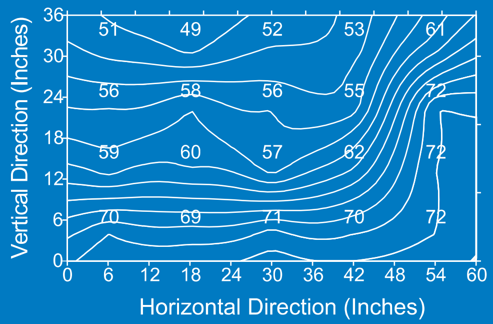
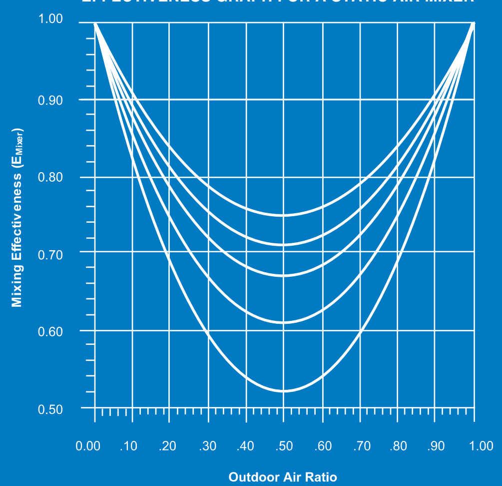
TEMPERATURE GRADIENT OF STRATIFIED AIR STREAMS



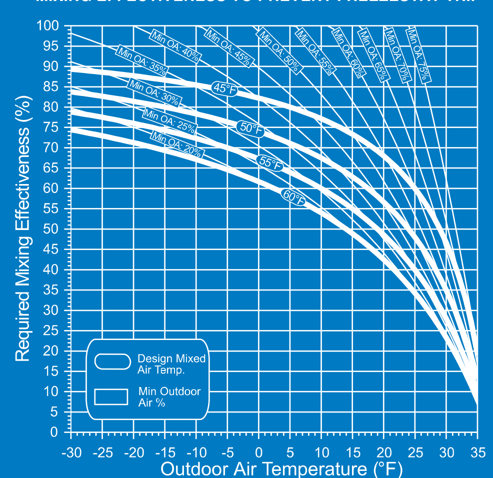
Mixing Effectiveness Design Guide

How to Specify Air Mixing Systems and Equipment to Eliminate Stratification

EFFECTIVENESS GRAPH FOR A STATIC AIR MIXER



MIXING EFFECTIVENESS TO PREVENT FREEZESTAT TRIP



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The Company

Since 1962, Blender Products, Inc. (formerly known as RM Products) has pioneered stratification abatement developments in air-handler mixing plenums and has been an innovator in the design of static mixers.

Over the years, the application personnel at Blender Products have developed mixing systems for thousands of applications in HVAC systems and industrial process systems. As a result, they have accumulated a large storehouse of knowledge and valuable expertise in the disciplines of stratification and static mixing.

Why This Guide Was Written

During its history, Blender Products has published a great deal of material dealing with stratification and mixing in HVAC systems. This material has appeared primarily in technical bulletins, catalogs and articles. To date, very little information about stratification in the HVAC environment has appeared in textbooks or journals. Now, due to increased interest in adding ventilation air to combat IAQ problems, there is an increasing need to solve the associated stratification problems.

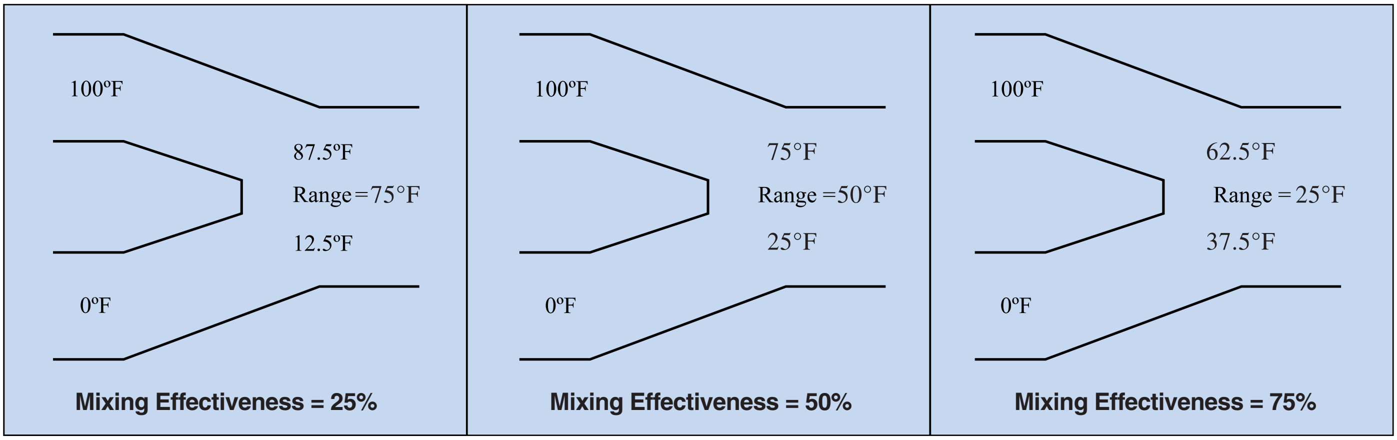
Up to this time, HVAC system designers have had few tools to use in designing mixing systems to minimize stratification during the design phase of a project. This has resulted in the industry taking a "wait-and-see" approach to stratification. The purpose of this manual is to provide the HVAC system designer with some basic information which may be used to help design and specify air handling unit mixing systems in order to minimize the effects of stratification. This proactive approach will allow a system designer to anticipate problems and provide solutions during system construction rather than trying to find a solution after system startup.

What is Mixing Effectiveness?

Mixing Effectiveness is one way to express how well a mixing device mixes two air streams. This rating indicates how much a mixing device reduces the temperature range. A perfect mixer will have a Mixing Effectiveness of 100% while a device that provides no mixing would have an effectiveness of 0%. The easiest way to understand this idea is to look at an example.

Assume that one air stream with a temperature of 100° is to be mixed with an equal air stream with a temperature of 0°, resulting in an entering temperature range of 100°. A mixing device with a Mixing Effectiveness of 50% will reduce the entering temperature spread by 50%, resulting in a temperature range of 50° at the discharge of the mixing device. If the mixing device had a Mixing Effectiveness of 25%, the entering temperature range would be reduced by 25%, resulting in a temperature range of 75° at the discharge of the mixing device. A Mixing Effectiveness of 75% would result in a temperature range of 25° at the discharge of the mixing device.

Figure 1: Mixing Effectiveness Example



Benefits of Mixing Effectiveness

The performance of mixing devices can be rated in many ways. Using Mixing Effectiveness to rate the performance provides two major benefits that make it preferable to other methods. These benefits are:

- The temperature range at a desired location downstream of the mixing device can be determined for any entering condition. This allows a system designer to predict when the temperature spread will exceed some critical value. For example, if the Mixing Effectiveness is known, the outdoor air temperature at which the freezestat will trip can be predicted before a system is built.

- The second benefit is that a system designer can **determine** and then **specify** the Mixing Effectiveness required for each particular system. This fact allows a system designer to determine and select what type of mixing equipment is required for each particular air-handling unit. Once the mixing requirements are known, then the correct mixing equipment can be specified. Again, all of this can take place before the system is built. This will eliminate the need for costly retrofit solutions.

The charts on the following pages use these two advantages of Mixing Effectiveness to make it possible to specify three different levels of mixing: Mixing for Freeze Protection, Mixing for Minimal Sensor Error, and Mixing for Outdoor Air Distribution. This flexibility allows an engineer to design a mixing system to provide the amount of mixing needed for each air-handling unit.

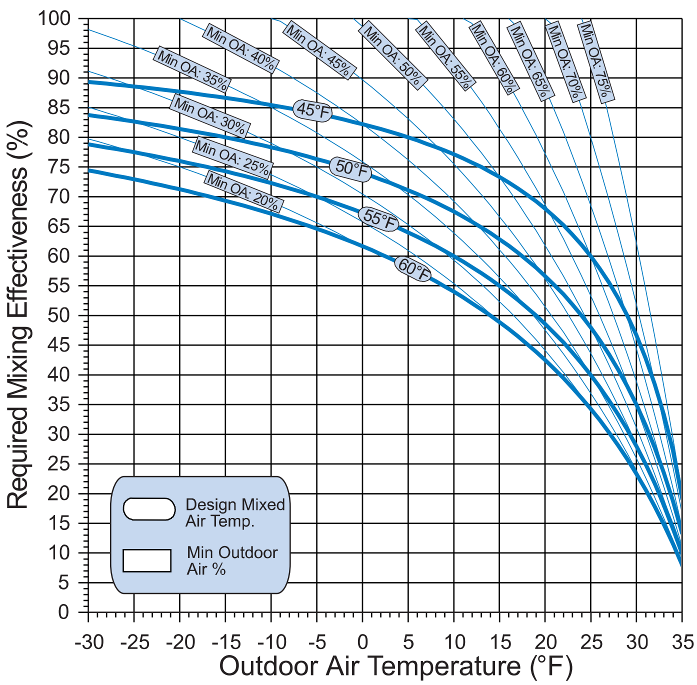
Mixing for Freeze Protection

The first type of mixing in an air-handling unit is mixing to provide freeze protection. The goal of this mixing is to insure that the minimum temperature at the face of a coil is above the freezestat set point or freezing point of the coil. The amount of mixing required to prevent a freezestat trip is a function of the outdoor air temperature, the return air temperature, the amount of outdoor air being introduced into the system, and the freezestat set point. Figure 2 shows the amount of mixing required to prevent a freezestat trip with a return air temperature of 75°F, and a freezestat set point of 37°F.

To use this chart, it is necessary to know the winter design temperature, the desired mixed air temperature, and the minimum outdoor air percentage. For variable volume systems, the minimum outdoor air percentage should be calculated using the minimum supply airflow. The first step is to draw a vertical line from the design outdoor air temperature through the design mixed air temperature curve and the minimum outdoor air percentage curve. Next, horizontal lines should be drawn from these two intersections to the vertical axis. This results in two values for the Required Mixing Effectiveness. The higher of the two Required Mixing Effectiveness ratings indicates the Mixing Effectiveness required for the system.

It is usually necessary to use a heating coil whenever the operating point lies in the region above the 45°F mixed air temperature line. This is due to two items. First, the mixed air temperature is too low and overcools the building spaces. Secondly, the required Mixing Effectiveness increases to extremely high levels. If the operating point lies in this region, the control strategy and the flow rates need to be evaluated.

Figure 2: Required Mixing Effectiveness to prevent freezstat trip.

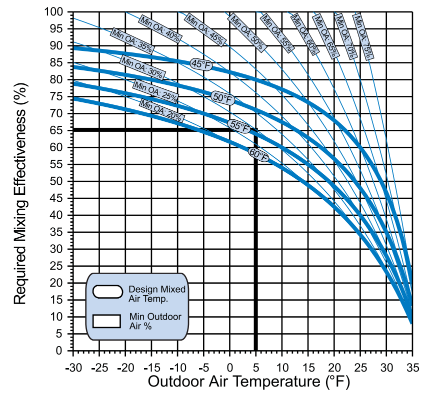


Example Selections & Specifications

Constant Volume System

A 15,000 CFM constant volume air handling unit is located in an area with a winter design temperature of 5°F. The return air temperature will be 75°F and the freezestat will be set at 37°F. The control system will use an economizer strategy to maintain a mixed air temperature of 55°F. The minimum amount of outdoor air will be 30% (4,500 CFM). What Mixing Effectiveness is required to prevent a freezestat trip when the outdoor air temperature is at the winter design temperature?

Draw a vertical line from the design outdoor air temperature through the design mixed air temperature and the minimum outdoor air percentage. Draw a horizontal line from each of the intersections to the vertical axis. The higher of two values for Required Mixing Effectiveness, in this case 65%, should be specified.

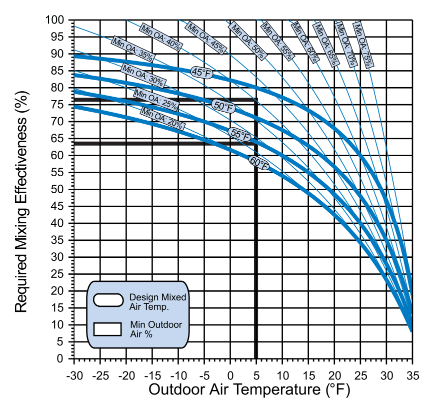


Specification: Air handling unit mixing system shall have a Mixing Effectiveness of 65% when system is operating with an outdoor air percentage of 30%. This specified Mixing Effectiveness will insure that the minimum temperature at the face of the cooling coil will be 37°F or higher when the outdoor air temperature is 5°F and the return air temperature is 75°F.

Variable Volume System

A Variable Volume system is to be located in an area with a winter design temperature of 5°F. The volume of air will vary from 10,000 CFM to 15,000 CFM. The control system will use an economizer strategy to maintain a mixed air temperature of 55°F. The minimum amount of outdoor air will be 4,000 CFM. What Mixing Effectiveness is required to prevent a freezestat trip when the outdoor air temperature is at the winter design temperature?

The minimum outdoor air percentage when the supply flow rate is at its minimum amount will be 40% (4,000 CFM/ 10,000 CFM). Draw a vertical line from the design outdoor air temperature through the mixed air temperature and the minimum outdoor air percentage. Drawing a horizontal line from each of the intersections results in a Required Mixing of 76%.



Specification: Air handling unit mixing system shall have a Mixing Effectiveness of 76% when system is operating with an outdoor air percentage of 40%. This specified Mixing Effectiveness will insure that the minimum temperature at the face of the cooling coil will be 37°F or higher when the outdoor air temperature is 5°F and the return air temperature is 75°F.

Mixing To Minimize Sensor Error

One of the most important parts of an air-handling unit is the control system. If the control system works improperly, the performance of the system will suffer. In most cases, a poorly operating control system will increase the amount of energy used by a system. One of the most common measurements that control systems rely upon to make logic decisions is temperature. Since the uncertainty in a temperature measurement increases as the stratification in an air handling unit increases, an error in a temperature measurement can have a significant impact upon the amount of energy used by an air-handling system. For example, a supply temperature measurement that is too high will result in not enough cooling in the space, increasing the amount of air that must be delivered. On the other hand, a supply temperature measurement that is too low results in a buildup of heat within the occupied space. Either one of these scenarios results in more energy usage. Minimizing the stratification in a system will help minimize the errors in the temperature measurements.

Figure 3: Required Mixing Effectiveness to reduce error in mixed air temperature measurement.

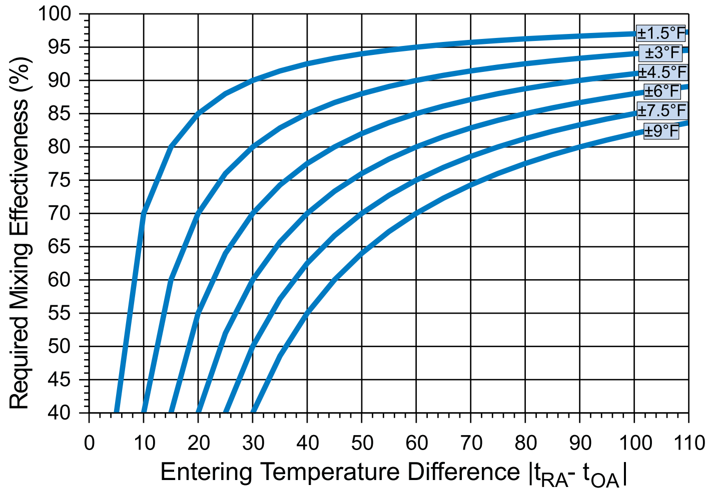


Figure 3 shows the Mixing Effectiveness required to reduce the error in the mixed air temperature to different levels of error. Since the temperature range at the discharge of a mixing device is a function of the temperature difference entering the mixing device, the required Mixing Effectiveness increases as the entering temperature difference increases.

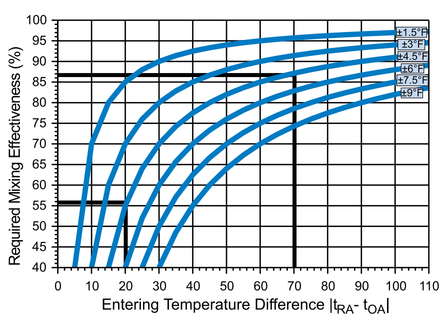
Example Selection & Specifications

Constant Volume System

A 15,000 CFM constant volume air handling unit is located in an area with a winter design temperature of 5°F and a summer design temperature of 95°F. The control system will use an economizer strategy to maintain a mixed air temperature of 55°F. The minimum amount of outdoor air will be 4,500 CFM. The return air temperature will be 75°F. The maximum error desired in the mixed air temperature is ±4.5°F. How much mixing is required to achieve this level of error?

The maximum error will occur when the outdoor air temperature is near the design temperatures. The entering temperature difference at the winter design temperature is 70° (75°- 5°) and the entering temperature difference at the summer design temperature is 20° (95°- 75°). Using Figure 3 indicates that the required Mixing Effectiveness is 56% when the outdoor air temperature is at the summer design temperature and 87% when the outdoor air temperature is at the winter design temperature.

Specification: Air handling unit mixing system shall have a Mixing Effectiveness of 87% when system is operating with an outdoor air percentage of 30%. This specified Mixing Effectiveness will insure that the error in the mixed air temperature measurement will be no more than ±4.5°F when the outdoor air temperature is 5°F and the return air temperature is 75°F.

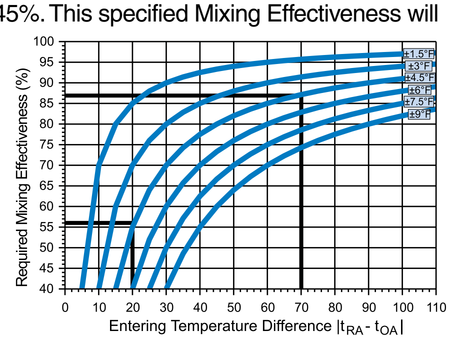


Variable Volume System

A Variable Volume system is to be located in an area with a winter design temperature of 5°F. The volume of air will vary from 10,000 CFM to 15,000 CFM. The control system will use an economizer strategy to maintain a mixed air temperature of 55°F. The minimum amount of outdoor air will be 4,500 CFM. The desired maximum error in the mixed air temperature measurement is ±4.5°F. What Mixing Effectiveness is required to achieve this level of error?

The maximum error will occur when the outdoor air temperature is near the design temperatures. The entering temperature difference at the winter design temperature is 70° (75°- 5°) and the entering temperature difference at the summer design temperature is 20° (95°- 75°). Using Figure 3 indicates that the required Mixing Effectiveness is 56% when the outdoor air temperature is at the summer design temperature and 87% when the outdoor air temperature is at the winter design temperature. Since the winter design temperature requires a higher level of mixing, it will be used as the selection criteria. When the outdoor air temperature is at the winter design temperature the supply flow rate will be close to the minimum flow rate of 10,000 CFM. The outdoor air percentage at under these conditions will be 45%.

Specification: Air handling unit mixing system shall have a Mixing Effectiveness of 87% when system is operating with an outdoor air percentage of 45%. This specified Mixing Effectiveness will insure that the error in the mixed air temperature measurement will be no more than ±4.5°F when the outdoor air temperature is 5°F and the return air temperature is 75°F.



Mixing for Outdoor Air Distribution

ASHRAE Standard 62-1989 requires a minimum amount of outdoor air to be delivered to each area in a building. Indoor Air Quality standards indicate that the amount of outdoor air introduced into an air handling system should be known to within ±10%, i.e. if the desired outdoor air flow rate is 10000 CFM then the uncertainty would be ±1000 CFM. This requirement can be used to develop a curve showing the minimum acceptable mixing to insure that this level of uncertainty exists through all spaces within a building.

If stratification exists in an air-handling unit, the outdoor air is not mixed with the return air. As a result, there is no way to know how much outdoor air is being received by each space. Specifying a mixing system capable of adequately mixing the outdoor and return air will increase confidence that each space is receiving an adequate supply of outdoor air.

One benefit air handling units provide is that the supply fan creates some additional mixing between the two air streams. However, no fan manufacturer publishes data that indicates how well a fan mixes. In addition, the mixing depends upon the type of fan and how the air enters the fan. As a result, relying upon the supply fan to provide all of the mixing within an air-handling unit can be risky. The best way to reduce this uncertainty is to specify a mixing box and/or static air mixer in the air-handling unit that provides a majority of the required mixing.

Figure 4: Requried Mixing Effectiveness to achieve different levels of Outdoor Air distribution.

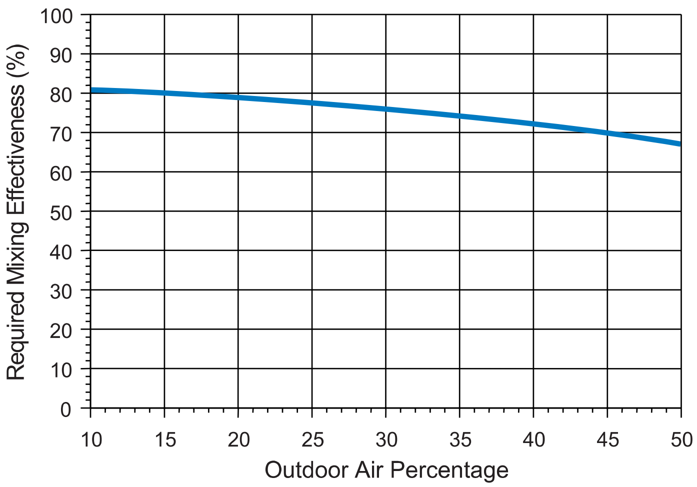


Figure 4 presents the Mixing Effectiveness required to achieve good outdoor air distribution assuming that the supply fan provides some additional mixing between the return and the outdoor air streams. This figure indicates that the Mixing Effectiveness of the air-handling unit mixing system needs to be at least 67% with an outdoor air percentage of 50% in order to achieve acceptable outdoor air distribution. With an outdoor air ratio of 20%, the required Mixing Effectiveness increases to 79%.

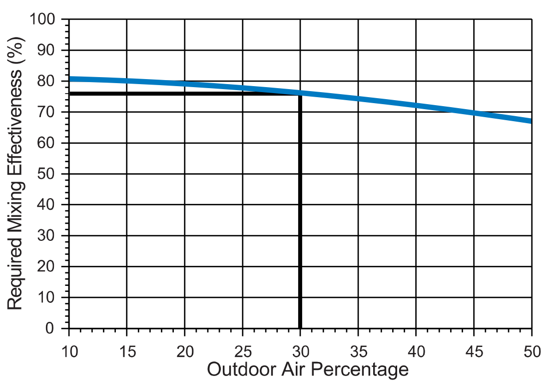
Example Selection & Specifications

Constant Volume System

A 15,000 CFM constant volume air handling unit is located in an area with a winter design temperature of 5°F. The minimum amount of outdoor air will be 4,500 CFM. What Mixing Effectiveness is required to insure that the outdoor air distribution within the supply air stream is acceptable?

The minimum amount of outdoor air for this system is 30% (4,500 CFM/ 15,000 CFM). Draw a vertical line from the horizontal axis at 30% until it intersects the required Mixing Effectiveness curve. Draw a horizontal line to the vertical axis to find the required Mixing Effectiveness of 76%.

Specification: Air handling unit mixing system shall have a Mixing Effectiveness of 76% when system is operating with an outdoor air percentage of 30%. This specified Mixing Effectiveness will insure that the uncertainty in the Outdoor Air distribution will be no more than ±3%.



The Static Air Mixer Solution

The selection charts and example specifications in the previous section can be used to determine how much mixing is required to avoid specific problems. However, no suggestions are made as to how these levels of mixing can be achieved. Static mixers provide an efficient means to achieve the mixing required for each air handling unit.

The primary benefit of static mixers is predictable mixing effectiveness, distance and pressure drop. This means that the correct mixing equipment can be selected and specified during the design phase. This eliminates the need for costly and annoying retrofit projects to solve stratification problems.

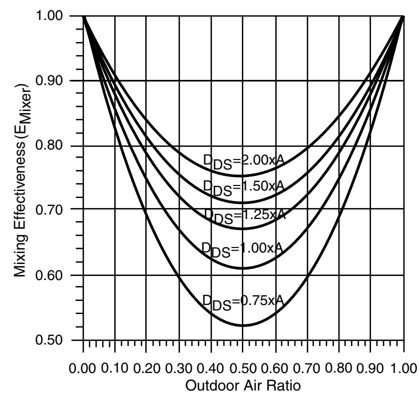
It is important to note that there are no performance standards for static air mixers at this time. As a result, it is necessary for the design engineer to keep several items in mind when evaluating competitive options. These items are Outdoor Air Ratio, Downstream Distance, and Area Ratio. Each of these items is discussed in the section below.

What Factors Need To Be Considered To Assure The Mixer Is Applied Correctly?

There are three major factors that must be considered when specifying a static air mixer. These factors are 1) outdoor air ratio, 2) downstream distance, and 3) area ratio. Below is an overview of each factor and its importance to specifying and applying a static air mixer.

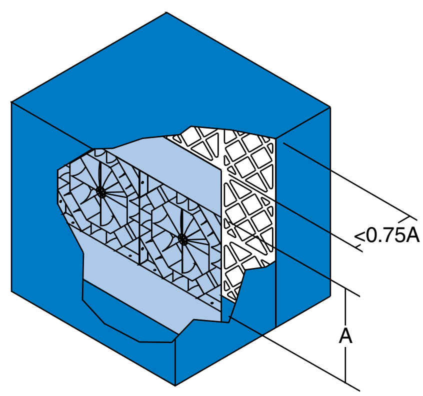
1. Outdoor Air Ratio

The graph on the right presents the performance curves for the Series IV AIR BLENDER® static air mixer by Blender Products, Inc. at varying outdoor air ratios. The mixing performance of other static mixers will typically have a similar shape as the curves in this figure and will be 50% or less at an outdoor air ratio of 50%. This figure clearly shows that relative amount of outdoor air being mixed in the system has a dramatic effect upon the mixing performance of the static mixer.



2. Downstream Distance

The distance downstream of a mixer also has a dramatic effect upon the performance of the mixer. Typically, a mixer provides little or no mixing if the distance downstream of the mixer is less than 0.75 times the diameter of the mixer. For example, if two mixers with a diameter of 60" are installed in an air handling unit, it will be necessary to have about 45" between the mixers and the filters and/or coil before significant mixing takes place.

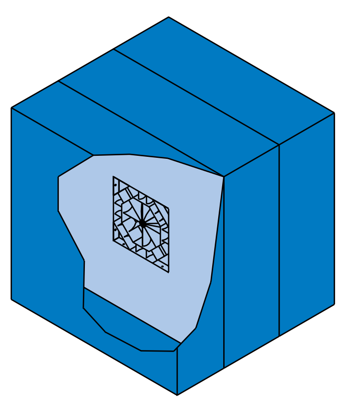


Minimal Mixing Distance is 0.75 x Diameter of Mixer.

3. Area Ratio

The third factor that must be considered is the area ratio of the mixer. In most cases a mixer is not the same size as the duct in which it is mounted. As a result a mixer acts like an orifice. As the area ratio decreases, the pressure drop across the device increases. When this area ratio falls below 0.40 (40% free area) the pressure drop increases dramatically. If this area ratio is not taken into account it is possible that the pressure loss of the mixer will be up to ten times more than the stated pressure loss.

The illustration at right represents a mixer to plenum area ratio of below 0.40. This ratio will result in excessive pressure loss.



Writing the Specification

One approach to specifying a static mixer is to specify the desired Mixing Effectiveness, the desired mixing distance, and the desired pressure loss. Once this competitive specification is written, any manufacturer wishing to supply air mixers should supply performance curves that indicate the mixing effectiveness of the static mixer at different outdoor air ratios and downstream distances. The pressure loss of the mixer, including the orifice effect, should also be supplied. By requiring this information, the specifying engineer can be assured that the mixing system for each particular air handling unit will provide adequate mixing to prevent problems associated with air stratification.

By combining a specification written using the guidelines in this document and requiring any manufacturer of mixing equipment to supply Mixing Effectiveness curves and pressure drop curves, a design engineer can be confident that problems associated with stratification will not appear after a system is started.

Suggested Reading

If more detailed information about mixing or the effects of stratification is desired, the following articles provide useful information:

Blender Products, Inc., "Air Mixing Handbook", Blender Products, Inc., 1996.

Buchko, T., "Minimizing Stratification to Achieve Air Mixing Effectiveness", *TAB Journal*, October 1999, pp. 9-12.

Coggan, D., "Mixed Air Control with DDC", *Heating, Piping and Air Conditioning*, May 1986, pp. 113-115.

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Kao, J.Y. ,"Sensor Errors", *ASHRAE Journal*, Volume 28, No. 1, January 1985, pp.100-104.

Roberts, D., Kelly, D., "Keep Coils Comfy, Cozy", *Engineered Systems*, February 1998, pp. 56-60.

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Robinson, K.D., "Rating Air-Mixing Equipment", *ASHRAE Journal*, February 2000, Volume 42, No. 2, pp. 63-70.

Robinson, K.D., "Static Air Mixer Fundamentals", *Heating, Piping and Air Conditioning*, August 1997, pp. 85-90.

Suhail, K., "Maximizing the Savings from Economizer Systems", *Building Design & Construction*, May 1989, pp. 100-102.

Ventresca, J.A., "Economizer Operation and Maintenance for Indoor Air Quality", *ASHRAE Journal*, Volume 35, No. 1, January 1992, pp. 26-36.

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