IT EQUIPMENT RESPONSE TO EXTERNAL PRESSURE

A Dell™ Technical White Paper

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Introduction

The integration of IT equipment and facility cooling solutions can produce both unexpected and undesirable results. Containment solutions are highly recommended. After eliminating the mixing of hot and cold air in the data center, large efficiency gains can be achieved by turning up room temperatures and dropping facility flow rates. In general, the more rigorous the segregation of hot and cool air, the larger the potential efficiency gain. Rack level containment can be so tight however, that it can induce external air pressure effects on the IT equipment. External air pressure may cause internal component temperature increases and/or power increases associated with the fans within the IT equipment. This paper discusses the potential effects of external pressure applied to the IT equipment and the fan response of the IT equipment.

External Pressure

HVAC manufacturers have historically specified external static pressure limits for their equipment. For example, CRAC/CRAH units are rated for a specific airflow with a particular external pressure assumption. This means that full-rated flow can be anticipated as long as the resistance against which the unit is pushing (for example, raised floor, venting, etc.) does not exceed the static pressure limit. If the limit is substantially exceeded, a large reduction in flow rate can be expected. Likewise, IT equipment faces challenges due to external static pressure. Any condition external to the individual IT equipment chassis that is more resistive to airflow is considered an external resistance and can be represented as an "external pressure curve." Typical items would include things like a standard rack and cable management apparatus. Even a rack with no doors causes some external resistance. Dell takes these common resistances into account when designing the fan control scheme within our products. Our equipment should operate as intended when coupled with our rack and cable management products. It should also work as intended with 3rd party racks as long as they have at least a 60% perforation pattern in the doors. There is little resistance difference between 60% and the 80% opening on Dell's current rack products.

There are, however, other rack products which result in larger, external static pressure.

A chimney rack is the simplest example to visualize. It is much easier to push air through a standard perforated door than it is to force air up through a length of chimney in a rack with a sealed rear. Unless it is actively assisted with chimney fans or aided by air handlers coupled through the return ceiling plenum, a chimney rack is a resistance that the IT fans must overcome. Other examples of tight containment include, but are not limited to:

- A passive rear-door coil
- A self-contained rack where rack flow rate is not adequately matched to IT flow rate

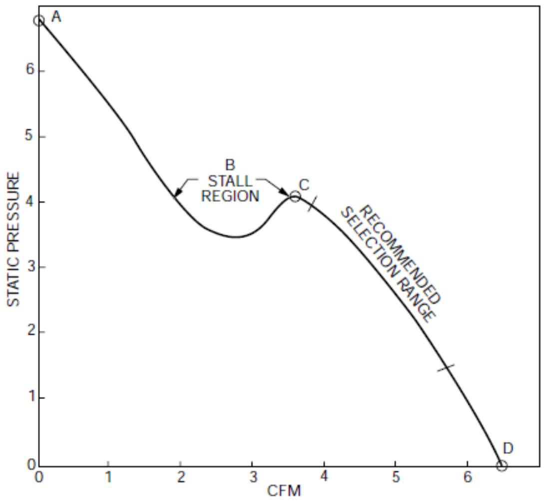
This paper will quantify some of these external resistances as well as the resistance for a standard rack. For the purposes of this paper, external resistance will be defined as the sum of the absolute values of the pressure in front and in back of the IT equipment. For front-to-back cooled equipment, there should be a negative pressure (relative to the room) in the front cavity and a positive pressure at the back. Depending upon the IT equipment, there are several possible reactions to this external pressure.

IT Equipment Fans—How They Operate

Air-cooled IT equipment utilizes internal fans to move air into and out of its chassis. The IT equipment may use control algorithms to increase or decrease the fan speed based on temperature, configuration, or load characteristics. The fan speed setting, however, is not the only driver of the equipment airflow magnitude. Airflow is also a function of the amount of pressure, or impedance, against which the fans push. Consider the following generic fan curve:

IT Equipment Response to External Pressure

Figure 1: Generic Fan Curve

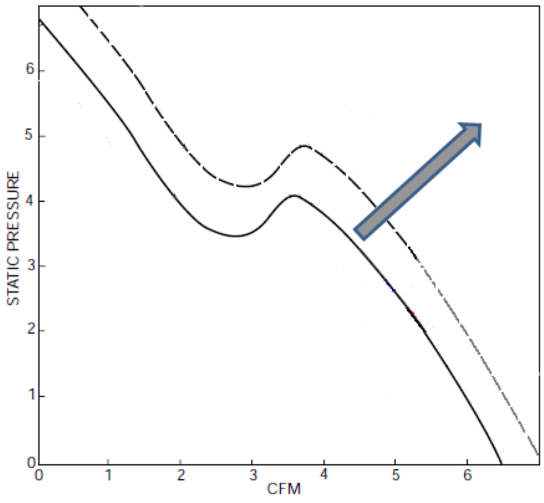


The curve is displayed in terms of flow rate (CFM, or cubic feet per minute) and static pressure (typically inches of water). The curve shows that the fan produces maximum flow rate (point D) when it is not pushing against any airflow impedance (zero static pressure). The fan delivers no flow (point A) when it is pushing against nearly 7 units of pressure. At a pressure just above (to the left of) point C, many fans reach an unstable region. An interesting point to note is that CRAC/CRAH units are designed such that if the external static pressure approaches the vendor's specified limit, the combination of the external resistance and the coil resistance places the operating point very close to point C on this curve. If the static pressure is exceeded much past its limit, the unit could slip into the stall region and experience a drastic reduction in flow.

During the early stages of IT equipment design, thermal engineers typically architect the equipment fans to operate below (to the right of) point C. This curve, however, is representative of a fan operating at one specific speed. With variable systems, a speed change would be reflected as a diagonal shift in the operation curve. If the fan speed is increased, for instance, the fan would operate on a similarly shaped curve that is shifted both up and to the right (Figure 2).

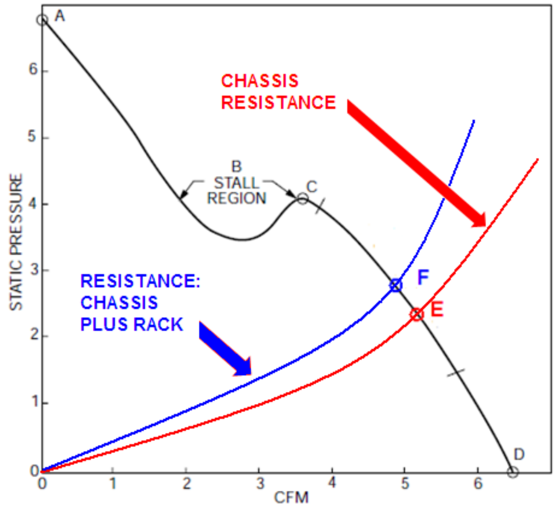
IT Equipment Response to External Pressure

Figure 2: Variable Speed Operation



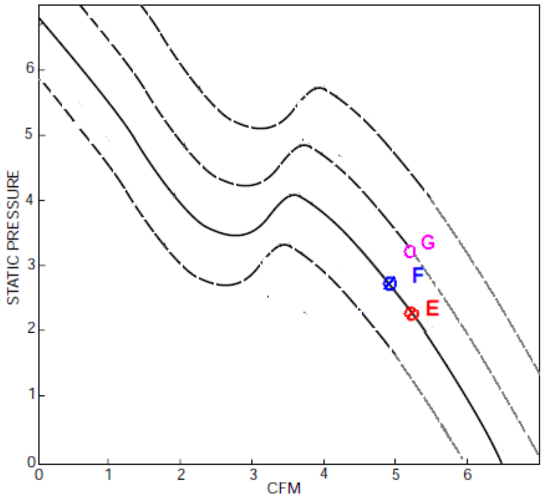
Within any particular piece of IT equipment, as air is pulled into the chassis by the fans, it moves through, around, between, over, and under grills, hard disk drives, walls, board components, heat sinks, and expansion cards before exhausting out of the back side of the equipment. The fans see these "obstacles" as resistances that must be overcome to produce a targeted amount of airflow. All these system "resistances" add up and may be represented as a curve where pressure increases exponentially with flow rate (in other words, the curve passing through point E in Figure 3).

Figure 3: Resistance Curves



In this case, the flow through the fans would be slightly over 5 CFM (point E). This is typically not the only pressure the fans experience. In this example, the curve through point E is only representative of the resistances located within the IT equipment. Once placed in the rack, the equipment competes with others to ingest its volumetric requirement of air. Even without the perforated doors closed, there is increased resistance; but, with the doors closed, it is even higher. The apparent pressure on the IT fans is now represented by the curve passing through point F. It can be seen that the increase in pressure has a corresponding decrease in flow rate at point F. With less airflow moving through the equipment, component temperatures would likely increase. Depending on the sensitivity of the IT equipment fan control, this temperature increase may alternatively be countered by a fan speed increase.

Figure 4: Alternative Response to Pressure

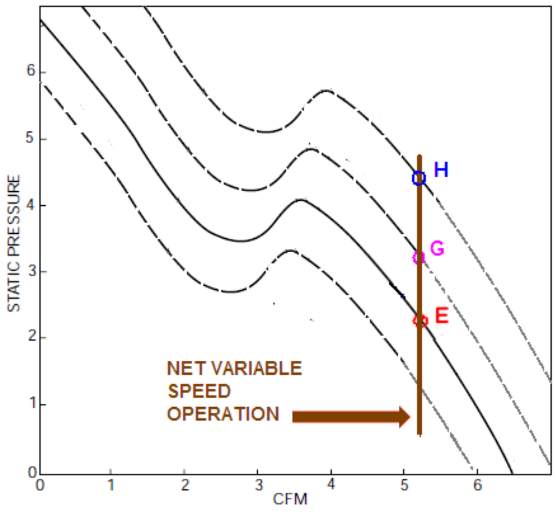


In a variable speed system, rather than the pressure-induced shift to a lower flow rate (represented by point F), the system may respond with a fan speed increase. Point G is an example where rather than a slowing of flow rate, the system fan control speeds up the fans and counters the effects of the pressure increase.

In Dell systems, fan speeds are controlled by the baseboard management controller (BMC). Custom algorithms are generated for each server that can reflect changes in component configuration or temperatures. Because temperatures are affected by application loading and external system pressure, the algorithms can respond to these variables as well. In simple terms, each server design has an established lowest flow rate; the fans are set not to turn any slower. The choice for the lowest flow rate is made on multiple, platform-specific decision points. The fans also have a maximum flow rate. Our designs typically target adequate cooling at the maximum fan speed after a loss of one fan. The BMC sends individual signals to each fan to achieve its target speed which could be any of 100 steps between lowest and full speed, so it is a very granular transition from lowest to highest speed.

Figure 5 reflects a trend that was apparent during the testing of the latest generation of Dell servers. We tested multiple external pressures which included high pressures that greatly exceeded what would be expected for known rack solutions. In each case, as pressure was increased, the server responded with a fan speed increase that resulted in a near vertical flow rate line relative to pressure. Essentially, the fans compensated but had to work harder to produce about the same amount of airflow.

Figure 5: Server Compensation for External Pressure



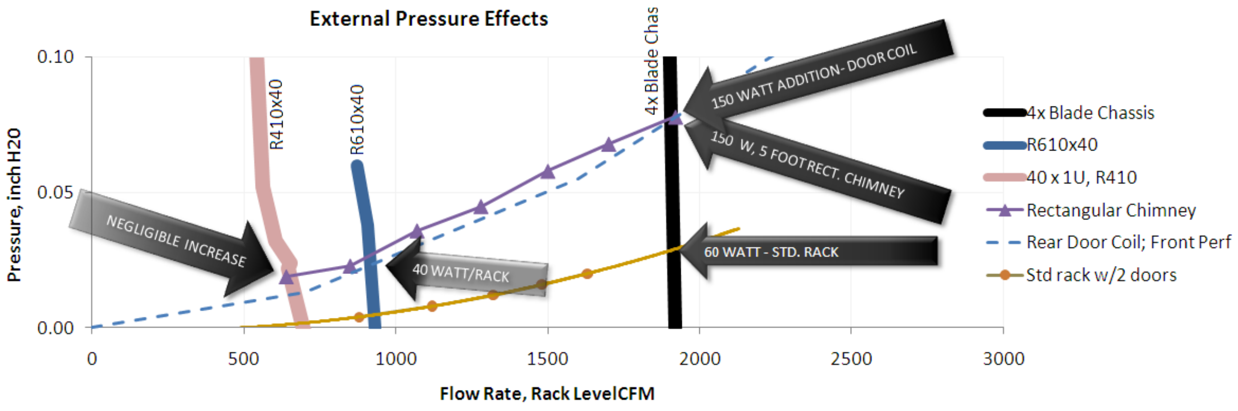
Specific Server System Response

Figure 6 shows the response of three specific Dell servers of the current generation. In each case, the rack is occupied by 40U of each server (40 1U Dell R410 systems, 40 1U Dell R610 systems, or four Dell M1000e blade chassis). Each responds with a near-vertical flow rate curve relative to external pressure (similar to the "net variable speed operation" curve of Figure 5). The pressure effects for three common rack resistances are also shown on the graph:

- A standard rack with front- and rear-perforated doors
- A chimney rack with front-perforated door
- A rack with a front-perforated door and a rear cooling coil

Unlike Figure 3, the pressure/resistance curves are representative of the external resistance only. Any intersection between a server curve and a rack resistance curve represents the operating point for the aggregate of the systems in the rack filled to 40U. The chimney rack had a sealed rear cavity and a 5-foot rectangular chimney vented to the room (no connection to a return plenum).

Figure 6: Specific Dell Server Response to External Pressure



In each case, the operating points are labeled with the resulting server-fan power increase. The R410, for instance, had a negligible power increase for any of the rack solutions. The R610 responded with about 1 watt per server or

40 watts per rack when coupled with the chimney or door coil. The larger flow rates associated with the blade rack resulted in larger server power increases (about 150 watts for a rack operating at ~20 kW).

Each of the server curves in Figure 6 is configuration and inlet-temperature dependent. The server tests were done at normal lab temperatures (~23°C/73°F), which typically results in low fan speeds. Had the testing been done at higher temperatures, pressure induced fan power increases would most likely have been larger. The blades that were tested were a rich configuration (~20 kW over 4 chassis). Lighter configurations would produce a near vertical pressure response but at a lower flow rate (curve shifted left in Figure 6). The PowerEdge R410 *appears* to be more susceptible to pressure; the flow rate curve is the least vertical of the three servers tested. The particular test configuration was a light configuration in which a couple of fans were depopulated. Because of this, there is a greater potential for internal recirculation. Individual fan increases may have actually been comparable for this server, but the resulting system flow-rate measurements were somewhat muted due to increased internal recirculation. In each case, server component temperatures were quite consistent over the range of external pressures.

Key Takeaway

Servers have not always responded this closely to external pressure. Most storage systems probably still do not. The evolution of fan control in servers has progressed quite rapidly. Component level inclusion of temperature sensing has enabled more discrete points to be used as feedback for fan speed control. Just a few short years ago, only the processors had the ability to give temperature feedback. The remainder of the system relied on gross level air temperature measurements. Conservatism had to be used in the fan control design to ensure adequate component temperatures; in other words, fans were run faster to take into account the uncertainty associated with air temperature rather than component temperature measurements. A risk lies in the fact that pressure-induced higher temperatures might go unnoticed in these older servers because of the lack of discrete temperature monitoring=. If an unspecified external pressure is applied to equipment for which it was not designed or to which it does not adapt, the effect is unknown. This risk exists for older servers, with new server designs that do not compensate for pressure, and also with other IT equipment that may not compensate. What are the risks? If the pressure effect can be quantified, it is not hard for an IT vendor to assess the response. A solution like the door coil is a stand-alone solution with a measureable resistance. A representation like that in Figure 6 would suffice to compare to any IT system and assess its impact. A passive chimney poses more difficult problems. The resistance of the passive chimney system is going to depend on the rear cabinet depth, the size and length of the chimney, and how the chimney interacts with the return plenum. It is somewhat more complex to quantify the risk.

There are other risks if the pressure is not compensated for. Elevated component temperatures are a possible outcome. There could be minor reliability impacts, but they are probably less significant than performance concerns. Temperatures could potentially rise to a point of component throttling that would affect performance. This is a server-centric statement more so than one for storage. An increase in hard drive temperatures in a storage system would not likely result in performance degradation, but it could slightly lower the long term reliability of the drives. Fan control is a differentiating point between server vendors. Not all vendors take full advantage of temperature enablement within today's components.

Is there a downside? Unless you intend to run your equipment at the maximum specified operating temperature 24 hours every day, you should not experience complications with the servers compensating for pressure. As mentioned, server thermal design typically provides for operation with in-specification component temperatures at worst-case inlet temperature (typically 35°C/95°F), at full configuration (maximum DIMM, highest power processors, etc), running worst-case loading, and with a fan failure. If operating with all those extremes, the fans would be running at, or close to, 100% speed. If, however, pressure has caused an increase in fan speed, some of the thermal headroom has been exhausted. The maximum temperature might not be attainable (or at least attained with redundancy).

Other Pressure Effects

Although this paper is about IT equipment response as it relates specifically to pressure, there is a secondary effect that should be mentioned. Recirculation between IT systems in a rack can result in elevated IT-inlet temperatures. Elevated temperatures can cause higher IT fan power and also limit the intentional increase in room temperature which is an energy savings strategy and one of the main goals of containment. The increased pressure differential within a tightly contained rack can exacerbate the amount of recirculation, especially in racks with many gaps (i.e., 1U or 2U deployments).

Conclusions and Summary

IT equipment has historically been designed to accommodate the resistance of a standard “flow-through” rack at most. Some new rack solutions impose pressures that exceed those of standard racks. IT equipment reactions can vary, for example:

- New Dell servers counter the added pressure with fan speed increases:
    - Proper component temperatures are maintained.
    - Increased fan speed uses extra power; examples cited were less than a 1% increase. The server responds to pressure as a result of the temperature of a component exceeding an acceptable limit. This only happens if the airflow design is optimized and delivering only as much air as that component needs, so that it is just below its limit.
- Less sophisticated servers may not be taking advantage of discrete component feedback and may not have as granular a response:
    - Fans may not speed up:
        - It is possible that the server had margin and that component temperatures did not increase past acceptable levels; in this case, the server was overcooled to begin with.
        - Component temperatures could exceed thresholds where throttling occurs.
        - There could be minor reliability concerns.
- Servers with less-sophisticated discrete fan speed control might have a large step increase to counter the pressure-induced temperature increase. The fan increase could overshoot the necessary additional airflow; causing waste, in contrast to Dell’s continuous fan speed control. Storage and networking equipment fan control has typically lagged behind servers in complexity and effectiveness.

Care should be used when pairing equipment with tight containment systems; the vendor of your IT equipment may need to be consulted to assess the impact of pressure on the equipment.

The purpose of this paper is for containment designers and facility architects to obtain a better understanding of IT equipment response to external pressures. This should aid in designing and implementing containment solutions more effectively. Facility owners should note that not all passive containment systems have a net “passive” result since they can impose external pressures that result in increased component temperature, increased fan speed and power consumption, or a combination of the two. Facility owners should also be aware of external pressure issues associated with some forms of containment and of the unintended consequences mentioned in this paper.

The passive rear-door heat exchanger and passive chimney solutions cause less than a 1% increase in fan power for the 20 kW blade rack cited in this paper; the percentage increase was even less for the 1U racks cited—a small increase considering the benefits associated with containment. Energy savings elsewhere in the data center far exceed this small increase in the IT equipment fan power; for examples of savings, see the Energy Advantages of Containment whitepaper[1]. Special attention should be paid to chimney containment. The example in this paper was for a specific diameter and length of chimney. Smaller cross sections or longer chimney lengths would increase the detrimental pressure on the IT equipment if the pressure exists. While it is possible that the air handlers will actually draw through the return plenum and aid the flow through the chimneys, there is no guarantee for this scenario, depending on the chimney location relative to the air handler. The entire design should be examined (plenum, chimney, and rack design) to ensure there is no negative effect on either the IT equipment or the air handlers. If you already have a chimney system in place, it is easy to check. If the rear of the rack has a positive pressure relative to the room, the servers are successfully pushing air up the chimney. If the pressure is negative, the air handlers are most likely helping the chimneys. Although this may raise your confidence level in the IT equipment, the static pressure limit on the air handlers should not be ignored. Not only are the air handlers pushing against the pressure of the raised floor (if that is the delivery mechanism), but they are also pulling against the pressure of the return plenum and chimneys. As mentioned earlier in this paper, applying a load greater than the static pressure limit of a CRAC/CRAH unit could push the unit into the stall region described in Figure 1. The resulting flow rate could end up on the other side of the stall region which is a drastic flow reduction.

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[1] Energy Advantages of Containment Systems; David L. Moss, 2009; http://content.dell.com/us/en/corp/d/business~solutions~whitepapers~en/Documents~dci-energy-advantages-of-containment-systems.pdf.aspx