CPI CABINET THERMAL MANAGEMENT

WHITE PAPER

How Cabinet Perforation Impacts IT Airflow

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Nomenclature:

E = Energy

P = Static Pressure

ρ = Density

V = Velocity

g = Gravitational Constant

h = Height

F = Loss Coefficient

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

$\mathrm{S_D}$ = Total door open surface area

$\mathrm{F_{ea}}$ = Perforation percentage

$\mathrm{A_c}$ = Open area width

$\mathrm{H_{rmu}}$ = Height of rmu

$\mathrm{N_{rmu}}$ = Number of rmu

rmu = Rack-mount unit height

Introduction

When choosing a cabinet door for your data center it is essential to ask yourself what level of perforation will be needed. Opinions on this subject are extensive, and some experts will tell you that for high-density heat loads of 30 kW and above, you need 80% perforation, while others will say only 64% perforation is needed. Data center technology develops at a rapid pace and every day new discoveries are uncovered, which is why there is more to this question than just a single number. This study will give you the tools to identify what level of cabinet perforation best suits your specific application and will show that for a large cross sectional area, using a perforation of 64% does not impact airflow and there is no loss in performance even at extreme density loads of 30 kW and above.

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, we need to 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:

$$\mathrm{E1} = \mathrm{E2} + \mathrm{Ef}. \qquad [1]$$

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

$$P_1 + ½\rho_1 {V_1}^2 + \rho_1 g h_1 = P_2 + ½\rho_2 {V_2}^2 + \rho_2 g h_2 + ½\rho_f \mathrm{F} {V_2}^2 \, . \qquad [2]$$

Where the last term of equation 2 represents the minor energy loss due to the perforated plate:

$$Ploss = ½\rho_f \mathrm{F} {V_2}^2 \, . \qquad [3]$$

What equation [3] implies is 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.

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

1. How large is my perforated area?
2. What is the open area ratio of the perforation?
3. What is the loss coefficient associated with the type of perforation that I'm choosing?

We have completed extensive studies of each of these parameters and in the following sections we will illustrate how each of these should be considered, and the limits of each type of perforation.

It is important to note that this body of work is an extension beyond the BICSI 002-2011 Data Center Design and Implementation Best Practice Guideline. Whereas the airflow capacity for mesh doors (AFCMD) ratio of the BICSI 002-2011 specification is:

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

$\mathrm{AFC_{MD}}$ is the airflow capacity ratio of the mesh door

$\mathrm{S_D}$ is total door open surface area

$\mathrm{F_{ea}}$ is the perforation percentage

$\mathrm{A_c}$ is the width open area (17.75in)

$\mathrm{H_{rmu}}$ is the height of a single rmu (1.75in)

$\mathrm{N_{rmu}}$ 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 IT equipment. In addition, the BICSI Standard further also surmises that if the perforation has an equivalent 63% of open space, there will be minimal pressure impact due to the presence of the perforation.

This study takes the BICSI Standard 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 determining pressure loss through the door. This analysis is not meant to replace the airflow capacity ratio, but to further enhance the understanding of the standard.

Determining Proper Perforation Size and Type

Now that it's known from equation 3 how perforation, velocity, and loss coefficients can impact the pressure loss through a cabinet, it's time to understand how this impacts real world applications. The first step in determining the proper perforation for your application is to understand the airflow requirements of the equipment that will be used in your cabinet. If, for example, you want the cabinet to support 30 kW of IT load with servers, switches and other heat generating devices, you can expect that the equipment will operate at a 30˚F (16.7˚C) temperature rise from the intake of the equipment to the exhaust of the equipment and would need 3,154 CFM (1.49 $\mathrm{m^3/s}$) of airflow to cool your cabinet.

To place this further in perspective, we used IBM's BladeCenter Power Configuration tool to model a real world application. We modeled a fully loaded 42U 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 30˚F (16.7˚C) temperature rise. This correlates to a maximum 2,288 CFM (1.08 m^3/s) of measured airflow consumption. It's important to note that most of the OEM configuration tools will directly provide the CFM consumption of the IT equipment. If you don't have the airflow readily available, we have provided Table 1 for you to estimate the required CFM for your application.

Delta T (˚F)	CFM	Power (W)
20	1577.3	10000
20	3154.6	20000
20	4731.9	30000
30	1051.5	10000
30	2103.0	20000
30	3154.6	30000
40	788.64	10000
40	1577.3	20000
40	2365.9	30000

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

Next, we need to use our previously specified cabinet CFM, identify the type of perforation we want to analyze (free air ratio), and determine the overall cross-sectional area we have available for the perforation. Figure 1 illustrates common perforation types for a given FAR. Common perforations range in size and shape depending on the application used. In our study we have chosen samples of perforation ranging from 40% FAR up to 80% FAR to illustrate the extremes of our analysis.

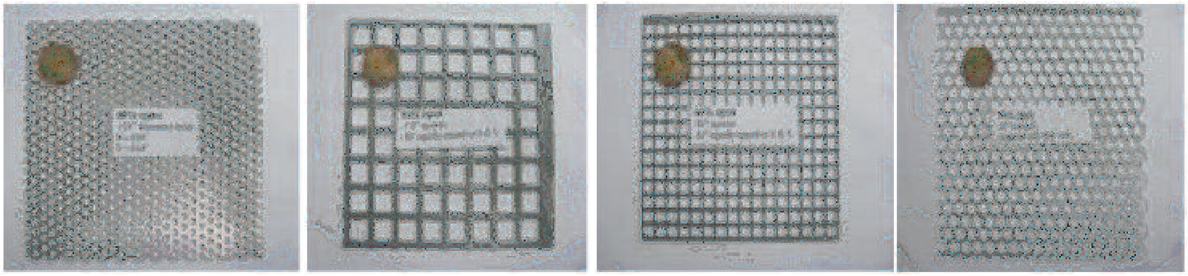

Figure 1: Perforation samples from left to right, 40%, 56%, 64%, and 80%

We can now use the cross-sectional area, and cabinet level CFM to determine our approach velocity. If we continue to use our previous example that requires 3,154 CFM (1.49 m^3/s), and our perforated door is 2' by 6' (0.6 m x 1.8 m), the overall approach velocity of air through our cabinet door is calculated to be 263 LFM (1.3 m/s). This was calculated from the following equation;

$$V = \frac{\text{Volumetric Flow}}{\text{Total Area}} \qquad [5]$$

From equation 3, you can see that the velocity is squared and is the dominant term in the pressure calculation, and from equation 5, it is very important to understand that total cross- sectional area is used to determine the velocity through the perforation. If our perforation area had only been 2' by 3' (0.61 m x 0.91 m), our overall velocity would have doubled to 526 LFM (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. All you need to do is identify which cross-sectional area from the following tables you would like to use, and look up the approach velocity through the perforation. In the next section we will use this velocity to investigate the pressure loss through the perforation.

Delta T (°F)	CFM	Power (W)	Door Width (ft)	Door Height (ft)	Total Area (ft^2)	Total Velocity (ft/min)	Velocity (m/min)	Velocity (m/s)
20	1577.3	10000	2	6	12	131.4	40.1	0.7
20	3154.6	20000	2	6	12	262.9	80.1	1.3
20	4731.9	30000	2	6	12	394.3	120.2	2.0
30	1051.5	10000	2	6	12	87.6	26.7	0.4
30	2103.0	20000	2	6	12	175.3	53.4	0.9
30	3154.6	30000	2	6	12	262.9	80.1	1.3
40	788.64	10000	2	6	12	65.7	20.0	0.3
40	1577.3	20000	2	6	12	131.4	40.1	0.7
40	2365.9	30000	2	6	12	197.2	60.1	1.0

Table 2: Velocity through perforated door for 2' by 6' perforation are

Delta T (°F)	CFM	Power (W)	Door Width (ft)	Door Height (ft)	Total Area (ft^2)	Total Velocity (ft/min)	Velocity (m/min)	Velocity (m/s)
20	1577.3	10000	2	3	6	262.9	80.1	1.3
20	3154.6	20000	2	3	6	525.8	160.3	2.7
20	4731.9	30000	2	3	6	788.6	240.4	4.0
30	1051.5	10000	2	3	6	175.3	53.4	0.9
30	2103.0	20000	2	3	6	350.5	106.8	1.8
30	3154.6	30000	2	3	6	525.8	160.3	2.7
40	788.64	10000	2	3	6	131.4	40.1	0.7
40	1577.3	20000	2	3	6	262.9	80.1	1.3
40	2365.9	30000	2	3	6	394.3	120.2	2.0

Table 3: Velocity through perforated door for 2' by 3' perforation area

Delta T (°F)	CFM	Power (W)	Door Width (ft)	Door Height (ft)	Total Area (ft^2)	Total Velocity (ft/min)	Velocity (m/min)	Velocity (m/s)
20	1577.3	10000	1	3	3	525.8	160.3	2.7
20	3154.6	20000	1	3	3	1051.5	320.5	5.3
20	4731.9	30000	1	3	3	1577.3	480.4	8.0
30	1051.5	10000	1	3	3	350.5	106.8	1.8
30	2103.0	20000	1	3	3	701.0	213.7	3.6
30	3154.6	30000	1	3	3	1051.5	320.5	5.3
40	788.64	10000	1	3	3	262.9	80.1	1.3
40	1577.3	20000	1	3	3	525.8	160.3	2.7
40	2365.9	30000	1	3	3	788.6	240.4	4.0

Table 4: Velocity through perforated door for 1' by 3' perforation area

Now that the velocity is known for our given application, we can now determine the pressure loss through our cabinet perforation. To do this, we need to understand the loss coefficients associated with the various perforation types. This is accomplished via experimental testing of the various perforation samples shown in Figure 1. 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% perforation up to 80% perforation. The summary of the test data is illustrated in Figure 2.

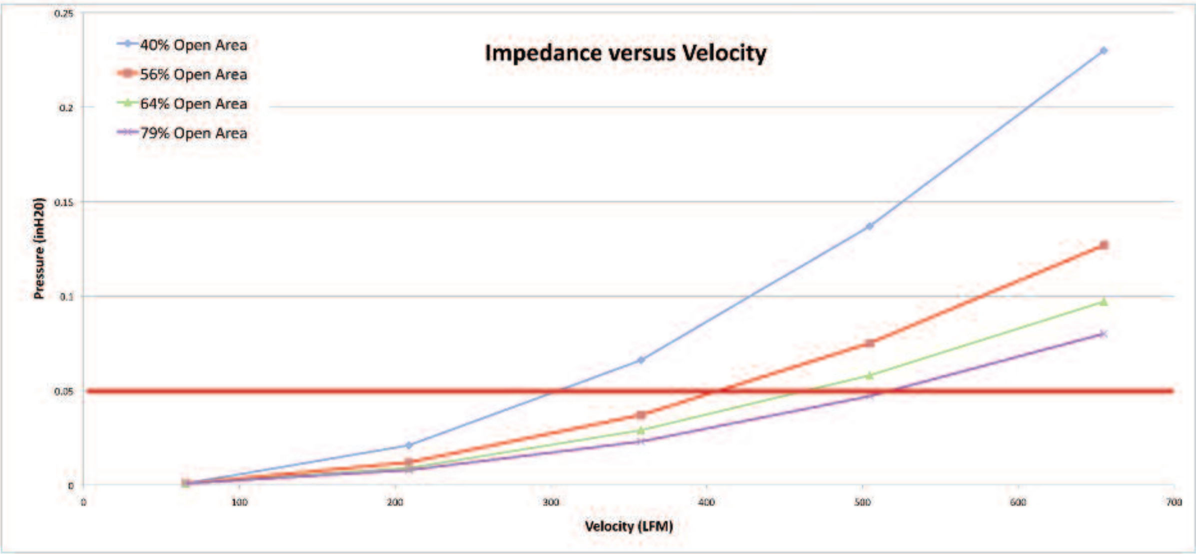

Figure 2: Perforation Impedance Test Results

If we use our prior example of a 2’ by 6’ (0.61 m x 0.91 m) cross-sectional perforation area with 3,154 CFM (1.49 m^3/s) of IT airflow consumption (which supports 30 kW of IT loading) the overall approach velocity of air into the perforated material was 263 LFM (1.3 m/s). If we now use our impedance curves obtained via experimental test data, shown in figure 3, and cross reference each type of perforation for our approach velocity of 263 LFM (1.3 m/s) shown, you can see that for a 40% door perforation we have only a 0.025”H_20 (6.2 Pa) pressure loss. At 56% perforation, we only have 0.015”H20 (3.7 Pa) pressure loss, and 64% and 80% have perceptibly equal pressure losses of 0.01”H_20 (2.5 Pa).

To understand how much pressure loss is acceptable, it’s important to understand how IT fans operate. At higher speeds, IT fans can have operating pressures on the scale of 0.6”H_20 (149.5 Pa) to above 1.0”H_20 (249 Pa) depending on the design and system operating point, and we have determined that 0.05”H_20 (12.5 Pa) is the critical point in which the pressure will cause the server/IT fans to consume additional power. This critical pressure limit is illustrated in Figure 3 as the red horizontal line. It’s illustrated that even at 40% perforation, the pressure loss of 0.025”H_20 (6.2 Pa) is minimal compared to the operating point of the IT system fans, and will have negligible impact to the performance of the IT equipment. It’s also important to note that this is the pressure through a single perforated door. If a front and back perforated door are used the pressure terms are additive. For our example above you can see that all the various perforation types satisfy our design requirement, and all are less than 0.05”H_20 (12.5 Pa) and would be acceptable to use.

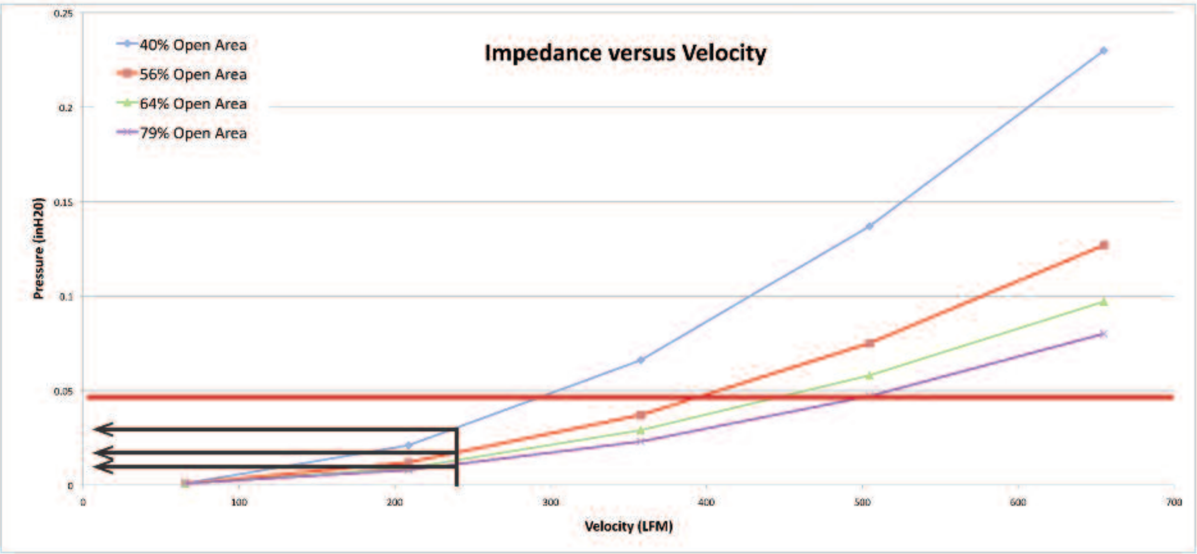

Figure 3: System operating points for various perforations at 263 LFM

If we take this to the extreme case of 30 kW of IT load at a 20˚F (11.1˚C) temperature rise through our equipment, using Table 2 you can see our CFM consumption per rack would be 4,731 CFM (2.2 m^3/s) with an approach velocity of 394 LFM (2.0 m/s), which is more than double the airflow requirement of a fully configured rack of IBM BladeCenter systems. Again, if we use our impedance data to cross-reference our system operating point illustrated in Figure 4, you can obtain the various pressure losses for each type of perforation. In this extreme case:

- 40% perforation causes a pressure loss of 0.08”H_20 (20.0Pa)
- 56% perforation causes a pressure loss of 0.045”H_20 (11.2Pa)
- 64% perforation causes a pressure loss of 0.034”H_20 (8.5Pa)
- 80% perforation causes a pressure loss of 0.03”H_20 (7.5Pa)

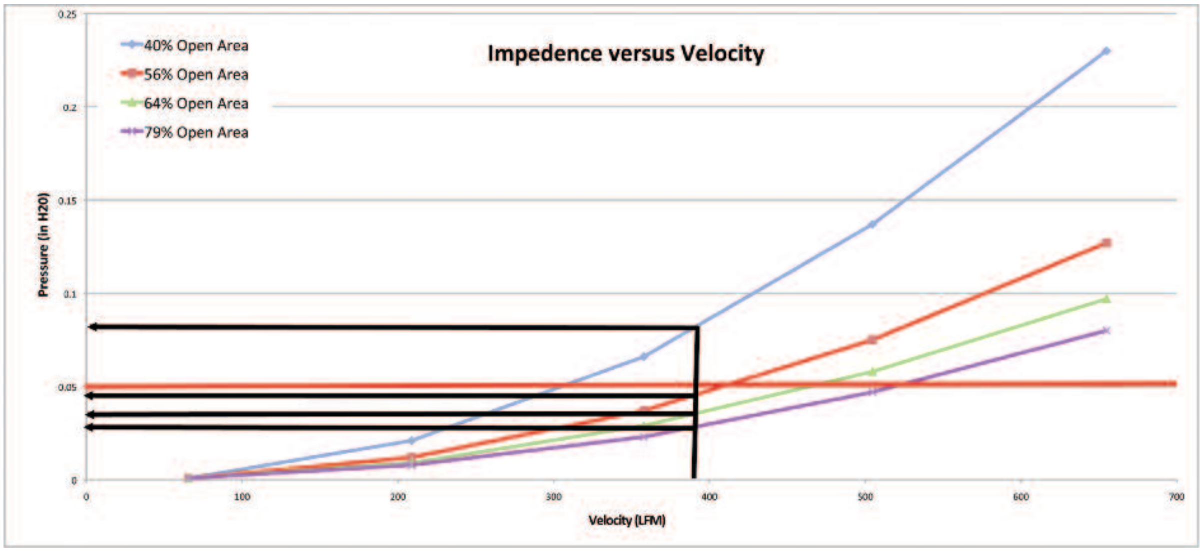

Figure 4: System operating points for various perforations at 394 LFM

Even in this extreme case, you can observe that the pressure loss between 80% and 64% is less than 0.004"H_20 (1 Pa), which is not perceivable by the IT equipment. From these two examples you can see that if the designed cabinet velocity, for a 2' by 6' (0.61 m x 0.91 m) perforation area, is less than 263 LFM (1.3 m/s), perforation type has minimal impact. And at extreme cabinet velocities of 394 LFM (2.0 m/s) the pressure loss through 56% is acceptable and the difference between 64% and 80% perforation is minimal.

Comparing this analysis to the BICSI 002-2011 specification shown in equation 4, you can now see the assumption used to determine the maximum allowable open air ratio of 63% over the total IT door opening is a good assumption. This would correlate to a maximum typical IT airflow pressure drop of 0.034" for the extreme case of 394 LFM (2.0 m/s) for the previous test case.

Conclusion

In this study we provided the fundamental analysis of how to calculate the pressure loss of air flowing through a perforated plate. We learned that pressure loss (or energy loss) is not only dependent on cabinet level perforation, but 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% up to 80% for a range of IT loads. For the two examples of extreme cabinet loading, 30 kW at a 30˚F (16.7˚C) temperature rise and 20˚F (11.1˚C) degree temperature rise, we illustrated that the pressure loss difference between 64% and 80% perforation was minimal, and is so small that the pressure due to the perforation would have negligible impact on the IT fan energy consumption. Additionally, it's important to understand that pressure loss is not the only factor to consider when choosing a perforation type. Other factors to consider regarding cabinet door and perforation to properly support your IT equipment, as well as pressure loss, are cabinet security, structural rigidity, and industrial design. Consider these factors when determining what percent of perforation you will need to balance features and performance to ensure the best total solution.

Travis North is an expert in the field of single-phase and two-phase heat transfer and in the design of electro-mechanical systems. Prior to joining Chatsworth Products, Travis held the role of Senior Thermal Architect for Dell Inc. and was responsible for designing many of Dell's Workstation products. Travis serves on the Green Grid Operations committee, DCDG committee, and consults to the thermal management workgroup. Travis is currently responsible for developing Chatsworth's line of thermal solutions.