White Paper 03

Fan-less Data Centers:

Is It Possible?

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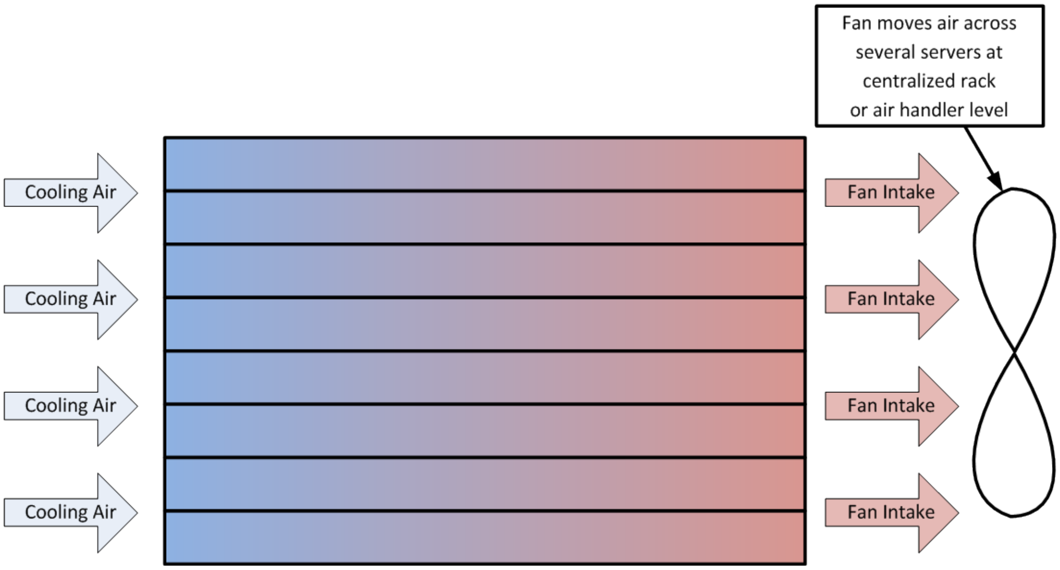
CONTENTS

INTRODUCTION

As the demand for data center space grows, enterprises are looking for more efficient and cost effective ways to build their next generation critical facility. Several large enterprise companies and equipment manufacturers are exploring the option of removing the fans from inside the servers and translating them to the rack or air handler levels.

Figure 1(a) shows the traditional design where the cooling airflow required for the internal components is drawn through the server by an integral fan within the server itself. Figure 1(b) shows the concept behind fan-less servers where the prime-mover of the cooling air is a fan outside the server and resident within the rack or central air handling stations of the data center.

(a) Schematic of computer server with integral fan



(b) Schematic configuration of fan-less servers

FIGURE 1: ELEVATION VIEWS OF SERVERS WITH FANS AND FAN-LESS SERVER CONFIGURATIONS

There are several advantages to removing fans from the servers and centralizing them as shown in Figure 1(b). First, centralized fans can be selected to operate at a more energy efficient design point than the fans integral to the servers. Under uniform loads where each server requires the same amount of cooling airflow, the more efficient centralized fans increase the data center energy efficiency compared with individual server fans. Second, a centralized fan system can be engineered with redundancy whereas integral server fans have no such redundancy. Third, centralizing fans gives engineers the ability to acoustically engineer the data center to operate more quietly.

There are also disadvantages to removing fans from the servers and centralizing them. The most obvious disadvantage is that data centers do not have servers operating at the same loads throughout. A centralized fan cannot vary the airflow to individual servers in case they require more cooling airflow than neighboring servers within the same rack. In order to be conservative, a centralized fan system needs to operate at a point that guarantees all servers have enough airflow. This means overcooling the servers that are not at full load. In spite of being more energy efficient at the design condition, a centralized fan that overcools servers is most likely less energy efficient than fans integral to the servers because integral fans can vary airflow based on the individual servers' needs.

A second disadvantage is the cost of fan-less servers which are more expensive than standard servers because they are not commonplace in the industry. Servers are already the most expensive part of a data center. The economics become better for operators who can choose from the full panoply of servers available on the market rather than relegating them to buying fan-less servers that significantly increase the overall cost of their data centers.

A third disadvantage related to cost is the fact that fan-less servers are not "in control of themselves." A server purchased with fans inside means the manufacturer's warranty covers the airflow performance within the server. This is not the case with centralized fan systems and a server manufacturer would have a good case to not honor the warranty of failed servers if the performance of the centralized fan system was suspect.

If decreasing the quantity of fans in a data center has the potential to increase net energy savings, which it does, then is it possible to design a data center without any centralized fan systems? A fan-less data center is the focus of this paper where the only fans in the data center are within the servers themselves.



PURPOSE

The purpose of this investigation is to determine the feasibility of designing a data center without any centralized fans by making use of a best-case scenario where thermal buoyancy and the server fans themselves are the prime movers of cooling airflow.

DISCUSSION

MODEL DATA CENTER DESCRIPTION

This study will analyze the data center model shown in elevation in Figure 2. The facility is a four-level structure including an intake plenum on the first level, the white space with contained cold aisles on the second level, the electrical equipment on the third level, and a relief plenum on the fourth level. For the purpose of this study each level is assumed to be 10-feet tall. The orthographic view of the data center is shown in Figure 4. The cold aisles are 4-feet wide as are the hot aisles between the cold aisles. The two outer hot aisles parallel to the perimeter are 4.5-feet wide and the ends of the aisles are 8-feet from the perimeter. The overall dimensions of the data center in plan view are 64-feet by 64-feet square. Each aisle contains 24-racks for a total of 48-racks per cold aisle and 192-racks overall in the data center.

The “vertical data center” concept shown in Figure 2 has been done before, but it is not commonplace. Besides ensuring that there will be a thermal gradient within the building, the benefit of which is discussed below, there are other significant advantages.

Notice that the Power Block is directly above the server racks. In most data centers the Power Block is remotely located to the side of the data center, whether on the same story or not, and this increases the length of electrical conduit runs between the Power Block and the servers. A vertical data center decreases the length of conduit runs by increasing the proximity of the power equipment to the data center racks.

Another advantage of the vertical data center concept is how it maximizes land use while still allowing for 100% outdoor air economization. Today's data center load densities make it almost impossible to cool servers solely with outside air unless they are housed in a one-story facility. There are exceptions; however, multi-story facilities will need large portions of the floor plate to house mechanical systems in order to maintain the capability for outdoor air economizing. The vertical data center concept still maintains the single story data center, but the supporting electrical and mechanical components fit within the same footprint as the data center itself.

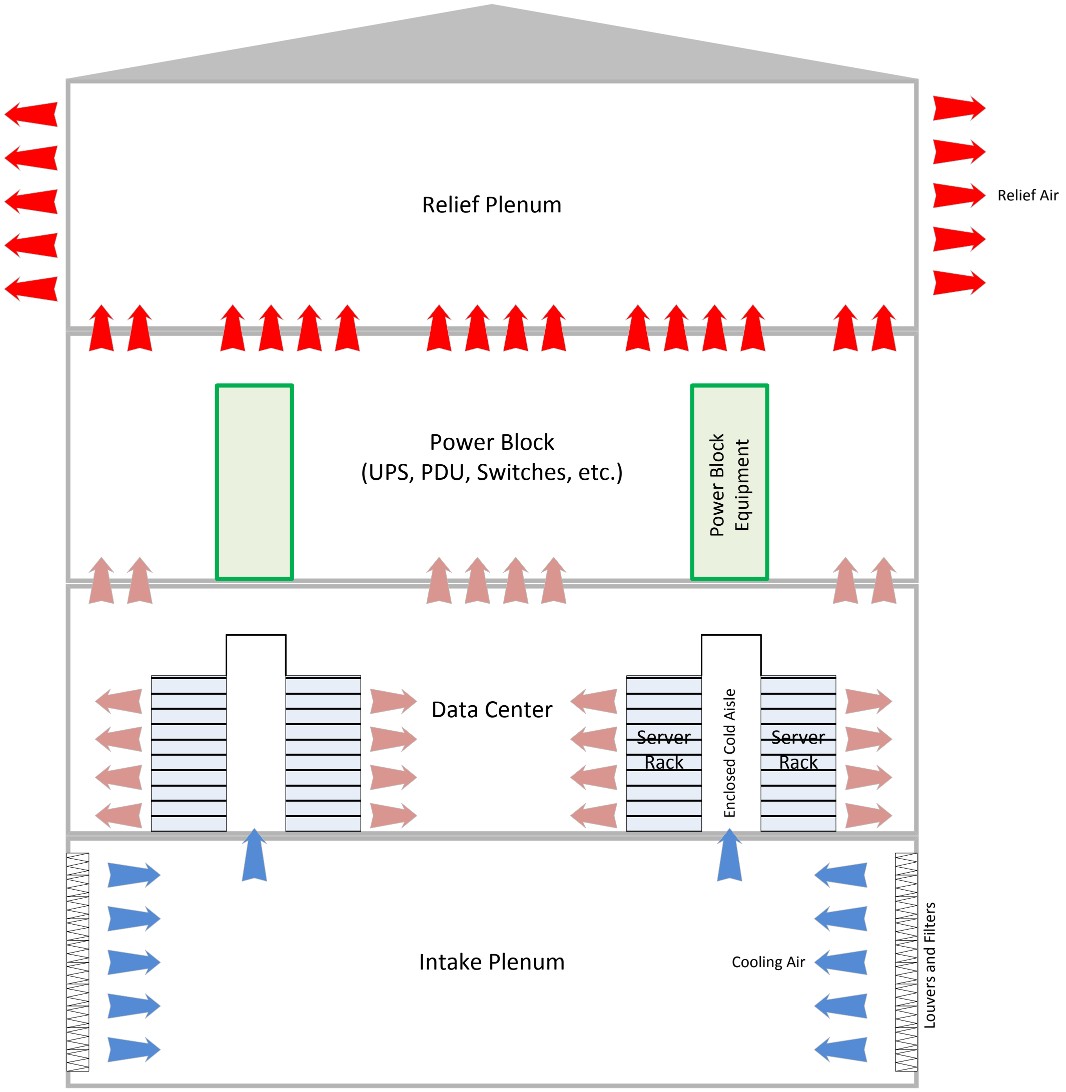


FIGURE 2: ELEVATION VIEW OF DATA CENTER

BUOYANCY / STACK EFFECT

Notice from the side view in Figure 2 that the air temperature increases as elevation within the facility increases. The sharpest increase comes as the air passes from the cold aisle through the servers and into the hot aisle. The temperature increases again as the hot aisle air of the data center is used to cool the electrical equipment on the level above. This orientation guarantees that the air at the first level of the data center will always be cooler than the air at the fourth level.

When there are openings at different levels in the exterior of a structure, then there is a possibility that a temperature difference within the structure can induce flow into or out of the building from the outside. This is known as stack effect and it is due to thermal buoyancy of the air inside the building compared to the air outside of the building. Figure 3 is an illustration of how the stack effect can infiltrate outside air into a typical home during winter. Cold air enters into the lower openings of the structure and exits out of the upper openings. The air will flow in the opposite direction during summer months due to the stack effect.

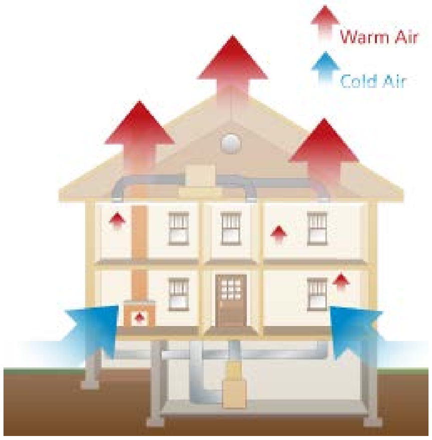


FIGURE 3: ILLUSTRATION OF STACK EFFECT IN A RESIDENCE

Comparing Figure 3 and Figure 2 shows that, in the data center modeled for this study, there will always be a stack effect because the servers and the electrical equipment will add heat to the air. This stack effect will induce air into Level 1 and out of Level 4 regardless of the season or the outside air temperature.

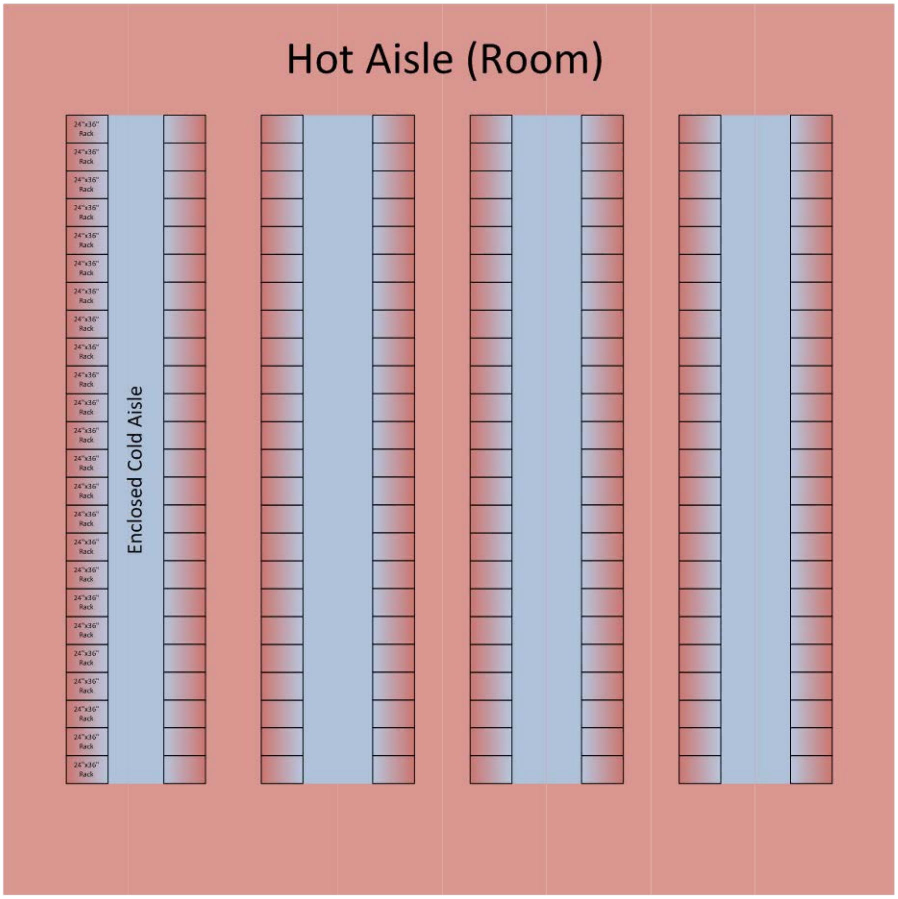


FIGURE 4: ORTHOGRAPHIC VIEW OF DATA CENTER

The fans in the servers themselves are in series (additive) to the stack effect from thermal buoyancy. Any extra pressure that they add to the air will work in favor of the general cooling airflow path of the facility. Whether or not it is fair to include any contribution from the server fans, save to move the air across the server, will be addressed later in this study.

Data Center Airflow Pathways

Figure 5shows the airflow pathway that will be analyzed in this study through the use of electrical circuit symbols. The resistors are pressure drops that the fan-less data center must overcome. The batteries are fans that add pressure to the air as it flows along the path. The letters are nodes for the purpose of calculations. The airflow pathway is detailed as follows:

Node A to Node B: Outside air Intake

The outside air enters the building first through a louver and then through a filter rack. The louver and filter used for this analysis are a model EME 3625 by Ruskin and a NovaPleat HC by Filtration Group, respectively. The combined effect is represented by one resistor in Figure 5. Assuming the intake plenum makes use of the full height and length of the walls, The table below shows the velocities and respective pressure drops of the louvers and clean filters for different temperature increases across the servers.

$\Delta T_{servers}$	10°F	15°F	20°F	25°F	30°F	35°F	40°F	45°F	50°F
Velocity[1] (ft/min)	116	78	58	47	39	33	29	26	23
ΔP_{Louver} (inches)	0.007	0.004	0.0015	0.000	0.000	0.000	0.000	0.000	0.000
ΔP_{Filter} (inches)	0.01	0.007	0.004	0.001	0.000	0.000	0.000	0.000	0.000

The pressure drop across the louver is insignificant once the temperature increase across the servers reaches 25°F because the velocity becomes so low. The same is true for the clean filter once the temperature increase reaches 30°F. For the purpose of this study the pressure drop from nodes A to B will be taken at 0.1-inches water gauge and the temperature rise at 30°F. The pressure drop would be the reading in which the facility operators would recognize that the filters are loaded and need to be changed. In a standard filter application this pressure drop would be considered quite low, but in this application the low velocities behoove selection of an atypically lower pressure drop to determine whether or not the filters are loaded.

Node B to Node C: Perforated Floor tiles

The cooling air enters the cold aisle through perforated floor tiles. The tile used for this analysis is a model Grateaire without dampers by Tate. The gross area of one of the four cold aisles shown in Figure 4 is 4-feet by 48-feet (192-ft^2). From the perforated tile cut sheet the pressure drop across the tiles at the airflow for 30°F is 0.01-inches.

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[1] The free area of the louver is 45% of the total area; therefore, the velocity across the louver is the value shown in the table divided by 45%. The velocity in the table is the velocity across the filter media.

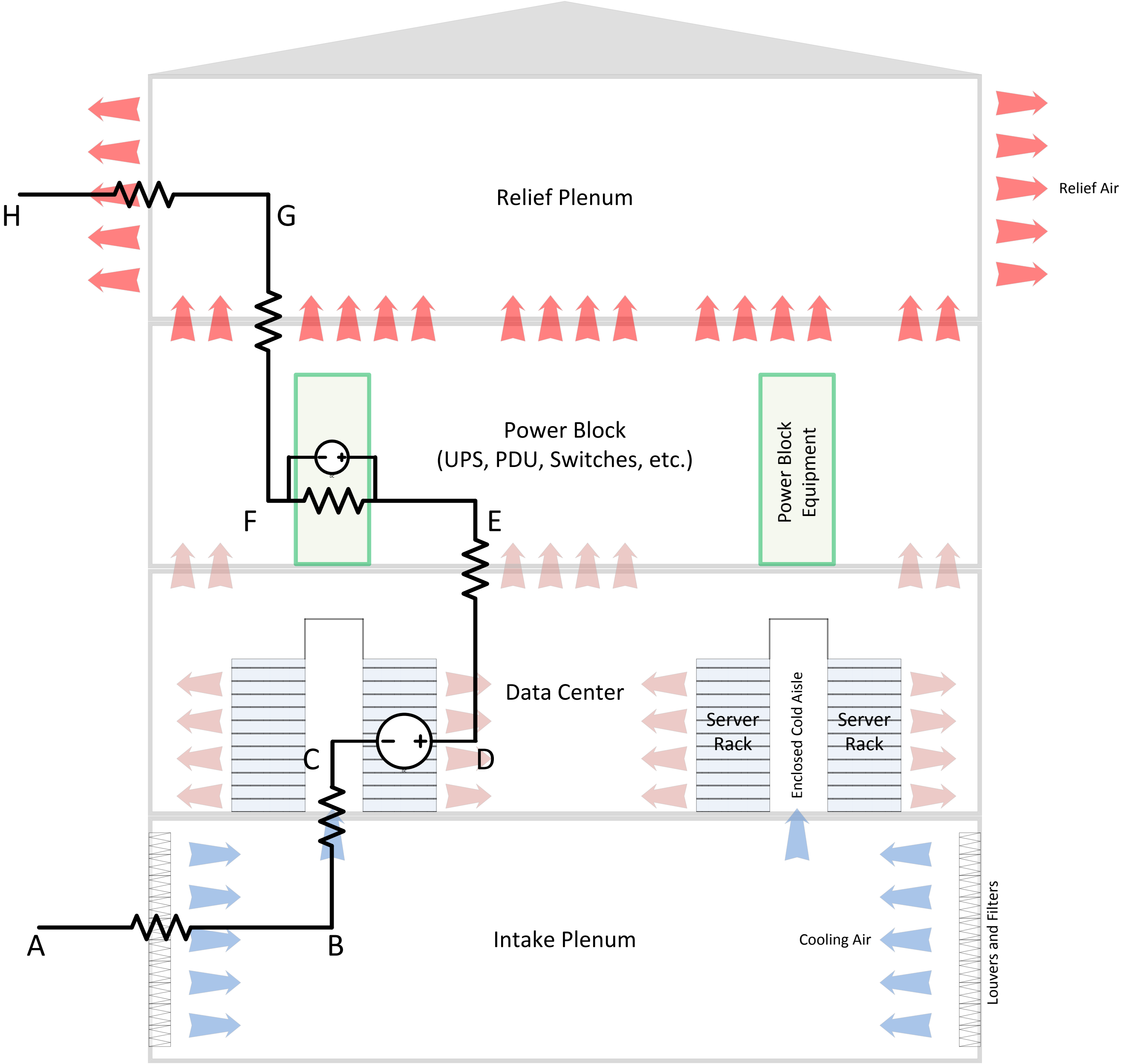

FIGURE 5: NODES, RESISTANCES AND MECHANICAL FANS OF AIRFLOW

NODE C TO NODE D: SERVERS

The air passing through the server is driven by the fan(s) within the servers. Under worst-case conditions, the server fans will only add enough pressure to overcome the pressure drop of the server itself. In reality, the server fans add slightly more pressure than what is required to draw cooling air through them. In the author's experience, data centers operate with 0.1-inches of extra pressure contributed by the fans between the front and backs of the servers. For the purposes of this investigation, the extra pressure added by the server fans shall be taken as 0.08-inches water gauge.

NODE D TO NODE E: HOT AISLE CEILING, POWER BLOCK FLOOR

After the air enters the hot aisle it is warmed by the servers; however, the equipment in the power block can still use the warm air for cooling because that equipment has less-stringent operating temperatures compared to servers. The ceiling of Level 2 and the floor of Level 3 need not be an architectural barrier; rather, a simple structural lattice to hold the electrical equipment is all that is required. For the purposes of this investigation the assumption is that there will be no ceiling at Level 2 or floor at Level 3. This means the pressure drop from Node D to Node E is insignificant.

NODE E TO NODE F: POWER BLOCK EQUIPMENT

Some components in the power block, like most UPS equipment, have integral fans that draw cooling air through them. Other components like switchgear rely on natural convection to induce airflow. This is why there is a battery shown in series with a resistor for this pathway in Figure 5. In this study, the assumption is that the powered exhaust of the UPS equipment will be just enough to overcome the overall resistance of the switches and PDU's that rely on natural convection. For this reason the pressure drop from Node E to Node F is zero. There will also be a temperature increase across the electrical power equipment. Typically the losses from all the electrical equipment is approximately 7%. For the purpose of this investigation the assumption will be 6.67% losses resulting in an additional 2°F to the air flowing through the data center.

NODE F TO NODE G: POWER BLOCK CEILING, RELIEF PLENUM FLOOR

The ceiling of Level 3 and the floor of Level 4 also need not be an architectural barrier; rather, a few beams for structural integrity are all that is required. Given that assumption there will be no ceiling at Level 3 or the floor at Level 4. This means that the pressure drop from Node F to Node G is insignificant.

NODE G TO NODE H: POWER BLOCK CEILING, RELIEF PLENUM FLOOR

The same louver will be used for the relief opening as the intake opening. There will be no filter at the relief opening. Recall that the louver pressure drop was insignificant at the intake for the airflows of this data center and the same is true for the relief louver. This means that the pressure drop between the interior of the relief plenum and the outside is insignificant.

CALCULATIONS

TEMPERATURE INCREASE

The temperature increase of the air as it travels from Node A through Node H in the data center is the sum of all individual temperature increases between the nodes. There are only two places where heat is added to the air. The first is through the servers and the second is through the power block equipment. Recall the temperature increase through the servers is 30°F and the increase through the electrical equipment is 2°F for a total of 32°F.

FRICTION AND FAN PRESSURES

The pressure drop through the data center from outside the intake louver to outside the relief louver, without including any allowance for stack effect, is given by summing the pressure drops from Node A through Node H. The total pressure drop becomes:

$$\Delta P_{Total} = 0.1\text{-inches}_{A\text{-}B} + 0.01\text{-inches}_{B\text{-}C} - 0.08\text{-inches}_{C\text{-}D} + 0.0_{D\text{-}E} + 0.0_{E\text{-}F} + 0.0_{F\text{-}G}$$

The result is that the pressure drop across the data center due to fans and friction is 0.03-inches water gauge. A centralized fan could easily overcome this pressure drop.

How can a fan-less data center overcome this pressure drop? There is one phenomenon that has not yet been accounted for.

STACK EFFECT

From 2009 ASHRAE Fundamentals (page 16.7), the pressure added through stack effect for a building with an insignificant internal resistance is given by the following equation:

$$\begin{aligned}\Delta p_s &= 0.00598(\rho_o - \rho_i)g(H_{\mathrm{NPL}} - H)\\ &= 0.00598\rho_o\left(\frac{T_i - T_o}{T_i}\right)g(H_{\mathrm{NPL}} - H)\end{aligned}$$

where

T_o = outdoor temperature, °R
T_i = indoor temperature, °R
ρ_o = outdoor air density, $\mathrm{lb/ft^3}$
ρ_i = indoor air density, $\mathrm{lb/ft^3}$
H_{NPL} = height of neutral pressure level above reference plane without any other driving forces, ft

The quantity ($H_{NPL} – H$) is taken from the midpoint of Level 1 to the midpoint of Level 4 which amounts to 30-feet for this data center. Assuming the data center is at sea level for the density and the outside air is at 70°F, then the pressure added through stack effect becomes 0.03-inches water gauge. Recall that the pressure deficit that the fan-less data center needed to overcome was 0.03-inches of water. The pressure added by thermal buoyancy through the stack effect can overcome the deficit required without adding any centralized fan system.

CONCLUSION

The results of this study support the conclusion that it is viable to engineer a fan-less data center by relying solely on the fans integral to the servers coupled with thermal buoyancy. This is a superior method for removing a fan system from within data centers because it guarantees energy savings without requiring owners to purchase uncommon fan-less servers. It also removes the need to load all servers equally because server fans are already capable of modulating based on the server's individual requirements while centralized fan systems cannot do that.

Further study of the vertical data center concept with airflow driven by thermal buoyancy will lead to incorporating heat recovery in the model for cold climates as well as mechanical or adiabatic cooling in hot climates.

ABOUT NXGEN MODULAR

NxGen Modular is a provider of mission critical modular data centers, designed to improve operational performance and efficiency, lower overall costs, and facilitate seamless growth. Fueled by a commitment to innovation, NxGen Modular is pioneering new ways to meet the needs of the world's leading data center owners and operators by providing a faster, more efficient means of building and scaling data centers. For more information, please visit www.nxgenmodular.com

ABOUT THE AUTHOR

Sargon Ishaya has over 20 years of experience in mechanical engineering with a specialty in data center design. He has analyzed and designed energy-efficient mechanical systems for over 1,000,000 square feet of data centers around the world. He is also a leader in the emerging solar-thermal industry and has worked in the biotech, semi-conductor and commercial office building sectors.

Currently leading all mechanical engineering activities at NxGen, Sargon has worked at several design/build firms in the Bay Area as well as heading his own consulting business. He is an adjunct Mechanical Engineering Professor at San Jose State University and serves as an advisor for several Master’s Degree students every year.

Sargon received his Master's Degree from Stanford University and his Bachelor's Degree from California Polytechnic University. He is a registered Mechanical Engineer in California, a LEED Accredited Professional, a NEBB Associate and a two-time past president of the San Jose ASHRAE chapter.