MAKING DATA CENTERS SUSTAINABLE

Simulated Failure Analysis of a Distributed Liquid Cooled Data Center

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Contents

Introduction

This paper describes the redundancy and availability characteristics of a water cooled passive rear door system in a retrofit implementation at Purdue University's data center. As the most performance- and cost-efficient solution for the data center growth and densification, the implementation has also been proven to have the redundancy and availability needed for high availability applications. Redundancy and availability have been demonstrated by intentionally introducing a failure condition of a Coolant Distribution Unit (CDU); the CDU being the main concern for reliability as it includes a couple of mechanical pumps.

The failure condition consisted of denying cooling water to half of the doors in the data center. The two recovery conditions tested were:

1. Utilizing a CRAC unit as back up, and
2. Increasing water flow in the active (non-failed) CDU, thus lowering water temperature for maximizing performance to compensate for loss of cooling

In both scenarios, temperatures in the hot and cold aisles remained stable, as did the IT junction temperatures.

Abstract

Energy management of High-Performance Computing (HPC) system data centers is evolving. The removal of heat generated by computing, networking, and storage equipment from the data center is changing from the practice of exclusively moving chilled air to also include the removal of heat by liquid cooling. Here, liquid cooling involves the application of rack door heat exchangers, fed and controlled by Coolant Distribution Units (CDUs). Each CDU can effectively remove sensible heat from several 42U racks. Therefore, the use of CDU technology represents a distributed heat removal paradigm, one that requires less energy than traditional computer room air conditioning methods.

A section of the Purdue data center is designed such that racks are cooled by a plurality of CDUs and their accompanying rack door heat exchangers. The system is interleaved into groups; each group cooled by several CDUs, effectively creating a physical heat removal system where adjacent racks are not cooled by the same CDU. This design is intended to reduce "hot spots" in the room by spreading the heat over a wider area, so that racks adjacent to those that have lost cooling due to the failure of a CDU can aid their overheated neighbors.

This work presents the results of experiments conducted to simulate the failure of a single CDU in a live HPC data center. By simulating a single CDU failure, we were able to study the reactions of the remaining CDUs, the effects on the racks affected by the CDU failure, and those racks still serviced by the remaining CDUs. We also report on the effects of intuitive counter-measures taken and the relative reaction time required to manage the system as compared to an air-only data center cooling implementation.

Facility Configuration

The space examined in this simulation is an older facility, with a cold-air plenum in the ceiling fed by CRAC units on the periphery of the room. While a raised floor system is present, the floor is not used in air handling within the facility. Additionally, obstructions in the ceiling air plenum can limit air handling effectiveness and overall airflow.
Primary cooling is provided by rear door heat exchangers connected to the CDUs in an interleaved fashion as described above. The CRAC units provide supplementary cooling, to support equipment lacking a rear-door heat exchanger and to maintain airflow through the facility. CRAC units are two-compressor models, able to run with zero, one, or two compressors engaged (at correspondingly increasing levels of cooling).

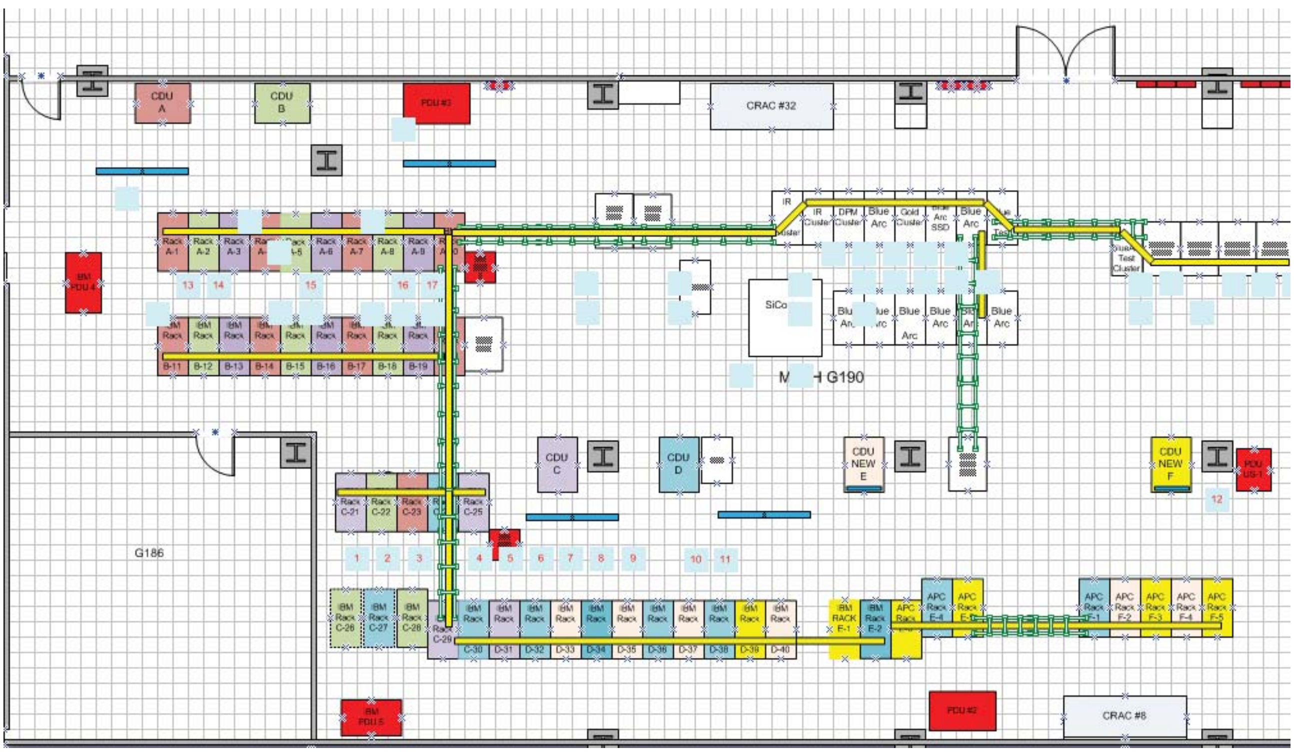

Figure 1: Facility Floor plan

Experimental Instrumentation

A recently-installed CDU (labeled "CDU NEW-E" in the figure above) was shut down in order to simulate failure of a cooling distribution unit. Prior to the experiment, the facility was instrumented to provide a sense of the expected state of the environment. Chilled water entering the facility was supplied at 43.8° F; CDU secondary-side temperature set points were maintained at 56.0° F. In general operation, the four CRAC units servicing this room operated slightly below capacity; three units were running both compressors, while one (CRAC #8, in the figure above) was completely idle (with 72.0° F intake air).

Airflow in the facility was measured at seventeen points scattered throughout the room. As mentioned above, the room's ceiling serves as a somewhat obstructed cold air plenum. The effects of this obstruction are apparent in the airflow measurements where, depending on location, values ranging from 334 CFM to 873 CFM were observed. Airflow remained relatively constant for the duration of this test. Prior to testing, ceiling temperature was measured at an average of 66.0° F.

The load under test consisted of a row of 20 racks, each containing 32 HP DL 165G5p systems, with an average power consumption of 9.1 kW per rack. Prior to testing, the cold aisle temperature (intake air, measured 5' above the floor in front of a typical rack) was measured at 74.6° F. Hot aisle temperature (exhaust air, measured 5' above the floor behind a typical rack) was measured at 70.7° F – indicating that an overall temperature decrease was occurring across the rack. The rear door heat exchanger units were providing a net cooling effect within the room prior to test.

In addition to the measurements described above, a central temperature sensor (located at "CDU D", in the figure above) was monitored throughout the test. Prior to testing, the ambient temperature was 76.0° F.

Simulation and Results

At 13:20, CDU E was deactivated, simulating a failure. Ambient temperature was measured at 76.0° F.

By 13:35 (T+15 minutes), cold aisle temperatures had risen to 75.0° F and hot aisle temperatures had risen to 74.1° F. By 13:55 (T+35 minutes), cold aisle temperatures had dropped; one of the compressors in an idle CRAC unit (CRAC #8, in the figure above) had activated. Hot aisle temperatures had climbed to 76.2° F. A similar temperature change in the cold aisle was observed at 14:20 (T+60 minutes), when the second idle compressor (again in CRAC #8) activated. At that point, cold aisle temperatures had dropped to 72.5° F, and hot aisle temperatures had fallen slightly to 75.5° F.

Temperatures seen by the processor thermal sensors in equipment racks remained unaffected during this test, showing negligible change before and after CDU deactivation. Secondary-side water temperatures seen in adjacent CDUs (serving racks next to those connected to the unit under test) were similarly unaffected.

Additional Measures

Following the test period, we adjusted the secondary-side temperature set points of adjacent cooling distribution units – moving from a set point of 56.0° F to 53.0° F. This drop in internal temperature caused the CDU to work harder; internal valves were opened, and pumps were run at maximum speeds. Initial results appeared promising, with cold aisle temperatures dropping to 72.3° F, and hot aisle temperatures dropping to 74.8° F. After 10 minutes in this mode, one of the compressors in CRAC #8 also deactivated due to the decrease in the return air temperature. While the specific impact of set point changes in other units is difficult to measure (as it will be highly location-dependent), the adjustment provides some evidence that additional cooling capacity in rear door heat exchangers can be exploited to provide additional longer-term cooling during a unit failure.

Conclusions

Passive rear door heat exchangers can supply a significant amount of cooling in a modern compute environment. The impact of an individual component failure can be minimized by simply distributing the heat exchangers across a number of racks in the data center, so that any single cooling distribution unit serves racks scattered over a wide area. As this test demonstrates, cooling can still be maintained in the presence of failure with either a small amount of supplementary cooling, or by delivering more cooling from the non-failed CDU by reducing the door water supply temperature. Additionally, proper use of rear door heat exchangers may allow for further facility benefits – including net cooling effects and greater overall cooling resiliency.