This report focuses primarily on the application of dampers in typical HVAC processes. Damper selection criteria for two position, static pressure controlled, temperature controlled, face and bypass, and mixed air temperature controlled applications will be investigated.

The purpose of a damper is to either throttle or stop the flow of air through a duct or opening. There are several different types of dampers:

1. Barometric Dampers - These dampers automatically open and close to maintain a predetermined differential pressure across them. They are often used to insure proper air flow in boiler flue exhausts or as a high static pressure limiting safety for ductwork.

2. Fire/Smoke Dampers - These dampers are used to prevent the spread of smoke or fire from one area to another through openings or ductwork. They are typically closed via a fusible link which melts when the air temperature exceeds a predetermined setpoint in the range of 160°F - 286°F.

3. Round Dampers - These dampers are used for air balancing or proportional control applications in variable air volume terminal units.

4. Rectangular Dampers - These dampers are the most commonly specified type of damper for proportional control applications. Depending on the configuration of the damper linkage, the damper blades will be modulated in one of two ways. The blades of a damper with a parallel type linkage all move together at the same rate and in the same direction. These dampers are commonly called parallel blade dampers. Conversely, adjacent blades of a damper with an opposed type linkage turn in opposite directions. These dampers are commonly called opposed blade dampers.

This report will focus primarily on the application and installation of rectangular control dampers.

Damper Flow Characteristics

To select a damper which will meet the requirements of a particular application, the relationship between the flow rate through the damper and the position of the damper blades must be understood. This relationship is commonly called the damper flow characteristic.
Damper flow characteristic curves are generally shown in graph format with the percent stroke of the damper on the X-axis and the percent of the wide open flow on the Y-axis. The resulting curve is a function of two items.

First, the shape of the curve is related to how the damper blades move relative to one another. Thus a damper with a opposed blade linkage will have a different characteristic than a damper with a parallel blade linkage. Secondly, the shape of the curve is related to the differential pressure across the damper.

If the differential pressure across the damper is held constant regardless of the position of the damper blades, the resulting flow characteristic is called the **inherent** flow characteristic. The inherent flow characteristic is normally determined in a certified testing laboratory. The inherent flow characteristic curves for the Johnson Control, Inc. (J.C.I.) opposed and parallel blade dampers are shown in Figure 1.

![Inherent Flow Characteristics](image)

**Figure 1**

The inherent flow characteristic curves shown in Figure 1 are valid only when the damper is operating with a constant differential pressure difference across it. In a real fan/duct system; the ductwork, balancing dampers, filters, coils, and fittings will also have a pressure drop across them. As the damper throttles, the flow rate and pressure drop through the other components of duct system will be reduced. The differential pressure across the damper will increase by the same amount as the differential pressure across the other components of duct system decreased. Thus a trade-off occurs at the damper.
The damper blades are closing which tends to reduce the flow, but the differential pressure across the damper is increasing which tends to increase flow. This pressure shift from the duct system to the damper has a significant impact on the shape of the damper flow characteristic. The amount of actual deviation from the shape of the inherent characteristic curve is related to a property called authority.

By definition authority is the ratio of the wide open pressure drop through the damper to the total duct system pressure drop at design flow.

\[
\text{Damper Authority} = \left( \frac{\Delta P_d}{\Delta P_t} \right) \times 100 \quad \text{EQ. 1}
\]

Where:
\[
\Delta P_d = \text{Pressure drop across wide open damper.}
\]
\[
\Delta P_t = \text{Total pressure drop in that portion of the system in which the damper is to be installed.}
\]

The value of \( \Delta P_t \) is generally equal to the total pressure drop which can be expected across the damper in the closed position. Several examples which illustrate how to determine the value of \( \Delta P_t \) are provided later in this report.

The damper shown in Figure 2 has an authority of 5%.

If the damper authority is known, the installed damper flow characteristic curve can be determined. The installed flow characteristic curve is the actual flow characteristic obtained when the damper is applied to a given air handling system. It takes into consideration the pressure shift to the damper.
Figures 3 and 4 show a family of installed characteristic curves for the J.C.I. damper lines. Each curve is labeled based on percent of damper authority. Therefore a curve labeled “A=5%” would reflect the relationship between percent of damper stroke verses percent of wide open flow for an installation with a damper authority of 5%. Figure 3 is appropriate for dampers with opposed blade linkages. Figure 4 is appropriate for dampers with parallel blade linkages.

The application of the damper will determine which installed damper flow characteristic will provide the best control. The value of the damper authority which matches the desired flow characteristic is used to determine the wide open pressure drop through the damper. The correct damper can then be selected. There are five basic damper applications: 2-position; static pressure control; temperature control; face and bypass; and mixed air control.
In this application the damper is maintained in either its fully open or closed position depending on the condition of a binary input. The shape of the installed damper flow characteristic is not important since the damper is not used as a modulated control device. The only requirement is that it must be possible to obtain the wide open design flow rate through the damper with a pressure drop which is less than or equal to the value specified by the consulting engineer. Generally, dampers used for this application are duct sized to provide the lowest wide open pressure drop possible. The exception is the case where the damper size is reduced to minimize leakage. The amount of air which leaks through a closed damper is related to the damper size, construction, and differential pressure across the damper.

In this application the damper is modulated as required to maintain a static pressure setpoint at some downstream point in the ductwork. The damper is generally installed near the fan discharge. This application is less common today with the advent of variable speed drives and the use of inlet vanes to control fan capacity. The pressure drop across the damper must compensate for the increase in pressure developed by the fan and the reduction in the pressure drop across the ductwork as the system flow rate is decreased. Figure 5 provides a graphical representation of how these changes are related.

In Figure 5 the damper is modulated as required to maintain a setpoint of 0.5 in W.G. at “Point A.” At 100% of the system flow rate (vertical line X) the damper should be fully open. At reduced system flow rates, the damper should be partially closed so that the pressure drop across the
damper is equal to the pressure developed by the fan less the sum of the system pressure drop (ductwork, coils, etc.) and the static pressure setpoint.

\[ \Delta P_{\text{damper}} = \Delta P_{\text{fan}} - (\Delta P_{\text{system}} + \Delta P_{\text{setpoint}}) \]  

EQ. 2

Therefore, the vertical distance between the fan curve and the system resistance curve less the required setpoint equals the desired pressure drop across the damper. At 25% of the system flow rate (vertical line Y), the pressure drop across the damper must be equal to \([2.4 - (0.05 + 0.5) = 1.85 \text{ in. W.G.}]\) to maintain setpoint.

Figure 6 shows the relationship between the damper pressure drop which is required to maintain the differential pressure setpoint as a function of the system flow rate.

To enhance controllability, the installed flow characteristic of the damper should complement the relationship shown in Figure 6. The damper flow characteristic which does the best job of providing this relationship would be a damper authority of 100%. Practically speaking, damper authorities above 50% are not often recommended due to excessive pressure drops and potential noise problems. There are also diminishing gains in achieving the curvature of the inherent flow characteristic at damper authorities greater than 50%. The authority recommendations take these issues into account.

![Figure 6](image)

**Figure 6**

Note: The relatively high authorities and associated damper pressure drops required for this application should have been considered when the fan was selected. If the damper pressure drop was not considered, it may not be possible to achieve the required flow rate in the ductwork.
Authority Recommendations (Static Pressure Control)

1. For opposed blade dampers, size for an authority of between 20 and 50 percent.
2. Parallel blade dampers are not recommended for this application.

For this application, the value of $\Delta p_t$ to be used in Equation 1 would be equal to the design static pressure generated by the fan. Therefore, if a fan generates 2 in. W.G. of static pressure at design and the desired damper authority is 20%, then the damper should be selected for a wide open pressure drop of $(2 \text{ in. W.G.})(0.2)$ or 0.4 in. W.G.

Dampers are frequently utilized to regulate the amount of conditioned (supply) air which is introduced into a zone. A variable volume terminal unit is a good example of this application. Varying amounts of supply air are used to compensate for the heat gains or losses within the space. The amount of sensible energy transferred to or from the room by the supply air can be determined by Equation 3.

\[
\text{Sensible Heat Transfer (BTUH)} = (1.08)(\text{CFM})(T_{sa}-T_{r}) \quad \text{EQ. 3}
\]

Where:  
- $\text{CFM} = \text{Flow Rate Through The Damper}$
- $T_{sa} = \text{Temperature Of The Supply Air}$
- $T_{r} = \text{Temperature Of The Room Air}$

If the supply and room air temperatures are being maintained at setpoint, the flow rate into the room will be directly proportional to the amount of heat transfer required to maintain the space temperature setpoint. As a result a linear damper characteristic is desired for this application.

Authority Recommendations (Temperature Control)

1. For opposed blade dampers, size for an authority of between 8 and 10 percent to obtain a linear installed flow characteristic.
2. For parallel blade dampers, size for an authority of between 20 and 25 percent to obtain a linear installed flow characteristic.

Face And Bypass Applications

The parallel blade damper lends itself to the face and bypass application because it provides for better downstream air mixing. Figure 7 shows the recommended method of installing parallel blade dampers to enhance mixing.

The face and bypass dampers should be sized so that the combined flow rate through them is relatively constant. Most manufacturers arbitrarily install coil face dampers which are the same size as the coil face area. Since coils must be selected with relatively low velocities (300-500 fpm)
the face damper, which is the same size as the coil, will have a very low pressure drop and damper authority. As a result, it probably won’t have the desired linear flow characteristic. To compensate the bypass section damper should be downsized.

![Figure 7](image)

**Figure 7**

To achieve a relatively constant flow rate through the face and the bypass sections, it is desirable to have the same full flow resistance in both the coil face and bypass sections. The bypass damper should then be sized so that its full flow resistance would be equal to the sum of the full flow resistance of the coil and the coil face damper. Figure 8 can be used to size the damper in the bypass section.

![Figure 8](image)

**Figure 8**
The values on the X-Axis represent the pressure drop across the coil at design flow. The pressure drop across the face damper is generally insignificant compared to the coil pressure drop so it has been ignored. The values on the Y-Axis represent the recommended size for the bypass damper in percent of the size of the coil.

Assume the coil, of a face and bypass air handling unit, has a face area of 10 ft$^2$ and a pressure drop of 0.2 in W. G. at a design flow rate of 5000 CFM. The value of the Y-Axis corresponding to the intersection of the 500 fpm curve and the 0.2 from the X-axis is approximately 40%. Therefore, the area of the bypass damper should be 40% of the area of the coil or 4 ft$^2$.

Dampers are frequently utilized to regulate the flow rate of two air streams so that the temperature of the mixed air stream can be maintained at some predetermined temperature. Economizer cycle control is an example of this application.

There are two independent conditions which should be satisfied when sizing dampers for this application. The first condition involves matching the dampers so that the combined flow rate through them is held relatively constant regardless of their position. This is very important! Figure 9 illustrates a set of well matched dampers while Figure 10 illustrates a set of poorly matched dampers.

**Figure 9**

![Diagram of Combined Flow Characteristics](image)
Instability in both temperature and static pressure control loops can occur if the variation in the combined flow characteristic is excessive. Large variations can cause the mixing plenum pressure to fluctuate significantly as the dampers are modulated. In turn, the flow rate of each air stream will vary in an unpredictable manner which can make it very difficult to maintain the mixed air setpoint. In extreme cases, this instability can cascade and cause vacillation in the supply fan static pressure control loop of a variable volume system. Generally, if the magnitude of the combined flow characteristic does not deviate by more than 15% from the nominal value of 100%, the dampers are adequately matched to one another. The graph shown in Figure 11 can be used to match the authorities of the two dampers to provide a nearly constant combined flow rate.

Figure 11 is valid if both mixing dampers have either opposed or parallel blade linkages. It is not valid if one damper has a parallel blade linkage and the other has an opposed blade linkage. To use the graph, locate the intersection of a vertical line drawn though the authority of the first damper with the appropriate curve on the graph. Make sure you use the curve which applies to the type of dampers to be installed (opposed or parallel linkages). Now draw a horizontal line from this point of intersection to the Y-Axis. The corresponding value of the Y-Axis is the desired damper authority for the second damper. Thus if an opposed blade outdoor air damper with an authority of 5% is installed, the opposed blade return air damper should have an authority of approximately 10% to provide a near constant combined flow characteristic.

In most cases, it is not practical to select a damper with an authority greater than 50%. There are diminishing gains in trying to achieve a characteristic similar to the inherent damper characteristic after an authority of 50% is achieved. In other words, the damper pressure drop
will increase significantly while the installed flow characteristic changes only slightly for authorities greater than 50%.

Figure 11

The second condition which must be considered when selecting dampers for mixed air control involves matching the damper flow characteristics with the process dynamics of mixed air control.

When two air streams are mixed together, the resultant mixed air temperature can be determined with Equation 4.

\[
T_m = \frac{(T_1)(Flow_1) + (T_2)(Flow_2)}{(Flow_1 + Flow_2)} \quad \text{EQ. 4}
\]

Where:
- \(T_m\) = Temperature Of Mixed Air Stream
- \(T_1\) = Temperature Of Air Stream #1.
- \(T_2\) = Temperature Of Air Stream #2.
- \(Flow_1\) = Flow Rate Of Air Stream #1.
- \(Flow_2\) = Flow Rate Of Air Stream #2.

Ideally, a percent change in the output of the controller would be matched with a like percent change in the value of the mixed air temperature under all operating conditions. Unfortunately due to the non-linear processes involved and the effect of different outdoor air temperatures, this desired condition is almost impossible to achieve. The mathematics involved to do this analysis are beyond the scope of this report so only recommendations based on the results of this analysis will be given.

A compromise which provides an acceptable solution for meeting both the constant flow requirement as well as matching the process dynamics, is to select the mixing dampers to have a linear flow characteristic. Thus if job conditions permit, the outdoor, return and exhaust air dampers should all be sized for an authority of 8-10 percent for opposed blade dampers and 20-25 percent for parallel blade dampers.
Sometimes, due to space considerations, the outdoor air damper is installed at the louver. As a result of this installation, the outdoor air damper is significantly oversized and the velocity through the damper is kept between 300-500 fpm. This is required to prevent the entrainment of snow, rain or dirt.

When this situation is encountered, it will not be possible to size the outdoor air damper for a linear flow characteristic. This louver size damper will likely have an authority which is less than the desired 8-10 percent for opposed blade or 20-25 percent for parallel blade dampers. To compensate, Figure 11 should be used to determine the authority of the return air damper. This will minimize the opportunity for instability. The exhaust air damper should be sized for the same authority as the outdoor air damper.

Unfortunately, in many installations duct sized dampers are arbitrarily installed in the outdoor air louver, return air duct and exhaust air duct. These installations have historically been troublesome, particularly when less sophisticated controllers are installed. In many cases when Proportional (P) or Proportional with Integration (PI) type controllers are installed, the only way to achieve stability is to lower the controller gain. In the case of the P only controller, this is undesirable because the throttling range will increase. In other words, the average amount of deviation from setpoint will increase. For PI controllers, the low gain can cause sluggish performance and provide slow response to system changes. The only good solution would be to utilize a controller which is capable of on-line readjustment of its gain to match the process dynamics.

Unfortunately, the cost of a self-tuning controller may be prohibitive for many jobs.

### Authority Recommendations (Mixed Air Control)

<table>
<thead>
<tr>
<th>Opposed or Parallel Blade Dampers</th>
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<tbody>
<tr>
<td>1. If the outdoor air damper is installed in a duct (not at the louver) size it for an authority of (8-10% for opposed linkage) or (20-25% for parallel linkage). The return and exhaust air dampers should also be selected for an authority of (8-10% for opposed linkage) or (20-25% for parallel linkage).</td>
</tr>
<tr>
<td>2. If the outdoor air damper must be installed at the louver face, its size may match the louver. For the design flow rate and damper size determine the authority of the outdoor air damper. Use Figure 11 to determine the authority of the return air damper. Select the exhaust damper for the same authority as the outdoor air damper.</td>
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