Award-Winning Innovation in Data Center Cooling Design

Oracle's Utah Compute Facility

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Introduction

Although free cooling from outdoor cold air – air-side economization – is as old as civilization, data centers have been reluctant to adopt this technology in the past. The conventional approach to humidifying large quantities of air requires injection of steam into air whose generation requires energy. The industry learned quickly that it required more energy to humidify dry outdoor air than the energy saved from the use of its free cooling, and air-side economization did not make much headway in data centers. These problems were addressed efficiently in an innovative system installed in one of Oracle's new state-of-the-art data centers in West Jordan, Utah. The 25,000 ft^2 (2323 m^2) data center is supported with a 95,000 ft^2 (8826 m^2) structure to house infrastructure equipment and a 44,000 ft^2 (4088 m^2) office space. The innovations center on the use of waste heat from the IT equipment for space humidification in the winter; evaporative cooling in summer; reduced primary airflow to the IT equipment; strategic hot air separation with recirculation; and novel controls that enabled the data center to achieve very high cooling efficiency at a lower initial investment cost. With efficient operation and low operating Power Usage Effectiveness (PUE), the system is expected to save over 41,000 MWh a year and the equivalent of 37,000 metric tons of CO2 annually compared to an average efficient data center.

ORACLE UTAH COMPUTER FACILITY

Location	West Jordan, Utah
Owner	Oracle USA
Principal Use	Data Center
Includes	25,000 ft^2 data center white space
Employees/Occupants	30
Gross Square Footage	164,000
Conditioned Space Square Footage	44,000 office space
Substantial Completion/Occupancy	April 2011
Occupancy	80 percent of data center capacity

Overview

The project to build a new data center was commenced in 2008. At the time, the use of outside air in cold climates for data centers was limited, as data centers have been quite reluctant to using free cooling from cold outside air, or air-side economization. Climatically, outside cold air is naturally dry, and when it picks up heat in data center spaces, its relative humidity drops to levels where humidification is needed to protect the IT equipment from static electricity.

Although some advocate maintaining much lower level of indoor humidity in data centers which would reduce the need for humidification[1], data center operators have yet to embrace it. The conventional approach to humidifying large quantities of air requires injection of steam into air, typically from boilers or pan heaters. However, the industry was quick to realize that it required more energy to humidify dry outside air than the energy saved from using its 'free' cooling, and airside economizers did not make much headway in data centers. The potential for airborne contaminants and the subsequent need for increased filtration were also seen as additional reasons for concern.

An innovative system that was installed in a new state-of-the-art Oracle data center in West Jordan, Utah, overcame these problems. The 25,000 square foot data center is supported with 95,000 square foot structure to house infrastructure equipment and 44,000 square feet of office space. Only the first of four 7.2 MW super-cells was built, leaving room for future expansion.

The system has been in operation since 2011 and its operational fine tuning is ongoing. The monthly energy use from August 2012 to July 2013 by the IT equipment as well as the supporting cooling equipment (air circulation fans and cooling plant) for the main data center hall and the supporting uninterrupted power supply hall are summarized in *Table 1*.

TABLE 1: ENERGY USE HISTORY (DATA FROM PANEL AND SUB-METERS)

			COOLING EQUIPMENT ENERGY USE			
Month	**Electricity Into UPS[2], kWh**	**Electricity out from UPS to IT equipment**	**Electricity Use by Air Moving Fans in Data Hall, kWh**	**Electricity Use by Air Moving Fans in UPS Hall, kWh**	**Electricity Use by Chiller Cooling Plant, kWh**	**Total Electricity Used for Cooling Data Center, kWh**
Aug 12	3,225,601	2,867,735	250,557	58,518	200,313	**509,338**
Sep 12	3,370,541	3,002,963	203,399	52,518	57,654	**313,171**
Oct 12	3,648,867	3,253,247	176,042	46,532	397	**222,971**
Nov 12	3,607,933	3,217,234	171,926	41,878	495	**214,298**
Dec 12	3,853,849	3,440,646	167,033	40,485	1,343	**208,860**
Jan 13	3,927, 458	3,507, 297	203, 364	32,667	2,124	**238,155**
Feb 13	3,547,351	3,168,147	126,983	31,768	962	**159,713**
Mar 13	4,059,953	3,623,900	180,202	38,420	20,664	**239,285**
Apr 13	3,969,617	3,534,803	186,535	36,861	5,783	**229,178**
May 13	4,236,367	3,779,710	267,702	42,200	9,146	**319,048**
Jun 13	4,080,895	3,640,735	360,421	47,727	65,763	**473,911**
Jul 13	4,194,005	3,738,073	427,788	51,503	423,552	**902,843**
Annual	**45,721,463**	**40,774,490**	**2,721,951**	**520,675**	**788,195**	**4,030,822**

1 ASHRAE TC 9.9, Mission Critical Facilities, Data Centers, Technology Spaces and Electronic Equipment is revising its recommendations to lower recommended and acceptable humidity levels in order to increase use of airside economizers.

2 Uninterrupted Power Supply

The cooling energy use as a ratio of the total IT equipment energy use varies from a low of 1.05 in cold weather to a maximum of 1.25 in summer, depending on ambient wet-bulb temperature[3]. Its partial cooling-only Power Usage Effectiveness (PUE)[4] was measured at less than 1.05 for the month of February and less than 1.10 for the entire year as summarized in *Table 2* and *Figure 1*.

TABLE 2: ENERGY USE BY COMPONENTS OF COOLING EQUIPMENT AS A FRACTION OF THE IT EQUIPMENT ENERGY USE (PARTIAL PUE OF COOLING EQUIPMENT)

	COOLING EQUIPMENT ENERGY USE PER UNIT IT ENERGY CONSUMPTION			
Month	**Electricity Use by Air Moving Fans in Data Hall, kWh/kWh of the IT equipment**	**Electricity Use by Air Moving Fans in UPS Hall, kWh/kWh of the IT equipment**	**Electricity Use by Chiller Cooling Plant, kWh/kWh of the IT equipment**	**Total Electricity Used for Cooling Data Center, kWh/kWh of the IT equipment**
Aug 2012	0.087	0.020	0.070	0.178
Sep 2012	0.068	0.017	0.019	0.104
Oct 2012	0.054	0.014	0.000	0.069
Nov 2012	0.053	0.013	0.000	0.067
Dec 2012	0.049	0.012	0.000	0.061
Jan 2013	0.058	0.009	0.001	0.068
Feb 2013	0.040	0.010	0.000	0.050
Mar 2013	0.050	0.011	0.006	0.066
Apr 2013	0.053	0.010	0.002	0.065
May 2013	0.071	0.011	0.002	0.084
Jun 2013	0.099	0.013	0.018	0.130
Jul 2013	0.114	0.014	0.113	0.242
Annual	**0.067**	**0.013**	**0.019**	**0.099**

Figure 1 shows a plot of the operating partial cooling only PUE versus daily average ambient wet-bulb temperature. The cooling energy use consisted of three components: fans for air distribution to the data hall; fans for air distribution for the UPS hall; and chiller plant to distribute trim cooling to the air-handling units. Total cooling energy required to remove each kWh of the IT equipment generated heat was quite low during periods of low ambient wet-bulb temperatures when free cooling and humidification were available, but increased when ambient wet-bulb temperatures increased as evaporating cooling needed to be supplemented with trim cooling of ambient air.

In the design and operation the system operated with free cooling when ambient wet-bulb temperatures were generally below 52°F (11°C) – 74 percent of hours annually – with supply air of less than 59°F (15°C). It is thought possible to obtain free cooling even at higher ambient wet-bulb temperatures approaching 65°F (18°C) – 99 percent

3 The wet-bulb temperature is the temperature of adiabatic saturation, indicated by a moistened thermometer bulb exposed to the air flow

4 PUE: measured as a ration of all cooling energy consumption divided by the IT equipment energy consumption. The Green Grid. "PUE: A Comprehensive Examination of the Metric." White Paper #49

of the time in this climate – since cold air can still supplied at 72°F (22°C) with a 7°F (4°C) approach with evaporative cooling effect.

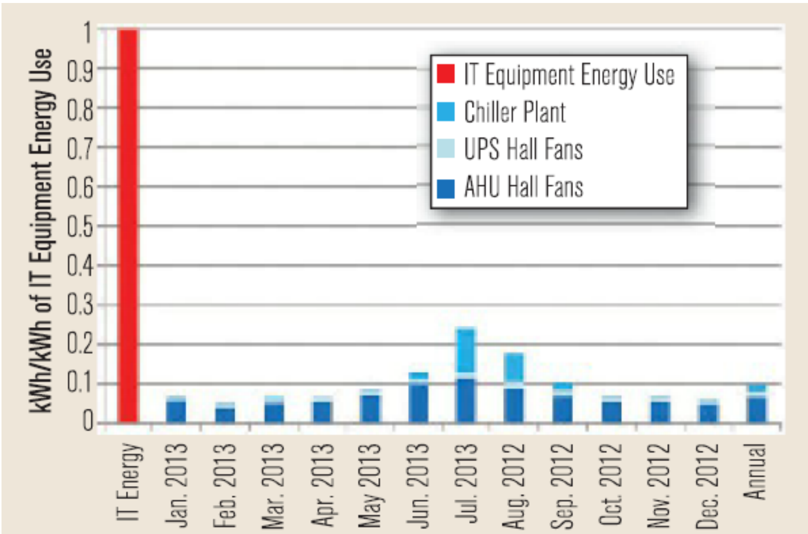

Figure 1: Plot of energy use by components of cooling equipment as a fraction of the IT energy consumption (contributing components of the partial PUE)

The partial cooling-only PUE varied slightly from 1.05 to 1.10 between low ambient wet-bulb temperatures of 20°F to 52°F (-7°C to 11°C). At temperatures above 52°F (11°C), ambient air dry-bulb temperatures were pre-cooled just enough so that its wet-bulb temperatures were 52°F (11°C). The trim cooling was provided by the chiller plant for the remaining 26 percent of the time. The amount of trim cooling varied – e.g., reducing wet-bulb temperature by only 1°F (0.55°C) when ambient wet-bulb temperature was 53°F (12°C) to reducing it by 13°F (7°C) when ambient wet-bulb temperature was 65°F (18°C). Though the chiller was sized to run the cooling system in a complete air recirculation mode, in the event the outdoor air quality is unacceptable - either due to smoke or dust particles in the air - the actual amount of trim cooling requirement was quite small, only 0.19 kWh/kWh of the IT energy on annual basis. The energy consumption for chiller plant versus ambient wet-bulb temperature is also shown in *Figure 1*.

Since 100 percent or a very large fraction of outside air is used all the time unless the system needs to be run in recirculation mode, the indoor air quality is excellent. The air flows over a wet media that captures dust particles and also provides excellent filtration of outside contaminants as well as enhanced indoor air quality. So far Oracle has never had to run the system in a complete recirculation mode.

Innovation in Energy Efficiency

Several innovations, as well as best practices learned from operating other data centers, were implemented in the Utah facility.

Humidification

The system uses the waste heat from the IT equipment to evaporate water into moisture instead of using additional energy to generate steam. Moving hot dry air over a wet media to cool it is a well-known technology, but its use to primarily humidify air has not yet found its way into the industry. The hot air from the IT equipment—mixed with cold and dry outside air—flows over a wet media where it picks up moisture and gets humidified as shown in Figure 2.

The air is cooled in the process, which is also known as evaporative cooling. The cooling is certainly helpful but incidental in this application: the primary objective is to get 'free' humidification.

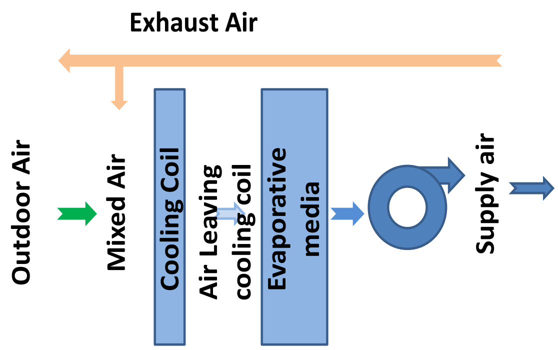

Figure 2: Schematic of air-handling unit

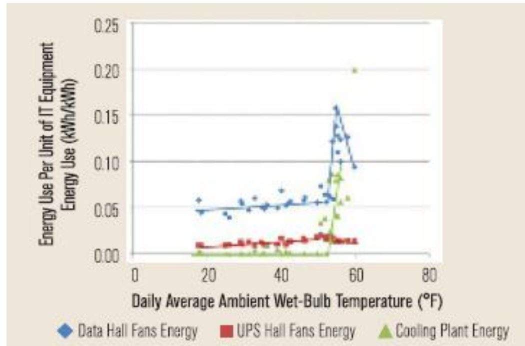

Figure 3: Cooling energy use vs. ambient wet-bulb temperature

In West Jordan, Utah, humidification is needed for over 78 percent of the hours in a year when the outside dew-point temperature is below the current minimum acceptable dew-point temperature of 41.9°F (5.5°C) as shown in *Table 3*, which also shows a comparison of the number of hours when free cooling is available with conventional air-side economizer as well as with the installed cooling system.

TABLE 3: Number of hours in a year when free cooling is available in West Jordan, Utah

	Conventional airside economizer	Innovative economizer
Number of hours of 'free' cooling (<67.5°F)	73%	99%
Number of hours backup cooling needed	27%	1%
Number of hours humidification energy needed	78%	0%

The solution provides complete free humidification and cooling for 74 percent of the time and partial free cooling for the remaining 26 percent of the time with the controls set-points that were selected. It has the ability to provide free cooling and humidification for 99 percent of the time if supply air temperatures of 72°F (22°C) are acceptable. In comparison, the conventional economizer only provides free cooling for 73 percent of the time, but requires humidification energy for 78 percent of the time. The large number of hours when humidification is needed in cold climates explains why conventional humidification systems required more energy than cooling energy saved from cold outdoor air, and economization was shunned by the industry.

Controls

Conventional controls are based on dry-bulb temperatures and use feedback from the discharge air temperature to control sensible cooling. This innovation in controls is based on using the wet-bulb temperature of the incoming air for control of humidification. This also provides stable supply air temperature and prevents wet/dry cycling of the evaporative media and associated wide variation in supply air humidity and temperatures. The simplicity of these controls lies in the fact that the return/exhaust air is mixed with cool outside air to continually achieve a desired wet-bulb temperature. The mixed air is then passed over a wet media to achieve stable supply air temperature and the mixed air wet-bulb temperature is allowed to float between a minimum and a maximum set point. The maximum set point was based on the air distribution effectiveness. When the outside air wet-bulb is within the range, no mixing is needed. When outside wet-bulb temperature exceeded the maximum set point, the chiller plant was activated to precool incoming air, which reduced its dry-bulb as well as wet-bulb temperatures. In most scenarios, only small amounts of sensible cooling of the dry air ambient air was sufficient to bring its wet-bulb temperature to desired levels. The amount of cooling required was only that which was needed to trim outdoor air wet-bulb temperature to the desired level, which is much smaller than what would be needed to provide 100 percent cooling of the recirculation air. This explains why Oracle's chiller plant was not required for most of year except in the hot months of July and August and even then the amount of cooling energy required was small, as shown previously in *Table 2* and *Figure 1* and *3*.

Cold Air Distribution and Un-Containment

A design oversight was turned into an asset. Containment of hot air or cold air and preventing mixing between the two in the data center space is now widely accepted. However, the intentional choice was not to fully isolate cold and hot air streams, but to allow some directed mixing between the two in the data center space to overcome design limitation and gain energy efficiency. This may sound counterintuitive to the now widely-accepted practice of fully isolating hot and cold air, but its rationale is explained below and it is providing excellent energy savings in the field. For the record, in 2004 Oracle was likely the first organization to demonstrate and champion the use of physical barriers between hot and cold air streams to prevent its mixing at its large data center in Austin, Texas[5].

For proper functioning of any containment, the airflow across the IT equipment must be equal to the airflow across the cooling equipment. If not, either the airflow over the IT equipment or the one over the cooling equipment will starve. Therefore, the airflow of the cooling equipment must be sized to meet the airflow of the IT equipment. The airflow over the IT equipment is derived from the design temperature rise when air passes through it. The average design temperature rise in IT equipment is ever increasing as it becomes more power consuming. The data center was designed to handle the latest IT hardware, and most of these are designed with lower airflow and higher temperature rise of ~30^{o}F (17◦C) across the IT equipment.

The cooling equipment air-handling units were thus sized to match the lower airflow for a 30^{o}F temperature rise. However, the average temperature rise across the current IT equipment was less than 20^{o}F. This meant that the airflow capacity or size of the air-handling equipment needed to be increased by 50 percent in order to use full containment. This posed a major problem: redesign the entire data center, including all mechanical, civil and electrical infrastructures with 50 percent larger air-handling equipment. This would increase the data center infrastructure costs substantially as well as delay the implementation, which this fast-track project could not afford.

A very creative approach—un-containment— was devised to overcome this problem. Instead of redesigning the entire data center with full containment, only a partial barrier was used between the cold and hot air, which allowed some directed mixing of hot air back into the cold aisles. This permitted Oracle to supply less cold air to the data center, which after mixing with some of the recirculated hot air within the data center space met the total airflow requirement of the IT equipment. Therefore, it allowed supplying less quantity of colder air and still being able use the smaller sized central air-handling unit and cooling system infrastructure without redesign and at a much lower first cost.

The smaller Air-handling Unit (AHU) fans also significantly reduced air distribution fan power. The cold climate of Utah allowed the datacenter to supply below 59^{o}F (15^{o}C) free cold air for 74 percent of the time. For the remaining 26 percent of the time, only trim cooling was used. This turned out to be a very cost effective (smaller size AHUs, smaller civil structure and space, etc.) as well as energy efficient (less airflow with free cooling for 74 percent of the time) solution. The low airflow quantity at lower temperature supply air has helped Oracle achieve such low operating partial cooling PUEs in cold, as well as warm but dry weather. The partial un-containment in a cold aisle is shown in Figure 4.

5 ASHRAE Journal, Dec. 2007 and ASHRAE Journal, Dec. 2010

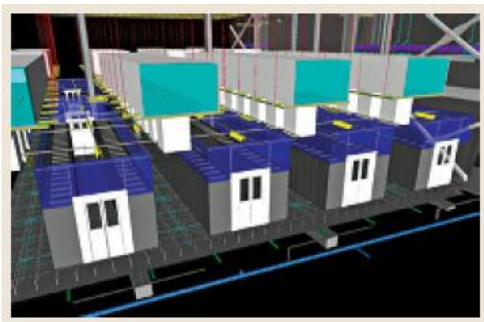

Figure 4: Un-containment air distribution

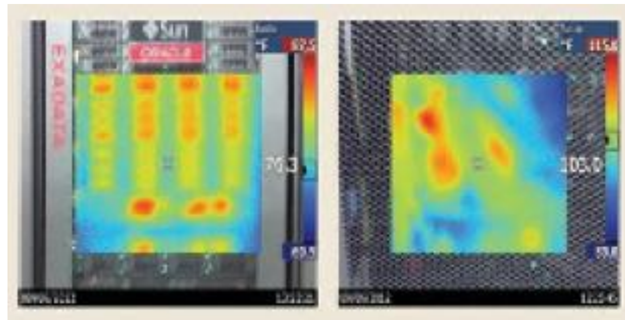

Figure 5: Thermograph of temperature profile at rack discharge

The supply air temperature was further allowed to float to below 59°F (15°C) to take advantage of the free cooling in this cold climate by reducing fan speed and thus fan energy consumption, and counting on the recirculation hot hair to make up the remaining requirement. As seen in *Figure 3*, the fan power required for air distribution in the data hall and the UPS hall are lower when ambient wet-bulb temperatures are lower and rise slowly as the wet-bulb temperatures increases.

A thermograph of temperature profile at the inlet of the rack is shown in *Figure 6*. The cold air is delivered through an overhead duct. Since there is a partial barrier and not complete isolation between cold supply and hot return air, hot air is allowed to seep into the cold aisle, which can be seen in the temperature profile of inlet air to the IT equipment. A low temperature of about 60°F (15.5°C) near the bottom of the rack and a high of about 80°F (27°C) near the top of the rack was observed.

Figure 5 shows a thermo-graphic image of the inlet and discharge air to IT equipment. The average temperature difference across this IT equipment of about 27°F (15°C) is representative of newer IT equipment. However, the average temperature difference across all IT equipment, including new and legacy compute, storage and networking IT equipment was about 18°F (10°C). Only about two-thirds of the primary airflow from the air-handling unit at low temperature of about 59°F (15°C) are supplied, counting on about one-third of the hot air to re-circulate in the cold aisle.

This allowed Oracle to undersize the AHUs and associated infrastructure by one-third. It also reduced the fan power requirement. As mentioned earlier, free cooling is available for more than 74 percent of the time in this cold climate and trim cooling is needed for the remaining time.

The overall operating energy consumption is quite attractive as shown in Table 1 with partial cooling-only PUE of less than 1.06 in winter and 1.10 annually.

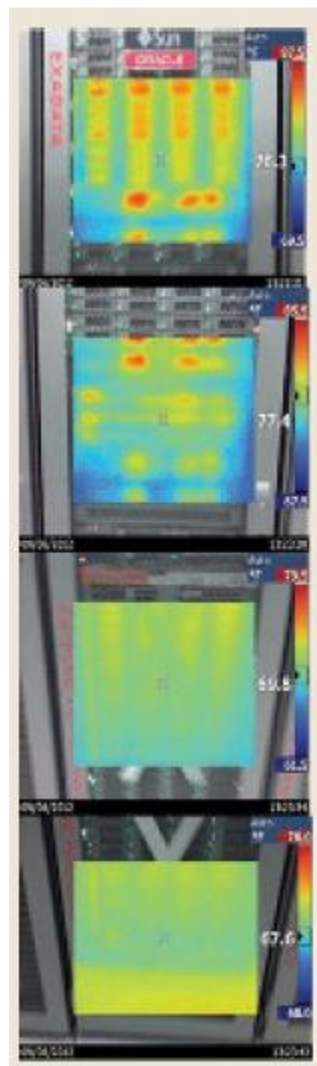

Figure 6: Thermograph of temperature profile at IT rack inlet

Trim Cooling with Chiller

The placement of cooling coils as shown in *Figure 2* in the air-handling units is such that it pre-cools ambient air in summer just enough so that its wet-bulb temperature reaches the desired level. For example, no cooling is needed when the outside temperature is 90^{o}F (32°C) with an air dew-point temperature below 42^{o}F (5.5^{o}C). At temperatures warmer than 90^{o}F on hot dry days with an air dew-point temperature below 42^{o}F, air needs to be cooled only to 90^{o}F. Besides requiring a lower amount of cooling, this also allows the chilled water temperature to be much higher than the conventional 45^{o}F – 65^{o}F or warmer – enabling the chiller system to run much more efficiently.

Finally, overhead air distribution prevents uncontrolled leakage around cable cuts in raised floors that were observed in Oracle's other data centers.

Business Benefits

Operation and Maintenance

The novel controls implemented at Oracle's Utah Data Center prevent frequent dry/wet cycling of the evaporative media, improve performance and extend its life. Since the design is primarily moving air and circulating water in the evaporative media, and do not need chiller or mechanical cooling for most of the time, the operational and maintenance costs are far less than for systems that require mechanical cooling. The simplicity of the control scheme is a further asset.

Cost Effectiveness

Since the system requires only evaporative media and could run on it for 99 percent of the time if designed with the right airflow quantity, it is a very cost effective solution. Oracle, however, chose to have a 100 percent backup mechanical cooling system just in case it was ever needed in the event of fire or other natural calamity that would prevent the use of outdoor air. Once the chiller system was selected, it was leveraged for use in the summer to supply colder air, which coupled with partial and un-containment, helped selecting AHUs one-third smaller and provided significant first cost savings on AHU equipment and the civil structure to house it, as well as additional operating cost savings from smaller fans.

Environmental Impact

With such efficient operation and low operating Power Usage Effectiveness (PUE), the system is expected to save over 41,000 MWh a year and 37,000 metric tons of CO_2 annually compared to the average efficient data center when in full operation.

Independent Verification of Performance

The system's operating performance was independently verified by the electric power utility, Rocky Mountain Power and its consultant. It also received significant incentive payment based on its measured field performance.

ORACLE

Oracle Corporation, World Headquarters
500 Oracle Parkway
Redwood Shores, CA 94065, USA

Worldwide Inquiries
Phone: +1.650.506.7000
Fax: +1.650.506.7200

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Author: Mukesh Khattar, PhD, Former Energy Director at Oracle

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