Enclosure Thermal Testing

Heat Removal In The Real World

Switch to perfection

RITTAL

I. INTRODUCTION

As a leading manufacturer of enclosure solutions, Rittal is frequently asked to make recommendations for cooling cabinet-installed active components supporting network and server operations. With a host of sometimes contradictory information being published, the tests were performed in an active data center, with active components and well established operational parameters. This "Real World" test program provides results for how entire facilities – servers, enclosures, climate control, etc. work together to remove heat generated in these spaces.

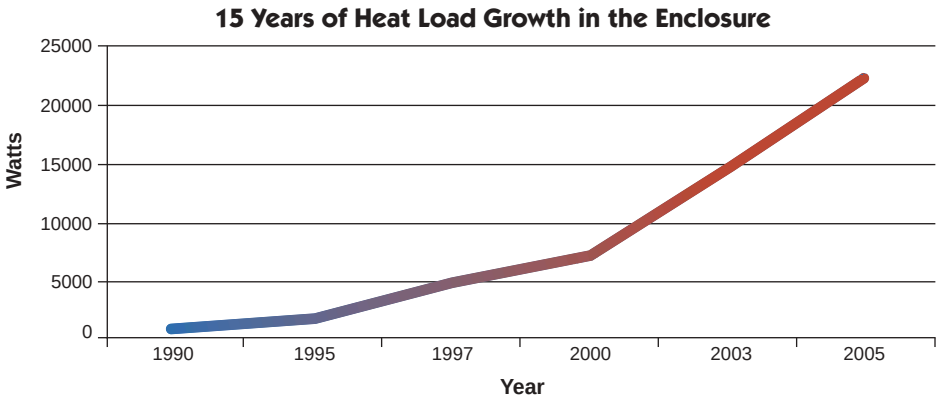
With an eye towards "Best Practices", the purpose of the testing program is to provide temperature data from a variety of enclosure and facility configuration variables; set-ups commonly found in today's data center environments. While the data indicates certain designs perform better than others, each reader is left to draw individual conclusions as to the `Best' cooling solution based on specific site and end user criteria. Finally, this paper will provide recommendations and suggestions, based on empirical data, for climate control and enclosure design and selection.

II. HEAT ON THE RISE

Cooling and heat removal, in a data center and at the enclosure level, have quickly become the most critical factors in data center design. With the exponential increase in deployed servers, heat loads have almost quadrupled in the last seven years. While early sites were designed to support 50 – 100 watt/sq.ft. loads, today's facilities are required to support up to 200 watts/sq.ft. and greater. Can 350 watts/sq.ft. be far behind? Worse, these increasing loads are often concentrated in limited floor spaces in the data center.

In the last 2-3 decades, the unparalleled growth of computing power and information storage has been staggering *(See Figure 1)*. The first data facilities were designed to handle large main-frame systems. IBM, DEC and others were the leaders in this field, building more powerful systems while keeping to a relatively fixed footprint. Some of these systems were liquid cooled, with chilled water (usually from building supply) channeled through mainframe hardware. With the advent of the microprocessor, chips took over as the brains of computer systems. Simultaneously, storage moved from tape and disk to much smaller form factor media. As computational power increased and chip size decreased, water was phased out, replaced by ambient air as the primary cooling medium. Existing facilities were not ready to handle these growing heat loads.

Climate control requirements in the data room impacted other areas of data room design. Computing power and storage needs grew as the way we do business progressed. Eventually, the Data Center was born. And then rack mount servers were introduced. Originally thought to be for standalone applications of one or two enclosure-based systems, the rack mount server quickly evolved to be THE enterprise. Servers could not be deployed quickly enough to support the growing demands of Information Technology. Data facilities



Year	BTU/Hr	Watts	Comments
1990	500	145	Early Token Ring and Ethernet Components
1995	1200	348	Tower or Desktop PC's
1997	15000	4350	1st Generation Rack Mount Servers
2000	22000	6380	2nd Generation Rack Mount Servers
2003	45000	13050	High Density (1U) Rack Mount Servers
2005	70000	20300	Blade Servers and Future

Figure 1

were quickly populated with hundreds of enclosures supporting ever-increasing numbers of rackmount servers and storage devices. As these were deployed in greater numbers, existing spaces could not handle their specialized physical plant and environmental demands. Power and cable management, access for service, room for expansion and storage systems and even disparate mounting hardware and specifications all contributed to the problems. And the room just kept getting hotter.

Old data facilities and new construction centers have addressed many of these issues. Higher raised floors, upgraded power distribution, redundant sources for power and connectivity, enhanced cable management and of course improved climate control have all contributed to greatly enhanced reliability and overall uptime.

But when addressing specific cooling issues, there is a potential conflict; a conflict over enclosure airflow paths and the best way to remove heat. Rackmount server manufacturers require front to rear cooling across servers, best accomplished with the traditional server cabinet – fully perforated doors front & rear with >65% openings. However, there remain proponents of alternative cooling methods, most commonly bottom to top (chimney) airflow paths, some using solid instead of vented front doors. There are also differing solutions using fans to remove and redirect hot air out of and away from enclosures. Even fan quantity, capacity and placement are debated.

The test protocol and results described in the following sections are designed to evaluate various enclosure configurations and their effects on heat removal and dissipation. The following sections review site and enclosure layouts, the testing protocol, components evaluated and test results. A brief analysis is provided along with suggested installation and climate control guidelines

Figure 2A: Row with test cabinets

Figure 2B: Hot aisle

Figure 2C: Test cabinets with roof fans

III. TEST SITE & ENCLOSURE REVIEW

The thermal test program was designed to measure enclosure cooling capabilities in an active data center. The following variables were tested:

- **Enclosure Door Configuration**
  - Vented
  - Solid
  - Partial Vent (Front &/or Rear)
- **Floor Tiles**
  - Perforated
  - Solid (In front of enclosures)
- **Enclosure Fan Placement**
  - Rear Door
  - Bottom
  - Roof (w/solid roof)
- **Cabinet Heat Load –** 2100 watts or 5500 watts

Thermal dissipation tests were conducted on three enclosures in the data center. The enclosures were configured identically for each test scenario. The test enclosures were part of a larger row of cabinets in the room *(See Figure 2A)*. All three enclosures were bayed together with no internal dividers (except for the tests using divider panels). A sidewall was installed between the third test enclosure and the adjacent active cabinet and the rest of the row. Component installation, wiring, blank panels and related hardware were identical for each test enclosure.

Data Center Parameters:

- Approximately 25,000 sq.ft. raised floor space
- 18" Raised floor plenum height w/17" clearance floor to tile bottom
- 12 Foot Raised Floor to Ceiling height
- Open Ceilings
- Hot Aisle/Cold Aisle Orientation
- CRAC Units located on inner walls
- Overhead (copper and fiber connectivity) and under floor (copper and power) cable entry

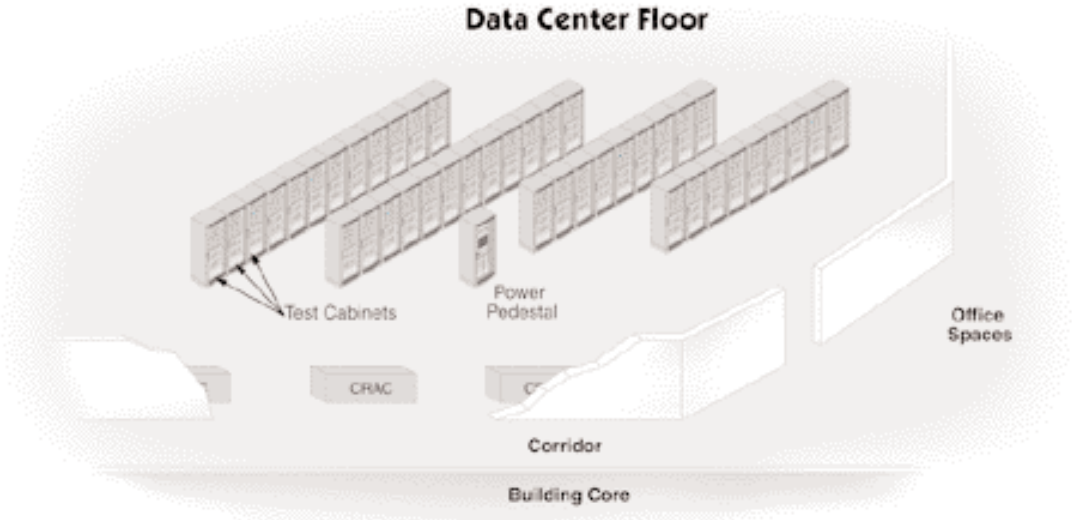


Figure 3: Data Center Layout

Figure 4A: Front of test cabinets

Figure 4B: Thermal probes on the rear door of the cabinet

A series of tests was conducted with 2.1KW heat loads per enclosure. Thirty-one 1RU Dell servers were installed from the 5RU to 35RU positions in each enclosure. Power to all servers was provided by three vertical and one rackmount powerstrips, the powerstrips equipped with load monitoring capability.

See *Table 1* for complete list of 5.5kW Testing Configurations.

To create a greater heat load, eight servers were removed from each test enclosure and a Load Bank placed in the vacant space. Each load bank was set to provide 4KW of heat. A total of 5.5KW per test enclosure (servers + load banks) was achieved. Rackmount servers continued to draw power from the powerstrips; the load banks were serviced by two 20amp circuits from under the floor per load bank. Each load bank was installed in the lower section of each enclosure to simulate installation of a larger rackmount server (i.e. HP7410, Proliant ML750, Sun V880z). Standard industry practices place heavier components lower in an enclosure to provide ease of access and reduce chance of tip-over. These larger units produce significantly greater heat loads then 1 – 3 RU systems, concentrating the heat in the bottom section of an enclosure.

See Figure 4A and 4B above for details of active components installations.

19" Rackmount blank panels were installed in all unused rack spaces on the front mounting rails in all three enclosures. To support installation and operation of bottom mount blowers (when tested) the first three RU were left open for all tests. All power strips were installed in the rear of the enclosures, vertical strips positioned outside the 19" mounting plane and the rackmount strip in the 4RU position from the bottom (behind and above bottom mount blowers).

Thermal Testing Protocol: Table 1

Listed below are the various cabinet, fan and facility configurations tested. Approximate Cabinet Heat Load 5500Watts

Test Number	Front Door	Rear Door	19" Rail Location	Floor Tile	2 x Rear Fans	Bottom Blower	Divider Panel	Roof Fan	Test Start Time	Test End Time	Total Hours Tested
1	Perf	Perf	Front	Vented	–	–	–	–	2:30PM	11:05AM	20.58
2	Perf	Perf	Front	Solid	–	–	–	–	11:30AM	11:15AM	23.75
3	Perf	Perf	Front	Vented	Installed	–	–	–	11:35AM	12:30PM	24.92
4	Perf	Perf	Front	Vented	–	Installed	–	–	1:00PM	11:30AM	22.50
5	Perf	Perf	Front	Vented	Installed	Installed	–	–	12:30PM	11:30AM	23.00
6	Perf	Perf	Front	Solid	Installed	Installed	–	–	12:40PM	2:30PM	97.83
7	Perf	Perf	Front	Solid	–	Installed	–	–	3:30PM	12:30PM	21.00
8	Perf	Perf	Front	Vented	–	–	Installed	–	2:00PM	12:10PM	22.17
9	Perf	Perf	Front	Solid	–	–	Installed	–	12:05PM	12:05PM	24.00
10	Solid	Perf	4" Back	Solid	–	–	–	–	4:00PM	11:00AM	19.00
11	Solid	Perf	4" Back	Solid	–	Installed	–	–	12:15PM	3:00PM	26.75
12	Solid	Perf	4" Back	Solid	Installed	–	–	–	3:45PM	12:00PM	20.25
13	Solid	Perf	4" Back	Solid	Installed	Installed	–	–	12:30PM	11:30AM	23.00
14	Solid	Perf	4" Back	Solid	–	–	Installed	–	5:10PM	11:30AM	18.34
15	Solid	Perf	4" Back	Solid	–	Installed	Installed	–	12:30PM	2:20PM	25.83
15A	Solid	Perf	4" Back	Solid	Installed	–	Installed	–	12:15PM	12:10PM	23.92
16	Solid	Perf	4" Back	Solid	Installed	Installed	Installed	–	12:45PM	10:30AM	69.75
17	Solid	Solid	4" Back	Solid	–	–	Installed	Installed	11:45AM	10:30AM	22.75
17A	Solid	Perf	4" Back	Solid	–	–	Installed	Installed	2:30PM	11:15AM	44.75
18	Solid	Solid	4" Back	Solid	–	–	–	Installed	11:40AM	12:15PM	24.58
18A	Solid	Perf	4" Back	Solid	–	–	–	Installed	10:40AM	10:05AM	23.42
19	Solid	Solid	4" Back	Solid	–	Installed	–	Installed	12:50PM	10:15AM	21.42
19A	Solid	Perf	4" Back	Solid	–	Installed	–	Installed	10:40AM	10:15AM	23.58
20	Part Vent	Solid	4" Back	Solid	–	–	–	Installed	10:40AM	10:30AM	47.83

Dimensions and initial configuration for the test enclosures:

- Height: 79"/42RU Width: 24" Depth: 40"
- Fully perforated (67% open) doors – Front and Rear
- Vented Roof with cable entry slots
- 2 Sets Vertical Mounting Rails – EIA Standard Hole Pattern
- Front mounting rails approximately 1.5" off front door.
- 19" Mount Blank Panels installed in unused rack spaces on front rails
- Perforated floor tiles in front, solid tiles behind each enclosure
- 18" x 17" cutout in front floor tile under each cabinet + 2" x 4" diameter cutouts under cabinet back
- 23 1U Dell Servers in the 13U - 35U rack location
- 1 load bank providing 4kW of heat

IV. TEST & MONITORING SYSTEM

Detailed monitoring, data collection and logging were essential to insure the results accurately reflected actual operating conditions. The Rittal CMC-TC Enclosure Monitoring System was used for these tests. The CMC-TC system provided real-time monitoring of the various temperature points in each cabinet, recorded the data for each test period for each enclosure and provided trend data to insure no transients occurred during each test.

Each test enclosure was equipped with a CMC base unit and Input/Output (I/O) modules. Twelve temperature probes were connected to each CMC in each enclosure. Each CMC was connected via the onboard 10BaseT port to a hub, creating a standalone monitoring network for the test enclosures. Using SNMP, the CMC's communicated all test data to a central computer for each test. The monitoring computer was set up to capture and store data in a separate file for each CMC. Trend data for each CMC was also stored in individual files.

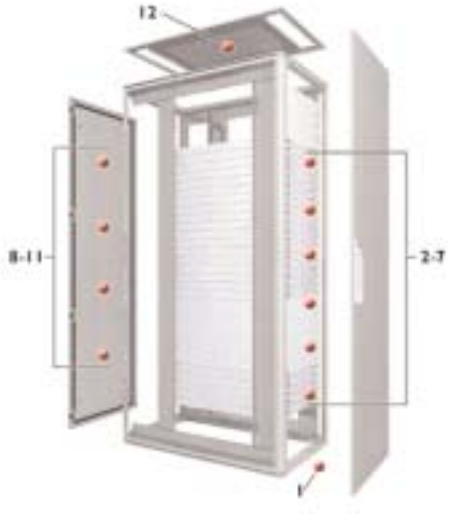


Figure 5
– denotes thermal probe locations

Test probes were placed in the following locations:

- **1:** Under floor in front of cabinet
- **2-7:** Front, at server air intakes
  2-@ 5U, 3-@ 12U, 4-@ 20U, 5-@ 25U, 6-@ 30U, 7-@ 35U
- **8-11:** Centered on rear door
  8-@ 6U, 9-@21U, 10-@31U, 11@ top
- **12:** Center of roof

Probe Placement Notes:

Front probes were attached directly to the servers to measure inlet air as it entered the units. When servers were moved back (4") for solid door tests, inlet temperature probes moved with the servers. Please see *Figure 6* for a schematic view of the CMC monitoring setup.

Rear probes (1 – 4) were secured directly to the rear door and not at server discharge. This location recorded discharge temperature of exhaust air as it vented into room spaces.

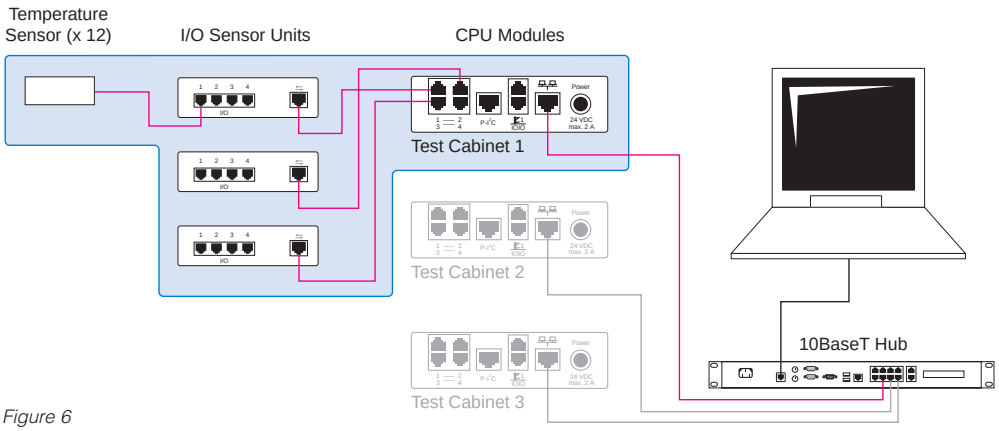


Figure 6

V. TEST PROTOCOL

At the start of a test, each enclosure was set up with the appropriate configuration. All servers and load banks were constantly kept on, with the servers running a program to continuously exercise the processor. Rackmount servers were installed using Dell installation brackets in accordance with manufacturer's specifications. After set up was completed, all doors were closed and the test begun. Each test ran for at least 20 hours, some ran over two days. The computer was configured to capture data every two minutes from each test probe (36 total) to create trend logs. These logs verified operating conditions during the span of each test, insuring there were no transients, i.e. door opening, fan failure, facility condition.

At the end of each test period a final set of temperatures was recorded and the test was stopped. Please see *Table 2* for a sample of the test data sheet. Temperatures were averaged across the three enclosures. The enclosures were set for the next test configuration and the process was repeated; data recorded at the end of each test run.

At the completion of all tests, data was recorded on a master spreadsheet for the three main enclosure configurations tested:

- Server Cabinet with fully perforated doors front and rear
- Equipment Cabinet with a SOLID front door and PERFORATED rear door
- Equipment Cabinet with SOLID front door, solid or perforated rear door AND roof mount exhaust fans

The data collected shows results for each test and compares similar cabinet configurations with one or two different test variable (ex: rear fan vs. roof fan, perf door vs. solid door). Results for all tests at 5.5KW heat loads are provided in the following tables and charts.

Sample Data Sheet: Table 2

Test Number: 20
Approx Heat Load: 5500 Watts
Cabinet Configuration: Partial Vented View Door - Front
Solid Door - Rear, 2 x 550 cfm Roof Mount Fans
Solid Floor Tiles - Front

Temperature Probe Locations		Average Temperature of cabinets during 2 day testing - ° Fahrenheit			
		Cabinet 1 Temp	Cabinet 2 Temp	Cabinet 3 temp	Average For Test 20
Air Intake					
1	Under Floor - In front of Cabinet	68.0	68.0	66.2	67.4
2	Front - Server @5U	68.0	68.0	64.4	66.8
3	Front - Server @12U	68.0	69.8	68.0	68.6
4	Front - Server @20U	69.8	71.6	68.0	69.8
5	Front - Server @25U	71.6	73.4	68.0	71.0
6	Front - Server @30U	75.2	77.0	69.8	74.0
7	Front - Server @35U	75.2	73.4	71.6	73.4
Air Discharge					
8	Rear Door - @6U, Center	87.8	77.0	77.0	80.6
9	Rear Door - @21U, Center	100.4	100.4	98.6	99.8
10	Rear Door - @31U, Center	93.2	93.2	86.0	90.8
11	Rear Door - Top, Center	93.2	87.8	86.0	89.0
12	Roof - Center	93.2	87.8	84.2	88.4

Temperature results represent an average of all temperatures recorded at each probe every 2 minutes

Installation Notes:

- Vented floor tiles were only installed in front of cabinets with perforated front doors .
- Solid tiles were used with solid doors to insure airflow was directed into enclosures and not dissipated in front of enclosures.
- Front 19" mounting rails were recessed 4" from front doors when solid doors were installed to insure a sufficient column of air was available to server intakes.
- Two rear door mount server fan panels were installed in each test enclosure. Rear door mount exhaust fan panels were positioned in the same location for the appropriate test.
- Fan positions were the same for all three enclosures, equal to 20 and 30 RU.
- Bottom mount blowers were installed in the 2 - 3 RU position in each enclosure. Bottom mount blowers drew air through identical cutouts in under cabinet floor tiles.
- Rear door mount temperature probes were fixed in the same locations *(see page 6)* as described above when rear doors were switched from perforated to solid doors.

VI. TEST RESULTS

As discussed above, data was recorded for each cabinet configuration. The tables 3, 4, and 5 in the appendix represent temperatures measured for each test conducted. The complete results tables display temperature differences for the three main enclosure test configurations with similar test variable (Ex: Server Cabinet vs. Equipment Cabinet with Rear Door Mount Server Fan Panels). There are also 2 comparison tables highlighting the differences with door and roof options. (see tables 6 and 7 in the appendix).

See full test results in Appendix. Each probe temperature value is an average of the 3 cabinets.

Figure 7A: This thermal drawing represents the heat dissipation for test 3 with perorated front and rear door and vented roof

Figure 7B: The thermal drawing represents the heat dissipation from test 18 with solid front and rear door with roof fan

VII. ANALYSIS AND CONCLUSIONS

NOTE: When reviewing the data, the reader must consider existing site conditions (i.e. airflow velocity, CRAC discharge temperature, under-floor pressure and other variables) and how they compare to the test site conditions described above.

It is apparent that server enclosures (perforated doors F & R) showed the best thermal performance (*see Figure 7A*). This was true for 2.1KW and 5.5KW heat loads. With consistent under floor temperatures, pressure and cool air delivery to server intakes, exhaust temperatures to the room were within 10°F of inlet temperatures. **This reduced Delta T provided discharge temperatures from the enclosures that were easily absorbed by the room and well within tolerance for CRAC unit intakes.** Rear door fans and/or bottom mount blowers affected performance, but did not have a significant impact on discharge temperatures. Equipment enclosures with solid front doors (and in some cases solid rear doors) had significantly higher discharge temperatures (*see Figure 7B*). In these configurations, supplemental fans did have an effect on exhaust temperatures, lowering exhaust temperatures, but not as well as seen in server cabinets. Again, the room was able to accommodate the higher temperatures. However, if many more enclosures had the higher heat loads with these configurations, it might be possible to adversely affect a room's ability to dissipate the heat.

As can be seen when comparing results from 2.1KW and 5.5KW heat loads, that even with these loads almost tripled, discharge temperatures remained fairly consistent. It can be inferred that with a well-designed data center cooling plant, server enclosures are most effective at evacuating and dissipating the increasing heat loads being generated.

Based on these results, and additional experience with large data center design and implementation worldwide, Rittal offers the following recommendations:

Climate Control:

- Maintain Front to Rear Cooling Air Flow Path
- Provide a Hot Aisle/Cold Aisle Orientation
- Place Server Air Intakes as Far Forward as Practical
- Maintain Strict Floor Tile Control
- Limit Number of Cutouts in Floor Tiles Under Cabinets
- Use Supplemental Fans to Reduce or Eliminate Hot Spots in Enclosures
- Install Blanking Panels In ALL Unused Rack Spaces
- Install full height x depth divider panels to segregate equipment clusters

General Enclosures:

- Select A Common Cabinet Configuration (ex: Server)
- Deploy Enclosures by Application (Termination/Network/Server)
- Install The Maximum Footprint (WxD) Possible
- Use Multiple Widths For Various Configurations – Even in a single row
- Group Common Components Together
- And… Make Sure The Doors Are Closed

APPENDIX

THERMAL TESTING RESULTS

Table 3

Server Cabinet: Perforated Doors Front & Rear, Various Fan Options & Floor Tile Configurations

Approx Heat Load: 5500 Watts

Cabinet Configuration	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**
Front Door	Perf	Perf	Perf	Perf	Perf	Perf	Perf	Perf	Perf
Rear Door	Perf	Perf	Perf	Perf	Perf	Perf	Perf	Perf	Perf
Roof	Vent	Vent	Vent	Vent	Vent	Vent	Vent	Vent	Vent
Floor Tiles	Vent	Solid	Vent	Vent	Vent	Solid	Solid	Vent	Solid
Fans	-	-	Rear	Bottom	Rear & Bottom	Rear & Bottom	Bottom	-	-
Divider Panels	-	-	-	-	-	-	-	Panels	Panels

Temperature Probe Locations		**Average Temperature of 3 cabinets - ° Fahrenheit**								
Air Intake										
1	Under Floor - In front of Cabinet	67.4	68.0	68.0	67.4	66.8	66.2	66.8	66.2	66.2
2	Front - Server @5U	67.4	69.3	67.4	68.0	68.0	68.0	68.6	66.8	66.2
3	Front - Server @12U	68.7	70.5	68.7	69.2	68.0	66.8	69.8	68.0	69.8
4	Front - Server @20U	70.5	73.0	69.3	68.6	66.2	67.4	70.4	67.4	69.2
5	Front - Server @25U	71.1	74.3	69.3	69.3	66.8	69.2	71.6	67.4	73.4
6	Front - Server @30U	71.8	75.5	70.5	71.7	68.7	71.6	74.6	72.8	75.2
7	Front - Server @35U	69.9	73.3	72.0	70.4	69.5	72.1	74.4	75.2	77.6
Air Discharge										
8	Rear Door - @6U, Center	72.9	73.5	73.6	75.8	79.0	77.6	77.6	71.0	71.6
9	Rear Door - @21U, Center	77.7	81.3	76.5	76.4	78.5	79.4	79.4	74.6	75.2
10	Rear Door - @31U, Center	77.1	80.8	75.8	76.4	75.2	76.4	80.6	76.4	78.2
11	Rear Door - Top, Center	76.5	78.3	74.3	74.6	74.3	75.2	78.8	75.8	75.8
12	Roof - Center	76.4	75.2	73.9	72.6	73.3	74.5	77.6	75.8	76.4

Temperature results represent an average of all 3 test cabinets with temperatures recorded at each probe every 2 minutes

Cabinet Configurations:

Test 1: Perf Doors - F & R, Vented Floor Tile - Front

Test 2: Perf Doors - F & R, Solid Floor Tile - Front

Test 3: Perf Doors - F & R, Vented Floor Tile - Front, 2 x Server Fan Panels - Rear Door

Test 4: Perf Doors - F & R, Vented Floor Tile - Front, Bottom Mount Blowers

Test 5: Perf Doors - F & R, Vented Floor Tile - Front, 2 x Server Fan Panels - Rear Door, Bottom Mount Blowers

Test 6: Perf Doors - F & R, Solid Floor Tile - Front, 2 x Server Fan Panels - Rear Door, Bottom Mount Blowers

Test 7: Perf Doors - F & R, Solid Floor Tile - Front, Bottom Mount Blowers

Test 8: Perf Doors - F & R, Vented Floor Tile - Front, Divider Panels

Test 9: Perf Doors - F & R, Solid Floor Tile - Front, Divider Panels

NOTE: All Configurations: Solid Floor Tiles - Rear, Front 19" Rails - 1.5" Off Front Door, Vented Roof

Color Key:	
	60-69°
	70-79°
	80-89°
	90-99°
	100°+

APPENDIX

THERMAL TESTING RESULTS

Table 4

Cabinet: Solid Door - Front, Perf Door - Rear, Various Fan Options, Floor Tile Configurations

Approx Heat Load: 5500 Watts

Cabinet Configuration	Test 10	Test 11	Test 12	Test 13	Test 14	Test 15	Test 15A	Test 16
Front Door	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid
Rear Door	Perf	Perf	Perf	Perf	Perf	Perf	Perf	Perf
Roof	Vent	Vent	Vent	Vent	Vent	Vent	Vent	Vent
Floor Tiles	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid
Fans	-	Bottom	Rear	Rear & Bottom	-	Bottom	Rear	Rear & Bottom
Divider Panels	-	-	-	-	Panels	Panels	Panels	Panels

Temperature Probe Locations		Average Temperature of 3 cabinets - ° Fahrenheit							
Air Intake									
1	Under Floor - In front of Cabinet	65.6	66.2	66.8	66.2	68.0	66.2	66.8	66.8
2	Front - Server @5U	68.0	68.6	68.6	68.6	69.8	69.2	66.8	68.6
3	Front - Server @12U	73.4	74.6	70.4	76.4	72.8	75.2	69.2	74.6
4	Front - Server @20U	85.4	76.4	74.6	74.0	78.8	76.4	72.8	77.6
5	Front - Server @25U	91.4	74.0	77.6	72.8	81.8	73.4	74.6	77.6
6	Front - Server @30U	92.6	73.4	77.0	71.6	84.8	72.8	77.6	75.2
7	Front - Server @35U	92.0	73.4	75.8	71.6	89.0	71.6	78.8	71.0
Air Discharge									
8	Rear Door - @6U, Center	72.8	87.2	73.4	80.0	76.4	87.2	71.6	80.0
9	Rear Door - @21U, Center	92.6	84.8	101.6	96.2	85.4	85.4	93.2	
10	Rear Door - @31U, Center	93.2	83.0	85.4	83.6	89.0	80.0	83.0	87.2
11	Rear Door - Top, Center	89.6	77.0	78.2	77.0	85.4	75.2	79.4	80.0
12	Roof - Center	82.4	76.4	77.0	77.6	74.6	75.8	78.2	79.4

Temperature results represent an average of all 3 test cabinets with temperatures recorded at each probe every 2 minutes

Cabinet Configurations:

Test 10: Solid Door - Front, Perf Door - Rear

Test 11: Solid Door - Front, Perf Door - Rear, Bottom Mount Blowers

Test 12: Solid Door - Front, Perf Door - Rear, 2 x Server Fan Panels - Rear Door

Test 13: Solid Door - Front, Perf Door - Rear, Bottom Mount Blowers, 2 x Server Fan Panels - Rear Door

Test 14: Solid Door - Front, Perf Door - Rear, Divider Panels

Test 15: Solid Door - Front, Perf Door - Rear, Bottom Mount Blowers, Divider Panels

Test 15A: Solid Door - Front, Perf Door - Rear, 2 x Server Fan Panels - Rear Door, Divider Panels

Test 16: Solid Door - Front, Perf Door - Rear, Bottom Mount Blowers, 2 x Fan Panels - Rear Door, Divider Panels

NOTE: All Configurations: Solid Floor Tiles - Front, Front 19" Rails - 4" Off Front Door, Vented Roof

Color Key:

- 60-69°
- 70-79°
- 80-89°
- 90-99°
- 100°+

APPENDIX

THERMAL TESTING RESULTS

Table 5

Cabinet: Solid Door - Front, Solid or Perf Door - Rear, 2 x 550cfm Roof Mount Fans, Solid Floor Tiles, with or w/o Bottom Mount Blowers

Approx Heat Load: 5500 Watts

Cabinet Configuration	Test 17	Test17A	Test 18	Test 18A	Test 19	Test 19A	Test 20
Front Door	Solid	Solid	Solid	Solid	Solid	Solid	Partial vent
Rear Door	Solid	Perf	Solid	Perf	Solid	Perf	Solid
Roof	Fan	Fan	Fan	Fan	Fan	Fan	Fan
Floor Tiles	Solid	Solid	Solid	Solid	Solid	Solid	Solid
Fans	-	-	-	-	Bottom	Bottom	-
Divider Panels	Panels	Panels	-	-	-	-	-

	Temperature Probe Locations	Average Temperature of 3 cabinets - ° Fahrenheit						
Air Intake								
1	Under Floor - In front of Cabinet	65.0	68.0	66.2	68.0	66.2	66.2	67.4
2	Front - Server @5U	67.4	71.0	67.4	69.2	70.4	69.8	66.8
3	Front - Server @12U	69.8	74.6	70.4	72.2	77.6	77.0	68.6
4	Front - Server @20U	71.6	77.6	73.4	76.4	78.2	78.8	69.8
5	Front - Server @25U	71.0	81.2	76.4	79.4	79.4	79.4	71.0
6	Front - Server @30U	77.6	84.2	81.2	84.2	82.4	78.2	74.0
7	Front - Server @35U	80.6	86.0	81.2	83.6	79.4	73.4	73.4
Air Discharge								
8	Rear Door - @6U, Center	69.8	74.0	69.2	73.4	100.4	76.4	80.6
9	Rear Door - @21U, Center	102.8	85.4	101.6	84.8	99.8	92.6	99.8
10	Rear Door - @31U, Center	93.8	80.6	93.8	81.8	96.2	84.8	90.8
11	Rear Door - Top, Center	90.8	82.4	90.8	83.0	94.4	80.6	89.0
12	Roof - Center	84.8	80.0	87.2	81.2	84.2	80.6	88.4

Temperature results represent an average of all 3 test cabinets with temperatures recorded at each probe every 2 minutes

Cabinet Configurations:

Test 17: Solid Doors - Front & Rear, 2 x 550cfm Roof Mount Fans, Divider Panels

Test 17A: Solid Door - Front, Perf Door - Rear, 2 x 550cfm Roof Fans, Divider Panels

Test 18: Solid Doors - Front & Rear, 2 x 550cfm Roof Mount Fans

Test 18A: Solid Door - Front, Perf Door - Rear, 2 x 550cfm Roof Fans

Test 19: Solid Doors - Front & Rear, 2 x 550cfm Roof Mount Fans, Bottom Mount Blowers

Test 19A: Solid Door - Front, Perf Door - Rear, 2 x 550cfm Roof Fans, Bottom Mount Blowers

Test 20: Partial Vented View Door - Front, Solid Door - Rear, 2 x 550cfm Roof Fans

NOTE: All Configurations: Solid Floor Tiles - Front, Front 19" Rails - 4" Off Front Door, Solid Roof w/fans

Color Key:	
	60-69°
	70-79°
	80-89°
	90-99°
	100°+

APPENDIX

THERMAL TESTING COMPARISON

Table 6

Cabinet: Perforated Doors (F&R) vs. Solid Door (F) & Perf Door (R)

Approx Heat Load: 5500 Watts

Cabinet Configuration		Test 1	Test 10	Test 3	Test 12	Test 4	Test 11	Test 5	Test 13
Front Door		Perf	Solid	Perf	Solid	Perf	Solid	Perf	Solid
Rear Door		Perf	Perf	Perf	Perf	Perf	Perf	Perf	Perf
Roof		Vent	Vent	Vent	Vent	Vent	Vent	Vent	Vent
Floor Tiles		Vent	Solid	Vent	Solid	Vent	Solid	Vent	Solid
Fans		-	-	Rear	Rear	Bottom	Bottom	Rear & Bottom	Rear & Bottom
Divider Panels		-	-	-	-	-	-	-	-
Temperature Probe Locations		**Average Temperature of 3 cabinets - ° Fahrenheit**							
Air Intake									
1	Under Floor - In front of Cabinet	67.4	65.6	68.0	66.8	67.4	66.2	66.8	66.2
2	Front - Server @5U	67.4	68.0	67.4	68.6	68.0	68.6	68.0	68.6
3	Front - Server @12U	68.7	73.4	68.7	70.4	69.2	74.6	68.0	76.4
4	Front - Server @20U	70.5	85.4	69.3	74.6	68.6	76.4	66.2	74.0
5	Front - Server @25U	71.1	91.4	69.3	77.6	69.3	74.0	66.8	72.8
6	Front - Server @30U	71.8	92.6	70.5	77.0	71.7	73.4	68.7	71.6
7	Front - Server @35U	69.9	92.0	72.0	75.8	70.4	73.4	69.5	71.6
Air Discharge									
8	Rear Door - @6U, Center	72.9	72.8	73.6	73.4	75.8	87.2	79.0	80.0
9	Rear Door - @21U, Center	77.7	92.6	76.5	101.6	76.4	84.8	78.5	96.2
10	Rear Door - @31U, Center	77.1	93.2	75.8	85.4	76.4	83.0	75.2	83.6
11	Rear Door - Top, Center	76.5	89.6	74.3	78.2	74.6	77.0	74.3	77.0
12	Roof - Center	76.4	82.4	73.9	77.0	72.6	76.4	73.3	77.6

Temperature results represent an average of all 3 test cabinets with temperatures recorded at each probe every 2 minutes

Cabinet Configurations:

Test 1: Perf Doors - F & R, Vented Floor Tile - Front

Test 10: Solid Door - Front, Perf Door - Rear

Test 3: Perf Doors - F & R, Vented Floor Tile - Front, 2 x Server Fan Panels - Rear Door

Test 12: Solid Door - Front, Perf Door - Rear, 2 x Server Fan Panels - Rear Door

Test 4: Perf Doors - F & R, Vented Floor Tile - Front, Bottom Mount Blowers

Test 11: Solid Door - Front, Perf Door - Rear, Bottom Mount Blowers

Test 5: Perf Doors - F & R, Vented Floor Tile - Front, 2 x Server Fan Panels - Rear Door, Bottom Mount Blowers

Test 13: Solid Door - Front, Perf Door - Rear, Bottom Mount Blowers, 2 x Server Fan Panels - Rear Door

Color Key:

60-69°
70-79°
80-89°
90-99°
100°+

APPENDIX

THERMAL TESTING COMPARISON

Table 7

Server Cabinet: Vented Roof vs. Roof Mount Fans

Approx Heat Load: 5500 Watts

Cabinet Configuration		Test 1	Test 10	Test 18A	Test 4	Test 11	Test 19A
Front Door		Perf	Solid	Solid	Perf	Solid	Solid
Rear Door		Perf	Perf	Perf	Perf	Perf	Perf
Roof		Vent	Vent	Fan	Vent	Vent	Fan
Floor Tiles		Vent	Solid	Solid	Vent	Solid	Solid
Fans		-	-	-	Bottom	Bottom	Bottom
Divider Panels		-	-	-	-	-	-
Temperature Probe Locations		**Average Temperature of 3 cabinets - ° Fahrenheit**					
Air Intake							
1	Under Floor - In front of Cabinet	67.4	65.6	68.0	67.4	66.2	66.2
2	Front - Server @5U	67.4	68.0	69.2	68.0	68.6	69.8
3	Front - Server @12U	68.7	73.4	72.2	69.2	74.6	77.0
4	Front - Server @20U	70.5	85.4	76.4	68.6	76.4	78.8
5	Front - Server @25U	71.1	91.4	79.4	69.3	74.0	79.4
6	Front - Server @30U	71.8	92.6	84.2	71.7	73.4	78.2
7	Front - Server @35U	69.9	92.0	83.6	70.4	73.4	73.4
Air Discharge							
8	Rear Door - @6U, Center	72.9	72.8	73.4	75.8	87.2	76.4
9	Rear Door - @21U, Center	77.7	92.6	84.8	76.4	84.8	92.6
10	Rear Door - @31U, Center	77.1	93.2	81.8	76.4	83.0	84.8
11	Rear Door - Top, Center	76.5	89.6	83.0	74.6	77.0	80.6
12	Roof - Center	76.4	82.4	81.2	72.6	76.4	80.6

Temperature results represent an average of all 3 test cabinets with temperatures recorded at each probe every 2 minutes

Cabinet Configurations:

Test 1: Perf Doors - F & R, Vented Floor Tile - Front

Test 10: Solid Door - Front, Perf Door - Rear

Test 18A: Solid Door - Front, Perf Door - Rear, 2 x 550cfm Roof Fans

Test 4: Perf Doors - F & R, Vented Floor Tile - Front, Bottom Mount Blowers

Test 11: Solid Door - Front, Perf Door - Rear, Bottom Mount Blowers

Test 19A: Solid Door - Front, Perf Door - Rear, 2 x 550cfm Roof Fans, Bottom Mount Blowers

Color Key:

60-69°
70-79°
80-89°
90-99°
100°+

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