highest fume hood exhaust requirement and the greatest turndown requirement for each fume hood. Min. CFM is based upon a fully closed sash and the minimum exhaust airflow as explained in footnote [6]. Max. CFM is based upon a full open sash height of 30 inches and an exhaust airflow rate that provides a 100-foot per minute average face velocity.

Total Miscellaneous Room Exhaust
Chemical laboratories typically have some miscellaneous exhaust provisions in addition to the fume hoods. This includes canopy exhausts and other types of dedicated exhausts. Flexible bench snorkel exhausts are perhaps the most common having an exhaust airflow of approximately 100 cfm each. The example in Table 1 assumes that each room has at least two snorkels with the quantity being proportionately increased in the larger size rooms.

Total Room Exhaust
Total room exhaust is the sum of all room exhausts. In the Table 1 examples, the Min. CFM is the sum of the total fume hood minimum exhaust and the snorkel exhausts. The Max. CFM is the sum of the total fume hood maximum exhaust and the snorkel exhausts. In some instances, a laboratory room may require a room general exhaust if additional exhaust is needed to maintain the room's minimum ventilation rate or negative room pressurization or to enable sufficient supply airflow to maintain the room's ambient conditions. (More information is provided in the Room General Exhaust section.)

Room Minimum Air Changes Per Hour
The requirements most referenced for laboratory room air changes per hour (ACH) are:
- National Institutes of Health:.....6 to 10 ACH
- NFPA 45....Unoccupied labs:.....4 ACH
- NFPA 45....Occupied labs: .......8 ACH
- U.S. OSHA:................................4 to 12 ACH
- ANSI/AIHA Z9.5...(No recommendation given)

Experienced ventilation designers generally prefer a minimum of 10 to 12 ACH when a laboratory room is occupied and a minimum of 4 ACH when the room is unoccupied. Note that the combination of the minimum airflow requirements for fume hoods (Footnote 6) and the miscellaneous room exhaust provisions very often prevent reducing the unoccupied ventilation rate down to 4 ACH. In all of the examples in Table 1 the minimum room ventilation rate is considerably higher than 4 ACH. Note that for Rooms 8, 16, and 24 the minimum ventilation rate is 24 ACH.
Room Supply Airflow
The Room Supply Airflow Min. CFM equals the Total Room Exhaust Min. CFM minus the Excess Room Exhaust Airflow For Negative Pressure.

The Room Supply Airflow Max. CFM equals the Total Room Exhaust Max. CFM minus the Excess Room Exhaust Airflow For Negative Pressure.

Room Supply Turndown Ratio
The room examples in Table 1 show the supply airflow turndown ratios (right most column) vary from a high of 7-to-1 for Room 1 down to a low of 4.3-to-1 for Room 17. If a room general exhaust were used (for the reasons described in the following paragraph), the room supply airflow turndown ratio would decrease since the Room Minimum Supply Airflow would increase.

Room General Exhaust
A room general exhaust (typically located in the ceiling) must be provided whenever there will not be sufficient exhaust from the fume hoods and miscellaneous exhaust provisions to maintain the required minimum room ventilation (ACH) rate, ensure negative room pressurization or to maintain the required room ambient conditions. If Rooms 1 and 2 in Table 1 did not have the two 100 cfm snorkels, the minimum and maximum total room exhaust values would only be 150 cfm and 200 cfm respectively. This would not be sufficient to provide the 250 cfm of Excess Room Exhaust Airflow For Negative Pressurization. In such situations, a room general exhaust provision must be added to remove at least another 100 cfm to maintain the room's negative pressurization and a sufficient minimum room ventilation (ACH) rate.

Sometimes a room general exhaust is needed to help increase the supply airflow in order to maintain the required room ambient conditions, especially cooling and dehumidification needs. Since laboratory rooms typically have an expected heat gain of between 5 and 25 Btu per square foot per hour\(^{13}\), a laboratory room of 250 square feet could have a heat load as high as 6250 Btu/Hour. If a room ambient temperature of 72°F were desired with 55°F supply air, a supply airflow of 334 cfm would be required\(^{14}\). The minimum total room exhaust in

\[\text{Cooling cfm} = \frac{\text{Btu/HR}}{\text{Air Temp. Rise}} \times 1.10\]
\[\text{Cooling cfm} = \frac{6250}{(72 - 55)} \times 1.10 = 334.2\]

Rooms 1 through 5 would not allow that much supply airflow without the addition of a room general exhaust of 250 cfm for Room 1 and 50 cfm for Room 4.

Room General Exhaust Maximum Airflow
When desirable, a room general exhaust typically only needs to provide a few hundred cfm (approximately 1 cfm per square foot of lab floor area). When a relatively small general exhaust is required, it may be more economical to implement it as a simple constant volume exhaust provision rather than incorporating VAV control. When more general exhaust capacity is required, perhaps 500 cfm or more, it may be implemented as a VAV exhaust to enable reducing the ventilation energy when maximum general exhaust airflow is not required.

Room General Exhaust Minimum Airflow
Since fume hoods and snorkels only exhaust air from mid room height, buoyant fumes, gasses and warm air will often accumulate at the ceiling level and may not be adequately purged from the room. Therefore, when a VAV room general exhaust is used, it is good design practice to always maintain sufficient minimum exhaust airflow to maintain 12 ACH for the room area that extends down to at least 1 foot below the ceiling. This equates to about 1 cfm for every 5 square feet of laboratory room area.

Room General Exhaust Turndown Ratio
Based upon a nominal maximum of 1 cfm per square foot of laboratory room area and a nominal minimum of 1 cfm per every 5 square feet of laboratory room area, the turndown requirements for a room general exhaust becomes approximately 5-to-1.

Ensuring Proper VAV Airflow Turndown Ratios
Designers of VAV laboratory ventilation systems do not need to determine and specify every different turndown ratio required or establish a "one size fits all" turndown to cover all airflow control situations. Rather, its only necessary to specify the minimum
and maximum airflows required for each airflow control application in an appropriate airflow control schedule. The turndown ratios required for each individual airflow control application will be inherent when these maximum and minimum airflows are specified. This puts the responsibility for providing the required airflow control turndown ratios on the control system provider.

The control system specifications then only need to state: "The turndown requirements for each individual air terminal and airflow control application shall be sufficient to provide the full range of minimum to maximum airflows listed in the airflow control schedules."

Conclusion

This paper provided an in-depth analysis of many VAV laboratory airflow control situations in conjunction with the applicable standards requirements and good design practices to establish the actual turndown ratios typically needed for laboratory airflow control applications. In virtually every instance, it has been shown that high turndown ratios (more than 8-to-1) are not required. The following statements summarize the results of this analysis:

- Large turndown ratios do not reflect proportionately larger control ranges. (For instance 16-to-1 does not cover twice the range of 8-to-1.)
- Larger turndown ratios do not equate to superior control performance. Rather, optimum performance will be attained when the control elements and control system closely match actual needs.
- VAV Laboratory rooms typically require airflow control turndown ratios within 7-to-1.
- VAV fume hood turndown ratios are limited by the need to always maintain a minimum exhaust of 25 cfm per square foot of interior work surface. This effectively limits VAV fume hood turndown ratios to 5-to-1.
- A room general exhaust may be needed to allow sufficient supply airflow to meet minimum ventilation rates, ensure adequate room negative pressurization, maintain room ambient requirements, and to remove contaminants at the ceiling level. Room general exhaust turndown ratios will typically be 5-to-1.