DESIGN ASPECT OF ENERGY EFFICIENT DATA CENTER

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ABSTRACT

This paper provides an overview of design aspect of energy efficient data center which covers categories Information Technology (IT) systems and their environmental conditions, data center air management, cooling and electrical systems. IT system energy efficiency and environmental conditions are presented first because measures taken in these areas have a cascading effect of secondary energy savings for the mechanical and electrical systems. This paper concludes with a section on metrics and benchmarking values by which a data center and its systems energy efficiency can be evaluated.

Keywords: Data Center, Design Aspect, Efficiency, Cooling, Benchmarking

I. INTRODUCTION

Data Center is now a day's one of the most critical for successful business operations. Its suitable planning and designing allows sufficient guarantees of quality, efficiency and service continuity, irrespective of its dimension and sector in which it operates. In recent years, data center complexity and criticality has increased with steady growth in capacity and density which strains resources and consequently results in poor performance. The design of energy efficient and reliable data center is the key for business continuity and its success. The data center energy requirements are primarily for running IT and its support systems. Therefore, design aspect of data center spans across IT systems and their environmental conditions, cooling and electrical systems, air flow management and heat recovery, and on-site generations. Energy efficiency of IT systems and their environmental conditions have cascading effect of energy savings for mechanical and electrical systems. This paper also discusses metrics and bench marking values by which a data center and its systems energy efficiency can be evaluated.

II. INFORMATION TECHNOLOGY SYSTEMS

In a typical facility, IT equipment loads can account for over half of the entire facility's energy use. Use of efficient IT equipment with in a data center can significantly reduce these loads, which consequently downsize the equipment required to cool them. The IT equipment loads can be reduced by going for energy-efficient processors, fans, and power supplies, high-efficient network equipment, consolidating storage devices, consolidating power supplies, and implementing virtualization.

2.1 Servers

Servers used in Data Centers are generally rack servers which are main culprit for wasting energy and consumes largest chunk of IT energy load. Though servers are driver of data center operations, still they run below 20%

utilizations most of the times and still draw full power. With the improvement of internal cooling systems and processors, servers are being made to minimize the wasted energy. One of the features available may include variable speed fans which can deliver sufficient cooling while running slower and thereby consuming less energy. It is also to mention that Energy star program recognised high efficiency servers will, on an average, be more efficient by 30% than the standard servers. Another approach will be IT power management by throttling down drive that will put idle servers to sleep while reducing power consumption on idle processors. However, many IT team fear that could negatively impact server reliability but, hardware is designed to handle tens of thousands of on-off cycles. Power drawn by servers can also be regulated by installing “power cycler” software, which on low demand can direct individual devices to power down. But this may cause potential power management risks like slower performance and possible system failure which should be assessed against the potential energy savings.

Energy efficiency can be achieved by using multi-core processors which offer improved performance within same power and cooling load and consolidate shared devices. However, graphic intensive applications and high computing require high speed single core design processor. Energy savings can be further achieved by integration and consolidating IT system redundancies. For example, integrated rack mounted power supplies will operate with higher load factor in comparison with individual power supplies. As shown in Fig.1, increment in load factor improves power supply efficiencies. By sharing other IT resources like CPUs, disk drives, and memory also optimizes electrical usage.

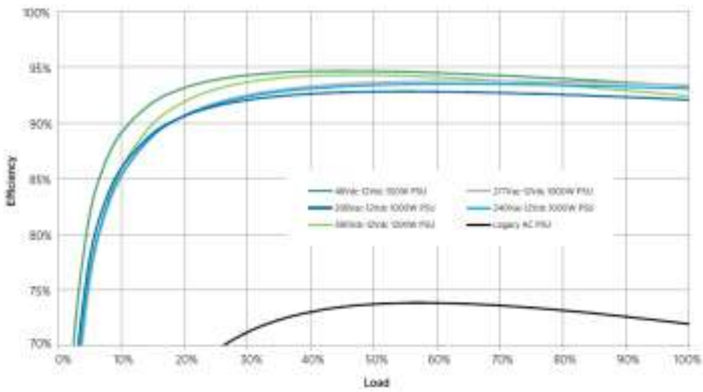

Figure 1 Efficiencies at Varying Load Levels for Typical Power Supplies

(Source: Quantitative Efficiency Analysis of Power Distribution Configurations for Data Centers, The Green Grid)

2.2 Storage Devices

Power consumed by storage devices is roughly linear to the number of storage modules used. The redundancy level for storage needs to be rationalized and right-sized. By using storage consolidating technologies like Storage Area Network (SAN) and Network Attached Storage (NAS) transports data offline which is need not to be accessed readily. By keeping unneeded data offline reduces the data in production environment which results in less storage and CPU requirement that corresponds to lower requirement of cooling and power.

Further, utilization and efficiency can be improved by adopting thin provisioning technology. In this method of maximizing storage capacity utilization, storage is drawn from shared pool on an as-need basis in contrast to traditional storage system where fixed amount of anticipated storage capacity is allotted. This allows addition of extra physical capacity at the later stage when need arises.

2.3 Network Equipment

As newer technologies network equipment can provide more throughput per unit of power consumed, active energy management measures can be adopted to reduce energy usage with the varied network demand. These measures include idle state logic, memory access algorithms, gate count optimization, and Input / Output buffer reduction. Increase of peak data transmission rates requires more power to transmit small amounts of data over time. By quickly switching the speed of the network links to the amount of data that is currently transmitted, efficiency of Ethernet network can be substantially improved.

2.4 Power Supplies

Typical internal or rack mounted alternating current/direct current (AC-DC) power supplies converts AC power to DC power at efficiencies of around 60% to 70%. By using higher efficiency power supplies of 85% - 95%, will directly lower data center's power consumption and indirectly reduce cooling system cost and rack overheating issues. The real operating load should also be considered for selecting power supplies that offers best efficiency at the most frequently expected load level. The optimal power supply load level is typically in the mid-range of its performance curve: around 40% to 60%, as shown in Fig.1.

As efficient power supplies usually have a minimal incremental cost at the server level. There are many certification programs that have standardized power supplies efficiencies. For example, the 80 PLUS program offers power supplies with efficiencies of 80% or greater at 20%, 50%, and 100% of their rated loads with true power factors of 0.9 or greater.

2.5 Consolidation

2.5.1 Hardware Location

The more efficient cooling system performance can be achieved by grouping together equipment with similar heat load densities and temperature requirements. Grouping equipment by their environmental requirements of temperature and humidity allows controlling of cooling system for each location to the least energy-intensive set points. This also applies for consolidating underutilized data center spaces to a centralized location which can improve data center efficiency by condensing the implementation to one location.

2.5.2 Virtualization

Virtualization is a method of running multiple independent virtual operating systems on a single physical system. It allows increase of server utilization. Virtualization allows combining of processing power of individual system onto fewer servers that operate at higher utilization. It will drastically reduce the number of servers in a data center, reducing required server power and consequently the size of the necessary cooling equipment. There are some overhead for implementation of virtualization, but results in higher saving and efficiency.

III. ENVIRONMENTAL CONDITIONS

3.1 Ashrae Guidelines and IT-Reliability

Designing of cooling and air management systems in a data center requires a look at the standardized operating environments for equipment recommended by the American Society of Heating, Refrigerating and Air-

Conditioning Engineers (ASHRAE) or Network Equipment Building System (NEBS). The recommended and allowable condition for Class 1 and 2 data centers are shown in Fig.2 and tabulated in Table 1.

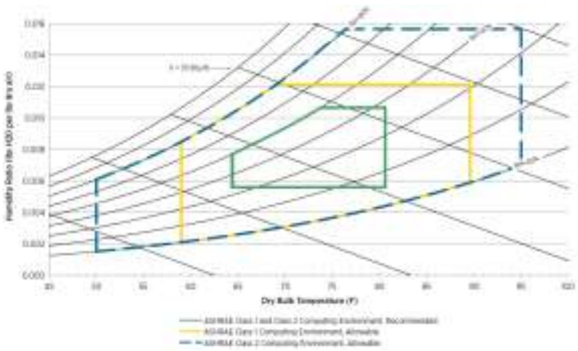

Figure 2 2009 ASHRAE Environmental Envelope for IT Equipment Air Intake Conditions

(Source: Rumsey Engineers)

	Class 1 and Class 2 Recommended Range	Class 1 Allowable Range	Class 2 Allowable Range
Low Temperature Limit	64.4°F DB	59°F DB	50°F DB
High Temperature Limit	80.6°F DB	89.6°F DB	95°F DB
Low Moisture Limit	41.9°F DP	20% RH	20% RH
High Moisture Limit	60% RH & 59°F	DP80% RH & 62.6°F	DP80% RH & 69.8°F DP

Table 1 ASHRAE Recommended and Allowable Inlet Air Conditions for Class 1 and 2 Data Centers

(Source: Rumsey Engineers)

The recommended environmental envelope is guidance for energy-efficient operation of data center while maintaining high reliability while allowable envelope outlines the environmental boundaries tested by equipment manufacturers for equipment functionality, not reliability.

IV. AIR MANAGEMENT

The purpose of design and configuration of air management in a data center is to minimize or eliminate mixing of cooling air supplied to equipment and the hot air rejected from the equipment. Effective air management implementation minimizes the bypass of cooling air around rack intakes and the recirculation of heat exhaust back into rack intakes. When designed correctly, an air management system can reduce operating costs, reduce first cost equipment investment, increase the data center’s power density (Watts/ square foot), and reduce heat related processing interruptions or failures. A few key design issues include the configuration of equipment’s air intake and heat exhaust ports, the location of supply and returns, the large scale airflow patterns in the room, and the temperature set points of the airflow.

4.1 Implement Cable Management

The obstructions in false flooring and false ceiling / overhead often interfere with cooling air distribution. This interference is undesirable as this can significantly reduce air flow being handled by air handlers and negatively affect the air distribution. Cable congestion in raised-floor plenums can sharply reduce the total airflow as well as degrade the airflow distribution through the perforated floor tiles. Both effects promote the development of undesirable hot spots. A minimum effective clear height of 2 feet must be provided for raised floor installations.

Greater under floor clearance can help achieve a more uniform pressure distribution in some cases. A data center should have a cable management strategy to minimize air flow obstructions caused by cables and wiring and should target the entire cooling air flow path, including the rack-level IT equipment air intake and discharge areas as well as under-floor areas. Persistent cable management is a key component of maintaining effective air management.

4.2 Aisle Separation and Containment

When equipment racks and the cooling system are designed to prevent mixing of the hot rack exhaust air and the cool supply air into the racks is called basic hot aisle/cold aisle configuration is created. In this quipment is laid out in rows of racks with alternating cold (rack air intake side) and hot (rack air heat exhaust side) aisles between them. Strict hot aisle/cold aisle configurations can significantly increase the air-side cooling capacity of a data center's cooling system. All equipment rows of racks are placed back-to-back, and holes through the rack (vacant equipment slots) are blocked off on the intake side to create barriers that reduce recirculation, as shown in Figure 3 below. Additionally, cable openings in raised floors and ceilings should be sealed as tightly as possible. With proper isolation, the temperature of the hot aisle no longer impacts the temperature of the racks or the reliable operation of the data center; the hot aisle becomes a heat exhaust. The air-side cooling system is configured to supply cold air exclusively to the cold aisles and pull return air only from the hot aisles.

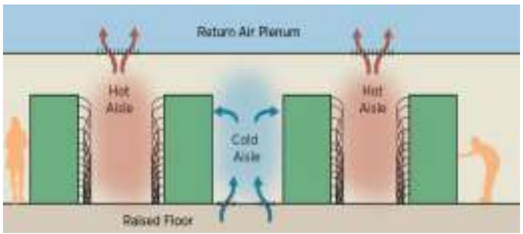

Figure 3 Example of Hot Aisle/Cold Aisle Configuration

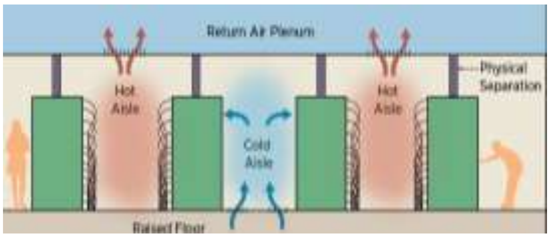

Figure 4 Sealed Hot Aisle/Cold Aisle Configuration

The hot rack exhaust air is not mixed with cooling supply air and, therefore, can be directly returned to the air handler through various collection schemes, returning air at a higher temperature. Further improvements can be achieved by using flexible plastic barriers, such as strip curtains to seal the space between the tops of the rack and air return location while allowing flexibility in accessing, operating, and maintaining the computer equipment below as shown in Fig.4.

4.3 Optimize Supply and Return Air Configuration

Hot aisle/cold aisle configurations can be served by overhead or under-floor air distribution systems. When an overhead system is used, supply outlets that 'dump' the air directly down should be used in place of traditional office diffusers that throw air to the sides, which results in undesirable mixing and recirculation with the hot aisles. The diffusers should be located directly in front of racks, above the cold aisle and temperature monitoring to control the air handlers should be located in areas in front of the computer equipment.

In under-floor air supply systems, under-floor plenum often serves both as a duct and a wiring chase. Coordination throughout design and into construction and operation throughout the life of the center is necessary since paths for airflow can be blocked by electrical or data trays and conduit. The location of supply tiles needs to be carefully considered to prevent short circuiting of supply air and checked periodically if users are likely to reconfigure them.

4.4 Raising Temperature Set Points

Higher supply air temperature and a higher difference between the return air and supply air temperatures increases the maximum load density possible in the space and can help reduce the size of the air-side cooling equipment required, particularly when lower-cost mass produced package air handling units are used. The lower required supply airflow due to raising the air-side temperature difference provides the opportunity for fan energy savings. Additionally, the lower supply airflow can ease the implementation of an air-side economizer by reducing the sizes of the penetrations required for outside air intake and heat exhaust.

V. COOLING SYSTEMS

When beginning the design process and equipment selections for cooling systems, it is important to always consider initial and future loads.

5.1 Direct Expansion (DX) Systems

Packaged DX air conditioners likely compose the most common type of cooling equipment for smaller data centers. These units are generally available as off-the-shelf equipment from manufacturers, commonly described as CRAC units. An enhancement to the air-cooled condenser is a device which sprays water over the condenser coils. The evaporative cooling provided by the water spray improves the heat rejection efficiency of the DX unit. Additionally, these units are commonly offered with air-side economizers.

5.2 Air Handlers

Better performance can be achieved with specifically designed central air handler systems. A centralized system offers many advantages like they use larger motors and fans that tend to be more efficient. They are also well suited for variable volume operation through the use of VSDs and maximize efficiency at part-loads. It also has maintenance benefits, and the reduced footprint. Implementation of an airside economizer system is simplified with a central air handler system. Optimized air management, such as that provided by hot aisle/cold aisle configurations, is also easily implemented with a ducted central system.

5.3 High-Efficiency Chilled Water Systems

Use efficient water-cooled chillers in a central chilled water plant. A high-efficiency VFD-equipped chiller with an appropriate condenser water reset is typically the most efficient cooling option for large facilities. Chiller part-load efficiency should be considered since data center often operate at less than peak capacity. Chiller part-load efficiencies can be optimized with variable frequency driven compressors, high evaporator temperatures and low entering condenser water temperatures.

5.4 Free Cooling

The cooling load for a data center is independent of the outdoor air temperature. However, a proper engineering evaluation of the local climate conditions must be completed to evaluate whether this is the case for a specific data center. Due to the humidity and contamination concerns associated with data centers, careful control and design work may be required to ensure that cooling savings are not lost because of excessive humidification and filtration requirements, respectively.

VI. ELECTRICAL SYSTEMS

Similar to cooling systems, it is important to always consider initial and future loads, in particular part- and low-load conditions, when designing and selecting equipment for a data center's electrical system.

6.1 Power Distribution

In Data center, typically have an electrical power distribution path consisting of the utility service, switchboard, switchgear, alternate power sources, paralleling equipment for redundancy, and auxiliary conditioning equipment. These components each have a heat output that is tied directly to the load in the data center. Efficiencies can range widely between manufacturers and variations in how the equipment is designed. However, operating efficiencies can be controlled and optimized through thoughtful selection of :

6.1.2 Uninterruptible Power Supplies

UPS systems provide backup power to data centers, and can be based on battery banks, rotary machines, fuel cells, or other technologies. A portion of all the power supplied to the UPS to operate the data center equipment is lost to inefficiencies in the system. To minimize these losses, first evaluate requires a UPS system. Increasing the UPS system efficiency offers direct, 24-hour-a-day energy savings, both within the UPS itself and indirectly through lower heat loads and even reduced building transformer losses. Evaluate the need for power conditioning. Line interactive systems often provide enough power conditioning for servers at a higher efficiency than typical double conversion UPS systems.

6.1.3 Power Distribution Units

A PDU passes conditioned power to provide reliable power distribution to multiple pieces of equipment. Maintaining a higher voltage in the source power lines fed from a UPS or generator allows for a PDU to be located more centrally within a data center. As a result, the conductor lengths from the PDU to the equipment are reduced and less power is lost in the form of heat.

6.1.4 Distribution Voltage Options

Another source of electrical power loss for both AC and DC distribution is that of the conversions required from the original voltage supplied by the to that of the voltage at each individual device within the data center (usually a low voltage around 120V AC to 240V AC). In order to provide electrical power in the most energy-efficient manner possible:

- Minimize the resistance by increasing the cross-sectional area of the distribution path and making it as short as possible.
- Maintain a higher voltage for as long as possible to minimize the current.
- Use switch-mode transistors for power conditioning.
- Locate all voltage regulators close to the load to minimize distribution losses at lower voltages.

6.1.5 DC Power

In a conventional data center power is supplied from the grid as AC power and distributed throughout the data center infrastructure as AC power. However, most of the electrical components within the data center, as well as the batteries storing the backup power in the UPS system, require DC power. As a result, the power must go through multiple conversions resulting in power loss and wasted energy. One way to reduce the number of times power needs to be converted is by utilizing a DC power distribution which may involve significantly higher cost.

6.1.6 Lighting

Data center spaces are not uniformly occupied and, therefore, do not require full illumination during all hours of the year. UPS, battery and switch gear rooms are examples of spaces that are infrequently occupied. Therefore, zone based occupancy sensors throughout a data center can have a significant impact on reducing the lighting electrical use. Careful selection of an efficient lighting, lamps and ballasts will also reduce not only the lighting electrical usage but also the load on the cooling system.

VII. DATA CENTER METRICS AND BENCHMARKING

Energy efficiency metrics and benchmarks can be used to track the performance of and identify potential opportunities to reduce energy use in data centers.

7.1 Power Usage Effectiveness (PUE)

PUE is defined as the ratio of the total power to run the data center facility to the total power drawn by all IT equipment:

$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power}$$

Standard	Good	Better
2.0	1.4	1.1

An average data center has a PUE of 2.0; however, several recent super-efficient data centers have been known to achieve a PUE as low as 1.1.

7.2 Data Center Infrastructure Efficiency (DCiE)

DCiE is defined as the ratio of the total power drawn by all IT equipment to the total power to run the data center facility, or the inverse of the PUE:

$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power}$$

Standard	Good	Better
2.0	1.4	1.1

PUE and DCiE are defined with respect to site power draw. These donot define overall efficiency of an entire data center. These metrics could be alternatively defined using units of average annual power or annual energy (kWh) rather than an instantaneous power draw (kW).

7.3 Source PUE

This is defined with reference to source energy.

$$Source\ PUE = \frac{Total\ Facility\ Energy\ (kWh)}{UPS\ Energy\ (kWh)}$$

7.4 Energy Reuse Effectiveness (ERE)

ERE is defined as the ratio of the total energy to run the data center facility minus the reuse energy to the total energy drawn by all IT equipment:

$$ERE = \frac{Cooling + Power + Lighting + IT - Reuse\ Energy}{UPIT\ Equipment\ Energy}$$

An ERE of 0 means that 100% of the energy brought into the data center is reused elsewhere, outside of the data center control volume.

7.5 Rack Cooling Index (RCI) and Return Temperature Index (RTI)

RCI measures how effectively equipment racks are cooled according to equipment intake temperature guidelines established by ASHRAE/NEBS. By using the difference between the allowable and recommended intake temperatures from the ASHRAE Class 1 (2008) guidelines, the maximum (RCIHI) and minimum (RCILO) limits for the RCI are defined as follows:

$$RCI_{HI} = \left[1 - \frac{\sum_{T_x > 80} (T_x - 80)}{(90 - 80)n}\right] \times 100\ [\%] \qquad RCI_{LO} = \left[1 - \frac{\sum_{T_x < 65} (65 - T_x)}{(65 - 59)n}\right] \times 100\ [\%]$$

where,

Tx = Mean temperature at equipment intake x n = Total number of intakes.

An RCI of 100% represents ideal conditions for the equipment, with no over or under temperatures. An RCI < 90% is often considered to portray poor conditions.

7.6 RTI

RTI evaluates the energy performance of the air management system. RTI is defined as:

$$RTI = \frac{\Delta T_{AHU}}{\Delta T_{EQUIP}} \times 100\%$$

where, Δ TAHU is the typical (airflow weighted) air handler temperature drop Δ TEQUIP is the typical (airflow weighted) IT equipment temperature rise.

The RCI and RTI parameters allow an objective method of measuring the overall performance of a data center air management system. They should be used in tandem to ensure the best possible design.

VIII. CONCLUSION

The Data Center is a complex system which requires thorough knowledge of different aspect of its design. These different areas are interrelated with each other and the impact others performance in reference to energy efficiency. It is also inferred that consideration of load while designing also plays role in overall dimensioning and achievement of required efficiency level.

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