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Thermal Management of Edge Data Centers

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OVERVIEW

Cooling system optimization and planning is one of the core subjects of traditional data center infrastructure. When a subset of the system is physically relocated closer to the end user as described in the Edge Data Center (EDC) concept, a solution to provide a data center like environment for high power equipment will be required in public locations such as office buildings, shopping centers, school campuses, event arenas, and wireless cell sites. However, the addition of a sophisticated cooling solution that will maximize compute, caching and networking performance may not justify the benefit of the Edge Data Center or may not be physically feasible.

As the Working Group for "Type and Location" categorizes different sizes of EDC's for various locations from a single small cabinet or container to a larger facility, we presumed the cooling method can vary depending on the total thermal load of the system, the thermal rating, and the vulnerability and survivability of the equipment used. In this paper, we have selected several topics for consideration when planning a cooling solution for an Edge Data Center.

I. THERMAL MANAGEMENT BASICS

Heat that is externally present or generated internally by the device, if not adequately removed, is detrimental to the performance and reliability of a communication and computational electronic circuit. Therefore, thermal management of an Edge Data Center must be considered for each level of cooling and heating.

- **Component Level**: The component is the base of the heat source. It often relies on conduction to a case mounted heatsink and printed circuit board (PCB).

- **Equipment (chassis, blade) Level**: The equipment must be designed to effectively remove heat from the component. It often relies on fans and air to remove the heat directly from heatsinks and PCBs, and therefore indirectly from the components.

- **Rack/Cabinet/Container Level**: Plan equipment layout to guide thermal path of removed heat from the equipment according to the thermal management design of the floor (Equipment stacking arrangement, heat baffle, thermal duct, fans, liquid bath).

- **Floor Level**: Plan the floor to maximize the performance of thermal management while minimizing the cost.

- **Environment that Equipment Deploys**: Consideration of temperature, humidity, contamination and hazards.

Considerations for the thermal management of data storage and transport equipment, includes the methods and systems sufficient to maintain the equipment operating environment (temperature and humidity) within the physical operating condition range.

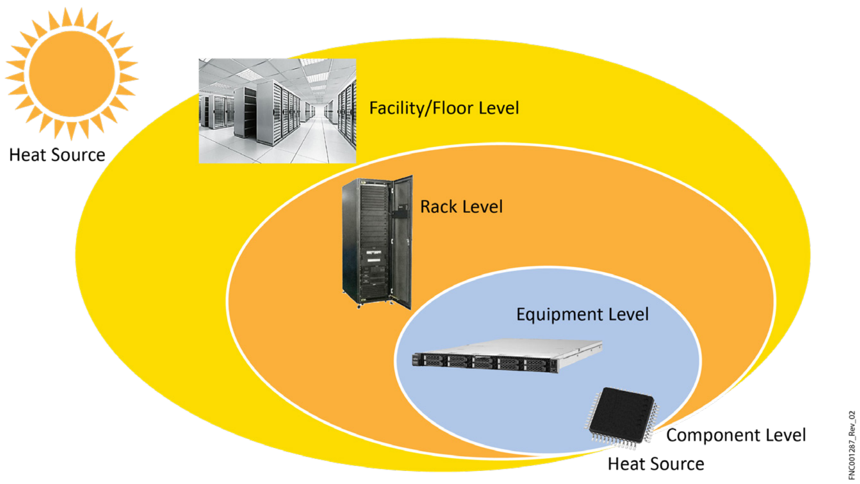


Figure 1: Heat Source and Cooling Domain, Courtesy of Fujitsu

II. ENVIRONMENTAL REQUIREMENTS - TEMPERATURE, HUMIDITY AND CONTAMINANTS

Temperature and humidity are critical environmental factors for EDC equipment. Unless equipment has requirements stating otherwise, EDC equipment with supply air should be controlled to meet ASHRAE TC9.9 guidelines which include one recommended and four allowable ranges (A1 to A4). The recommended range for all equipment is 18 to 27C.[1] Allowable ranges, as compared to the recommended range, can enable potential cost savings for environments, most notably, those relying on the free cooling technologies. Typically, these environments will operate at upper ASHRAE limits, reducing cooling need and expense. Allowable ranges, depending on equipment, extend the temperature range as wide as 5-45 C (41-113 F).

A1	15-32 C (59-89.5)
A2	10-35 C (50-95 F)
A3	5-40 C (41-104 F)
A4	5-45 C (41-113 F)

[1] ASHRAE recommends: Dry-Bulb temperature of 18 to 27C with a non-condensing humidity of -9C DP to 15C DP and 60% rh.

From GR-3108 - General Requirements for Network Equipment in the Outside Plant

CLASS 2	-40 to +65 C
CLASS 3	-40 to +70 C

Per TIA-942-B Section 6.4.3.2, the operating environment shall conform to environmental conditions of contaminants defined as a C1 classification in ANSI/TIA-568.0-D. Common methods to ensure meeting C1 classification include vapor barriers, positive room pressure (where permitted by the Authority Having Jurisdiction (AHJ)), or absolute filtration. Air and water quality and contaminants requirements of various types and locations of EDC should be referred to applicable standards such as ISO14644-1 for Class 8. This requirement relating to contamination mitigation would have significant impact on cooling and therefore needs to be factored in when deciding which cooling method to employ in any EDC.

III. EQUIPMENT SECTION

Selecting equipment suited for the application is important. For the equipment to be deployed in the traditional data center environment, ASHRAE TC9.9 recommends new networking equipment designs to be front to rear air flow rated to a minimum of ASHRAE Class A3 (40°C) and preferably ASHRAE Class A4 (45°C). The development of new products which do not adhere to a front to rear cooling design is not recommended. It is recommended that networking equipment, where the chassis doesn't span the full depth of the rack, have an air flow duct that extends to the front face of the rack. ASHRAE TC9.9 recommends the equipment be designed to withstand a higher inlet air temperature than the data center cooling supply air if: the equipment is installed in an enclosed space that doesn't have direct access to the data center air cooling stream, or the equipment has a side to side air flow configuration inside an enclosed cabinet.

Temperature hardened equipment is critical for the outdoor application with limited cooling capacity. Equipment categorized with temperature hardened rating can withstand operating condition of -40C to 65C. The device that meets this criterion is safe to operate without cooling methods that required chilled gas or liquid. Any equipment has its operating temperature range inside of -40 to 65C is considered non-temperature hardened equipment and requires active cooling to maintain its inlet air condition to meet its specific operating temperature and humidity range. Equipment deployed with liquid or immersion cooling system must meet its hardware compatibility requirement.

IV. SIZE AND TYPE OF EDGE DATA CENTERS

During the initial planning stage of designing a cooling system for an EDC, the plan would be based on the amount of heat generated by the equipment in the given space and ambient condition. The below TIA EDC white paper written by the Types and Location Working Group further describes this topic in detail: Types and Locations of Edge Data Centers.

V. COOLING CHALLENGE

Server, storage and switch gear power levels are on the rise which is driving higher power dissipation in racks. There are differing views as to what the average power levels per rack are today and will be in the future. For instance, ASHRAE published a chart, "Datacom Equipment Power Trends and Cooling Applications" showing rack power levels in 2019 are between 15 kW and 38 kW, while a chart published by AFCOM, "Data on cooling trends from the recent AFCOM State of the Data Center Survey" shows the average cooling levels per rack to be between 7 and 10 kW.

Showing a large disparity between predicted and actual levels of power per rack. This is critical as the green grid recommends moving from the more traditional cooling methods to liquid cooled systems at rack power levels of 20 to 25 kW and higher. This complicates things further because we do not know all of the use cases planned in the new 5G network which drives processing power, the amount of storage and the associated switches that connect these devices to the network fabric.

If rack power levels will be in the range of 10 kW per rack for the next 5 or even 10 years (or below 20 kW), then Edge Data Center solutions can employ more traditional cooling methods and take advantage of a large established supply chain which affords scale deployments and well understood cost models for not only the cooling equipment, but the servers, storage devices and switch gears. However, if rack power densities will pass the 20 kW level in the near future, then developing and deploying EDC infrastructure with the more traditional cooling methods that only support less than 20 kW per rack would decrease performance, efficiency and flexibility. Secondly, if we see rack densities greater than 20 kW per rack, the industry should be driving technology partners and a supply chain to support the need for these newer cooling methods and large-scale deployments. It is difficult to say what the power levels will be for these new EDCs, however, one must take into account the cooling methods needed to support the new compute, storage and switch gear as far out in the future as possible and compare these to the capital and operation expenses.

VI. TYPE AND MODE OF COOLING METHODS

All data center cooling solutions involve the removal of the heat generated by the IT equipment for its eventual dissipation into the environment. There are several different cooling options that are suitable to different equipment and environmental conditions. Cooling systems can be divided into two main categories: Direct and Indirect Cooling.

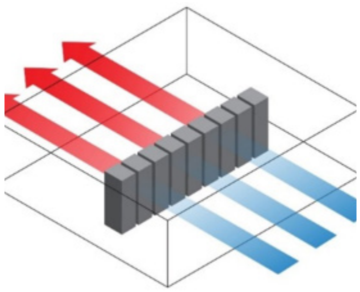
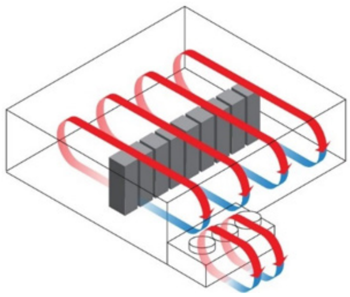
Direct Cooling

A direct cooling system is composed of a single cooling loop. Therefore, the outside air is circulated to the IT equipment to capture heat. Types of direct cooling involve free air, forced free air and adiabatic (or evaporative) free air.

Indirect Cooling

An indirect cooling system is composed of two or more cooling loops. In this type of cooling, the medium that removes the heat from the IT equipment is not in direct contact with the outside environment. For indirect cooling, the cooling loops can be divided into heat rejection/Outside Loop and the heat absorption/indoor loop. At least one type of heat rejection cooling needs to be coupled with at least one type of heat absorption. It is possible to have hybrid systems with multiple heat rejection and/or heat absorption mechanisms in the same data center.

HEAT REJECTION	HEAT ABSORPTION
• Free Air/Dry Cooler • Adiabatic • Condenser • Chiller	• Direct Expansion (DX) • Chilled Water • Single Phase Liquid Cooling • Two Phase Liquid Cooling • Liquid to the Chip

TYPE	PROS	CONS
Direct Cooling 	• No Mechanical Cooling • Lower Energy Consumption • Lower CAPEX* • Lower Operational Expenses* • Limited amount of failure components	• Limited Humidity Control • Limited Air Quality Control • Limited Heat Loads • Highly Dependent on Outdoor Conditions
Indirect Cooling 	• Air Quality and Humidity Control • Larger Array or Cooling Options • Suitable for any climate	• Higher Investment Expenses* • Higher Operational Expenses*

* Readers are encouraged to determine their own costs based on the unique circumstances arising from their implementations

VII. COOLING CAPACITIES, EFFICIENCY AND PERFORMANCE

Cooling complexity and costs related to increased cooling scale with EDCs total power loads. An EDC with a total power load under 10 kW may be cooled simply by managing supply airflow with fans, containment and separation of the IT exhaust from the EDC space. However, an EDC that has 8x 25 kW racks, or a 200 kW total load, will require significantly more effort and cost. This is true regardless of the cooling approach chosen. Further, as rack power densities continue, at some point the increased cooling capacity of liquid based cooling may outweigh these costs. The same 200 kW EDC with this approach could be implemented across 2x 100 kW racks. This will be an increasing consideration as liquid cooling options mature and become more common.

The coefficient of performance (COP) is generally used to evaluate the measure of cooling/heating efficiency and the performance of the cooling/heating system itself. COP is a ratio of energy used to remove given heat.

- COP = Q/W, where: Q = heat, W = work

Water usage efficiency (WUE) is often used to measure liquid cooling system efficiency. WUE is calculated by the annual water usage in liters divided by the IT load in KWh. The tables below summarize the general performances of different types of heat absorption and heat rejection systems.

HEAT ABSORPTION	EFFICIENCY	TOTAL EXPENSES	SERVER DENSITY
Room Cooling	Low	Low	Low
Cold/Hot Aisle	Low	Mid	Mid
In Rack Cooling	Mid	High	Mid
Single Phase Immersion	High	Mid	High
Two Phase Immersion	High	High	High
Liquid to Chip	High	High	High

HEAT REJECTION	EFFICIENCY	TOTAL EXPENSES	SERVICEABILITY	LOCATION SPECIFIC	SIZE
Direct	High	Low	Mid	High	S
Direct Adiabatic	High	Low	Low	Mid	S
Condenser	Low	Mid	High	Low	S-M
Chiller	Low	Mid	High	Low	M-L
Cooling Tower (Closed Adiabatic)	Mid	High	Low	Mid	S-L
Dry Cooler	High	High	High	High	S-L

*Cooling methods evaluated independently

COP or WUE is further evaluated against the overall power efficiency of the datacenter; **power usage effectiveness (PUE)**. PUE is a ratio of the total facility energy of datacenter to the energy of IT load.

- PUE = (Total Facility Energy) / (IT Equipment Energy)

Total Facility Energy includes power to maintain physical operation of the facility (cooling, lighting, etc.) and power to run IT equipment. Since the energy usage of cooling system typically takes up a large portion of total facility energy, improving the COP or WUE of a cooling system is important to optimize PUE. When considering the cooling efficiency of the IT boundary only, **partial PUE (pPUE)** is often used.

- pPUE = Total Energy within a boundary (IT Energy + Cooling Energy) divided by the IT Equipment Energy within that boundary. For further details on PUE and pPUE, refer to document: Data Center Efficiency Metrics: mPUE™, Partial PUE, ERE, DCcE

PUE is an often-misleading unit. The below table estimates power consumptions of different technologies. This table illustrates the reasoning for efficiency ratings in above tables. Normally pPUE uses the entire power consumption of the rack as its denominator.

In this table, this denominator was divided into 3 components: 1). power used by processors (pPUE primary), 2). power used by the fans (pPUE fans), 3). power used by all other server components (pPUE secondary) Added together the consumption of these 3 components show the total compute power as measured in the rack.

	IT Power (Main Components)	IT Power (Secondary Components)	Fans (7-20% usually)	Main pPUE**	Secondary pPUE**	Fan pPUE	Total IT and Cooling Consumption on (kW) per 1kW Server
Room Cooling	76.50%	13.50%	10%	1.70	1.70	1.70	1.7
Cold/Hot Aisle	76.50%	13.50%	10%	1.50	1.50	1.50	1.5
In Rack/Row Cooling	76.50%	13.50%	10%	1.20	1.20	1.20	1.2
Single Phase Immersion	76.50%	13.50%	10%	1.05	1.05	-	0.95
Two Phase Immersion	76.50%	13.50%	10%	1.03	1.03	-	0.93
Liquid To Chip	76.50%	13.50%	10%	1.50	1.50	1.50	1.16

By using the methods defined in this section, one can better determine the best cooling method to employ in your edge system.

VIII. RELIABILITY AND REDUNDANCY MEASURMENTS

A measure of the reliability of the cooling system is to define the mean time to failure (MTTF), which represents the length of time the system is expected to operate until the first failure. There are multiple mechanisms which can cause failure.

- **Failure** due to lack of adequate power source, including power outages, bad connections / wiring;
- **Failure** due to mechanical elements, including condensers, fans, capacitors, compressors; and
- **Failure** due to overstress, including a cooling system not adequately sized for the equipment, thermal load or external thermal load from an extreme environment.

Once failure occurs to the cooling unit, the length of the mean time to repair (MTTR) will vary depending on the EDC location and available repair service levels. Since electronic circuit performance and reliability are strongly influenced by temperature, cooling redundancy is beneficial and may be required.

Types of Redundancy

- N+1: Multiple modular systems that have at least one independent backup device;
- 2N: The entire system has a mirrored full backup; and
- Alternative cooling system for full or partial backup.

IX. PLANNING, MODELING/DESIGNING, ANALYSIS

EDC would be better suited than their larger counterparts to implement non-traditional cooling methods ranging from free cooling to some form of liquid cooling or a combination of more than one type. Factors that need to be considered before a cooling method is selected include but are not limited to: 1) IT Equipment density, 2) temperature limits, 3) air quality and humidity requirements, 4) refresh cycles, 5) budget, 6) water availability, 7) power cost, 8) environmental impact, 9) ambient conditions, 10) space available, 11) disaster resiliency, 12) security, 13) mean time to repair and 14) local regulations. Once the design has been determined, it is highly recommended that each of planning levels (equipment level, system level and floor level) include computer modeling (CFD analysis) to fully understand how the system will operate within the given environment, including during times of equipment failures (either within the cabinet itself or environmental stresses beyond).

There are tools for transient analysis which can predict temperature changes based on different configurations.[2]

X. MONITORING AND ALARMING

Monitoring the cooling system operation and having an alarm capability is necessary to maintain the overall EDC performance. These parameters can be monitored using various sensors to report through an alarm system that acts as a hybrid of BMS (building monitoring system) and DCIM (Data Center Infrastructure Management). Details of what is appropriate to monitor and how it is achieved will be included into the TIA's new Edge Data Center Standard that is currently under development.

[2] Data Center Temperature Rise Calculator, https://www.schneider-electric.com/en/work/solutions/system/s1/data-center-and-network-systems/trade-off-tools/data-center-temperature-rise-after-primary-power-loss-calculator/

XI. CLOSING THOUGHTS

EDCs are currently being deployed and potentially coming to neighborhoods and remote locations, before the industry standards and regulations are fully established. This paper suggests considerations and methods for the planning of an EDC cooling system. At a high level, the working group is planning a series of papers to cover each topic in more detail. The goal of these papers on EDC cooling is to help the reader understand the factors to consider in developing an EDC cooling system that is well suited for its application and to support the development of a TIA standard targeted at EDCs.

To learn more about the TIA's Working Group efforts in developing information and standards on Edge Data Centers (EDCs), go to the TIA website: **www.tiaonline.org**. If you have opinions or expertise to lend to this effort, please reach out to **edcinfo@tiaonline.org**.