The first step in determining the proper perforation for an application is to understand the airflow requirements of the equipment that will be used in the cabinet.

Understanding How Cabinet Door Perforation Impacts Airflow

by Travis North

Nomenclature

E= Energy

P=Static pressure

ρ=Density

V=Velocity

g=Gravitational constant

h=Height

F=Loss coefficient

AFC_{MD} =Airflow capacity ratio of the mesh door

S_D=Total door open surface area

F_{ea}=Perforation percentage

A_c = Open area width

H_{rmu}=Height of rmu

N_{rmu} =Number of rmu

rmu =Rack unit height

When choosing a cabinet door for a data center, it is essential to determine what level of perforation will be needed.

Opinions on this subject are extensive. Some experts believe that 80 percent perforation is needed for high-density heat loads of 30 kilowatts (kW), whereas others believe only 64 percent perforation is needed. Data center technology develops at a rapid pace, with new discoveries uncovered every day, which is why there is more to this issue than just a single number. This study will provide the tools to identify the level of cabinet perforation best suited for a specific application. It will show that, for a large cross-sectional area, using a perforation of 64 percent does not impact airflow, and there is no loss in performance even at extreme density loads of 30 kW and above.

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The Physics of Airflow through a Perforated Plate

To complete a full analysis of the energy loss (pressure loss) due to air flowing through a perforated plate, start with the fundamentals. The underlying relationship between the energy losses through a perforated plate is directly related to the overall velocity of airflow through that perforated plate and its associated friction losses (minor losses). This relationship is defined by the Bernoulli equation along a streamline in the form of energy as:

Equation 1: $$E1 = E2 + Ef$$

The basic energy equation can be broken down further into its fundamental form as:

Equation 2: $$P_1 + \tfrac{1}{2}\rho_1 V_1^2 + \rho_1 g h_1 = P_2 + \tfrac{1}{2}\rho_2 V_2^2 + \rho_2 g h_2 + \tfrac{1}{2}\rho_f F V_2^2$$

Where the last term of the previous equation represents the minor energy loss due to the perforated plate:

Equation 3: $$Ploss = \tfrac{1}{2}\rho_f F V_2^2$$

Equation 3 implies that the pressure loss due to a perforated plate is related to the velocity of air moving through the plate and the loss coefficient F associated with the design of the perforation. The velocity through the perforated plate is calculated from the free air ratio (FAR) of the perforation itself, the size of the perforated area and the overall volumetric airflow through the plate.

The actual pressure or energy loss for a given airflow due to the presence of the perforated plate is dependent on three key factors:

- Size of the perforated area
- Open area ratio of the perforation
- Loss coefficient associated with the type of perforation chosen

We have completed extensive studies of these parameters and will illustrate how each one should be considered and the limits of each type of perforation.

It is important to note that this analysis is an extension beyond BICSI 002-2011, *Data Center Design and Implementation Best Practices*. Whereas the airflow capacity for mesh doors (AFC_{MD}) ratio of BICSI 002-2011 is:

Equation 4: $$AFC_{MD} = \frac{S_D F_{ea}}{A_c H_{rmu} N_{rmu}}$$

- AFC_{MD} is the airflow capacity ratio of the mesh door
- S_D is the total door open surface area
- F_{ea} is the perforation percentage
- A_c is the width open area (450.85 millimeters [mm (17.75 inches [in])])
- H_{rmu} is the height of a single rmu (44.45 mm [1.75 in])
- N_{rmu} is the number of rmu

To develop this specification, certain assumptions and simplifications needed to be made about the maximum airflow and ultimate velocity of air through the perforation with a full rack of information technology (IT) equipment. BICSI 002-2011 also surmises that if the perforation has an equivalent 63 percent of open space, there will be minimal pressure impact due to the presence of the perforation.

This study takes BICSI 002-2011 a step further to explore both the total airflow associated through the perforated door and how it relates that to the velocity of airflow, size and type of perforation, as well as determine pressure loss through the door. This analysis is not meant to replace the airflow capacity ratio but to further enhance the understanding of BICSI 002-2011.

Determining Proper Perforation Size and Type

Equation 3 illustrates how perforation, velocity and loss coefficients can impact the pressure loss through a cabinet, which can be used to understand how this impacts real-world applications. The first step in determining the proper perforation for an application is to understand the airflow requirements of the equipment that will be used in the cabinet. For example, if the cabinet needs to support 30 kW of IT load with servers, switches and other heat-generating devices, the equipment will operate at a 16.7 Celsius (C [30 Fahrenheit (F)]) temperature rise from the intake of the equipment to the exhaust of the equipment and would need 1.49 cubic meters per second (m^3/s [3,154 cubic feet per minute (ft^3/m)]) of airflow to cool the cabinet.

To place this further in perspective, we used IBM's BladeCenter Power Configurator tool to model a real-world application. We modeled a fully loaded 42-unit rack with four IBM BladeCenter H chassis at a maximum configuration using six PS702 blades per chassis. The configuration consumed a maximum measured power of 21.3 kW at a 16.7 C (30 F) temperature rise. This correlates to a maximum 1.08 m^3/s (2,288 ft^3/m) of measured airflow consumption. Most original equipment manufacturer (OEM) configuration tools will directly provide the cubic feet per minute (CFM) consumption of the IT equipment. If the airflow is not readily available, Table 1 can be used to estimate the required CFM for the application.

Delta T (ºF)	CFM	Power (W)	Delta T (ºF)	CFM	Power (W)
20	1577.287	10000	40	788.6435	10000
20	3154.574	20000	40	1577.287	20000
20	4731.861	30000	40	2365.931	30000
30	1051.525	10000			
30	2103.049	20000			
30	3154.574	30000			

Table 1: Relationship between cabinet loading, temperature rise and required cooling airflow

Next, using the previously specified cabinet CFM, identify the type of perforation to be analyzed (free air ratio) and determine the overall cross-sectional area available for the perforation. Common perforations range in size and shape depending on the application used. This study uses perforation samples ranging from 40 percent to 80 percent FAR to illustrate the extremes of this analysis.

The cross-sectional area and cabinet level CFM can be used to determine the approach velocity. If using the previous example that requires 1.49 m^3/s (3,154 ft^3/m), and the perforated door is 0.6 meters (m) by 1.83 m (2 feet [ft] by 6 ft), the overall approach velocity of air through the cabinet door is calculated to be 1.3 m/s (263 ft/m). This was calculated from the following equation:

Equation 5:

$$V = \frac{\text{Volumetric Flow}}{\text{Total Area}}$$

From Equation 3, the velocity is squared and is the dominant term in the pressure calculation. From Equation 5, it is important to understand that total cross-sectional area is used to determine the velocity through the perforation. If the perforation area had only been 0.6 m by 0.91 m (2 ft by 3 ft), the overall velocity would have doubled to 526 ft/m (2.7 m/s), ultimately quadrupling the pressure through the door.

Tables 2 through 4 expand upon Table 1 to provide various approach velocities for a given cross-sectional area. Identify the cross-sectional area to be used from tables 2 through 4 and look up the approach velocity through the perforation. In the next section, this velocity is used to investigate the pressure loss through the perforation.

Now that the velocity is known for the given application, the pressure loss through the cabinet perforation can be determined. To do this, the loss coefficients associated with the various perforation types must be understood. This is accomplished via experimental testing of 40, 56, 64 and 80 percent perforation samples. A flow bench designed in accordance with ACMA standard 210-99 was used to determine the impedance from each of the various samples ranging from 40 percent perforation up to 80 percent perforation. The summary of the test data is illustrated in Figure 1.

Using the previous example of a 0.6 m by 0.91 m (2 ft by 6 ft) cross-sectional perforation area with 1.49 m^3/s (3,154 ft^3/m) of IT airflow consumption (which supports 30 kW of IT loading), the overall approach velocity of air into the perforated material was 1.3 m/s (263 ft/m). If using the impedance curves obtained via experimental test data, shown in Figure 2, and cross-reference each type of perforation for the approach velocity of 1.3 m/s (263 ft/m) shown, there is only a 0.64 mm (0.025 in) H_2O (6.2 pascal [Pa]) pressure loss for a 40 percent door perforation. At 56 percent perforation, there is only a 0.38 mm (0.015 in) H_2O (3.7 Pa) pressure loss, and 64 percent and 80 percent have perceptibly equal pressure losses of 0.26 mm (0.01 in) H_2O (2.5 Pa).

To understand how much pressure loss is acceptable, it is important to know how IT equipment fans operate. At higher speeds, fans can have operating pressures on the scale of 15.24 mm (0.6 in) H_2O (149.5 Pa) to above 25.4 mm (1.0 in) H_2O (249 Pa) depending on the design and system operating point. The critical point in which the pressure will cause the server/IT fans to consume additional power is 1.27 mm (0.05 in) H_2O (12.5 Pa). This critical pressure limit is illustrated in Figure 2 as the red horizontal line. Even at 40 percent perforation, the pressure loss of 0.64 mm (0.025 in) H_2O (6.2 Pa) is minimal compared with the operating point of the IT system fans and will have negligible impact to the performance of the IT equipment. It is also important to note that this is the pressure through a single perforated door. If a front and back perforated door is used, the pressure terms are additive. For the example above, all the various perforation types satisfy the design requirement, and all are less than 1.27 mm (0.05 in) H_2O (12.5 Pa) and would be acceptable to use.

If taken to the extreme case of 30 kW of IT load at a 11.1 C (20 F) temperature rise through the equipment using Table 2, the consumption per rack would be 2.2 m^3/s (4,731 f^3/m) with an approach velocity of 2 m/s (394 ft/m), which is more than double the airflow requirement of a fully configured rack of IBM BladeCenter systems. Again, if using the impedance data to cross-reference the system operating point illustrated in Figure 3, the various pressure losses for each type of perforation can be obtained. In this extreme case:

- 40 percent perforation causes a pressure loss of 2.03 mm (0.08 in) H_2O (20.0 Pa)
- 56 percent perforation causes a pressure loss of 1.14 mm (0.045 in) H_2O (11.2 Pa)

Delta T (°F)	CFM	Power (W)	Door Width (ft)	Door Height (ft)	Total Area (ft2)	Total Velocity (ft/min)	Velocity (m/min)	Velocity (m/s)
20	1577.287	10000	2	6	12	131.4	40.1	0.7
20	3154.574	20000	2	6	12	262.9	80.1	1.3
20	4731.861	30000	2	6	12	394.3	120.2	2.0
30	1051.525	10000	2	6	12	87.6	26.7	0.4
30	2103.049	20000	2	6	12	175.3	53.4	0.9
30	3154.574	30000	2	6	12	262.9	80.1	1.3
40	788.6435	10000	2	6	12	65.7	20.0	0.3
40	1577.287	20000	2	6	12	131.4	40.1	0.7
40	2365.931	30000	2	6	12	197.2	60.1	1.0

Table 2: Velocity through perforated door for 0.6 m by 1.83 m (2 ft by 6 ft) perforation area

Delta T (°F)	CFM	Power (W)	Door Width (ft)	Door Height (ft)	Total Area (ft2)	Total Velocity (ft/min)	Velocity (m/min)	Velocity (m/s)
20	1577.287	10000	2	3	6	262.9	80.1	1.3
20	3154.574	20000	2	3	6	525.8	160.3	2.7
20	4731.861	30000	2	3	6	788.6	240.4	4.0
30	1051.525	10000	2	3	6	175.3	53.4	0.9
30	2103.049	20000	2	3	6	350.5	106.8	1.8
30	3154.574	30000	2	3	6	525.8	160.3	2.7
40	788.6435	10000	2	3	6	131.4	40.1	0.7
40	1577.287	20000	2	3	6	262.9	80.1	1.3
40	2365.931	30000	2	3	6	394.3	120.2	2.0

Table 3: Velocity through perforated door for 0.6 m by 0.91 m (2 ft by 3 ft) perforation area

Delta T (°F)	CFM	Power (W)	Door Width (ft)	Door Height (ft)	Total Area (ft2)	Total Velocity (ft/min)	Velocity (m/min)	Velocity (m/s)
20	1577.287	10000	1	3	3	525.8	160.3	2.7
20	3154.574	20000	1	3	3	1051.5	320.5	5.3
20	4731.861	30000	1	3	3	1577.3	480.8	8.0
30	1051.525	10000	1	3	3	350.5	106.8	1.8
30	2103.049	20000	1	3	3	701.0	213.7	3.6
30	3154.574	30000	1	3	3	1051.5	320.5	5.3
40	788.6435	10000	1	3	3	262.9	80.1	1.3
40	1577.287	20000	1	3	3	525.8	160.3	2.7
40	2365.931	30000	1	3	3	788.6	240.4	4.0

Table 4: Velocity through perforated door for 0.3 m by 0.91 m (1 ft by 3 ft) perforation area

- 64 percent perforation causes a pressure loss of 0.86 mm (0.034 in) H_2O (8.5 Pa)
- 80 percent perforation causes a pressure loss of 0.76 mm (0.03in) H_2O (7.5 Pa)

Even in this extreme case, the pressure loss between 80 percent and 64 percent is less than 0.10 mm (0.004 in) H_2O (1 Pa), which is not perceivable by the IT equipment. From these two examples, if the designed cabinet velocity for a 0.61 m by 0.91 m (2 ft by 6 ft) perforation area is less than 1.3 m/s (263 ft/m), perforation type has minimal impact. At extreme cabinet velocities of 2 m/s (394 ft/m), the pressure loss through 56 percent is

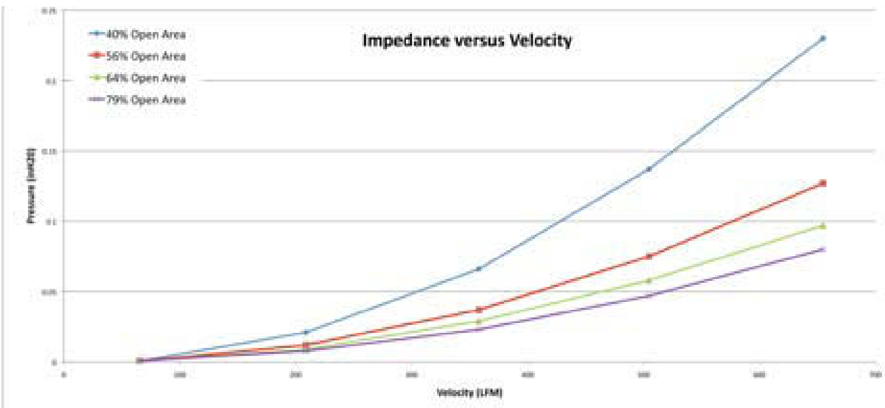

Figure 1: Perforation impedance test results

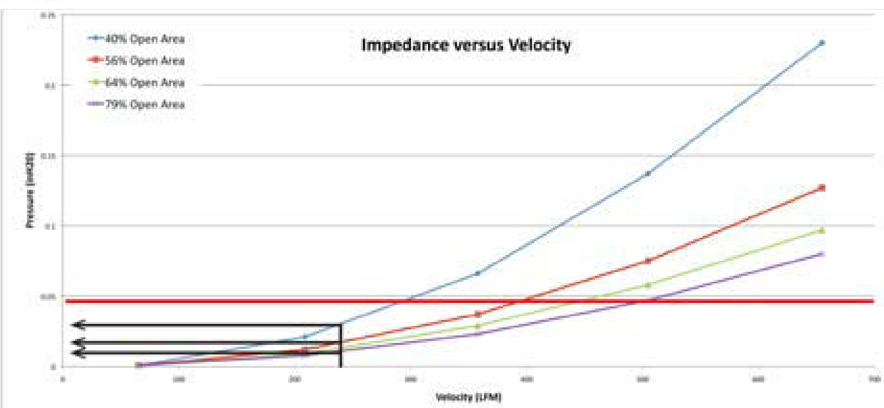

Figure 2: System operating points for various perforations 1.3 m/s (263 ft/m)

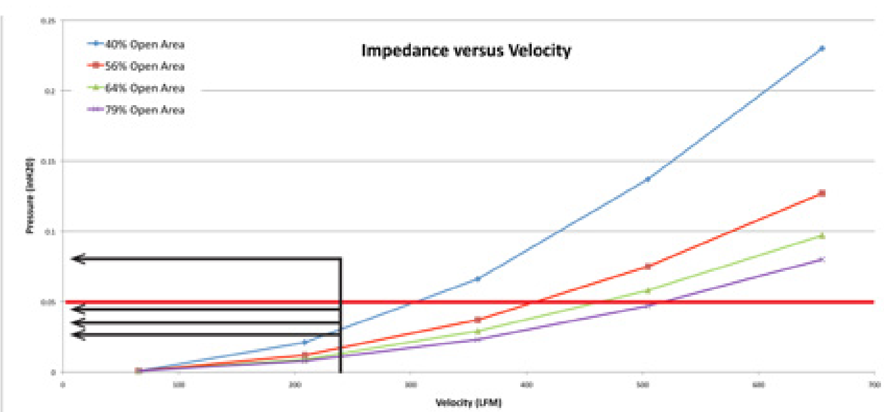

Figure 3: System operating points for various perforations 2 m/s (394 ft/m)

acceptable and the difference between 64 percent and 80 percent perforation is minimal.

Comparing this analysis with the BICSI 002-2011 specification shown in Equation 4, the assumption used to determine the maximum allowable open air ratio of 63 percent over the total IT door opening is accurate. This would correlate to a maximum typical IT airflow pressure drop of 0.86 mm (0.034 in) for the extreme case of 2 m/s (394 f/m) for the previous test case.

Conclusion

This study provides the fundamental analysis of how to calculate the pressure loss of air flowing through a perforated plate. Pressure loss (or energy loss) is dependent not only on cabinet level perforation but also on the total airflow through the perforation and the overall cross-sectional area of the perforation. The tools provided here can be used to determine the pressure loss through perforations ranging from 40 percent to 80 percent for a range of IT loads. For the two examples of extreme cabinet loading, 30 kW at a 16.7C (30F) temperature rise and 11.1C (20F) degree temperature rise, the pressure loss difference between 64 percent and 80 percent perforation was minimal. The difference is so small that the pressure due to the perforation would have negligible impact on the IT fan energy consumption.

Pressure loss is not the only factor to consider when choosing a cabinet door and perforation type to properly support the IT equipment. Other issues are cabinet security, structural rigidity and industrial design. Consider these factors when determining what percent of perforation will be needed to balance features and performance to ensure the best total solution. ■