Three Key-Elements for Data Center Facilities Sizing in Early Stage of Design

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Abstract

The growth in data trafficking, data processing, e-learning, social networking, digitization of services and in general, the simple fact that almost everything is shifting digital, necessitates an ever-increasing demand in information handling and processing. The massive amounts of data are stored and processed in "servers," "routers," "Firewalls," and storage devices (also known as IT load) installed within data centers (DCs). Data centers consume an important amount of electricity (about 2% per year), and it is forecasted that consumption will rise to more than 3.8% of global electricity consumption by 2030. Three key elements to be considered are the IT load rating, the layout-arrangement of the IT white space and cooling rating. These are related by the power density, which directly relates the data center size, the cooling capacity, and energy use. This paper covers the main technical infrastructure design for a case study of DC-500 kW in Hoa Lac-Vietnam, the design is following international guidelines and best practices. We present a better way for selecting DC's power density and optimal layout-arrangement for IT racks. It is a conjunction of cooling load and airflow sizing, and computational fluid dynamics (CFD) simulations to analyze the heat distribution (cold air intake, hot air exhaust) in DC rack-rows. Airflow analysis is a key consideration during the initial phase of DC sizing since it encompasses all the design and configuration elements that go into restricting or preventing mixing between the cooling air provided to IT equipment and the hot air rejected from the IT room.

Keywords
Data center, Power density, Precision cooling, IT rack, CFD simulation.

1. Introduction
Data centers (DCs) represent a large and growing energy use sector, and are energy intensive facilities, with considerable impact on global power consumption. DCs currently consume about 2% of the global electricity, and they are projected to touch 4% by 2030 [Bharany et al. (2022)]. In Vietnam, with the implementation of the data localization law, promoting digital transformation program, and other information services, data center investments are increasing in recent years. According to Research and Markets, Vietnam's data center market is predicted to rise to more than $1 billion by 2028, up from $561 million in 2022, at a compound yearly growth rate (CAGR) of 10.68%. Nowadays, there are over 30 data centers with a capacity of 45 MW, more than 46% located in the north, 35% in the south, and 18% in the center. About 80% of data centers are operated by local telecommunications companies such as VNPT IDC of the Vietnam Post and Telecommunications Group (VNPT), Viettel IDC of Viettel Group or FPT

Telecom of FPT Group. However, we can also make some remarks: lack of the statistics report regarding the total energy consumption as well as the carbon footprint of data center; a guideline regarding the standard technical design of data center is also unavailable publicly; most big data centers is designed according to Uptime Institute Tier 3 rate. Data centers typically have three major load sections: Information Technology (IT) loads, cooling, and internal power conditioning system (i.e., Uninterrupted Power Supply (UPS), Power Distribution Unit (PDU), and Power Supply Unit (PSU), including security and office supports). The IT load section or critical loads contains servers, storage, local cooling fans, network switches, etc. This critical IT equipment in the data center needs continuous and reliable operation in a 24/7/365-days business environment, where high availability of infrastructure is assured with multiple paths and systems for increasing redundancy. This leads to energy inefficiency and oversizing-design, due to architecture with many systems in parallel supplying the critical load, redundant sources (UPS, Battery Storage and Generators for backup power during grid outages, distribution paths, etc).

The technology evolution, especially infrastructure virtualization and digital technology application, have an important impact, IT racks densities are climbing, some server racks being now designed for more than 30kW, rack capacity of 8kW-10kW is still accounts for the highest percentage (more than 23%) according to the latest Uptime Institute survey report [Davis et al. (2022)]. The largest power consuming section in a typical data center is the IT load section at about 50% of total DC's power consumption. An important part of energy consumption is dedicated to the cooling system and auxiliary systems (lighting, power distribution, security, fire protection etc.). Only the cooling system may account for up to 40% average of the energy demands in a data center. Enhancing the efficiency and the reliability of the data center are the technical challenges for maintaining the quality of services for the end-users in the data center operation. The purposes of data center are to provide safe and secure information services like storing, processing, and disseminating data and applications. Therefore, it requires continuous power supply for continual functioning must be complied.

The objectives of this paper are to propose the design philosophy of data center facilities. The design must consider the functional requirements of the data center are: (i) to provide white space layout arrangement for IT racks including servers, storage, and networking devices; (ii) to provide the power needed with redundancy distribution path to maintain critical operations; (iii) to provide the cooling capacity, airflow circulation and environment working conditions within the parameters needed to sustain operations of IT equipment. This paper is divided into 3 parts: in Section 2, the authors intend to cover the research and understanding of the topology and classification of data centers based on their capacity and function. Extremely important research is devoted to describing three important factors that are key parameters to the design of a data center's physical infrastructure: layout footprint; power supply sizing and cooling capacity sizing. Calculating these parameters is basically referred to the power density of the IT racks. In Section 3, we mention the design of the main infrastructure of a data center that is quite popular in Vietnam with a scale of 500 kW. Key findings will be covered: optimal arrangement of IT racks, location of racks with high-power densities, reasonable selection of cooling capacity and power supply topology.

2. Right-Sizing a Data Center Physical Infrastructure

2.1 Project Planning and Infrastructure topology

A data center project planning to develop or update/retrofit an existing data center continues to be a key concern for many IT organizations. Each data center has been designed for different objectives and requirements such as location, sizing, tier rating, density operations, scalability, energy efficiency, or cost saving. Design requirements are very important while understood project planning reduces project distortion subject to more accuracy in transformation from design phase to build, operate and maintenance phases. Rasmussen (2014) has divided the project plan into six fundamental steps: plan design, build, commission, operate and maintenance, and assessment, as presented in Figure 1a. Energy conservation in data center starts from planning design requirements need to input from the outset of project plan as one of the key project metrics. To operate more energy efficiency means first design must be proposed for energy efficiency concern. Consequently, little upfront changes in the plan phase will have major cost effective on the 5th stage. In this paper, we are in the initial phase of DC infrastructure design, three key elements for a data center will be considered: IT load rating, the layout-arrangement of the IT space and cooling rating. These are related by the power density, which directly relates the data center size, the cooling capacity, and energy use.

The Tier classification system evaluates data centers by their capability to allow maintenance and to withstand a failure in the power supply system. In Figure 1b, Tier I (the least reliable) to Tier IV (the most reliable) are defined depending on the redundant components in the parallel supply path (electrical and cooling systems) to the critical IT loads [Arno et al. (2012)], [Turner et al (2008)].Based on the European Standard EN 50600-1:2012 [Val de Ha et al. (2014), Garcia et al. (2017)], there are three types of data center: enterprise DC, co-location DC and hosting DC. The main difference between these types of DC is the owner of the DC facility and the IT (equipment and services), and with that the possibility to synchronize the DC systems and the IT. According to the several research,

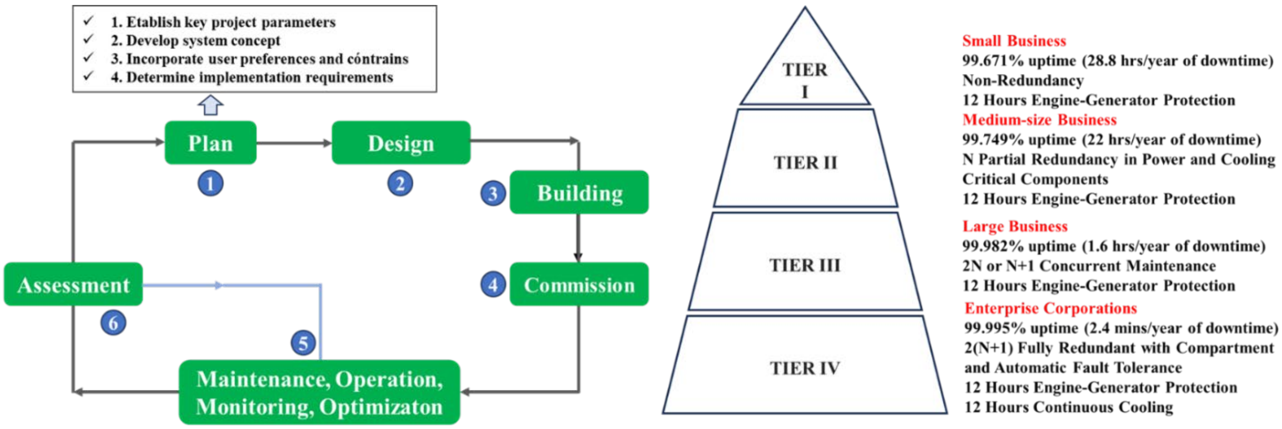


Fig.a) Data center life cycle ***Fig.b) Data center Tier-classification***

Figure 1. ***a)*** Six fundamental plan phases of the data center life cycle [Rasmussen (2014)];

b) Data center four - Tier classification according to Uptime Institute [Wiboonrat (2020)]

Table 1 presents a summary of the common data center archetypes based on its size (total power capacity), data center function and owner.

Table 1. Overview of common data center archetypes based on size (IT power), data center function [Val de Ha et al. (2014), Garcia et al. (2017)]

Items	**Classification**	**Data center size (IT power)**	**Data Center function/objective**
1	Server room	< 50 kW	✓ Supporting enterprise DC
2	Very small Data Centre	50 - 250 kW	✓ Supporting enterprise DC ✓ Business critical enterprise DC ✓ Co-location DC ✓ Hosted or Cloud Services Providers
3	Small Data Centre	250 - 1000 kW	✓ Supporting enterprise DC ✓ Business critical enterprise DC ✓ Co-location DC ✓ Hosted or Cloud Services Providers
4	Medium size Data Centre	1 - 2 MW	✓ Business critical enterprise DC ✓ Co-location DC ✓ Hosted or Cloud Services Providers
5	Large Data Centre	2 - 10 MW	✓ Business critical enterprise DC ✓ Co-location DC ✓ Hosted or Cloud Services Providers
6	Very large Data Centre	>10 MW	✓ Co-location DC ✓ Hosted or Cloud Services Providers

2.2 Energy Consumption and Power Supply

Data centers typically have three major load sections: IT loads (server, storage, network…), cooling, and power conditioning system (i.e., UPS, PDU, and PSU), and other auxiliaries loads. As shown in Figure 2a, the largest electricity energy consumption in a typical data center is the IT load section including IT equipment like server and storage (45%) and the network equipment (5%). The second position is cooling loads (38%), in which the cooling system consumes considerable amount of power to provide the air-cold into IT rack to remove the hot-air exhausted by IT equipment. The useful power for data center is the power directly delivered to the IT loads which is characterized by metrics as power usage effectiveness (PUE) meaning ratio between total data center energy and total energy used for IT. The total energy should include all energy needed to support the facility, energy lost in power conversion, distribution, energy used for cooling and support areas, lighting, security… (Figure 2b). Ideally, the value of PUE should be approached about 1, a lower PUE value indicates a more efficient data center. According to the Uptime Institute's data center survey in recent year, the global average PUE of largest data centers trends to decrease from 2.5 in 2007 to 1.55 in 2022.

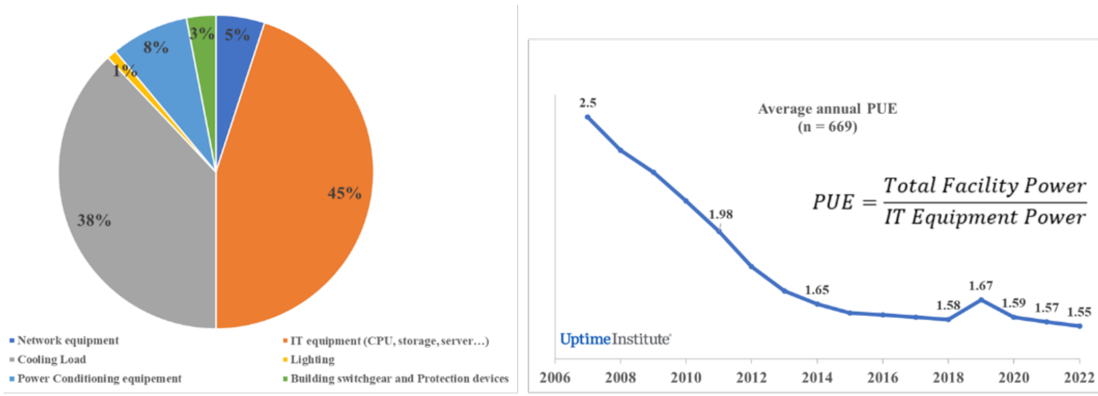


Fig.a) Electricity consumption ***Fig.b) PUE progress, data survey***

Figure 2. ***a)*** Analysis of power consumption proportionality [Ahmed et al. (2021), Vasques et al. (2019)]; ***b)*** Average annual PUE data survey by Uptime Institute [Davis et al. (2022)]

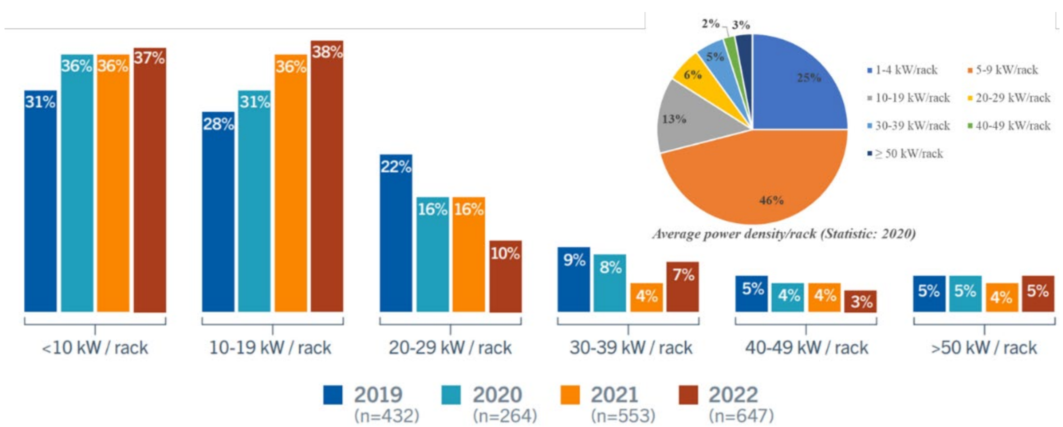


Figure 3. Average power density/rack trends today, data survey by Uptime Institute [Davis et al. (2022)]

The basic parameters, called power density, are used mostly for dimensioning design of DC, reflecting capacity attributes for a data center but don't express the overall availability and performance of the facility [Dumitrescu and Plesca (2016)]:

- Power/area (kW/m2) = power density for the data hall toward IT equipment. The IT room design layout is a determinant factor of energy consumption.
- Power/rack (kW/rack) = power density provides the distribution of IT equipment in a cabinet. At the rack level, power density refers to the power draw of a single, fully populated server rack, measured in kilowatts. Racks with different consumption (i.e., 1 kW or 10 kW) can be near each other. This parameter has often been used as the criteria to establish power and cooling capacity requirements. This approach may lead to inappropriate capacity projections but is often used during early stage of facility design if we either don't understand how

the various IT platforms impact capacity planning or do not have access to the necessary information about specific IT devices rating.

According to the annual Uptime Institute global survey (Figure 3), a decade ago, average power densities loomed around 4-5kW. Today, average power densities hover around 8-10kW per rack with a tendency of higher peak demands of 10-20 kW per rack [Davis et al. (2022)]. As rack power requirements exceed 20kW, operators will require more efficient cooling technologies regardless of facility size. Statistics survey show that Vietnam now has nearly 30 data centers with 45 MW of capacity, power density almost in the range 5-9 kW/rack accounts for 46%.

A continuous and smooth power supply system is the most basic requirement of the data center. To provide continuous power even during grid outages, IT racks are provided via a PDU system with uninterruptible power supply (UPS) and backup generators. UPS plays an important role in maintaining data center uptime by providing continuous, reliable, and high-quality power. The IT requirements like the IT process emergency shutdown that will need the time to properly shutdown the IT devices to not lose any data before the power blackout, so the storage system is necessary coupled with UPS. Among the storage technologies, about 99% of the UPS manufacturers use VRLA or Li-ion batteries as energy storage solution with a backup-time of at least 10 minutes [Avelar and Zacho (2017)]. Battery is not only limited for data center power availability but also for the power quality improvement and participation in energy management solution. To guarantee a reliable power supply 24/7/365, data centers employ a variety of energy resources as mentioned above and the electrical system have categorized with several topologies corresponding with different redundancy levels described in McCarthy and Avelar (2015) and Chalise, S (2015).

2.3 Cooling Supply and Airflow Distribution

In principle, all IT devices consume a lot of electricity in operation, in which 99% of power consumption is converted to heat load. It requires cooling to remove this amount of heat dissipated to ensure the IT equipment operates reliably. The IT devices are highly sensitive to temperature and humidity fluctuations, so a data center must keep restricted environmental conditions for assuring the reliable, correctly operation of IT's equipment [Alkharabsheh et al. (2015), Garcia et al. (2017), Xu et al. (2023)]. This requires precision air-conditioner cooling (PAC) to maintain the appropriate temperature and humidity in IT room [Evans 2015 & 2017]. In this research, the configuration and intended airflow directions of a typical raised-floor data center are used owing to its advantages for small to medium sized DCs, namely CRAC (in Figure 4, PAC with air-cooled and direct expansion) [Rasmussen (2015); Rasmussen and Dunlap (2015)]. The above-floor white space allocated for IT equipment in the data hall is separated into cold aisles and hot aisles by rows of racks. The raised-floor plenum and perforated floor tiles are assumed to uniformly distribute the cold air to the cold aisles.

The cold air from the CRAC units is supplied to the cold aisle, then flows through the front of IT racks and carries heat dissipated from IT equipment, and then exhausts to the hot aisle (rear of rack) and returns to the cooling system through the ceiling plenum. The [ASHRAE TC 9.9] guidelines set out an operational envelope for temperature and humidity within which it is acceptable to maintain operating environment inside the Racks. The recommended envelope: the air supplied to servers, storages, networks should be at a temperature range of 18°C to 27°C; the humidity range of 5.5°C dew point to 60% relative humidity and 15°C dew point. The allowable envelope of which is wider but presents a higher risk of equipment failure: depending on the type of data center, the allowable supplied air-inlet extends to a range of 5 to 45°C and the allowable relative humidity is wider at 20% to 80% or -12°C dew point and 8% to 90%. In this project, we consider using the recommended envelope for DC design.

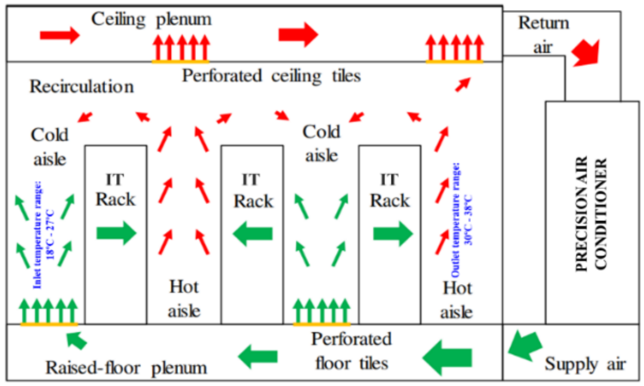


Figure 4. Airflow pattern in a typical raised-floor data center.

The required cooling capacity depends on multiple aspects like the rack layout arrangement in the data center, the spatial allocation of the IT power (simplified sizing by power density per rack), the airflow rate, air-distribution, and the efficiency of the PAC. An important factor for dimensioning cooling capacity is the exterior design conditions. While they typically have little impact on the cooling load that must be delivered, external conditions significantly impact on the capacity of the heat rejection plant (for example, with CRAC air-cooled, the outside ambient affect directly to the heat rejection capacity of the condenser unit).

As a critical facility with 8,760 hours continuous operation, extreme outdoor climate design conditions are often used to simulate the sensible capacity of PAC unit, which is the amount of cooling energy to be delivered to IT room. Along with cooling calculation and airflow rating calculation, a computational fluid dynamics (CFD) tool thanks to Schneider Electric has been widely used to improve data center thermal management, avoiding oversizing design. CFD simulation tool can be adopted to evaluate the temperature and airflow distribution for different scenarios of design, such as different layouts of the cold aisle, hot aisle, and IT racks. The CFD analysis output results can make reliable predictions of perforated-tile air flow rates and rack-inlet temperatures. This has been proven valuable in data center design as the designer can validate the cooling system design prior to installing the system. It is also beneficial to data center operators as they can advise:

- How the placement of IT rack in real installation will impact the cooling systems ability to meet the data hall cooling demand.
- Simulate various failure scenarios by "turning off/ hot standby" components within the CFD model and analyzing if the remaining cooling system can support the IT load.

3. Technical Design of a DC-500 kW in Hoa Lac, Vietnam

3.1 Constrains and Assumptions

This research aims to design a DC that can be served for many applications such as: supporting enterprise DC, business critical enterprise DC or co-location DC. The DC size is assumed to be equivalent with the typical DC in Vietnam at the same function as mentioned above section (power density/rack is in the range: 4-6 or 5-9 kW/rack for servers and storage devices, and 1-4 kW/rack for network devices). The DC installation location is assumed in Hoa Lac, a hi-tech area where many other DCs are currently being operated. All constraints and assumptions have verified subject to design capacity, occupancy rate, and Tier level, as shown in Table 2.

Table 2. Hoa Lac XXX data center design requirements

Items	Description
1	Data center location: Hoa Lac/ Vietnam

2	Data Hall area: 300 m2 2nd floor in a building of 6 floors, floor dimension (H x L x D) to be used: 6 x 30 x 15 m
3	Data center IT capacity:~500 kW, adaptable from 300 kW to 500 kW About 100 Racks: Server, Storage and Network IT equipment (Network Racks attribution: 20%)
4	Target availability: Tier-3 (Uptime Institute Tier rating guideline) Redundancy design for increased availability and concurrent maintenance
5	Target annualized PUE at 100% load: 1.6
6	Regional voltage and frequency: 22/0.4 kV, 50Hz
7	Integrated room-based air distribution (CRAC, air-cooled) Cooling system: precision air-conditioner with variable-speed compressors to increase efficiency.
8	Raised floor heigh of 750 mm to create enough open space under-floor tiles to help cold airflow travel to the Rack in the data hall; is also the space containing the power lines. Perforated tiles have 25% - 35% open.

Table 3. Critical IT load power consumption

No	**Item**	**Data Required**	**Load calculation**	**Remark**
	Critical Load - IT power consumption (kW)			
1	Server and Storage Rack	Average power density/rack	Power requirement (kW)	*Average power density based on best practice design for small DC*
1.1	*60 x Server Rack*	*5 kW/rack*	*300*	*Actual load*
1.2	*20 x Server Rack*	*7 kW/rack*	*140*	*Redundance design for scalable IT capacity*
3	16 x Network Rack	3 kW/rack	48	*Planning for 02 x network rack-rows*
4	**Total critical IT load (kW)**		**488**	*in IT Space-data Hall*

IT load planning:

- Dual power supply (that takes 50/50% on each distribution path, by 02 x PDU) to the IT equipment.
- Average power density per rack used as basic input parameter. The number of racks multiply by kW per rack is equal to total power draw from UPSs that will size ATSs, generators, and transformers respectively.
- The configuration of the IT room is determined by the number of racks per row, the number of rows, and the number or row per IT room.
- Nowadays new server power supply shows power factor above 0.95 [Neudorfer (2020)]. It is noted that when specifying the IT equipment, the capacity of each device (server, storage, network) in terms of active power (kW), reactive power (kVAr), and maximum current (amps) needs to be checked in the next phase.
- Total IT power required for the IT room is presented in Table 3 with 16 racks attributed for network racks and the rest reserved for server and storage racks. See Figure 6 for detailed information of data hall layout rack's arrangement).

Cooling load planning:

- Dual power supply (with embedded automatic transfer switch, that takes 100% one side and 0% on the other side of distribution path) to the PAC units.
- In-room precision air-conditioner with air-cooled, direct expansion units are preferred.

- Average power density per rack used as basic input parameter for cooling dimensioning.
- Presumption that all electrical energy used by IT equipment is converted to heat, that takes the cooling load equal to 100% of total power consumption by IT room.
- Total sensible cooling capacity demand is based on the: power density per rack; airflow demand. The cooling capacity demand should be exceeded by about 120% for heat losses reservation. This calculation should be referred to the ASHRAE climate design conditions for the use of heating and cooling load calculations and energy consumption modelling [ASHRAE (2021); Harmathy (2022)].

- Assumption that the air-distribution in the IT room is uniform (the cold air delivers to the rack from floor tiles with perforated tiles of 35% open).

3.2 Rack Layout Recommendation Based on Heat Load Sizing and Airflow Analysis

Figures 5 and 6 demonstrate the layout of IT rack rows inside the IT room (data hall): 04 PODs are racks for server and storage equipment (row 2 - row 9, with each row corresponding to 10 racks); 02 network rack-rows are arranged on two end sides of the data hall corridors to facilitate the connection of structured cabling systems to server racks. It is important to note that an optimal layout design is provided based on a combination of three factors: sensible cooling capacity calculation (Table 4), airflow demand (Table 5) and CFD simulation results of airflow distribution. With CFD analysis, we simulate an ideal scenario: uniform load and optimized distribution for airflow (variable perforated tile to adjust the air velocity, avoiding recirculation etc.) and increase the temperature in room to upper standard limit (i.e., increase energy efficiency). Raising the baseline temperature inside the data center, known as a set point, can save energy used for air conditioning. It's been estimated that data center managers can save 4 percent in energy costs for every degree of upward change in the set point [Miller (2011)].

There are 6 units of 100kW of sensible cooling capacity (5x100kW+1x100kW), for the uniform distribution of thermal load the design provides proper parameters and redundancy of systems. That means 01 CRAC unit is spare in hot standby. The PAC units located are recommended to be aligned with the hot aisle to maximize the distance from each unit to the closest perforated floor tile. This also simplifies the return airflow stream from the hot aisle directly to the PAC unit return air, which is more critical for IT room with open room return and low ceilings. Optimum placement for white space racks with high power density is in the middle or near the end of each rack-row (area further away from CRACs). For example, for rows 2-9: some racks have a power density distribution of 7 kW/rack; 6 kW/rack; 5 kW/rack positioned in the center of the PODs; alternating and at the top of the rack-row (closest to CRAC) are racks with lower power density: 2 kW/rack; 3 kW/rack; 4 kW/rack. This has been verified through a series of CFD simulations, yielding the results shown in Figures 5 and 6 (showing airflow rates throughout perforated floor). A minimum of 1200mm is recommended for cold aisle spacing and a minimum of 900mm is recommended for hot aisle spacing, with 1200mm preferred.

The exact aisle spacing 1200mm should be coordinated between the IT design (in this case we use standard 42U rack with 600W x 1200D) and the cooling system design to ensure that adequate air floor can be delivered from the cold aisle and returned to the CRAC unit from the hot aisle. There should be a minimum of 1200mm aisle space between the end of the IT rack-row and any CRAC unit, resulting in a minimum of 1200mm aisle around the perimeter of the data hall. It is also recommended to consider moving CRAC out of the data hall area, the maintenance works of any CRAC will not affect the operating environment of IT equipment. The minimum recommended clearance from the front air-discharge of CRAC units to the closest perforated floor tile should be at least 1800m (3 floor tiles of 600mm), which is verified by the airflow rates throughout perforated floor in Figure 6. If less, the pressure above the floor tile may be more than the pressure below the tile, with the air flowing from above the floor to the underfloor space. Perforated floor tiles with air flowing from above the floor to the underfloor space could be replaced by a solid floor tile as they are likely providing no cooling value to the IT equipment above the floor [Isaak (2021)].

Table 4. Facility cooling sizing for IT equipment in data hall.

No	Item	Data Required	Calculation	Subtotal (kW)		Remark
I	**Heat load Consumption - Cooling device selection for 96 IT racks**					
1	Heat load by IT rack	Rating of each IT device	IT electricity consumption	# 1	488.00	*Referred to Table 3*

2	PDU (Power Distribution Unit)	PDU nominal power rating - Power system rating	(0.02 * Power system rating)	# 2	9.76	
4	Lighting heat load	Total floor area - DC floor area (m2)	(0.0215*data hall floor area)	# 3	5.68	
6	Operators	Number of people working in the room	(100/1000*max Personnel)	# 4	0.50	
	Total cooling capacity requirement		**(# 1 + # 2 + # 3 + # 4)**	**# 5**	**≥ 494.18**	
	Cooling capacity selection: 05 x CRACs in operation and 01 x CRAC in stand-by (N+1 redundancy). Required cooling capacity as referenced as *sensible capacity*: 100 kW/unit. Extreme outdoor climate design conditions are often used to select the *sensible cooling* delivered by the CRAC units. In Hoa Lac, the extreme outdoor temperature can be referred as 41.1ºC maximum in 2021 (for a statistic of 20-year return period values of extreme temperature) [ASHRAE (2021)].					

Table 5. Supplied cooling airflow calculation based on ASHRAE guidance for CFD analysis of Data Center [Han et al (2020), Hu et al (2022)]

No	**Item**	**Data Required**	**Airflow calculation**	**Sub-total (m3/hr)**	
I	**Cold airflow sizing for 96 IT racks**				
1	**IT rack**	Rating of each IT device	Latest ASHRAE Guidance for CFD modeling	# 1	125 CFM/kW or 212 m3/hr/kW [Hu et al (2022)]
1.1	60 x Server Rack	5 kW/rack	212 m3/hr/kW	# 2	63,600.00
1.2	20 x Server Rack	7 kW/rack	212 m3/hr/kW	# 3	29,680.00
1.3	16 x Network Rack	3 kW/rack	212 m3/hr/kW	# 4	10,176.00
2	**Total cooling airflow requirement**		**(# 1 + # 2 + # 3 + # 4)**	**# 5**	**103,456.00**
	Cooling airflow selection: 05 x CRACs in operation and 01 x CRAC in stand-by (N+1 redundancy). Cooling airflow supply per unit: **25,000.00 m3/hr.** Total cooling airflow supply with 05 CRACs in operation: **125,000.00 m3/hr** (with 21 % oversupply for redundancy purpose).				

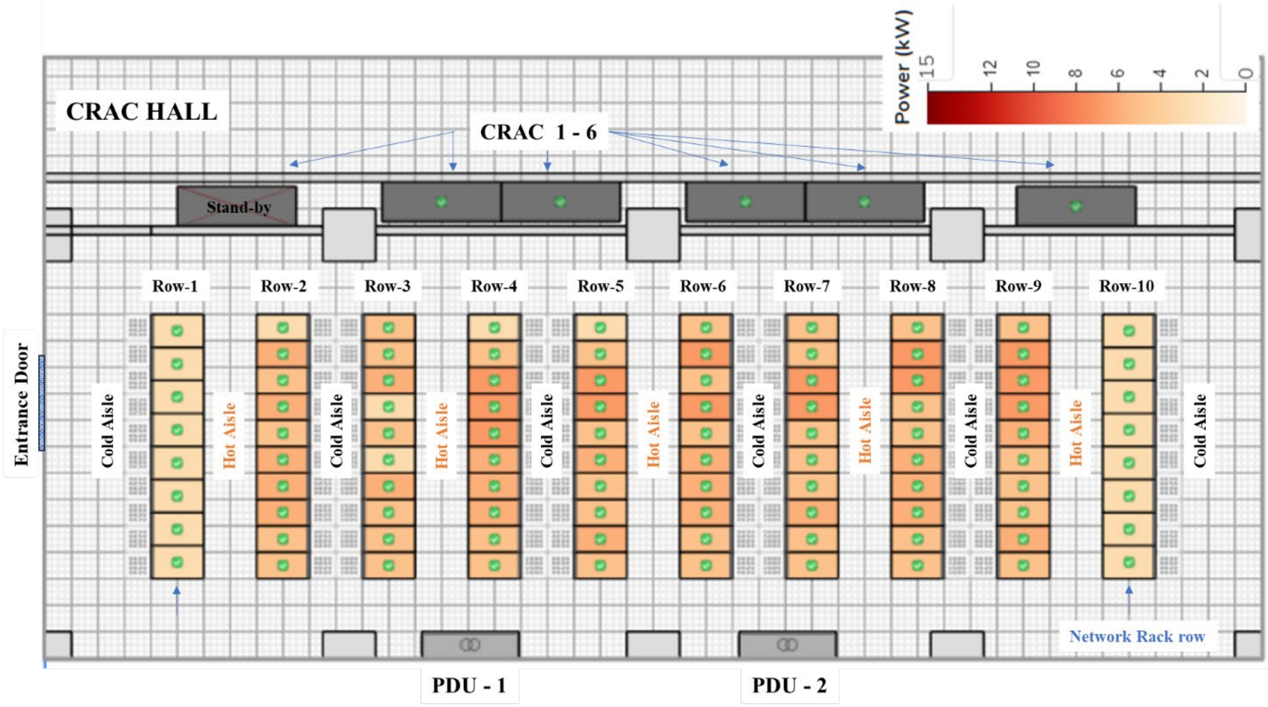


Figure 5. Optimal rack layout in data hall: racks with high power density are placed in recommended locations to avoid "hot pot" points.

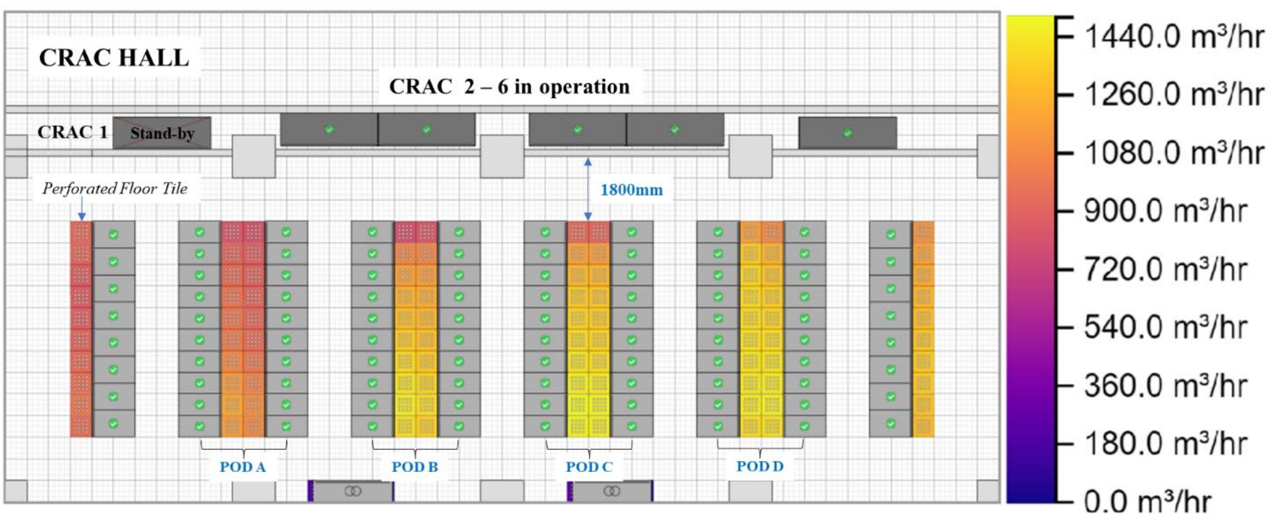


Figure 6. Tile airflow rates throughout perforated floor

The "Cold air IT inlet" temperature at the rack locations is different according to the rack position in different rows; according to the height of the rack as shown on Figures 7, 8, 9. The average inlet rack temperature is shown to be an average of 20.7°C to 25.5°C. In some rack locations, the inlet rack temperature could rise extremely near the ASHRAE guidelines limitation with an average of 21.9°C and maximum air inlet of 26.2° (even this rack is low-level of power density), as depicted in Figure 9. When the temperature does not meet the recommended criteria, the layout must be rearranged to lower the power density/consumption of the rack row. As such, it is recommended that airflow, temperature, and humidity analysis of the data hall be performed to design an optimal layout that complies with the operational environment in the IT room. The simulation results demonstrated the optimal IT rack layout placement to meet the conditions set by ASHRAE thermal guidelines in conjunction with giving important recommendations for the cold air supply setpoint of CRACs at maximum of 20ºC to deliver a limitation of air-cooled inlet at some rack of

27ºC. To achieve the energy efficiency of cooling, it is recommended by installing hot-aisle containments inside the hot rows of racks, the temperature "setpoint" of CRAC units can be raised more than 20ºC.

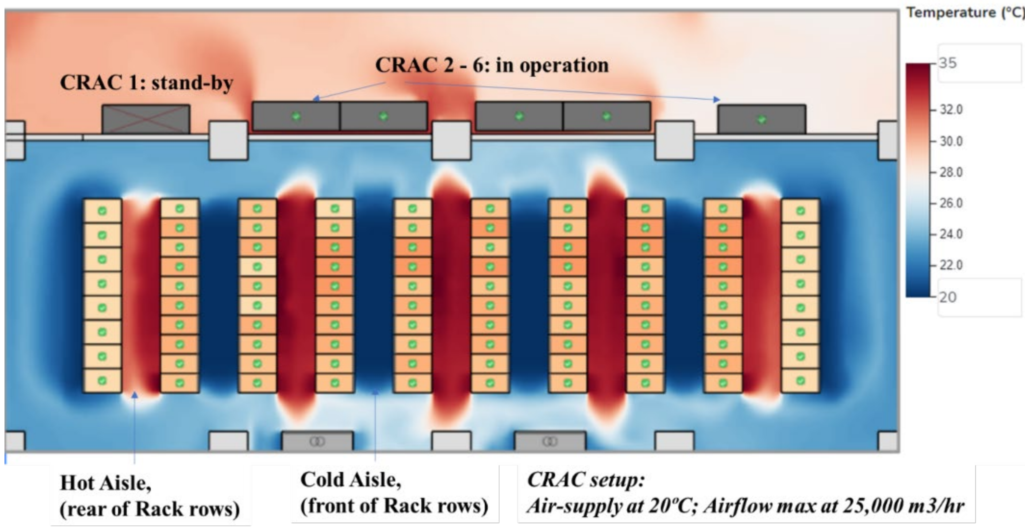


Figure 7. Top view - Cold and Hot air distribution in the Data Hall

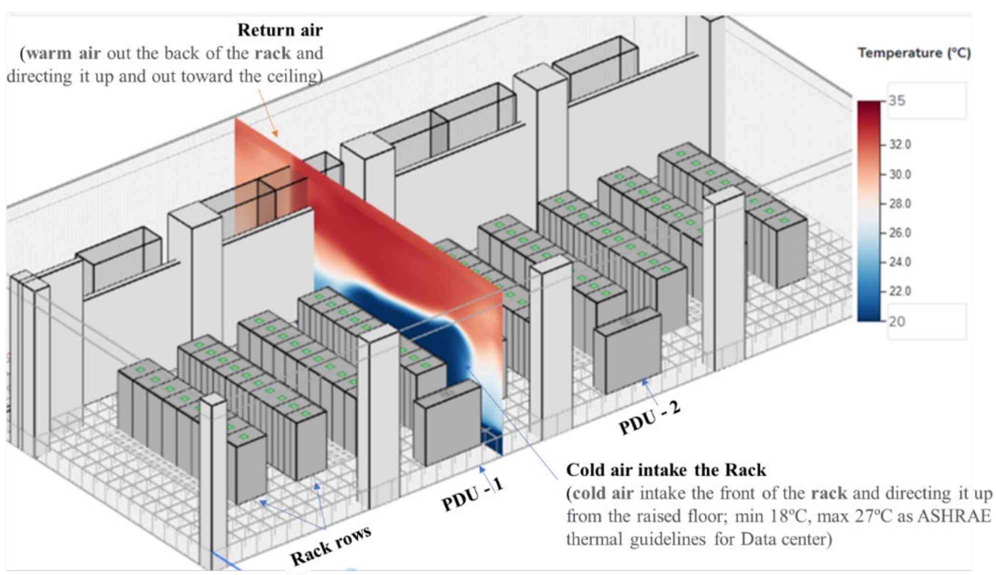
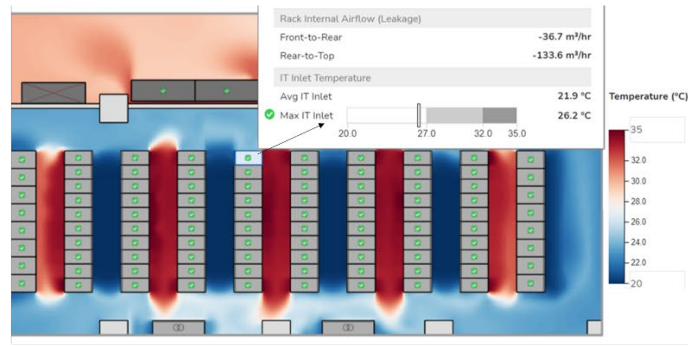


Figure 8. Cold and Hot air distribution following to room height.

Fig. a)



Cold air intake the Rack 1: Row 5
(**cold air** intake the front of the **rack** max at 26.2ºC is near the maximum recommended threshold as ASHRAE thermal guidelines for Data center)

Fig. b)

Figure 9. Cold air-inlet at racks: ***a).*** within the safety threshold 18ºC-27ºC; ***b)*** close to the threshold 27ºC

3.3 Power Supply Sizing

The total capacity to supply power to DC loads, as described in Section 2, includes power supply to critical IT equipment via UPS and PDU; power supply to the air conditioning system (CRAC and other cooling system); lighting system; and other loads (in meeting room, security room; control and security systems; fire protection system...). The sizing is based on the best practices and standards used for power facility sizing [Sawyer (2015)]. The results of the calculation are shown in Table 6:

Table 6. Power sizing for DC-500 kW with 96 IT racks [Sawyer (2015)]

No	Item	Data Required	Calculation	Sub-total (kW)		Remark
I	**Power Requirement – IT Critical load in Data Center (KW)**					
1	Critical load- sizing (IT load)	Rating of each IT device	Based on average power density/rack	# 1	488.00	*With 96 IT racks*
2	Peak power draw due to variation in critical loads	Total steady state critical load power draw	(# 1) *1.05	# 2	512.40	*Assumption: redundancy of 5% over-rating for safety factor*
3	UPS inefficiency and battery charging	Actual Load + Future Loads (in kW)	(# 1 + # 2 + # 3) *0.25	# 3	139.35	*Powe reservation for Battery charging: 20% of UPS rating. UPS efficiency at ≥ 95%*
	Total power to support electrical demands		**(# 2 + # 3 + # 4)**	**# 4**	**651.75**	*About 50% total DC's power consumption*
II	**Power Requirement - Cooling (KW)**					
1	Total power to support cooling demands	Total from # 4 above	Assumption about 40% DC power consumption	# 5	**521.4**	Cooling in Data Hall; Substation Room; NOC (90% for Data Hall)
III	**Total Power Requirement: Electrical load, Cooling load and other loads**				**1,329.57**	**DC total load**

1	Total power to support electrical and cooling demands	Total from # 4 and # 5 above	(# 4 + # 5)	# 6	1,173.15	Two major load sections: IT loads, cooling loads
2	Other loads	Offices; Control System; Lighting System	Assumption about 12% of DC power consumption	# 7	156.42	*DC area:600 m2*
IV	**Size of Electrical Service Estimate (kW or kVA)**					
1	Requirements to meet overcurrent occurrence	Total from (# 6+# 7) above	(# 6+# 7) * 1.25)	# 8	**1,661.96**	*Typically use the 125% (multiplier safety factor)*

In Figure 10, the power system has two pathways: active and redundancy distribution pathways [McCarthy and Avelar (2015)]. Each pathway is supplied by one main electrical utility grid, provided with the generator, one UPS system with battery backup at minimum of 10 minutes of 100% IT load and one PDU supplying power to the main IT racks. In Figure 10a, we can use a topology called Tier III level: *"concurrently maintainable"* with a redundancy on nonreliable equipment requirements and each equipment can be removed and repaired without a data center blackout. In Figure 10b**,** called **"***fault tolerant"*, a Tier III couple with a fault-tolerant architecture (no single failure point), this topology can avoid to some useless oversizing of the generator power plant to reach the requirements of Tier IV level which is acceptable if the utility grid has an availability above 99% [Megdiche et al. (2021)]. Data centers are very dynamic facilities, energy consumption estimation during initial design uses the static sizing and initial assumption nor the dynamic live environment. The facility design complies with Tier III requirements (defined by Uptime Institute), all the systems are redundant and concurrently maintainable (N+1). An example of a data center with 96 IT racks and 5 kW average power/rack has been designed. In the initial design, energy consumption is 50% for IT use, 40% for cooling, 12% others (infrastructure losses, lighting, fire suppression, security etc.). It is very important to consider during any assessment the load changes in real-time in data centers, the operation point of each sub-component and their specific efficiency.

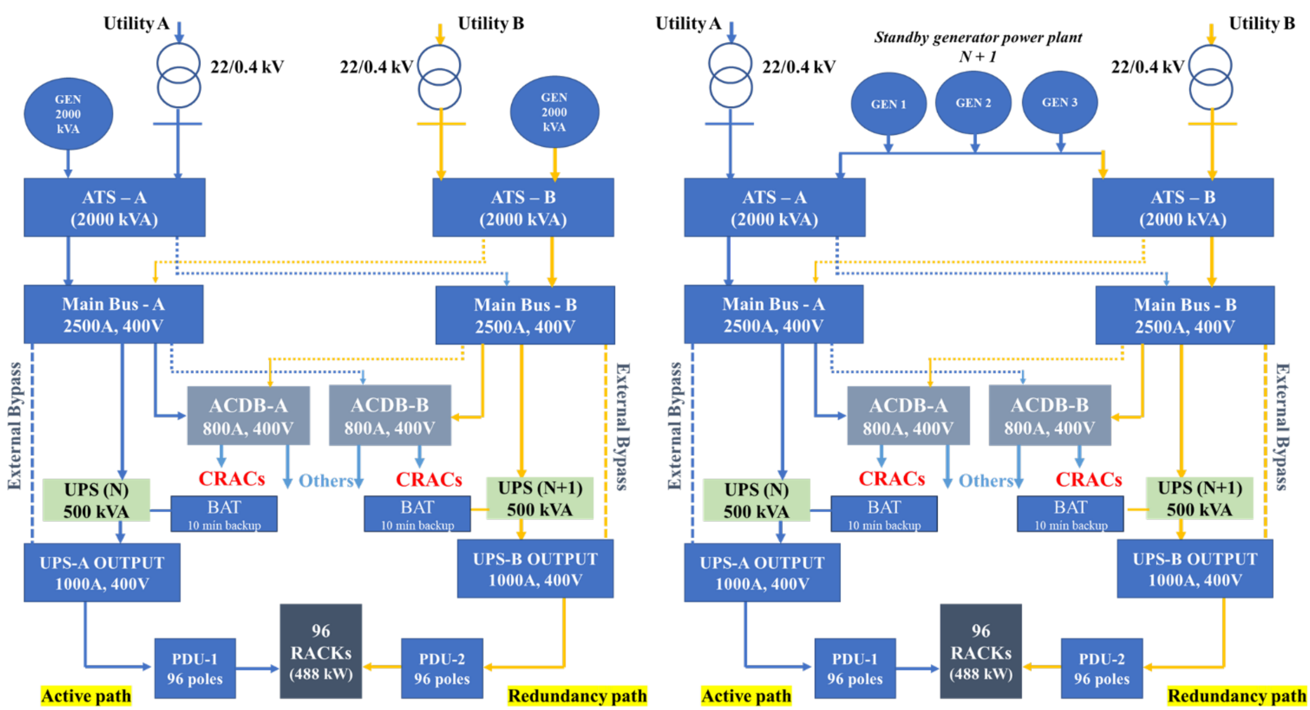


Fig.a) Topology with 2N redundancy ***Fig.b) Fault-tolerant architecture***

Figure 10. Topologies of power system, following Tier 3: ***a).*** topology with 2N redundancy; ***b)*** a fault-tolerant architecture (3 generator with N+1 redundancy of 1000 kVA)

4. Conclusion

This paper contributes to fill-in the technical research gaps related to data center facility sizing by analyzing the energy consumption of data center loads. Two key design parameters for a data center are the IT load rating in kW and the physical size of the IT rack equipment in a data hall. To understand from the outset of data center design, three main components (i.e., space footprint, power supply, cooling) are the right things to do at the first time, in which a data center capacity is specified by an average power density per rack (kW/rack) that allows consideration of the key design constraints such as power supplies and thermal requirements. Energy efficiency term by PUE value is also a guideline for improving waste due to oversizing design. To analyze the design proposal optimally, CFD airflow analysis was performed to estimate the temperature distribution, airflow patterns, pressure, and airflow velocity, as well as evaluate the optimum conditions of air distribution for the data center. The results demonstrated the optimal IT rack layout placement to meet the operation conditions inside the IT room following ASHRAE thermal guidelines in conjunction with giving important recommendations in operation of CRACs with the recommended "air-setpoint" level bellow of 20ºC. This paper has presented a logical approach to documenting data center space and capacity requirements that provides sufficient detail for a typical DC in Vietnam to assure that performance is predictable. Even data centers with incomplete information and uncertain plans can use this method. To assist users attempting to define a density specification, typical design values have been provided.

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