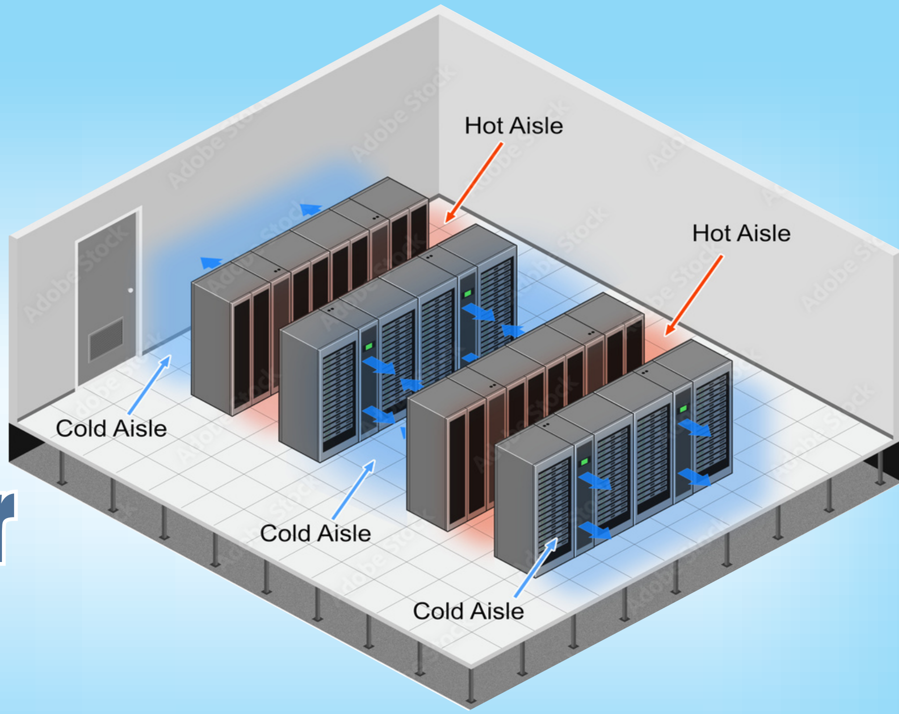

Data Center Cooling: a Guide for the Beginners

By Sangita Jhangiani
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Introduction

Digital technologies have revolutionized the world and have changed our lives in many ways. Whether we want to buy groceries or look for a life partner, all is possible through the digital network. The Coronavirus pandemic has further brought about changes in the way we work. Work from home, especially in our country, was not considered mainstream and not much prevalent pre-pandemic, but this became the norm during the pandemic and almost all organizations conducted businesses successfully during this period remotely, thanks to the internet.

Data Hall and Server Racks

The internet is nothing but a vast network that connects computers all over the world. To compute, store, send and receive information, information technology and communication (ITC) devices comprising server, storage and network devices are used.

About the Author

Sangita Jhangiani founded a consulting engineering firm Enova twenty-five years ago. She and her team have designed HVAC systems for large data centers. They include data center facilities located at Mumbai, Pune, Delhi, Chennai, and Gift City Ahmedabad. A recently designed 20 MW data center facility at Mumbai has gone live in March 2022. Sangita can be reached on *sangita@enova.co.in*

Servers, storage, routers, switches, hubs, networking devices, cables and other ITC devices are housed in steel racks that are designed to hold these devices. The steel structure that houses many pieces of ITC equipment is usually called a server rack.

When large amount of data needs to be processed, stored or distributed, many server racks are installed side by side in long rows within a room that is called a data hall or server hall.

Figure 1: A 42 U Universal Server Rack (approximate dimensions 600 mm wide x 1000 to 1200 mm deep x 2000 mm high)

Hundreds of racks are housed in the data halls. The racks keep things organized and secured, and maximized the use of floor space. Buildings that are specifically built to house multiple server (in thousands) halls for large data management applications along with their supporting infrastructure for power and cooling are called data center (DC) buildings.

A data hall is a compartmentalized space to form an independent fire zone as laid out in the National Building Code (NBC). Hence, a DC

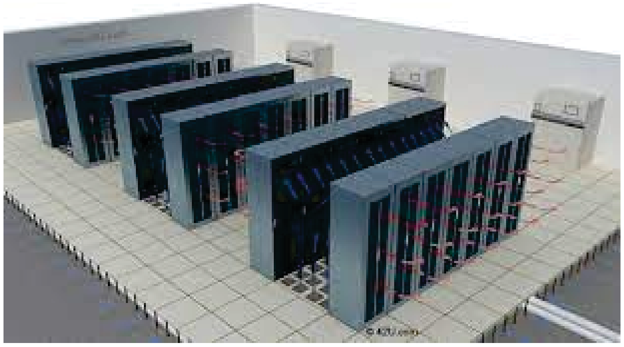

Figure 2: Rows of server racks in a data hall

building has multiple data halls within the building.

42 U indicates space in terms of height available for housing ITC devices. Each U is equivalent to 1.75 inch height. Although 42 U racks are mostly used, there is increasing trend of higher height racks like 47/48 U and 54 U for optimum space utilization.

Why is a Cooling Solution Required for a DC?

So, how is a DC building different from any other building and how should an HVAC application engineer approach design of a cooling system for a DC building? This article aims to guide beginners by providing an overview of what the design of an HVAC system for a DC application entails.

ITC devices use a large amount of electrical energy. We know that one form of energy gets converted to another. The majority of the electrical energy used to power a server and other storage devices gets converted to heat energy. Only a small amount of the electrical energy is used to send out signals to client computers by the servers. One watt of electrical power input to a server nearly produces the same amount (one watt that is 3.41 btu/h) of heat. And that is why cooling solution becomes an integral and important part of a DC building

.

Data Center Classification – Tier Standards

The Uptime Institute has created an unbiased set of infrastructure and operating criteria for a DC building. The Uptime Institute is an internationally recognized body and the principles laid down by the institute are considered as the standards for design, construction and operations for a DC facility. The Uptime Institute standards primarily focus on performance, efficiency and reliability of a DC facility.

The Uptime Institute has created a Four Tier classification system that defines criteria for maintenance, power, cooling and fault capabilities for a DC facility. Each higher Tier adds to the requirements of Lower Tier. The Tier classification needs to be chosen based on the business function that the DC facility is meant to support. Highly critical business operations with higher requirement of availability would opt for a Tier III/ IV classification, whereas non-critical business operations with lower availability requirement could opt for a lower Tier Classification like Tier I/II

Table 1: Tier Requirements Summary

	Tier I	Tier II	Tier III	Tier IV
Active Capacity Components to Support the IT Load	N	N+1	N+1	N
Distribution Paths	1	1	1 Active and 1 Alternate	After any Failure 2 Simultaneously Active
Concurrently Maintainable	No	No	Yes	Yes
Faults Tolerance	No	No	No	Yes
Compartmentalization	No	No	No	Yes
Continuous Cooling	No	No	No	Yes
Availability	99.671%	99.741%	99.982%	99.995%

Source. Uptime Institute

(Note: Uptime document has been updated recently and does not attach any quantitative availability value in terms of percentage with tier classification.)

Types Of Data Centers

Enterprise DC

These are built by companies for their own use. They are operated and maintained by end users.

Colocatio DC

Also known as Colo DC, this is a facility that rents out rack space to third parties or IT companies.

Cloud DC

It is a remote version of a DC wherein a company accesses its data online. The cloud provider maintains, updates, safeguards data during power outages and other failures. It is a service model and the client uses IT services on a pay as per use basis.

Typical DC Infrastructure

A DC facility typically includes the following:

Security Cabin

It is situated at the entrance of the building access and movement of personnel within the building is controlled for protection of the data that is stored in the servers.

GIS Substation Building

Total power requirement, for example, maybe 40 MW. Grid power supplied by the power company would be 100 kV high voltage network. The substation steps down the high voltage to say 11 kV for further distribution to the DC building. Transformers located locally within the building further step down the voltage to 415 Volts for further distribution.

Diesel Generator Facility

Since the DC is a mission critical facility, there must be a 100% power back up available at all times. Hence, DC facilities have diesel generators as a backup system to power critical loads during a power outage. The DG could either be housed within the building or in another structure built for this purpose. DG sets require fuel storage and fuel handling system, which also forms an important part of the project.

Generators need air for combustion as well as air circulation for removal of heat generated. It is, therefore, imperative for an HVAC design engineer to enquire and collect inputs for the design of appropriate ventilation system for the DG room.

Annex Building

This is a small footprint building that houses offices for administrative functions. Air-conditioning design is same as for comfort cooling application.

Main Building

This building has the data halls. These data halls are compartmentalized to create an independent fire zone as defined in NBC. The data halls are supported by UPS rooms, battery rooms, transformer rooms, electrical room to house power distribution units (PDUs), Critical Room Air Handling units (CRAH), meet me room (MMR) and main distribution frame (MDF) room. MDF houses core switches in communication racks for data or telephony to interconnect and manage telecommunication between itself and number of intermediate distribution frames located on other floors as well as MMR.

MMR room in a DC facility is a secure place from where various cable companies, Internet service providers inter connect with tenants in the facility. This room contains cabinets and racks with carrier hardware required for data transfer.

The Data Hall floor typically has a raised floor**. The void below the false floor helps in distribution of cables. It also acts as a path for distribution of cold air. The raised floor height should be sufficient to allow air flow. Care has to be taken to ensure that the air path is not obstructed in places by the cable management system. Cold air can also be supplied from the side wall. In this case, the AC unit selection has to be done accordingly.

(** Cloud and telecommunication companies are increasingly opting for hard floor design instead of false floor.)

High Density Server

The average power consumption of a server rack with current technology is 6 kW. When the power consumption of a server rack is much higher, the server rack is called a high-density server, although there is no clear-cut demarcation in terms of rack kW for high density racks.

For cooling a high-density server, the spacing between racks is increased. Alternatively, a localized cooling unit is placed in between adjacent server racks. The cooling unit supplies cool air to the rack directly instead of supplying air to the room. Such units are called in-row cooling devices and are used for cooling high density racks. High density localized cooling units come into different form factors like rear door cooling mounted over rack doors or ceiling mounted overhead cooling units.

Battery Room

Power to all critical equipment is provided through UPS. Batteries are installed to provide continuity in power supply for a few minutes. Battery life gets enhanced at lower temperatures and therefore, these rooms are also cooled. Lithium ion or valve regulated lead-acid (VRLA) type batteries are common types of batteries used in a DC. There is a remote chance of hydrogen leakage in VRLA batteries. It is important to keep the ratio of hydrogen in air less than one percent to prevent fire hazard. Therefore, an exhaust system needs to be planned for the battery room, which houses VRLA batteries. Hence, the design of ventilation system for the VRLA battery room has to be planned by the HVAC designer.

Temperature and RH

Two and a half decades ago, when these type of buildings were at the inception stage, the accepted norm was to maintain temperature as low as 18°C in the data hall. Current generation servers are more robust, reliable and efficient at higher temperatures. The current accepted design temperature at the inlet of racks or IT devices in a data hall is typically in the range of about 22°C to 27°C. The elevated temperature helps to reduce power consumption by the cooling devices.

The recommended relative humidity allowable is lower than RH 60%. This is to prevent damage caused due to failure due to corrosion in case of condensation due to high RH. ASHRAE has withdrawn recommended lower RH level in their recent thermal guidelines for data processing environments.

It may be noted that chilled water temperature for comfort cooling is generally in the range of 7°C to 12°C or 14°C. Since the requirement for a data hall application is higher, chillers are selected with higher inlet and outlet temperatures. The current trend is to select a chiller with elevated water temperatures with supply at 14°C and return at 21°C. However, hyperscalers (cloud operators) are increasingly opting for higher chilled water temperature even as high as supply and return of 20°C or 27°C.

Aisle Containment

All IT hardware have fans mounted on one side. The fans draw in cold air from the front and discharge hot air to the room on the rear side of the rack. Mixing of hot and cold air would lead to rise in air inlet temperature to the server rack. The mixing of cold and hot air also reduces the efficiency of cooling equipment as mixed air has a lower temperature than rack outlet temperature. Hence, to prevent mixing of hot and cold air, the rows in between the racks are compartmentalized with the help of containment. The racks are arranged in such a way that the front side of two adjacent rows face each other. The air supply grilles are located in the aisle between the racks. The adjacent row has racks with the rear side of racks facing each other. The hot air is discharged in this aisle. The rows of spaces where the cold and hot air are discharged are physically separated by creating partitions in between. This is called aisle containment.

If the enclosure is created around the cold aisle, it is called cold aisle containment. On the other hand, if the enclosure is created around the hot aisle, it is called hot aisle containment. The hot air (return air) has to be directed back to the air handling units (AHUs). The return air in a hot aisle

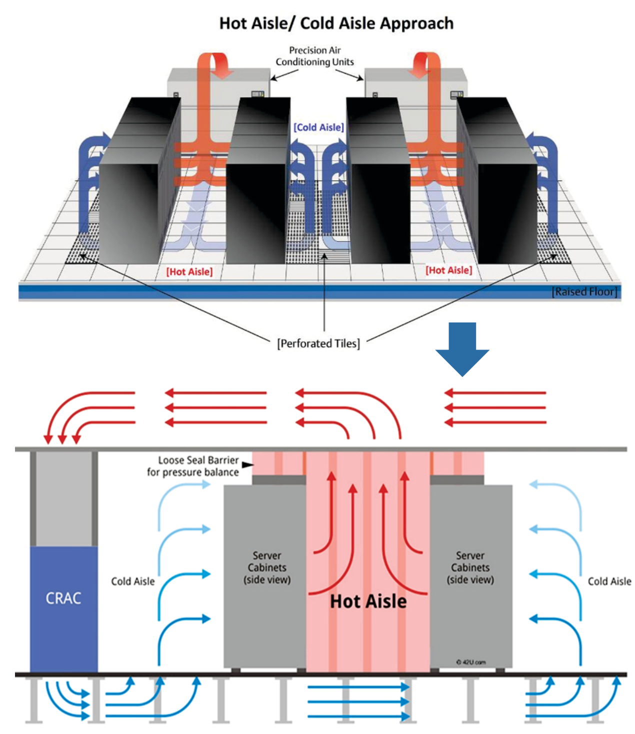

Figure 3: Aisle containment

containment may either be collected in the ceiling void or ducted-directly back to the AHU.

Chiller Selection for Data Center

Air Cooled Vs Water Cooled

Water has a very large thermal capacity as compared to air and is a better cooling medium than air. Water-cooled chillers are more energy efficient than air-cooled chillers. Buildings such as hotels, malls, residential complexes are densely occupied and have cooling water available from the Sewage Treatment Plant (STP). DCs are buildings with high sensible load and very less occupancy. Water consumption in a DC facility is less and therefore, cooling water from an STP is unavailable. Therefore, despite being more energy efficient, water-cooled chillers may not be the best choice for a DC, cooling water being unavailable.

However, with elevated chilled water temperature requirement, annualized power consumption for an air-cooled chiller works out to about 0.7 IkW/TR or even less.

Air Inlet Temperature to Condenser

Maximum capacity of air-cooled chillers is about 400 TR to 500 TR, which is available with most manufacturers. Total capacity of a DC facility in today's time runs in 1,000s of TR. A battery of multiple chillers is required for the facility. The selection of chillers considering 2°C over and above the extreme annual ambient condition for n=20 years for the location, in which the DC is situated. Number of redundant chillers is based on tier classification as mentioned in the *Table 1*.

Chiller Quick Start Feature

The DC facility has a dual source of power supply, so as to ensure an uninterrupted power supply. In case of a power outage, the DG sets get kicked in automatically. However, it takes about 45 seconds for power to be restored. Chilled water pumps and CRAH unit fans are, therefore, powered through UPS. Chillers once stopped cannot be re-started immediately. Therefore, chillers for DC facilities are provided with a quick start feature, which allows the chillers to re-start in about 180 seconds or so, after an interruption in power supply. This is achieved by powering the chiller controller and oil heaters through UPS.

Chiller Plant Manager

Chillers for a DC should be provided with a chiller manager, which can be accomplished by the Direct Digital Controller (DDC) of the Building Management System (BMS) also. The chiller manager ensures optimal power consumption; monitors and controls pump operation; allows auto sequencing, scheduling, equal run time of compressors; and staging in and staging out of chillers. Many chiller manufacturers provide sequencing, staging in and staging out facilities of chiller as a part of their chiller controller. Necessary redundancy in plant manager controller needs to be looked into so that the failure of chiller plant manager does not lead to interruption of the cooling system.

Data Center Efficiency

The other key parameter that is important for DC owners is PUE or Power Utilization Effectiveness. PUE is the ratio of total energy used in the facility to the IT load. PUE is an indicator of

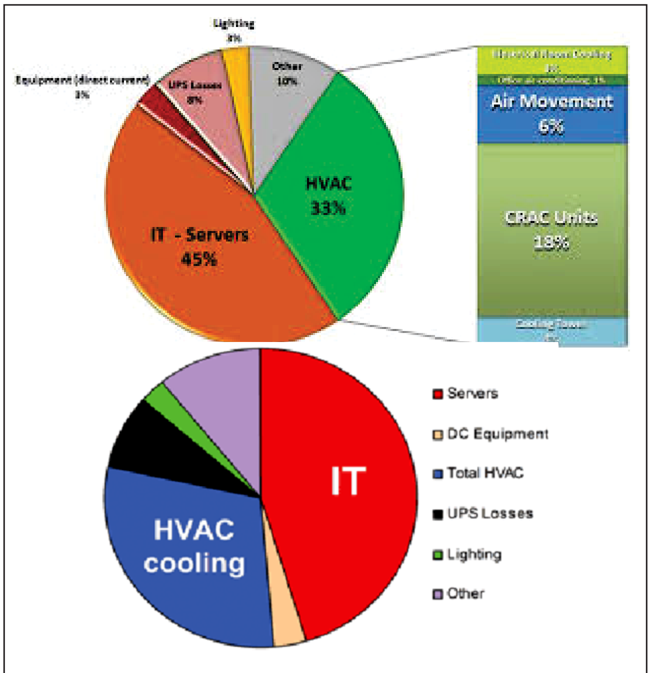

Figure 4: Distribution of power in a DC

the energy efficiency of a DC. Generally, it is measured annually. The distribution of power in a DC is as follows:

Air-conditioning is a major contributor to the power requirements and hence, it becomes extremely critical to select energy efficient equipment for the cooling system.

DCIM

For control and monitoring of all equipment special software designed for DC facilities are available. Data Centre Infrastructure Management (DCIM) tools monitor, measure, manage and control utilization and energy consumption of all IT equipment and other facility equipment such as Power Distribution Units (PDU) and CRAH.

CRAH Units and Floor Grilles

Air handlers for DC facility are called Computer Room Air Handling units or CRAH. These units have EC fans. The fan speed is modulated based on the cooling requirements. Since the data hall has a raised floor generally, the fans discharge cold air into the floor plenum. The air enters the cold aisle through floor grilles. The size of the floor grilles is typically the same as a floor tile. The floor tile is replaced by a floor grille wherever cooling is required. The air velocity through the grilles is considered as low as 250 to 300 cfm/sqft. A higher discharge velocity would allow less air to be drawn in by the servers located at the bottom of a server rack. It is important to note that the effective opening area (free area) of the floor grille would be lower than the overall size. If the size of floor tile is 600 mm x 600 mm, the effective opening size would be lower than 0.36 sqm (4 sqft). It is, therefore, important for an HVAC designer to check the effective size of floor grille to estimate the air volume that would be delivered per grille. Sometimes to increase the free area, floor gratings are used instead of grilles.

Figure 5: Cold aisle in a data center with under floor air distribution through floor grilles

In some cases, if there is a hot spot in the room, a floor tile could be replaced with a floor grille to mitigate the problem. If the problem still persists, the floor grille could be replaced with an active tile. An active tile is a floor grille with an EC fan, which responds to sensors located in the cold aisle. The fan assists in drawing in air from the floor plenum and therefore, assists in increasing cooling effectiveness.

Smaller data center could use air-cooled packaged type DX type CRAC units. These units are available from as small as 3 TR to about 30 TR capacity and have a DX cooling coil. The compressor is housed in the indoor unit. The outdoor condenser unit is located outside where free flow of ambient air is available. It is recommended to keep the outdoor condenser units close to indoor units at higher elevation within 30 meter preferable for higher efficiency. The compressor is normally a digital scroll or inverter unit.

For a larger DC project, this system is not feasible as too many outdoor units will need to be placed on the building periphery. Chilled water system design is more suited for larger projects.

The load in a server room is sensible in nature. The effective sensible heat ratio is, therefore, close to unity. The cooling coil of the CRAH units is, therefore, designed for sensible load. The CRAH units are designed to deliver about 500 cfm to 600 cfm/TR of cooling load.

A Computational Fluid Dynamics (CFD) analysis is carried out to ensure that there is uniform cooling and proper air distribution. Based on the CFD analysis reports, the floor grilles may be relocated for better effectiveness.

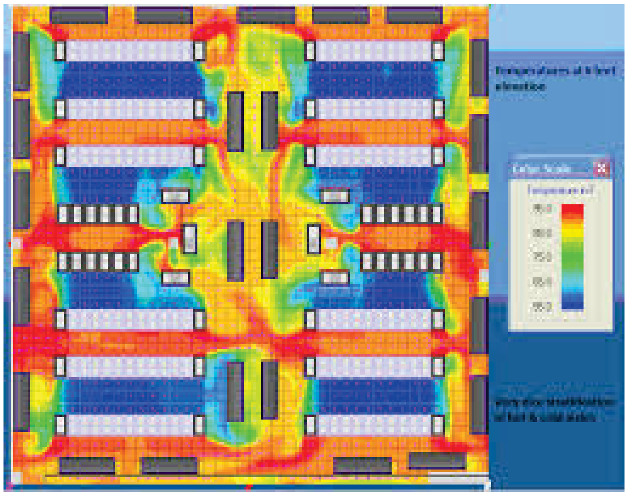

Figure 6: An image from data hall CFD report

The evaporator section of the CRAH unit has a drain pan, which is connected to a drain pipe. With elevated supply water temperatures, the cooling coil is normally dry. However, water leak detectors are still provided in the CRAH room to raise an alarm in case of water leakage.

A bund wall near the CRAH unit is also built in the false floor void to prevent water from spilling into the data hall during CRAH maintenance.

Fresh Air Distribution in Data Hall

The fresh air delivered to the space ensures positive pressurization and maintains indoor air quality. The important point to note is that dehumidification of outdoor air may be improper if the TFA is connected to the chilled water system with elevated temperatures. The TFA unit will, therefore, need to be either connected to an alternative chilled water source with lower chilled water temperature or could be a DX unit.

Modular and Scalable Design

A typical DC design intent is to be modular and scalable. This means that the total IT load of the DC project gets distributed to multiple data center floors or buildings built with a lower IT load. For example, if the final IT load for a DC project is for example 100 MW, the project may decide to build five buildings of 20 MW each. Phase 1 of the project could be for 20 MW capacity in a building or may be limited to a few floors in a single data center building. This is what is meant be modular and scalable design. The first facility could also be built in stages. The engineering design would be for the full IT load for the building. The wiring, piping installation would be for the full building. However, the major equipment (also known as long lead items) like chillers, transformers, DG sets etc. are procured and installed in phases. The major equipment is procured and installed as the DC gets populated. This helps in lowering the initial cost and helps the DC owner in financial planning.

Chilled Water Piping

The chilled water piping is generally a dual piping system. Each piping system is designed for 100% of flow. During operation, both the piping system are kept active to ensure availability of chilled water should a need arise to shift the entire load on a single piping system. In this case, CRAH units are either provided with dual cooling coils each of 100% capacity or single coil of 100% capacity. In tier-IV design, CRAH is with dual chilled water coils whereas for tier-III, a single 100% capacity can be adopted. In some designs, a ring main is created and equipment are connected with isolation valves so that they can be isolated without needing to shut down the system. The piping system for a DC facility is, therefore, complex and needs proper planning.

Enhancing Data Center Efficiency

Adiabatic Cooling Pads on Condensers

The power consumption of chillers increases with increase in ambient temperature. During months when the wet bulb depression is more than 3°C, the temperature of the inlet air is reduced by spraying water over water-soaked media pad or water mist system. Due to evaporation, the inlet temperature of air entering the condenser is reduced. This reduces the condensing temperature and saves energy. Evaporative cooling technique works only in hot and dry climates. A study of the climate data would help the designer to assess feasibility of this concept for the location.

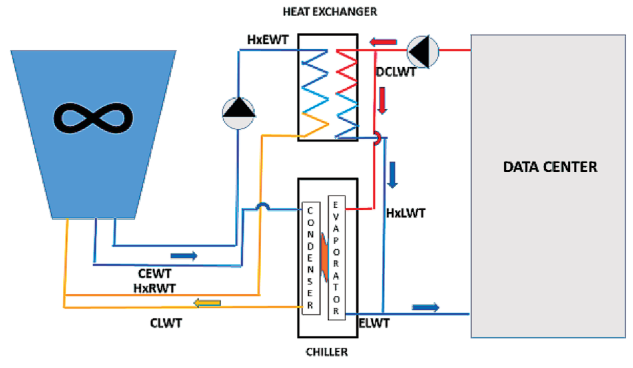

Figure 6: An image from data hall CFD report

Free Cooling

When the ambient air temperature is lower than the supply water temperature of the chiller, free cooling technique is used to cool water in place of the electrically-operated compressor. The study of the weather profile and sufficient hours available for free cooling application helps in determining the adoption of this technique. In some locations, partial free cooling is also used to reduce the power consumption of chillers. Water side economizers are better suited for DCs as compared to air side economizers.

Testing and Commissioning

Testing and commissioning of a DC facility is generally carried out by a third-party testing and commissioning (T&C) agent. A T&C agent is appointed from the initial stages of the project and reviews key documents like design basis report, schematic design, and sequence of operation. The T&C agent generates scripts for testing and commissioning of the facility in conjunction with the equipment suppliers. Testing of all major equipment at the factory may also be witnessed by the T&C agent jointly with the client. Clearance for dispatch is given post factory acceptance test (FAT). Post-installation at site, all equipment and systems are tested to ensure that they are performing as per design intent. Based on this, a Site Acceptance Test (SAT) report is generated before handing over the facility to the operations team.

Documentation, therefore, is a very critical part of a DC infrastructure. Document management must be paid due attention. Each equipment must be tagged in drawings and in the asset list for ease of identification and management during operations of the facility.

Conclusion

The dynamic nature of the IT industry and its fast pace change in requirements make DC cooling a very interesting subject.