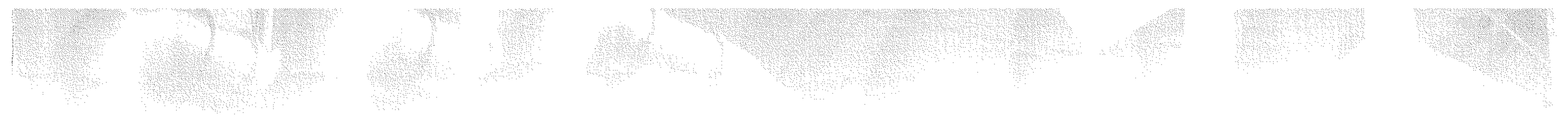

High-density heat containment

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Today's data centers are plagued with cool air oversupply and air distribution short-circuiting. Instead of supplying more chilled air, we can use a simpler approach to satisfy the same cooling requirements.

When designing an expansion of an existing data center to accommodate high-density rack equipment in 2004, Oracle decided to eliminate air oversupply to enhance energy efficiency. Historically, the company has taken a proactive approach in seeking and applying innovative energy efficiency and environment-friendly strategies. A recent project at Oracle recycles about one million gallons per year of condensate from air handlers to the cooling towers, reducing water use and water treatment chemicals at its Austin Data Center. It was among the first data centers in 2004 to receive significant power from sustainable energy sources and is a certified U.S. EPA Green Power Partner.

Its 50,000 [ft.sup.2] (4645 [m.sup.2]) of raised floor space accommodated an average of 4 kW rack load, and needed to be expanded to accommodate an additional 3 MW of high-density load with an average of 8 kW rack load. The existing data center floor uses a hot aisle/cold aisle configuration, and is cooled by distributed downflow computer room air-conditioning (CRAC) units supplying into a 30 in. (762 mm) underfloor plenum. The supply air to the IT (information technology) racks is distributed through perforated tiles and grates in the cold aisles and the return air is drawn from the space back to the CRAC units.

This article discusses the high-density heat containment (HDHC) system for the expansion section of the data center. The HDHC system offers a simple solution that uses standard off-the-shelf components to physically separate the cold supply and hot return air. This strategy is gaining popularity and suppliers are starting to supply components that support closed-loop airside cooling.

Conventional Cooling Limitations

Conventional hot aisle/cold aisle cooling for higher density equipment loads does not provide adequate separation between the cool supply and hot return airstreams. The hot air diffuses into the cold air near the top of the racks and on the end of the cold aisles causing mixed air temperatures in some cases to be unacceptably high. Beaty and Davidson (1) point out the common problem of cold air becoming hot by the time it reaches the inlet of electronic equipment located near the top of racks as a result of diffusion of hot air from the hot aisle into the cold aisle. Increased airflow in cold aisles helps, but also increases energy use. In addition, tile diffusers must be readjusted continually for air balance to adapt to changes in rack loads.

The visualization of hot air diffusion into the cold aisle and mixed air temperatures at the server inlet in front of the rack is illustrated with computational fluid dynamic (CFD) modeling for a simple data center in Figure 1. The CFD model simulates a total of 60 8 kW racks with 960 cfm (453 L/s) airflow for a temperature rise of 26[degrees]F (14[degrees]C) across the electronic equipment. Figure 1 illustrates the hot air diffusion or its mixing with cold air and resulting inlet temperature at the face of the IT equipment rack at different heights when 40% excess cool air is supplied compared to that required by the electronic equipment. The temperature at the upper-face of the IT rack in this model is 76[degrees]F (24[degrees]C) when the cold supply air temperature at the outlet of the floor grills is 59[degrees]F (15[degrees]C), a rise of 17[degrees]F (9[degrees]C). Figure 2 illustrates the results from the same CFD model when 100% excess cold air is supplied compared to that required by the IT equipment. The temperature near the top of the rack is reduced to 72[degrees]F (22[degrees]C), compared to 76[degrees]F (24[degrees]C) with 40% excess cold air. It is easy to understand why it is a common practice to supply excessive cold air to the IT equipment environment.

A fraction of the extra cold air delivered to the floor bypasses the electronic equipment and mixes directly with the hot return air from the racks, significantly lowering the return air temperature to the CRAC units. The return air temperature to the CRAC is 79[degrees]F (26[degrees]C) with 40% over supply versus 74[degrees]F (23[degrees]C) with a 100% oversupply of the cold air for the same 59 [degrees]F (15[degrees]C) supply air temperature. This explains why the CRAC unit thermostats are commonly set to a lower temperature setpoint with high power density racks in a conventional hot aisle/cold aisle configuration.

Conventional Return Air-Temperature Control Versus Supply Air Temperature Control

Using a conventional cooling strategy with return air-temperature control makes no sense if a steady supply air temperature is to be maintained. It is similar to controlling the temperature inside a house by placing the thermostat outside. The sensor must be in the process if the process is to be controlled. A comparison of two CRAC cooling strategies, return air and supply air temperature control is discussed below.

Figure 3 represents a conventional cooling strategy overlaid onto a psychrometric chart. The yellow zone represents the ASHRAE (2)-recommended standard for Class 1 mission critical electronic equipment operation, which recommends equipment inlet air temperature in the range of 68[degrees]F (20[degrees]C) to 77[degrees]F (25[degrees]C), a maximum 9[degrees]F (5[degrees]C) per hour rate of change, and a relative humidity between 40% to 55%. The red line overlaid on the chart shows typical supply and return air temperatures in conventional return air control systems. This strategy results in the supply air temperature and relative humidity outside of the ASHRAE standards. This cooling strategy reduces energy efficiency and is not ideal for the IT equipment because of the high relative humidity supplied at the inlet to the

IT equipment

Figure 4 illustrates the new supply air temperature control strategy that was implemented. The CRAC unit temperature and RH sensors were moved under the raised floor into the supply airstream. The automatic chilled-water control valve regulates water flow to maintain a steady 68[degrees]F (20[degrees]C) supply air temperature--the lowest temperature recommended by ASHRAE. A word of caution: when supplying air at 68[degrees]F (20[degrees]C), a CRAC unit will not cool it below the desired room dew-point temperature and remove moisture. Therefore, special precaution must be taken for proper humidity control when increasing supply air temperature. In our application, the humidity control was maintained from central makeup/pressurization air units and not locally by the CRAC units.

Cold and Hot Air Containment

The airflow patterns demonstrated in Figures 1 and 2 show a poor separation between the cold supply and hot return airstreams with the conventional cold aisle/hot aisle configuration. A high degree of separation between the cold supply and hot return airstreams is required to achieve reasonably uniform and predictable air temperatures at the inlet to the IT equipment. A physical barrier separating hot and cold airstreams is necessary to achieve the highest degree of separation. Any of the three approaches--cold aisle containment, hot aisle containment and rack containment--could provide the physical separation with each offering its own advantages and limitations.

Cold Aisle Containment/Enclosure

In a cold aisle enclosure, cold supply air to individual aisles is contained within the aisle by physical barriers at the top and sides of the aisle. The barrier prevents mixing of hot air from the outlet of the electronic equipment with the cold air and provides uniform temperature at the inlet of the electronic equipment. Supply air temperature can be reset to a higher value because the inlet air temperature to the IT equipment will be the same as the supply air. The increased supply air temperature will yield better chiller plant operating efficiency, as well as increase the number of hours when free cooling could be available. Of course, the required airflow quantity also is reduced leading to less direct energy use for air circulation. It also permits use of variable speed drives on the CRAC supply air fans, which helps to

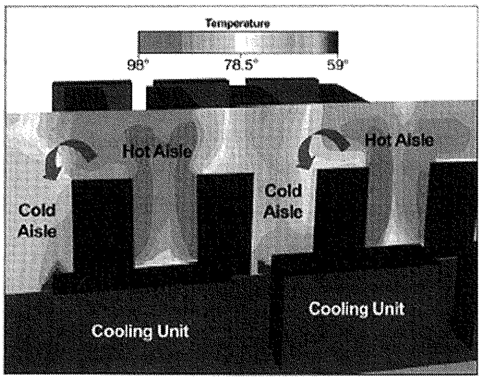


Figure 1: CFD model illustrating temperatures at the end of a row with 40% excess cold air supply.

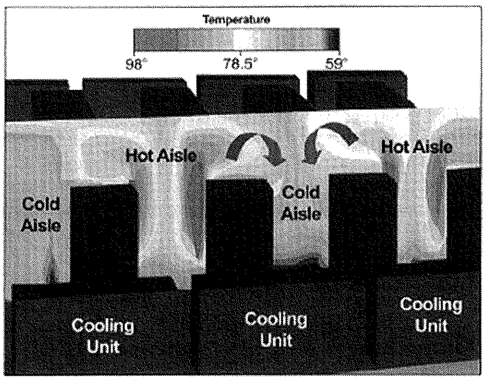


Figure 2: CFD model illustrating temperatures at the end of a row with 100% excess cold air supply.

avoid excess airflow.

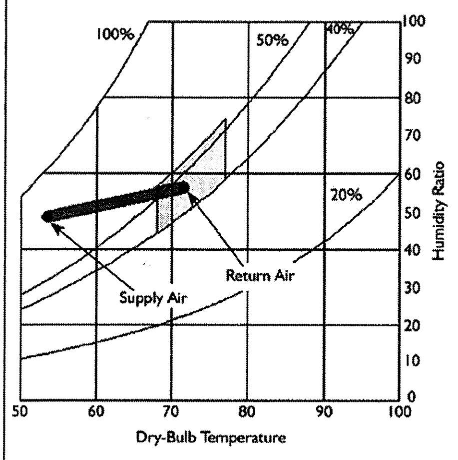
This arrangement requires access doors or strip curtains on the end of the aisles. It also requires provisioning of lighting and fire-safety sprinklers in the aisles below the aisle enclosure. This can be accommodated in new construction but may pose logistical problems in existing data centers. The primary limitation is that it is applicable to an aisle full with IT racks, and if racks are missing in the rows, then the aisle needs to be closed with blank panels.

Hot Aisle Containment/Enclosure

In a cold aisle enclosure, the entire data center, except for the cold aisle, is exposed to the hot air from the electronic equipment and is nearly at the same temperature as electronic equipment discharge air temperature, which could be 20[degrees]F to 40[degrees]F (11[degrees]C to 22[degrees]C) higher than the server inlet air temperature. As cold aisles permitted the supply air temperatures to be raised to 60s and even 70s (Fahrenheit), the rack discharge air temperature exceeded normal comfort conditions. Therefore, it became preferable to contain the hot air in hot aisles and open the rest of the data center to the cold supply air. The hot air containment offers similar advantages and limitations as cold aisle containment.

Rack Containment/Enclosure

A rack enclosure is similar to cold and hot aisle containment, but this containment is maintained within an individual rack. In a rack enclosure, separate paths for cold air intake and hot air discharge are maintained, preventing mixing of hot and cold air. In one arrangement, cold air enters the rack from the front and hot air is discharged directly to a return air plenum on the top through an exhaust duct connected to the top of the rack. The rack enclosure offers its own advantage; it is the smallest unit in a data center arrangement that can be placed anywhere without strict requirement of a hot aisle/cold aisle arrangement. However, a rack enclosure with an exhaust duct connection to a plenum increases pressure drop and requires additional fan power, and may require a supplemental fan to overcome the additional pressure drop. The rack enclosure also has somewhat similar limitations with respect to lighting and fire protection as with cold or hot aisle enclosure.



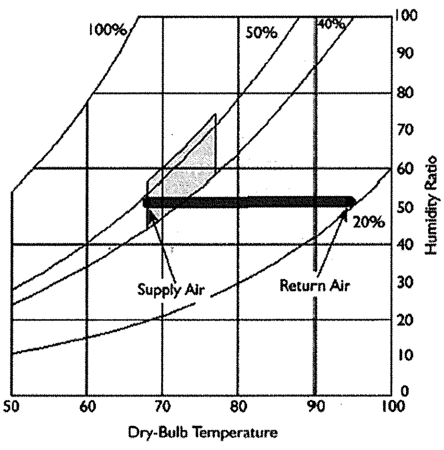


Figure 3 (left): Typical supply and return air conditions in conventional return air control systems.

Figure 4 (right): Typical supply and return air conditions in supply air temperature control systems.

A rack enclosure was selected for data center expansion for the high-density section because of its energy efficiency benefits and its ease of installation (because it could be installed rack by rack).

High-density Heat Containment System Architecture

Figure 5 shows a schematic of an HDHC system using the rack enclosure concept described previously. It uses a physical barrier to contain the IT equipment heat and provide a predictable pathway for this heat to return to the data center cooling systems. The cold air is delivered to the entry of the IT equipment through the raised floor perforated tiles as in a conventional system. The heated exhaust air from the IT equipment is removed from the rear of the rack enclosure and ducted to the ceiling plenum for return to the cooling units. A high-flow, low-power variable speed fan supplements airflow if the IT equipment fans cannot move required airflow against the additional pressure drop of the enclosure and exhaust duct. In this arrangement, all heated exhaust air is contained and physically separated from the supply air.

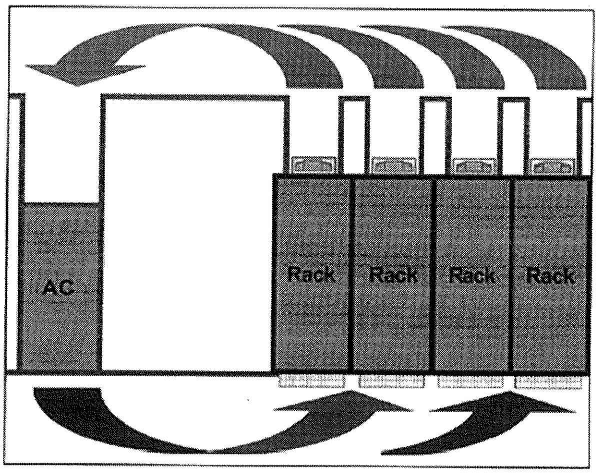


Figure 5: High-density heat containment system.

Figure 6 shows a picture of the HDHC racks installed in the high-density section of the data center.

The off-the-shelf components of a HDHC rack enclosure include: a) solid side panels; b) solid rear door with gasket; c) solid bottom panel with brush strip; d) high airflow, low power, variable speed supplemental fan system; e) fan airflow control; and f) exhaust duct. Additional hardware for installation includes sealing grommets to block cable openings and blanking panels to block unused IT equipment space within the racks.

HDHC Rack Supplemental Fan

Table 1 shows the airflow through a rack with and without assist from the supplemental fans. The combined design airflow for all electronic equipment in the rack is 1,400 cfm (660 L/s). When the supplemental fan is off, the pressure at the discharge side of the rack is higher as expected and observed from the measured data, and airflow is reduced. The airflow was calculated from the fan curves and measured pressure. This particular set of electronic equipment's fans was not able to maintain the design point of 1,400 cfm (660 L/s), and needed supplemental fan's assistance. When the supplemental fan is turned on at full speed, a total airflow of 1,640 cfm (774 L/s) was calculated. The fan uses 70 W at full speed. The challenge is to remove the same air volume from the rear of the rack as the IT equipment requires. The difference between the actual airflow and the design airflow, 240 cfm (113 L/s), is bypassing or short-circuiting the HDHC system. The supplemental fan needs to be controlled to avoid the extra airflow. Control of

IT Equipment Design Airflow, cfm	HDHC Supplemental Fan Status	Measured HDHC Airflow, cfm	Rack Plenum Pressure, in. w.c.	Rack Duct Pressure, in. w.c.	Ceiling Plenum Pressure, in. w.c.
1,400	On	1,640	–0.05	0.010	0.001
1,400	Off	1,040	0.16	0.002	0.001

Table 1: Supplemental fan power use.

Fan Power Comparison	Conventional Hot Aisle/ Cold Aisle Area	HDHC Rack Area
Total IT Equipment Load, kW	4,375	2,336
Number of CRAC Fans	63	27
CRAC Fan Power, kW	55 at 7.45 kW and 6 at 11.19 kW/each	4.69 kW/each
Rack Exhaust Fan Power, kW	0	500 at 0.07 kW/each
Total Fan Power, kW	499.300	158.100
Fan Power per Unit IT Equipment Load (kW/kW)	000.114	000.068

Table 2: Fan power comparison between conventional hot aisle/cold aisle versus high-density heat containment area.

fan speed based on rack plenum pressure is an effective method of supplemental fan speed control.

Nearly 500 HDHC return duct fans are in operation today, and many have been in operation for more than 24 months. There has not been a single fan failure to date.

Variable Airflow

Once the hot air is contained and prevented from mixing with the cold supply air, the risk of temperature rise at the inlet of the IT equipment is eliminated. A uniform air temperature at the inlet of the electronic equipment can be ensured and no need exists to oversupply the cold air. The CRAC units serving the high-density area were equipped with variable speed drives so that its airflow quantities could be matched by adjusting fan speed to what was needed by the IT equipment. Elimination of excess airflow in this 24/7 application provided significant energy savings.

Variable speed fans provide another benefit related to redundancy. In our conventional hot aisle/cold aisle area, we have one redundant CRAC unit for each of the six CRAC units. In normal operation, all CRAC units, including the redundant units, are always operating so, in case of any CRAC unit failure, there is seamless transfer of load to the other operating CRAC units. The redundant units are supplying at least 17% more air than needed under design conditions. Even if we were to match the CRAC unit's airflow to server airflow requirements and loads accurately, the extra 17% would still be supplied from running the redundant unit. By installing a VFD, we could slow the fans to reduce supply air as needed and reduce energy use. A 17% reduction in airflow alone would provide 43% fan energy savings using the cubic fan power laws shown in Figure 7. In our data center, racks were populated with electronic equipment over a prolonged period and the VFD fans operated at much lower fan speeds for a long time delivering more energy savings than calculated at design loads. Even at design loads, the fans operated at an average speed of 75%, providing 58% savings in fan power. Other benefits of VFD fans include soft start that further improves reliability, especially by limiting power demand during recovery after a power outage.

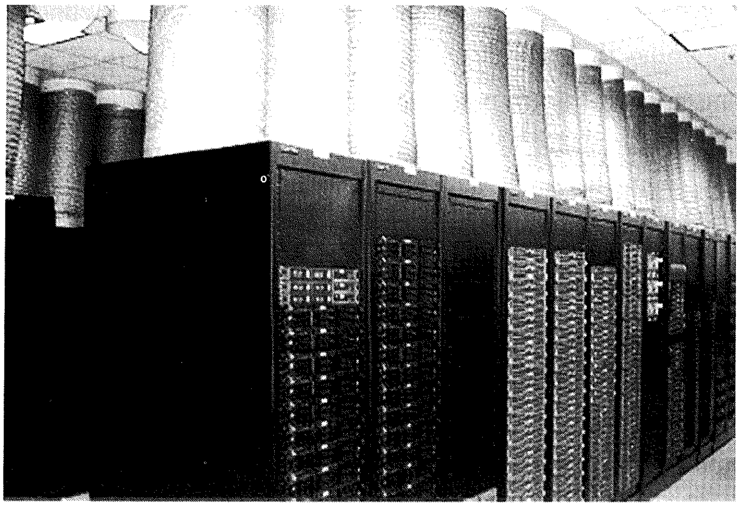


Figure 6: High-density containment systems installed in data center.

Fan Power Performance

Table 2 shows a recent snapshot of measured data comparing the fan power use in the conventional hot aisle/cold aisle section and the new high-density containment section area. The power data for the IT equipment were obtained from UPS and power delivery units in the data center floor. The power data for the CRAC unit fans was obtained from power measurements to a few fan motors. The representative power to supplemental fans in exhaust duct of the high-density racks was measured to be an average of 70 W. Out of the 640 high-density racks 500 used supplemental fans; the server fans in the other racks are powerful enough to overcome any additional pressure drop of the exhaust ducts.

The fan power in moving air in high-density area racks is 68 W/kW of the IT equipment load compared to 114 W/kW for the conventional hot aisle/cold aisle and represent a 40% fan power savings.

Controls for Variable Airflow

A conventional approach is to use a chilled-water valve position to control the VFD speed. However, this produces a variable underfloor pressure, which would vary the delivery of airflow to the environment. In a departure from this conventional practice, the VFD speed was controlled from a differential pressure sensor, which was installed in the underfloor plenum in the center of the high-density section. In addition a PID loop control was used for stability in controls. Further, the controls are set up to fail to full speed in the event of a sensor failure. We have found a differential pressure setting of 0.06 in. w.c. (15 Pa) as acceptable in our application.

Mechanical Systems Energy Efficiency Gains

A higher supply air temperature that is possible with HDHC system offers additional savings by improving the energy efficiency of the rest of the mechanical system. It would allow use of higher chilled-water temperature, which would reduce the chiller plant energy use; it would increase the number of operating hours when an airside or water-side economizer could be used. These savings could not be fully realized at the Austin Data Center since the central chilled water plant serves both the existing conventional hot aisle/cold aisle area as well as the new high-density area. Since chilled-water temperature requirements for the conventional area are lower than for high-density area, it governs the overall chiller performance. Even though some of the potential of energy savings were not realized, the direct energy savings from the fan power, as well as the indirect cooling energy savings of the avoided heat from the fan power, were significant. The estimated payback period of 19 months was achieved far sooner because the variable speed fans operated at much lower speeds during the prolonged period it took to populate the data center racks with IT equipment.

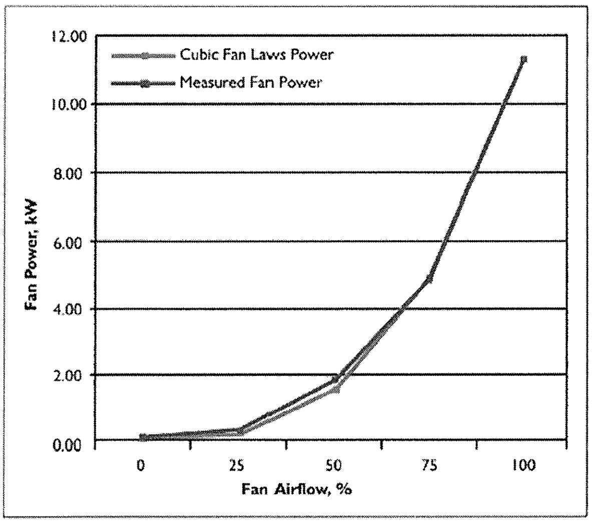


Figure 7: Measured fan power versus airflow for CRAC equipped with variable frequency drive.

A HDHC rack system has been successfully implemented to physically separate the hot and cold airstreams, eliminating excess airflow and providing the ability to raise the supply air temperature to the IT racks. It also allowed use of variable speed drives on CRAC unit fans to modulate airflow in a data center. Eliminating excess airflow reduced energy use by fans; the HDHC fans use were measured at 68 W compared to 114 W for the conventional hot aisle/cold aisle for each kW of the IT equipment load for a 40% power savings. Additional savings from improved chiller plant performance and use of economizers is possible. The power saving shown here is a snapshot in time, and the saving will vary somewhat with variation in operating conditions and IT equipment loads.

A HDHC system provides the necessary environmental conditions for high-density IT equipment loads while laying the foundation of significant energy efficiency improvement. Rack load capacities can be further increased since hot air no longer diffuses into the cool supply air.

Efficiency gains are significant and allow payback of mechanical systems upgrades within the lifetime of the operation of the equipment. Most important, using HDHC at the Austin Data Center allows Oracle to maintain high reliability using standard time-tested cooling systems and components.

Acknowledgments

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