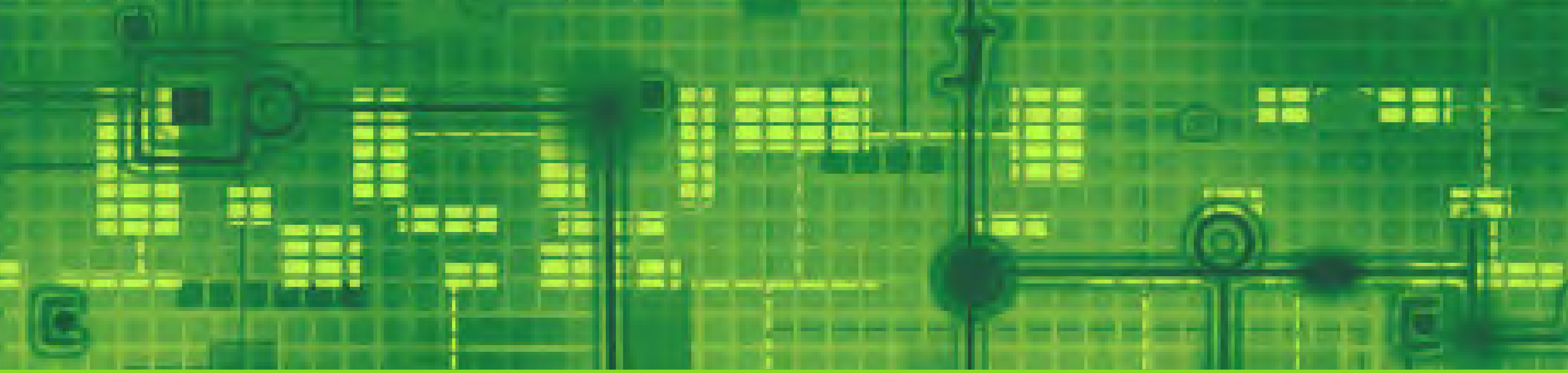

Data Center Hybrid Cooling:

A Cost Saving Method

Data centers are facilities which house numerous computer systems generally installed in rows of electronic racks. Data centers vary in size and may house up to thousands of racks, with each rack typically consuming 10-30 KW of power [4]. They are like backbones of the information economy, crucial to universities and government institutions, financial services, medical, media and high tech industries. Data centers contain enterprise servers, server communication equipment, and cooling and power equipment.

Data centers represent an important share of the national energy consumption and carbon footprint due to continuous growth of communication and data storage industries, that has caused a rapid increase in energy consumption in data centers. In the U.S. alone, the energy consumption of data centers is approximately 2% of total U.S. energy consumption and continues to increase steadily [1]. Figure 1 below, shows a typical energy distribution in data centers.

The components that consume the most energy are the IT equipment and cooling systems, with combined power consumption of more than 70% of total energy. Generally, the cooling equipment uses almost the same amount of energy as the IT equipment.

Looking at the above mentioned facts, Data center efficiency has been subject to more scrutiny than ever in recent years. Dramatically increasing operating costs and capital expenses have driven

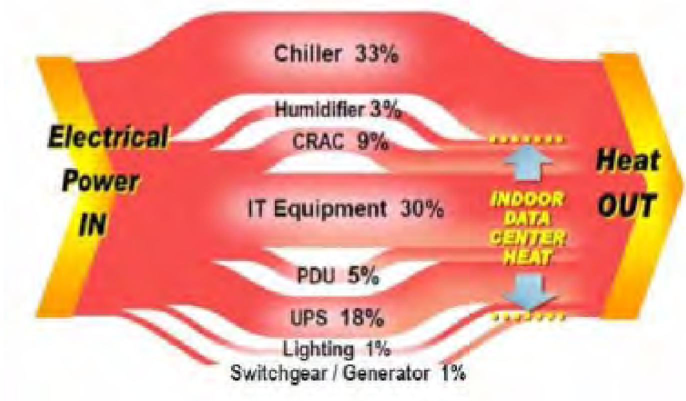

Figure 1. Typical Distribution Of Electricity Consumption In Data Centers [1]

the need for change in data center design and thermal management. There has been a great deal of work done to improve the cooling efficiency of the data center including proper layout of the equipment, dynamic monitoring and controls, localized air conditioning devices, software improvements such as virtualization and putting excess hardware to sleep are currently being implemented.

Nomenclature

IT = Information Technology
A/C = Air Conditioning
CPU = Central Processing Unit
PUE = Power Usage Efficiency
NWS = National Weather Service
CRAC = Computer Room Air Conditioning
CRAH = Computer Room Air Handler
APC = American Power Conversion

Data Center Air Cooling and Hybrid (air-liquid) Cooling

The most common method for data-center level thermal management is air-cooling. Air conditioners are placed throughout the data center to supply cool air to racks of IT equipment. Typically, as shown in Fig. 2, racks are aligned in rows and cold air intake is accomplished in "cold aisles" and hot air is exhausted to "hot isles." Blowers pull the hot air exiting the IT hardware along the ceiling and through the AC units. Cold air is then returned to the "cold aisles" via perforated tiles in a raised floor upon which the racks are mounted.

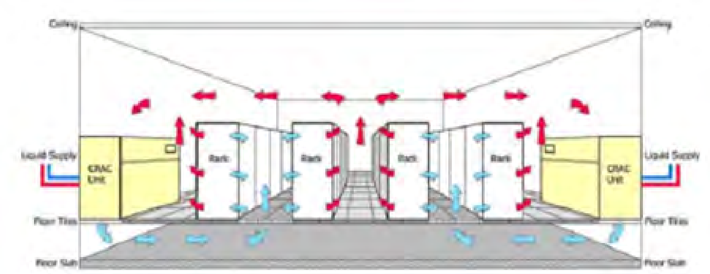

Figure 2. Hot/Cold Aisle Cooling Layout [3]

As data centers increase in size and the current air-cooling systems reach their limitations, cooling technology inevitably evolves towards air-liquid (hybrid) or liquid cooling systems.

A typical heat exchanger design for Hybrid cooling system starts with the existing air cooled system. In order to provide the best cooling with minimum volume and input power, a spiral cooling channel with a Reynolds number just above the laminar limit is used. This provides the best cooling with a reasonably sized channel that can pass contamination. Figure 3 below shows such heat exchanger.

The liquid cooled architecture above is an addition to an existing air-cooled heat exchanger. Heat from the CPUs, which represents up to 50% of the overall server power, can be directed to an outside cooling tower, with no chiller, room fans or air handlers. Bypassing the A/C system saves the data center cooling power and adds redundancy to the cooling system.

Figure 3. Air-Cooled Heat Sink With Liquid Cooling At The Base [2]

The liquid-air heat sink performance may be predicted based on the data center temperature, the coolant temperature, the CPU power and the thermal resistance. For example, consider the heat sink thermal resistance of 0.04°C/W from the water to the heat sink and 0.2°C/W to the air. Now, if the CPU power is 100 watts, water temperature is 59 oF (15°C) and the air temperature is 77°F (25°C), the heat sink will remove 25 watts from the air in addition to the 100 watts of CPU power. If the same heat sink is used with a CPU power of 50 watts and an 86°F (30°C) data center temperature, then, 55 watts of heat will be extracted from the data center air. This means that if the data center is allowed to warm up during periods of low occupancy, the computers are at low power and the wet bulb temperature is low then the HVAC system will stay off and the PUE drops to near 1 without having to build a custom building. The precise power savings for a given data center over a year can be calculated using the method above, combined with available data on hourly wet bulb temperature vs. time from the NWS and data center power consumption vs. time.

A Typical Data Center Air Cooled Loop

As shown in Figure 4 below the air cooled sub-system, heat is absorbed by the air forced through the enclosures. It is then transferred to the cold room air conditioning (CRAC) units. Because the air system is not necessarily sealed, there is recirculation of hot air to cold air allowed as well as short circuiting of cold air to hot air. This serves to lower the CRAC inlet and raise the rack inlet air temperature. From the CRACs, the heat is exchanged via a water loop to the chiller, which is assumed to be outside of the data center. The chiller then has a heat exchanger that rejects heat to the cooling tower.

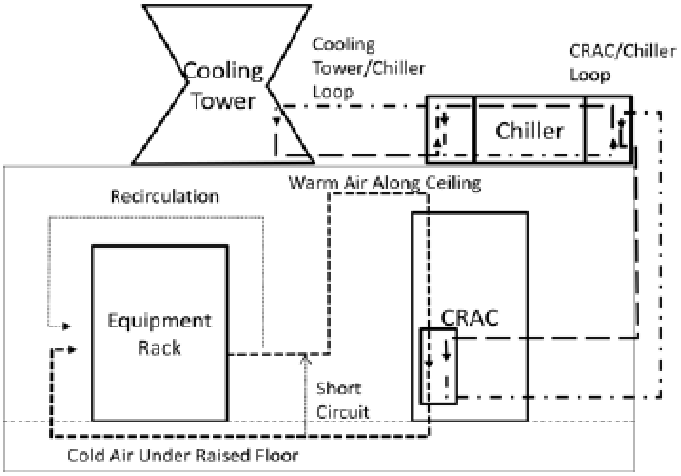

Figure 4. Air Cooled Schematic [5]

A Typical Data Center Liquid Cooled Loop

Figure 5 shows the general layout of the liquid-cooling sub-system. The heat from the systems is internally carried by liquid to a heat exchanger in the rack. The heat is delivered to the facilities water through that heat exchanger. It is then carried to the heat exchanger at the cooling tower where the heat is transferred to the facility cooling tower. The cooling tower then disposes of the heat through evaporative cooling.

Based on this brief introduction of various kind of cooling arrangement and set-up, an analytical case study, will be discussed in the next section, which will help to determine the difference between Air cooling and Hybrid cooling and will help to identify the benefits of Hybrid Cooling.

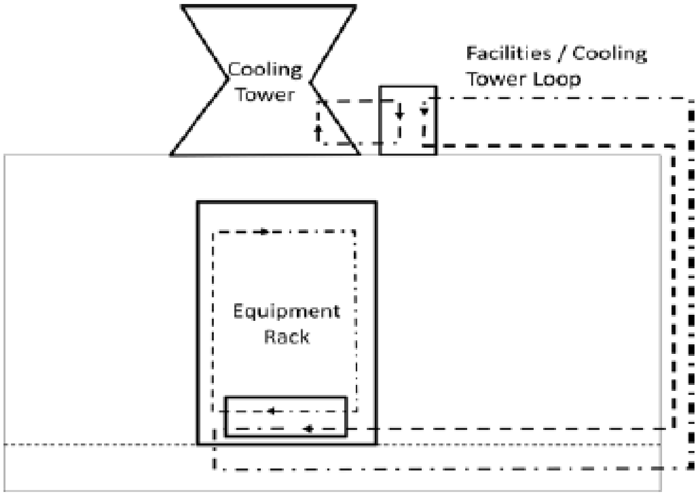

Figure 5. Data Center Liquid Cooled Loop [5]

Analytical Case Study

A 5000 square foot data center is used for this study which has the following attributes:

- System power dissipation of 100W/sq foot (3kW/rack on average)
- Hot-isle/cold-isle cooling scheme
- No air containment in place
- Raised floor cooling
- CRAC-Chiller-Cooling Tower cooling facilities for air cooling
- Air temperature delivery 20°C inlet to the computer devices
- Rack to cooling tower cooling facilities for water cooling
- Ambient conditions (5 cases):
  - o cool and dry – 15°C/30%
  - o moderate humidity – 20°C/50%
  - o hot and wet – 25°C/70%
  - o Tokyo – 31°C/74%
  - o Abu Dhabi – 41°C/84%
- 10 cents per KW-hr energy cost
- Liquid loop heat rejection of 50, 75 and 90% of total heat

This model is a water/air heat exchanger with no internal refrigeration. The chiller modeled is Thermal Care, model number TCR180. The single cooling tower used in the model uses the SAC 15146. The model focuses on the outdoor ambient varying parameters and the percentage of IT heat

removed by the liquid system.

To validate, the 100% air cooled data center model is compared to data collected on actual data centers. One of the popular measures of the overall power consumption of a data center compared to the load of the IT equipment is known as the Power Usage Effectiveness value or PUE (PUE = Total Facility Power / IT Equipment Power).

Figure 6 shows the percentage of power consumption by the various data center systems investigated.

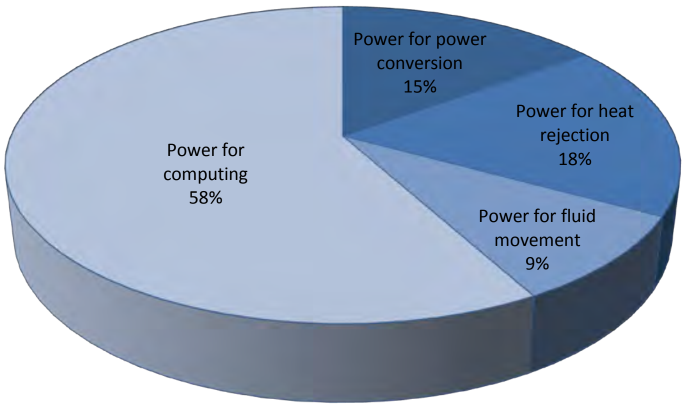

Figure 6. Air Cooled Data Center Baseline, Air Cooled Data Center, 20°C/50% RH [5]

Figure 7 below, shows the breakdown of the power used by the cooling system. The chiller consumes the maximum power followed by CRACs. Both of these components support the air cooling system, but are not needed for the liquid cooling system.

Figure 8 shows direct comparison to Figure 7. The total electrical power drawn by the IT systems and the power conditioning equipment remains constant. It shows the same power consumption information, but the Hybrid Data center dissipates 90% of IT load through liquid. Due to this, the power consumption of cooling system, drops from 27% in the air cooled data center to 12%.

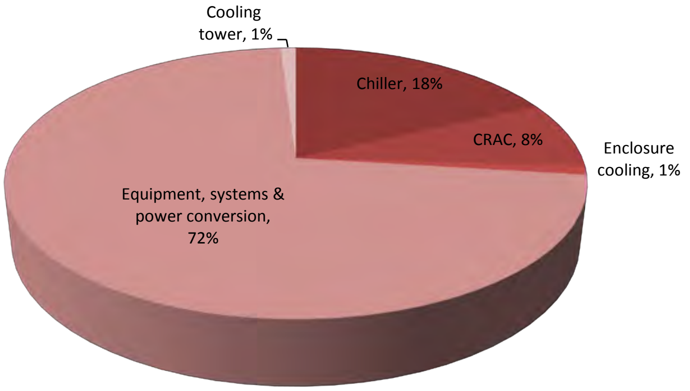

Figure 7. Air Cooled Data Center, Cooling System Component Power Consumption [5]

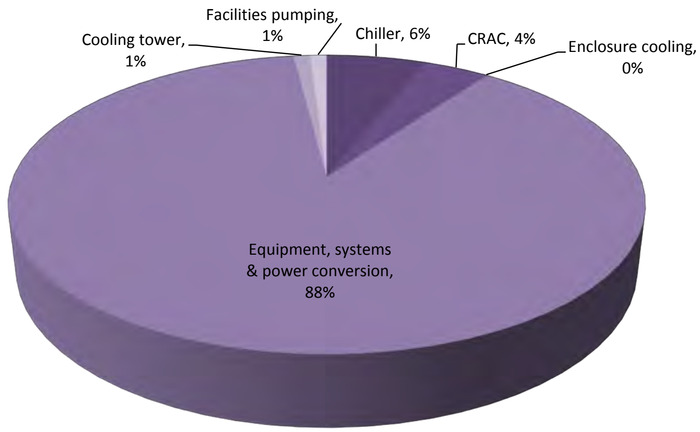

Figure 8. Hybrid Data Center, Cooling System Power Consumption, 90% Liquid Cooled [5]

Figure 9 shows that for Hybrid Data center, of the total power consumed by the heat management system of the data center, 85% of it is still consumed by the air cooling sub-system. This means that chiller and CRACs are still the major consumers, even when 90% of the IT equipment is cooled by the liquid loop.

Table 1 shows a comparison of the air cooled to the Hybrid system. The model indicates that at US$0.10/kW-hr, the yearly cost to operate the evaluated systems in the air cooled data center is US$758k. US$206k of that total is dedicated to the cooling systems. The 90% hybrid system costs

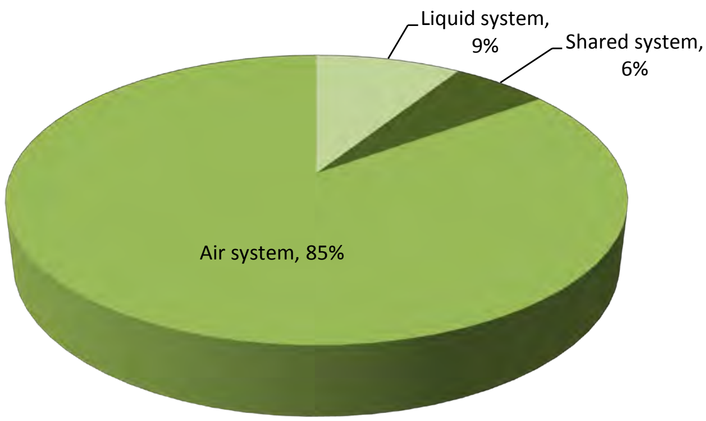

Figure 9. Hybrid Data Center, Comparing The Relative Power Consumption Of The Cooling Sub-Systems, 90% Liquid Cooled [5]

US$630k with a cooling system cost of US$79k, a savings of US$128k per year or a 16.6% annual reduction in energy consumption and operating cost.

	Total Energy, kW	Cooling System Energy, kW	Total OpEx/ yr	Cooling System OpEx/ yr	PUE
Air cooled	865	235	$758,089	$206,209	1.73
Hybrid 50%	779	149	$682,792	$130,912	1.56
Hybrid 75%	744	114	$651,784	$99,904	1.49
Hybrid 90%	720	90	$630,514	$78,684	1.44

Table 1. Energy and Operating Expense Comparison, 20°C/50% RH Ambient [5]

Cost Analysis of the Model

Hybrid cooling implementation indicates a cost savings in operating expense. Table 2 shows the calculated cost of the analysis.

The hybrid data center does not need as many CRACs and it can do with a lower capacity chiller or chillers. For this reason, the cost in CRAC/CRAHs and chiller(s) is lower for the hybrid data center.

Air Cooled Data Center Costs	
Cooling system cost for an air cooled enclosure	$778.00
Total cooling capex per rack, air cooled datacenter	$4,612.00
Total IT equipment cost, air cooled datacenter	$299,7800.00
CRAC capex, air cooled datacenter	$162,000.00
Chiller capex, air cooled datacenter	$62,991.14
Cooling tower capex, air cooled datacenter	$49,459.71
Total air cooled datacenter CAPEX	$574,230.86
Hybrid Data Center Costs	
Cooling system cost for a hybrid enclosure	$2,618.00
Cooling system cost for a rack	$750.00
Total cooling capex per rack, hybrid datacenter	$12,722.00
Total IT equipment cost, hybrid datacenter	$826,930.00
CRAC capex, hybrid datacenter	$72,000.00
Chiller capex, hybrid datacenter	$18,537.16
Cooling tower capex, hybrid datacenter	$47,662.00
Datacenter piping and pumping	$25,000.00
Total hybrid data center CAPEX	$990,129.86
CAPEX difference between air cooled and hybrid datacenter	**$415,899.00**
OPEX differences between air cooled and hybrid datacenter per year	**$127,574.89**
Payback time, years	**3.26**

Table 2. Estimated Cost Comparison, 20°C/50% RH [5]

In summary, there is a huge potential for operating expense savings in the hybrid data center cooling. For the 5000 square foot data center used in this model, the savings under 20°C/50% RH operational conditions is estimated to be over US$125k for the 90% liquid cooled data center and US$75,000 for a 50% liquid cooled data center. Through a combination of CRAC/CRAH and chiller size reduction and the operating expenses involved, the excess cost of the hybrid data center would be offset within 3 to 6 years depending on the configuration and environment. Considering a lifetime of 15 years for the data center, the overall savings is estimated to be US$727k to US$1.44M in a 20°C/50% RH environment.

Conclusion

Data center designers and managers need to take the energy savings, potential for growth, environmental impact, and costs into account when deciding if the hybrid data center is a good solution.

With today's accelerating power consumption and density demands balanced with environmental concerns and the cost of energy, the hybrid data center may provide data center users with a viable option for energy consumption reduction while retaining some existing IT equipment.

The key to obtaining a respectable ROI for Hybrid system is the water and air cooled heat sink that reverses the system thermodynamics so that the heat sink removes heat from the CPUs and the server interior and the data center in general in order to reduce the HVAC loads and fan power by a large margin.

It is logical to say that the above numbers can be scaled up, so for a larger data center let say 100,000 square feet, the saving in cooling can be in excess of US$25.00 M in 15 years.

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