Energy Efficiency in Cooling Operation: A case Study Analysis of Computer Room in Vietnam

Trung-Hieu Trinh
Faculty of Electrical Engineering
University of Science and Technology, University of Danang
Danang, Vietnam
tthieu@dut.udn.vn

Xuan-Truong Nguyen*
Department of Technology and Engineering
University of Science and Technology of Hanoi
Hanoi, Vietnam
*nguyen-xuan.truong@usth.edu.vn

Minh-Quang Luu
Department of Information and Communication Technology
University of Science and Technology of Hanoi
Hanoi, Vietnam
quanglm2410818@usth.edu.vn

Viet-Ninh Nguyen
DC Regional Application Center International
Secure Power Division, Schneider Electric Vietnam
Hanoi, Vietnam
ninh.nguyenviet@se.com

Abstract—**The rapid expansion of high-performance computing, artificial intelligence, and cloud-based services has significantly increased the demand load of data centers (DC). Operating information technology (IT) equipment generates significant heat, requiring precision cooling systems to accurately control air-supplied temperature, relative humidity and maintaining continuous 24/7/365 IT's operation with high performance. IT and cooling systems are two main consumers in energy consumption in DCs. Cooling accounts for up to 40% energy consumption and presents a significant efficiency challenge. To improve energy efficiency in DCs and enhance the performance of cooling systems, one of the key solutions emphases during DC operating phase is to regularly collect operational data such as actual IT rack power density and thermal profiles. Data analysis and thermal assessment are crucial to help identify the risks. Using several scenario thermal dynamic simulations, the study examines promising thermal management strategies to improve the energy efficiency of an existing data center of 200 kW capacity in which nearly 40 kW of IT load. Results indicate significant cooling efficiency, improved IT inlet airflow from coolers effectiveness and IT exhaust airflow to coolers effectiveness, while maintaining high reliability and safety for operating IT equipment. These findings demonstrate the possibility of thermal management as a potential and interpretable method to improve cooling efficiency, then reduce operational costs, and support reliability data center energy management in operating phase.**

Keywords-cooling systems; energy efficiency; thermal management; computational fluid dynamics; IT equipment

I. INTRODUCTION

Data centres (DC) operate continuously 24/7/365 to meet increasing demands for data storage, processing, and transfer, leading to substantial growth in energy consumption [1]. DC composes the rack that houses all IT equipment such as storage, server and network devices and other critical facility, which accounts for 2-3% of total electricity consumption worldwide, the annual increase is forecasted to reach 15% [2, 3]. In Vietnam, DC is rapidly growing due to the country's digital transformation, increased use of AI. Nowadays, DC has become a new type of consumer that consumes significantly more electricity [3, 4]. Reacting with this problem, both government regulations and major data center operators are pushing for energy-efficient "green data center" standards and increased use of renewable energy [4, 5]. Research on energy-efficient and operation assessment in DC are always a trial, without giving a reason why to do that, especially in the context of very limited research in DCs in Vietnam [3-5].

Understanding the energy-efficiency of DCs generally requires analyzing system and subsystem performance thorough the use of real-time data, such as operating temperatures (i.e. cold air-supply and hot air-exhausted), airflow rate measurements, dynamic thermal distribution, power consumption at each level like IT equipment; auxiliary facilities..., etc [6, 7]. The electricity consumption is used for running physical IT equipment and its workload, but also for cooling and other physical infrastructure (electrical main supply board, uninterruptible power supply, batteries strings, lighting system, building control system…) [6]. The operative flow diagram for a generic data center usually consists of four main facilities: IT infrastructure; power facilities; cooling facilities and other facilities. The DC capacity is the maximum power (kW) of IT load that the data center can support, either for power, cooling systems or auxiliaries [6-8]. This rating power refers to the input power of the data center or total facility power. The IT load is the actual IT power consumed in the data center as a percentage of the total IT capacity. The rack power density is the average kW of IT load per rack, and it determines the thermal requirements to cold data center during its operation [6-9]. The IT equipment under high computational loads will generate a great amount of heat, which can seriously affect their stable and resilient operation. To provide a suitable environment in a certain range of them, the precision cooling system has become an indispensable facility of DC, which also brings high power consumption, nearly 40% of total DC's energy consumption. For the IT devices, the operation temperature is an important factor that can greatly affect stability and their performance [10]. Effective and efficient cooling operating strategies are normally integrated into DC operation phase, particularly as energy-efficiency becomes important for reducing operational costs and maximizing profitability [11]. As a result, decreasing the energy consumption of the precision conditioner system is critical for overall data center energy efficiency improvement. Numerous studies related to improving energy efficiency for precision cooling system operation in data centers have been mentioned in [12-14], including details on design as well as operation phases. Emphasis to be placed on the period after several years of putting - operation of the data center, where actual operating conditions differ from the calculated parameters assumed during the design phase. In which, the air management solution dedicates to minimizing or eliminating mixing between the cold air supplied to IT equipment (i.e. inlet air into IT rack) and the hot air rejected from the IT equipment. Energy management incorporating with real-time monitoring can effectively reduce cooling loads by automating the demand response, predicting energy costs, detecting energy use anomalies, and scheduling energy use information. Through data-driven approaches, techniques such as deep learning and AI analysis combined with actual data from computational fluid dynamics (CFD) simulation may be very promising energy management [14-18].

This paper provides a comprehensive overview of thermal management for an existing computer room in Vietnam. In section II, we describe the methodology for preliminary analysis and assessment of the energy efficiency of cooling in a real-time operating data center. Through collected database for a small data center with a number of 18 IT racks and a capacity of 200 kW, in which 48 kW maximum to be supported to IT load and nearly 150 kW dedicated to power the cooling and auxiliary's systems. The precision air conditioner system uses a combination of water-cooled row-based air conditioner and air-cooled chiller technology. Operating parameters for the cooling system and heat consumption parameters at each IT rack will be described in detail. In section III, after preliminary assessment of the current operating conditions of the data center, we propose several solutions to improve energy efficiency. The results of thermal distribution simulations using CFD simulation tools will be discussed. Furthermore, it was verified that predictions by CFD simulation results were able to correctly predict the thermal distribution under different operating scenarios of cooling units. Finally, this research provides a direction for future research and development in data center energy efficiency improvement.

II. METHODOLOGY

A. Energy Efficiency Analysis Methodology

The research scope is based on a case study of a small data center (i.e. a computer room with small-scale of 48 kW IT load) in Vietnam. The logical flowchart is described in Fig. 1. In this regard, the operational situation of air cooling and thermal profiles in the computer room is considered. The overall cooling performance analysis of the data center is based on the analytical approach. By collecting actual operating parameters, combining computational fluid dynamics simulations to analyze thermal distribution and identify the current status, and highlight any issues and opportunities for improvements in relation to the best practices, according to cooling operating scenarios while always ensuring compliance with ASHRAE thermal guidelines. The cooling efficiency assessment and its issues highlight on: (i) identifying thermal risks and threats that can affect the safety and availability of IT equipment processing; (ii) proposition of thermal management pathway for improving energy efficiency and reliability in data center.

The working flow is described in Fig. 1 by two steps. The first step, we collect the actual data during the operating data center as follows: layout arrangement in the computer room; real-time power consumption in each IT rack, this value can be considered as the thermal consumption load by IT rack; cooling topology and technology used. The first analysis on the cooling operation situation in the data center is based on the actual temperatures and airflows supplied by operational coolers; and the inlet air cold, hot air exhaust temperatures at the rack level. The collected data is taken either via a measured tool like energy logger, thermometer or else by extracting data from the data center monitoring system. For the second step, by using CFD simulation tool thanks to Schneider Electric [8, 15], the findings intend to: (i) re-evaluate the thermal distribution in actual operational conditions in comparison with the observed phenomena realized in the first step; (ii) assess the proposed cooling strategies operating with several scenarios based on the referenced standards and initial concept design of the data center. The thermal environment possibility for resilient and safety IT equipment processing will be mainly analyzed using CFD simulation results. The input parameters for the first simulation are based on collected data at site such as real-time IT load per rack, supply air temperature and airflow required by precision air cooling. The important part related to the cooling efficiency that dedicated to air management solution. Several potential solutions will be discussed to assess the feasibility of proposing a more efficient operating method of the cooling system while maintaining high reliability of the data center. The objective of the suggested solution is to provide recommendations to improve energy efficiency in the operation of existing data center cooling infrastructure through the analysis of several scenarios for "airflow supply, and air-cold supply temperature" with minimal operational disruption.

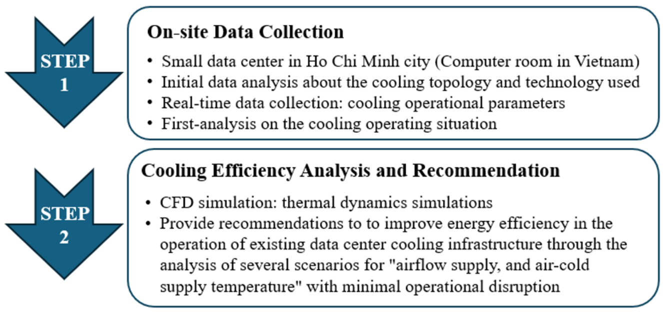

Figure 1. Cooling energy efficiency analysis methodology

B. Case Study: An Existing Operation Computer Room using Chilled Water Precision Air cooling Systems

The small data center of 200 kW capacity is composed of a computer room with 18 IT racks and the power room mainly containing power components. In this research, we focus on the cooling aspect dedicated to the IT room. In Fig. 2, the computer room is designed to support the maximum IT capacity of 48 kW. Noted that IT equipment generates a significant amount of heat, equivalent to its power consumption, and therefore requires continuous cooling by a precision air conditioning system. This is to ensure the safety, durability, and high-performance operation of IT devices, which is highly sensitive to temperature fluctuations as described in Section 1. There are two rack rows, in which ROW A and ROW B are arranged along a shared cold air corridor. Each row of racks is equipped with two precision air conditioners, arranged alternately in a row-based configuration or Inrow topology. The four Inrow units are staggered across the two rows to deliver sufficient cooling capacity, evenly distributing cold air to cool the racks from the front and simultaneously recovering heat radiating from the rear of the racks. To ensure continuous and reliable operation, even during temporary equipment maintenance, this precision air conditioning system is designed according to TIER 3 Uptime recommendations [14], ensuring a "3+1" operation at 24/7 (i.e, three air conditioners are active and one is in standby mode for redundancy). It should be noted that the amount of heat required to provide cooling to the IT equipment operation is based on the net sensible cooling capacity, described in [14-16]. Typically, the design thermal load for a computer room is always based on the total thermal load required by IT equipment plus a 10-20% reserve as safety margin factor [17]. In this case, the maximum thermal load demand is reserved for amount of about 58 kW. The cooling system topology uses chilled water-cooling technology combined with a chiller. The chiller system is air-cooled and widely used for small data centers with the power load rating of a few hundred kW [17-19]. The schematic refrigerant piping diagram of the cooling system and operating parameters are shown in Fig. 3 and Table 1.

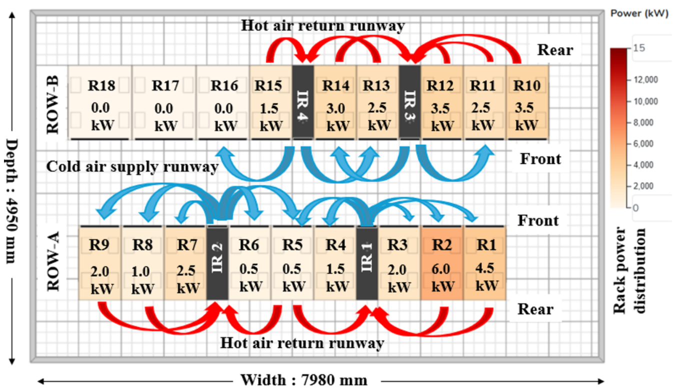

Figure 2. Computer room layout arrangement with the actual power density distributed in each IT rack at the survey time

TABLE I. COOLING LOAD CHARACTERISTICS

Items	*Description*	*Remark*
Total IT thermal load	37 kW	Total power actual load: 37 kW Maximum load: 48 kW
Chiller 1, 2	Nominal cooling capacity: 60 kW/unit. Purpose: 01 unit active and 01 unit in standby for redundancy capacity.	Capacity design: 35ºC at the condenser environment. Working condition: water in/out at 12ºC/ 7ºC.
Inrow 1 – 4 (IR 1…IR 4)	Net sensible cooling capacity: 20 kW/unit. Purpose: 03 units actives and 01 in standby for redundancy capacity.	Capacity design: 35ºC at the dry bulb temperature, 50% relative humidity. Working condition: water in/out at 7ºC/ 12ºC.
CRAC 1, 2	Net sensible cooling capacity: 5 kW/unit. Purpose: 01 unit active and 01 unit in standby for redundancy capacity.	Capacity design: 27ºC at the dry bulb temperature, 50% relative humidity. Working condition: water in/out at 7ºC/ 12ºC.

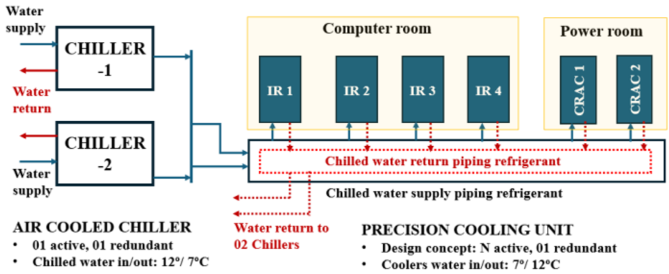

Figure 3. Cooling topology with two air-cooled chillers, four row-based cooling system (Inrow: IR 1 to IR 4) for computer room (IT rack) and two room-based cooling system (CRAC 1, CRAC 2) for power room (uninterruptible power supply, batteries packs and electrical supply board)

III. RESULTS AND DISCUSSIONS

A. Baseline Performance of Cooling Operation

Inrow system operational data was collected during 3-month period (February to June), with results shown in Fig. 4 and Table 2. The uneven distribution of IT load across rack locations (Fig. 2), along with heat loss at some rack locations, is due to the mixing of cold air flow to the front and hot air exhausted at the rear of the IT racks. In fact, many racks (racks 1, 3, 6, 9, 8, 11) have many empty U spaces, nearly 10 – 30% and are not properly insulated from cold air inlet and hot-air return flows. This is the cause of inefficient cooling in the data center and recirculation from the rear to front of the rack rows as results. For example, at racks 8, 10, and 11, several points of "hot spots" were recorded, with warnings of high temperatures in IT equipment in some cases (Table 2). This affects the operational performance of IT equipment and requires improved cooling efficiency. Therefore, in practice, all cooling devices in the computer room were forced to operate simultaneously, but most of them only provided 35 to 55 of their cooling performance equivalents to 7.0 kW to 11 kW. This led to unsafe operation, as there is no backup cooling device in standby mode, and maintenance of any cooler device is required in case of a malfunction. In addition, all cooler units were not operating at full performance of 20 kW – net sensible cooling capacity. In Fig. 4, we can see that the supply cooling temperature always had to be maintained at a low level about 16°C, meaning it is too cold, it is not in the area recommended by ASHRAE guidelines in the range 18 to 27ºC [14], and the hot air return temperature was also low level. These actual operating results are also compared with CFD simulation results shown in Fig. 5, in which we simulated the heat distribution based on the actual operating parameters of the coolers. It can observe similarities between the CFD simulation, and the onsite collected data as previous analysis.

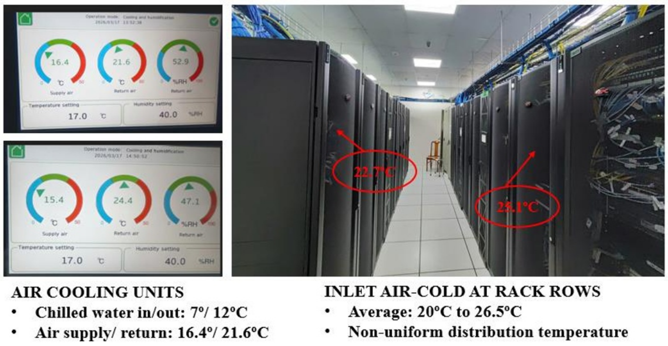

Figure 4. Onsite data collection on Rack and Cooling Systems

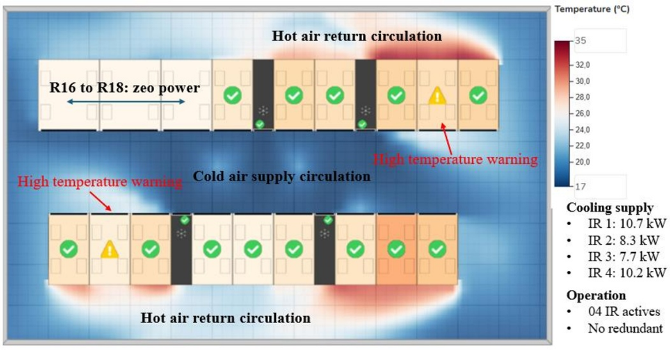

Figure 5. Onsite data collection on Rack and Cooling Systems

TABLE II. THERMAL RISK OBSERVATION AT THE RACK LEVEL

	Inlet air supply	*Hot air exhaust*	*Remark*
Rack 1	Average: 22.7 ºC Maximum: 24.9 ºC	Average: 26.8 ºC Maximum: 31.6 ºC	In the area recommended by ASHRAE guidelines [14]; but inefficient cooling operation
Rack 4, 5, 13	Average: 17.4 ºC Maximum: 18.9 ºC	Average: 23.8 ºC Maximum: 25.6 ºC	Too cold; not in the area recommended by ASHRAE guidelines [14]
Rack 8	Average: 22.4 ºC Maximum: ***27.8 ºC***	Average: 29.2 ºC Maximum: 32.5 ºC	Not in the area recommended by ASHRAE guidelines [14]; some risks are observed
Rack 10	Average: 21.2 ºC Maximum: ***27.2 ºC***	Average: 29.5 ºC Maximum: 32.7 ºC	Not in the area recommended by ASHRAE guidelines [14]; some risks are observed
Rack 11	Average: 22.1 ºC Maximum: ***28.0 ºC***	Average: 29.6 ºC Maximum: 33.2 ºC	Not in the area recommended by ASHRAE guidelines [14]; some risks are observed

B. Proposed Thermal Management for Improving Energy Efficiency and Reliability

In this section, we propose several solutions to improve the operational efficiency of the cooling system in the data center. As described in Section 1, many studies mentioned in [8-14] during the operation phase of the IT equipment mainly relate to air management. This solution for data centers involves all the design and configuration aspects that go into minimizing or eliminating mixing between the cooling air supplied to IT equipment and the hot air rejected from that equipment. Effective air management implementation minimizes the bypass of cooling air around rack intakes and the recirculation of heat exhaust back into rack intakes. Air management generally allows increasing the supply air temperature while ensuring the suitable cold air temperature for the IT equipment. According to the power density (and therefore thermal load) parameters at the IT racks as described in Fig. 2, we address these issues: (i) supplementing the cold aisle containment system located at the cold corridor of two rack rows; (ii) blanking panels at every empty U in each rack (to ensure the front-to-rear leakage at 3% maximum); (iii) implementing operating scenarios with the ability to increase the set-point temperature of the coolers while ensuring "3+1" operation capability (i.e. 3 coolers operating and 1 in standby mode).

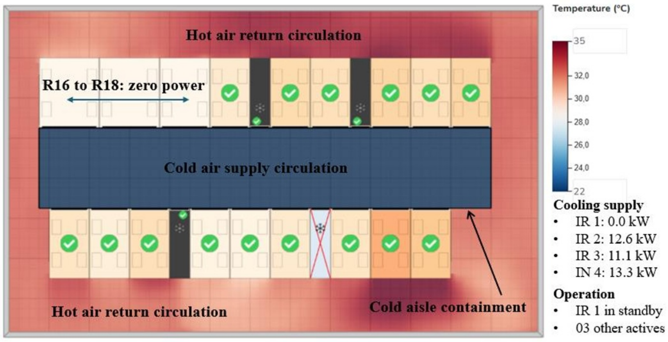

Figure 6. Scenario-1 for redundant operating of the cooling system with Inrow 1 at ROW A in standby and three others units in operation

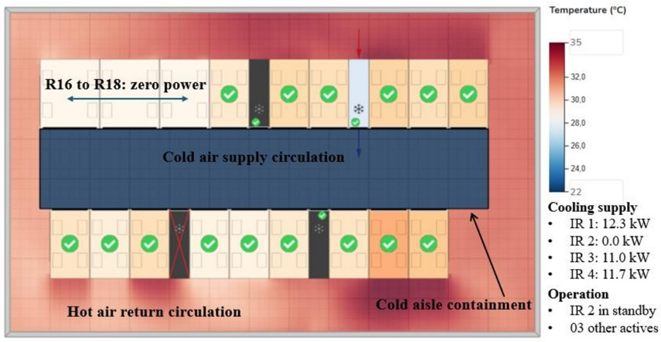

Figure 7. Scenario-2 for redundant operating of the cooling system with Inrow 2 at ROW A in standby and three others units in operation

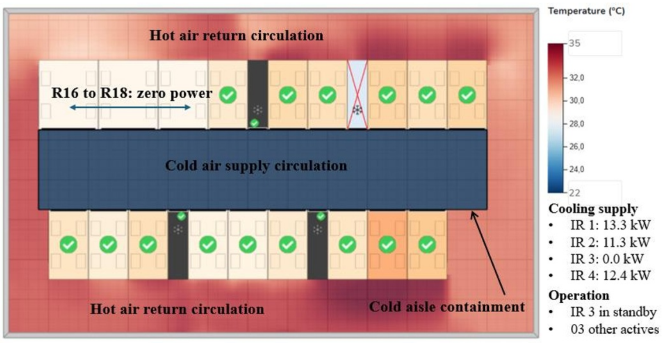

Figure 8. Scenario-3 for redundant operating of the cooling system with Inrow 3 at ROW B in standby and three others units in operation

TABLE III. SUPPLY COOLING CAPACITY OF 04 INROWS

	Inrow 1	*Inrow 2*	*Inrow 3*	*Inrow 4*
Scenario - 1	Standby	12.6 kW	11.1 kW	13.3 kW
Scenario - 2	12.3 kW	Standby	11.0 kW	11.7 kW
Scenario - 3	13.3 kW	11.3 kW	Standby	12.4 kW

TABLE IV. COOLING EFFICIENCY INDEX

	Value	*Remark*
Total net sensible cooling supply (kW)	60	At nominal working condition, from all active coolers.
Cooling-to-IT-airflow ratio	1.53%	53% airflow redundant, supply from all active coolers.
Total IT airflow (m³/hr)	7844	Minimum airflow requirement by rack: 125 CFM/kW or 212 m3/hr/kW [20]
Total cooling airflow (m³/hr)	12000	Nominal airflow supplied by 03 Inrows in operation (01 unit in standby mode)
IT airflow effectiveness	99.6%	Good, according to ASHRAE guidelines [21, 22]
Cooler airflow efficiency	65.4%	Meaning all active coolers provide only 65.4% of their nominal airflow.
Rack cooling index (RCI)	99.5%	Good, according to ASHRAE 2008 RCI standard [21, 22]

The CFD simulation results are shown in Fig. 6-8. In all these operating scenarios, we assume the air cold set-point temperature of the air conditioners is 22ºC. The heat distribution maps in all three scenarios show no warnings about temperature hot spot phenomena (exceeding the ASHRAE guidelines recommended level 18ºC to 27ºC) in any rack. The operating capacity of the Inrow is observed at 55 to 66.5% of their performance capacity, the detailed values are presented in Table 3. The cooling effectiveness is more efficient, for example IT inlet airflow from coolers with an effectiveness of nearly 100%, the IT exhaust airflow to coolers effectiveness is more than 98%. Table 4 shows the main performance index of the cooling in detail. In ASHRAE 2005 published the level index of cabinet cooling efficiency for data center IT racks, which is called the rack cooling index (RCI) [21, 22]. The main purpose is to prevent the temperature entering the cabinet from being too cold or overheating. The simulation results show a good rating of RCI's performance. It means that the air temperature intake is within the ASHRAE recommended range. In fact, due to the good insulation between the cold and hot aisles, the set-point temperature of the inrows and the inlet-rack temperature are preserved. The heat discharged from the IT Rack is recovered to the back of the coolers. Then, there is no difference between the hot air exhausted from the IT racks and the return temperature to the coolers.

V.CONCLUSION

This paper provides a scientific methodology to supplement research on improving the operation of precision cooling systems in data centers. Operational practices in server rooms always require real-time data collection regarding power consumption density distributed across IT racks; real-time monitoring and analysis of cooling temperatures supplied to the racks and hot air exhaust from IT equipment. This helps operators assess and predict operational risks related to cooling in data centers. Furthermore, equipment redundancy and cooling capacity redundancy, in accordance with Uptime/TIA-942 recommendations, are crucial. It is important to recognize the difference between the recommended [18 - 27ºC] and allowable envelopes (larger range, depending on each class A1 to A4) presented in the ASHRAE guidelines. The recommended values are intended to guide operators of data centers on the energy-efficient operation of IT equipment while maintaining high reliability. It should be designed and operated to target the recommended temperature range. The allowable envelope outlines the environmental boundaries tested by equipment manufacturers for equipment functionality, not reliability.

In this study, by collecting long-term operational data, evaluating and analyzing operating indicators related to cooling temperatures in a typical data center in Vietnam under tropical weather conditions, and in comparing with reference values from ASHRAE guidelines, we have initially identified current operational risks. Therefore, proposed solutions to eliminate operational risks related to cooling were suggested in step 2. In the operating scenarios, the efficiency of using precision air conditioning system is clearly demonstrated. Operating with air management solutions in this typical data center helps improve the performance of the air conditioners while ensuring the safety and resilient of the IT systems. Furthermore, raising the air cold set-point temperature of the Inrows to 22ºC does not create thermal risks at all rack locations, which allows for improved energy efficiency in the data center.

ACKNOWLEDGMENT

Thanks to Schneider Electric, in this research we can utilize the CFD simulation tool (Ecotruxure IT Advisor CFD). The CFD simulation results in this study are used for academic purposes only, not for commercial or marketing purposes.

REFERENCES

[1] C. Bux, R. L. Rana, M. Lombardi, et al, "A critical analysis of global warming potential of data centers in the digital era,". Int J Life Cycle Assess 30, 2390–2402 (2025).

[2] M. Koot and F. Wijnhoven, "Usage impact on data center electricity needs: A system dynamic forecasting model," Applied Energy, Vol. 291, 2021, 116798, ISSN 0306-2619.

[3] T. X. Nguyen, Q. M. Luu, M. H. Do and K. D. Vu, "Analysis of CO2 emissions and energy efficiency potential of data centers in Vietnam," International Journal of Technology, Health and Sustainability, Vol. 2, Issue 2, April-June 2026, pp. 421-427.

[4] VietnamPlus, "Vietnam develops digital infrastructure aligned with demands of AI era," access on 21 April 2026. Vietnam develops digital infrastructure aligned with demands of AI era | Vietnam+ (VietnamPlus)

[5] MST (2025), "Plan for development of digital infrastructure for the period 2025-2030," Decision 912/QĐ-BKHCN, Ministry of Science and Technology, Vietnam.

[6] M. T. Takci, M. Qadrdan, J. Summers and J. Gustafsson, "Data centres as a source of flexibility for power systems," Energy Reports, Vol. 13, pp. 3661-3671, 2025.

[7] S. Cai amd Z. Gou, “Towards energy-efficient data centers: A comprehensive review of passive and active cooling strategies,” Energy and Built Environment, Vol. 7, Issue 1, 2026, pp. 206-226, ISSN 2666-1233.

[8] H. M. Luong, T. T. Nguyen, Xuan-Truong Nguyen, “Cooling energy assessment of an existing data center in Hanoi,” EPU Journal of Science and Technology for Energy. Vol. 37 (4/ 2025), ISSN: 1859 -4557.

[9] W. X. Chu and C. C. Wang, “A review on airflow management in data centers,” Applied Energy, Vol. 240 (2019), pp. 84–119.

[10] H. Geng, 2015. “Data centers—strategic planning, design, construction, and operations,” in Data Center Handbook , Wiley, 2015, pp.1-14.

[11] A. Abdilla, S. P. Borg and J. Licari, “Relating measured PUE to the cooling strategy and operating conditions through a review of a number of Maltese data centres,” Energy Reports, Vol. 13, pp. 2612-2623, 2025.

[12] J. Zhou, B. B. Kanbur, D. V. Le, R. Tan and F. Duan, “Thermoeconomic assessment of the air-cooled tropical data center through energy-saving strategies,” Energy and Built Environment, Vol. 7, Issue 1, 2026, pp. 115-127, ISSN 2666-1233.

[13] G. S. Amorim, J. M. Belman-Flores, R. de Paoli Mendes et al*, “*Recent advancements in thermal management technologies for cooling of data centers,” J Braz. Soc. Mech. Sci. Eng. 46, 472 (2024).

[14] O. V. Geet and D. Sickinger, “Best practices guide for energy-efficient data center design,” National Renewable Energy Laboratory (NREL). Revised July 2024.

[15] Schneider Electric, “Cooling analysis using computational fluid dynamics for data center,” 25 Jan 2021.

[16] X. Yuan, Y. Liang, X. Hu, Y. Xu, Y. Chen, R. Kosonen, “Waste heat recoveries in data centers: A review, “ Renewable and Sustainable Energy Reviews, Vol. 188, 2023, 113777, ISSN 1364-0321.

[17] N. Rasmussen, “Power and cooling capacity management for data centers,” WP 150, Schneider Electric.

[18] T. Evans, “The Different Technologies for Cooling Data Centers,” WP 59, Schneider Electric. 26 September 2017.

[19] D. A. Kez, A. M. Foley, F. W. B.M. H. Wong, A. Dolfi and G. Srinivasan, “AI-driven cooling technologies for high-performance data centres: state-of-the-art review and future directions,” Sustainable Energy Technologies and Assessments, Vol. 82, 2025, 104511, ISSN 2213-1388.

[20] X. T. Nguyen, D. A. Dang, M.Q. Hoang, and H. M. Luong, “Three key-elements for data center facilities sizing in early stage of design,” 4th Asia Pacific International Conference on Industrial Engineering and Operations Management, pp. 730-744, September 2023, ISBN: 979-8-3507-0548-5.

[21] T. F. Yang, Y. C. Chen, B. L. Chen, C. H. Li, and W. M. Yan, “Numerical study of fluid flow and temperature distributions in a data center, “ Case Studies in Thermal Engineering, Vol 28, 2021, 101405, ISSN 2214-157X

[22] W. M. Yan, H. Kao, U. Sajjad, C. H. Li, S. Rashidi, “Experimental study on thermal management of data center with non-uniform heat load,” Case Studies in Thermal Engineering, Vol. 73, 2025, 106578, ISSN 2214-157X.