Data Center Efficiency with Higher Ambient Temperatures and Optimized Cooling Control

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Abstract

Advances in server technology have resulted in the cost of acquiring server equipment trending down, while economies of scale in data centers have significantly reduced the cost of labor. This leaves the cost of the energy as the next target for optimization. Energy costs are driven by operating the IT equipment, the switchgear that provides uninterrupted power to the equipment, and in cooling the IT equipment. In a typical datacenter, almost 40% of the total power consumption is spent on cooling. In addition, cooling effectiveness is a first order factor in determining the lifespan of the data center.

One of the emerging trends in the industry is to move datacenter operations to higher ambient temperatures with some Operators wanting to set supply air temperatures as high as 40°C while improving cooling system efficiency. This study will show that with optimized cooling control one could reduce the total cost of ownership at the datacenter level by optimizing the datacenter cooling budget while ensuring no performance loss at increased ambient temperature conditions.

This paper describes a platform-assisted thermal management approach that uses new sensors providing server airflow and server outlet temperature to improve control of the data centers cooling solution. This data is also used as input to a computational fluid dynamics (CFD) model for accurate predictive analysis and optimization of future change scenarios, thus increasing the data center efficiency and reducing power consumption. A key component of the study will be the use of computational fluid dynamics CFD analysis for optimizing the data center cooling system.

Keywords

Data Center, Efficiency, Sensor, Higher Ambient Temperature, Cooling Control, CFD.

1. Introduction

The problems of efficiency and under-utilization of data centers have been well publicized. Data centers seldom meet the operation and capacity requirements of their original design (Gartner [1]) typically only 50% of their capacity is being utilized (US Department of Energy [2]).

When data centers are designed, the total power and cooling capacity is based on some assumptions of how the IT load will increase throughout the life of the data center.

However during design it is impossible to foresee what IT Equipment will be deployed and where it will be installed and so simple assumptions of kW per unit area or kW per rack must be used.

In reality the data center deviates from the design assumptions from the onset of operation as real IT equipment is deployed. Different categories of equipment must be installed into the data center: servers; storage; switches. These have different cooling configurations and internal controls but must be accommodated in one thermal environment: some equipment breathes front to back, some side to side, some bottom to top. In all categories the power density is raising with each generation of equipment (ASHRAE [4]), so as equipment is refreshed the cooling requirements and the thermal impact of the equipment on the rest of the data center changes, making cooling control and airflow management more difficult.

This typically results in hot spots within the data center and a reduction in usable capacity and a reduction in the data center life.

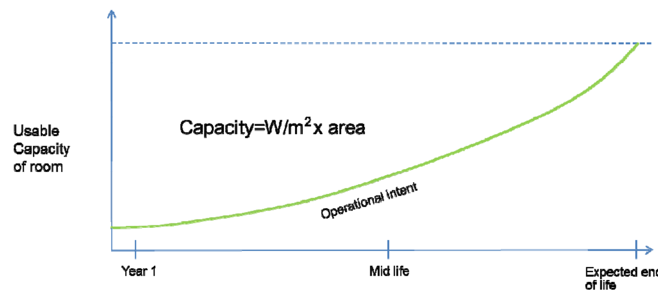

Figure 1: Data center design intent: how the capacity of a data center is intended to be utilized as IT equipment is deployed throughout the life of a data center.

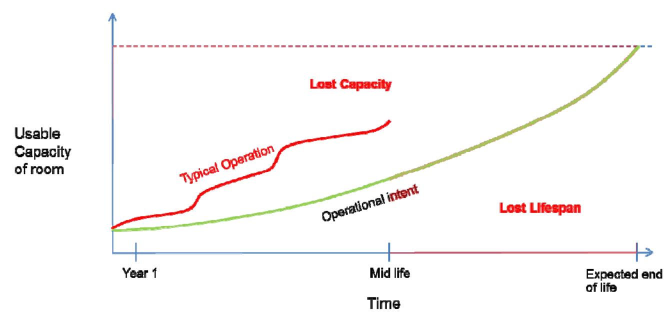

Figure 2: Data center reality: how the capacity utilization of a data center versus design intent.

Figure 2 shows how a data center deviates from the design intent as the capacity is used up faster than intended. Also note that the data center does not reach its full capacity as hot spots and thermal issues leave power capacity stranded, i.e. there is power provision but no adequate cooling to racks within the data center. The typical response to this situation is to turn down cooling set points to overcome hotspots and keep the data center operational, however this impacts the operational cooling costs of the facility, and cooling costs typically make up approximately 40% of the total operational costs of a data center:

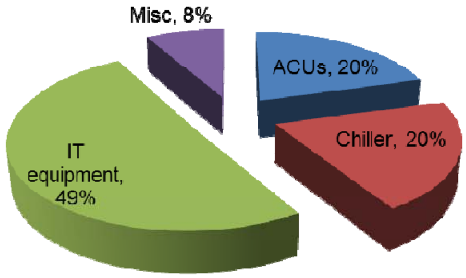

Figure 3: Typical power consumption breakdown, PUE of 2.0 (Koomey, LBNL [3])

It has been estimated that 30% improvement in infrastructure energy efficiency can be achieved with improved airflow management (EPA Report to Congress [6]).

Airflow management and cooling control are therefore critical factors when trying to maximise utilization of a data center.

This document is intended at several types of audience. 1) Serve architects and engineers of Original Equipment Manufacturers (OEMs) who want to provide improved thermal instrumentation in their platform, and 2) Data Center architects who want to understand new usage models to optimize the cooling system. It is based on work performed internally by Intel and simulations performed by Future Facilities.

2. The Current State of Data Center cooling control

In the modern data center there are many control systems working independently. Every modern piece of IT equipment controls its flow rate based on inlet air temperature and power utilization. Data center cooling units control their heat rejection using temperature sensors positioned on the units itself or positioned remotely in the data center. The latest generation of cooling units has electronically commuted fans that control their flow rate based on temperature or pressure sensors (or a combination of the two) and some legacy cooling units can be retrofitted to provide flow rate control. In addition to passive front to back cabinets, active cabinets are available from many rack manufactures that include fan trays controlling their flow rate using temperature of pressure sensors. This array of active components can result in thousands of independent controllers in a modern data center, with no integrated control.

Figure 4, below shows the supply chain from server to data center. At each stage airflow management and cooling control are critical to achieve resilience and energy efficiency, because of the CFD is used at each stage during design. However during operation the control system integration only connects the first two stages, i.e. from chip to chassis: the server can control the fans in the chassis to deliver the required airflow at the required temperature. At rack and room level cooling control becomes non-integrated as explained above.

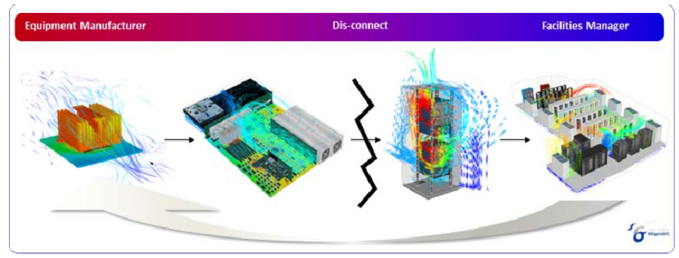

Figure 4: Lack of Integrated Control.

It should be noted that the purpose of the data center is to house, power and cool every chip inside it. Therefore philosophically it has the same goal as the chassis. However the chassis achieves the cooling requirements of the chips inside by taking data from the servers and using that to control its cooling system, this strategy not continue throughout the supply chain up to the data center.

Without knowledge of the actual cooling needs of the equipment the data center is quite often significantly over-cooled but there is also the possibility for under-cooling leading to performance impact.

There are moves within the data center industry to improve the control of data center cooling by moving sensors closer to the intended targets of the cooling, i.e. the servers. This has been seen in the move from control on return air temperature to supply air temperature, and then moving the sensors from the cooling unit supply to the cold aisles or the front doors of the cabinets. We will investigate the effectiveness of these developments in this paper using experiment and simulation.

3. The Future of Data Center cooling control?

The next generation of data centers could take this progress to its logical conclusion and control the data center cooling from the chip instead of remote sensors in the room or on cabinet doors.

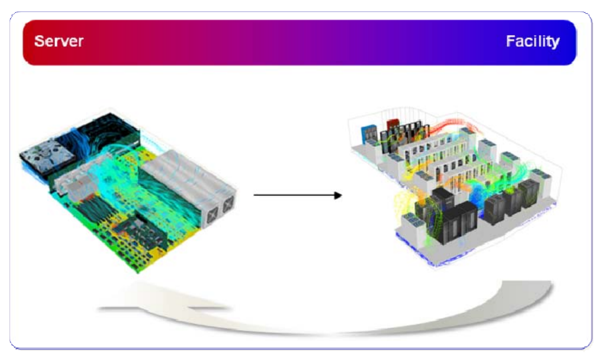

Figure 5: Controlling data center cooling from the server.

Intel is proposing to collect temperature and airflow data from all the servers in a data center and to make this data available to the data center operator.

Using the proposed thermal sensors exposed by the servers, the data center operator can determine whether airflow has been adequately provided to the equipment but also whether recirculation is occurring within a rack or set of adjacent racks by evaluating inlet temperature conditions.

In this paper we will predict what could happen if this thermal data was used to control the data center cooling units, looking at the effects on resilience and energy efficiency. We propose that the data center cooling units could deliver the required temperature based on the measured server inlet temperature.

The real time data from the server inlet temperatures, could be used to automatically cooling unit operating points, adjust chilled water temperature or simply to enable the DC operator to move or reposition floor tiles to eliminate the hotspots.

In this paper we use a simple one rack case to will predict the effects on server inlet temperature and cooling supply temperature when we control cooling from the server, then we will use a hypothetical case study to extrapolate this to a small data center.

3.1. Single Rack Demonstration

A data closet was used as a test site. It consisted of a single rack, with one supply vent in and one return vent in the ceiling. A partition wall sits between the supply vent and return vents, effectives segregating cold aisle from hot aisle. Temperature sensors were placed on the cooling supply vent, the cooling return vent and the front and back door of the cabinet.

Figure 6: Single rack used in cooling control experiments.

The test site was used to investigate the effects of moving the control sensor closer to the intended target of the cool air: we investigated 4 sensor locations:

1) The cooling control sensor was placed on the return vent, the set point was 28°C.
2) The cooling control sensor was placed on the supply vent, the set point was 18°C.
3) The cooling control sensor was placed on the cabinet front door, the set point was 23°C.
4) The servers in the cabinet were used as the cooling control sensor, the set point was 30°C.

The first three sites we chosen to represent the advances in data center control, the fourth is a simulation representing a future control set up using the new data available from Intel.

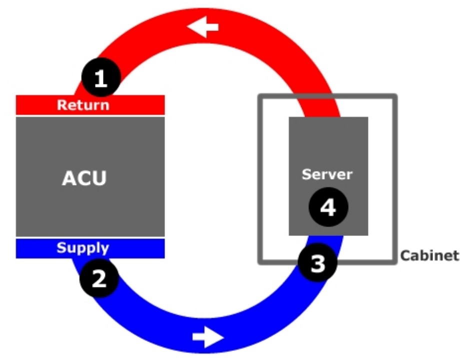

Figure 7: Schematic showing trend for moving cooling sensors closer to server inlet vents.

The experimental temperature data that was recorded can be seen in Figure 8. The data shows variation in time from left to right, section 1 shows control on return, section 2 shows control on supply, section 3 shows control using front door sensors.

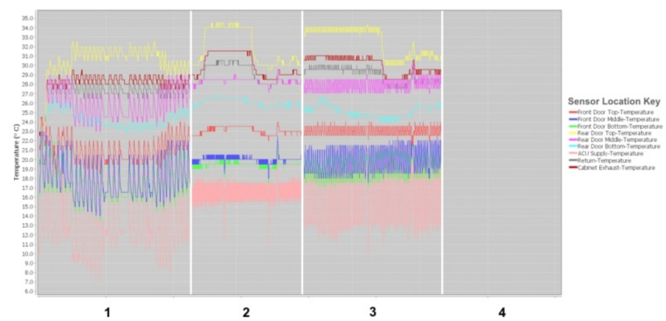

Figure 8: Experimental data showing temperature against time as sensor location is moved closer to the server inlets.

In order to understand the data we can pick out the key information: the cooling supply temperature and the range of maximum server inlet temperatures, these tell us about the energy efficiency of the system and the thermal resilience respectively.

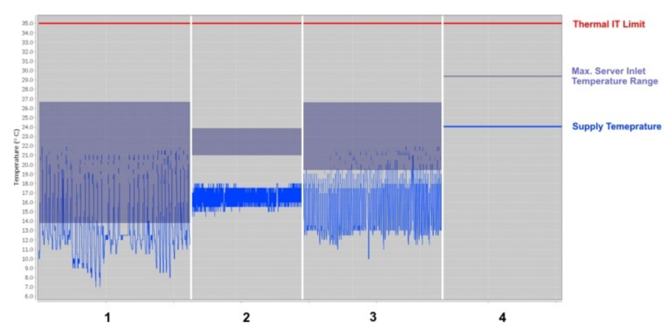

Figure 9: Variation in supply temperature and resilience as sensor location is moved closer to the server inlets.

The data in section 1 shows typical supply variation using control on return strategy – the cooling supply varies from 7 to 21°C. The server inlet temperatures ranged from 14 to 27°C.

Section 2 shows a much closer control on the supply temperature as we would expect, with a variation from 15 to 18°C. Server inlet temperatures ranged from 21 to 24°C

Section 3 shows that by controlling to the cabinet door temperature the cooling supply temperature was more variable that the supply control experiment but less variable than the return control setup. 13 to 21°C, Server inlet temperatures ranged from 20 to 27 °C.

Section 4 Controlled to a maximum server inlet of 30°C, resulted in a supply temperature of 24°C.

We conclude that in this case controlling on supply temperature increases the minimum supply temperature from 7 to 15°C and thermal resilience increased from 8 to 11°C.

Controlling on door temperature offered some benefits over control on return with a minimum cooling supply of 13°C. Controlling cooling using server inlet temperature offered the maximum benefit. We chose to control to maintain a 5°C resilience for each server and this resulted in a cooling supply temperature of 24°C.

3.2. Data Center Control example case

In this section of the paper we extrapolate this experience on one rack up to a small example data center. This hypothetical data center has a total cooling capacity of 100kW with 4 perimeter downflow cooling units (with N+1 redundancy). The data center has 4 rows of racks: one for network devices, one for storage and 2 for servers. The rows are not contained but do follow a hot aisle – cold aisle configuration.

Cable management follows a common modern design, with overhead power routes and under floor data routes. All cable penetrations through the raised floor have brush seals to prevent excessive leakage.

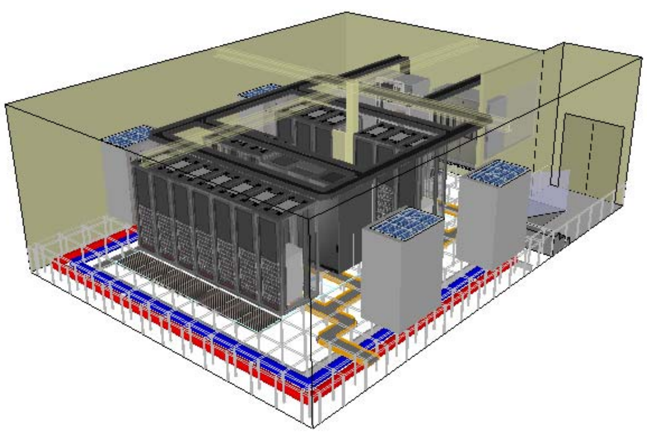

Figure 10: Small example data center.

Two cases were compared using CFD simulation; in the first a traditional control strategy was used: controlling return to 22°C with individual controller on the cooling units. In the second the cooling units were group controlled in pairs, grouping each cooling unit with the unit on the opposite wall. Each pair of cooling units was controlled by the maximum inlet temperature of any server in the corresponding cold aisle. The controller was set to maintain a worst case 5.6 °C of thermal resilience below the manufacturers operating conditions for any server in that aisle.

Figure 11: ASHRAE 2008 compliance with traditional return temperature control (ASHRAE [5]).

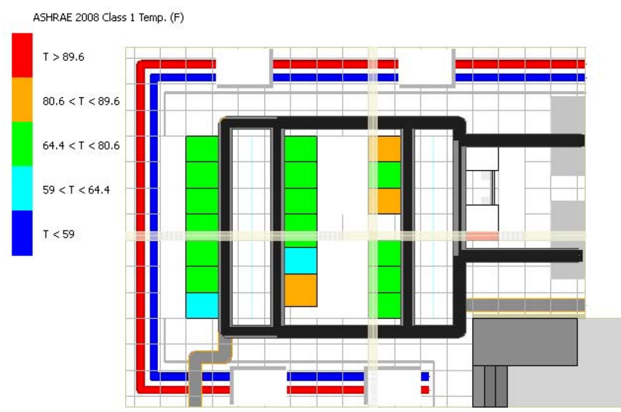

Figure 12: ASHRAE 2008 compliance with cooling controlled by inlet temperature of servers (ASHRAE [5]).

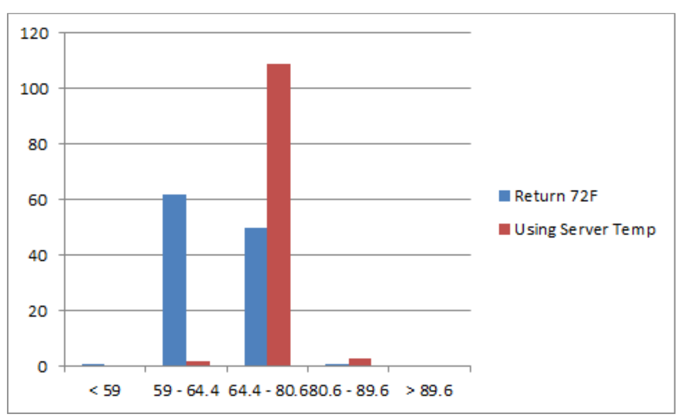

Figure 13: Number of servers in the ASHRAE 2008 recommended range, comparing cooling controlled by inlet temperature of servers with a traditional return control strategy (ASHRAE [5]).

Looking at the number of servers in each ASHRAE category we can see that using the server inlet temperature data to control the cooling units results in more servers in the ASHRAE recommended range (ASHRAE [5]).

It should be noted that in the case the minimum supply air temperature was 2.8 °C higher when using the server sensors than when controlled with the traditional return control strategy. Data center managers can save 4 percent in energy costs for every 0.6 °C of upward change in the set point, (High Performance Data Centers: A Design Guidelines Sourcebook [7]) – so this is an estimated 20% saving in cooling costs.

4. Conclusions

Intel proposes to leverage real time server data and to make it available to data center operators to use in thermal visualization, cooling control systems, and CFD simulations.

The combination of measurement and simulation provides data center operators with the ability to manage a dynamic cooling environment in their data center. A dynamic data center cooling environment will react to the requirements of the IT Equipment, allowing higher temperature and lower fan speeds therefore reducing running operating costs.

It should be noted that higher ambient temperatures give efficiency gains but may impact the resilience of the data center if the event of total power outage – as the window between failure and equipment overheat will be reduced. Simulation of failure scenarios will be essential as ambient temperatures are raised.

Another proposal by Intel is to measure and leverage real time airflow data from the servers in addition to server inlet temperatures. This data could be used to control the flow rate of cooling units using electronically commuted fans to match the required flow rate of the IT Equipment. This was not considered in the scope of this paper, but will enable further reduction in operating costs as cooling fan power will be reduced.

5. The Next Steps

Integrated platform assisted thermal management of data centers will make it easier to logically connect activities related to data center power and thermal management to specific business goals. There is still significant work to be done in defining the logical layers and the APIs in between.

Original Equipment Manufacturers of servers need to perform thermal characterization of their server chassis and expose the additional thermal sensors. Intel have provided an approach to do that which can be extended to other types of chassis like blades and micro-servers. Data centers should begin taking advantage of these new sensors to implement new and improved IT management and building management solutions.

Further proof of concept needs to be performed with the servers providing derived platform thermal sensors placed in a data center environment and the sensor data integrated with facilities management and simulation software. This will demonstrate the end-to-end feasibility of the usage model discussed in this paper

6. Future Challenges

There are two Future Challenges for the data center community:

Challenge 1: Data Center Architects will be able to use CFD simulation techniques to design the next generation of greener "dynamic" data centers that will be controlled from the server instead of remote sensors in the room or rack.

Challenge 2: The more important challenge: There are hundreds of thousands of under-utilized "static" data centers that were not designed to be controlled from the server. The unused capacity is a result from ineffective cooling management and control i.e. they have cooling capacity available in the room but it cannot be used as they cannot deliver the cooling to where it is needed. The challenge is to use the server temperature and airflow utilization data to improve the cooling control in these existing data centers and to reclaim this lost capacity:

The greenest data center is the one you don't need to build

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