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A Comprehensive Review of a Data Centre for a Cooling System

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Abstract - Cyber-Physical-Social Systems, commercial enterprises, and social networking use data centers to store, process, and distribute massive amounts of data. A data center serves as the foundation for all of these endeavors. The data center's workload and power consumption are increasing rapidly due to the demand for remote data services. Mechanical refrigeration and terminal cooling are the most critical components for most cooling systems. There is a way to transfer heat from the data center to the outside environment, but it's a complicated process. Air cooling systems and technology are most useful for room cooling and rack-level cooling. Because of their superior cooling performance and higher energy efficiency, air cooling has attracted more attention than water cooling in most existing data centers. The chillers and fans consume the most power of all the cooling equipment in the system. These methods can be divided into mechanism-based methods and data-driven methods for energy management of the cooling system. Operation management of cooling equipment is proposed to reduce power consumption, mainly using predictive model control and reinforcement learning-based methods. An overview of the data center's cooling system is presented in this paper, which focuses on the most common cooling solutions, power consumption modeling methods, and optimization control strategies, among others. In addition, the data center's cooling system is described as a current and future issue.

Index Terms – Data Center, Cooling System, Thermal Strategies

INTRODUCTION

Recently, data centers are believed to be the brains of the 21st century and house server, communications, and storage systems in the modern era. To accomplish one or more of the following tasks, they are equipped with extensive mechanical and electrical infrastructures. Data centers have been recognized as a crucial infrastructure component of today's generation, offering remote data services for companies, entertainment, and a wide range of other human requirements [1]. According to Ebrahimi et al. [2], in the role of information and communication technology, a data center is a structure that consists of housing the central part of configurable resources such as servers, switches, and storage areas. Moreover, managing the environmental factors (humidity, temperature, and dust) ensures that the systems operate reliably and efficiently. The utilization of centralized computing and storage resources provides a data center to address the problem of large-scale data processing while serving many users [3]. In general, the major components of a data center consist of information and communication technologies devices and additional equipment and accessories. The information systems devices, including the network, server, and routers, control the data center's essential parts, such as data processing and transmission [4]. Supporting equipment, such as the cooling and power supply systems, enables technology and telecommunications devices to operate stably. For their efficiency to be stable, they must operate at temperatures appropriate for the environment in which they are performing. Fulpagare et al. [5] have reported throughout the context of big data, the growing availability of cloud servers considerably facilitates the expansion of data center scales, which keeps the workloads on data centers from becoming too heavy to support. The increased cost of energy for corporations and organizations, rising energy consumption from power generation, including carbon dioxide emissions, increased pressure on existing power networks to meet the rising electricity supply. Additional capital costs for the increment of data center capabilities and the expansion of data centers are all implications of increased energy consumption [6].

When subjected to heavy computational demands, computers generate a significant amount of heat, negatively affecting their ability to maintain stable operations. In addition, the cooling system has become an essential component of a data center to create an appropriate environment for them, although it consumes a significant amount of energy. Consequently, one of the most significant issues in the operation and maintenance of data centers is removing heat via the cooling system [7]. Capozzoli et al. [8] has mentioned that an ordinary direct current cooling system comprises two subsystems: a mechanical refrigeration subsystem (MRSS) and a terminal cooling subsystem. The MRSS, which often consists of equipment such as chillers, pumps, and cooling towers, is responsible for supplying cold water to the terminal cooling subsystem to replace the heat removed by the TCSS. The thermal transfer system is responsible for transferring heat from the indoor to the outdoor environment. The most common options include air-cooling, liquid-cooling, and free-cooling techniques. Even during a direct center's operation, the cooling system accounts for around 30% of the total power consumption. The fan of the computer room air conditioner and the chiller are the two largest power consumers in the cooling system's operation. The use of adaptive control techniques based on multiple algorithms to alter their set-points in response to real-time factors such as workloads and operation temperatures has been proposed to lower their power consumption. Model-predictive control (MPC), which is based on system dynamics modeling of cooling equipment [9] [10], and reinforcement learning control (RLC), which is based on system feedback of decisions; two critical paradigms can be employed to find the optimal control strategy [11] [12]. Because of the increased workloads in data centers, research on the operation management of the cooling system should not only focus on the cooling technique itself but also consider the control strategies tailored to the characteristics of the scenarios and the users in the data center services shown in Figure 1.

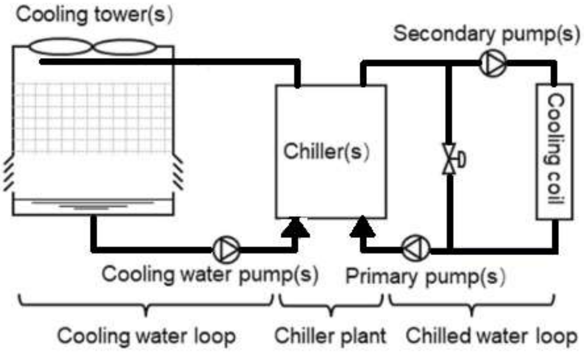

FIGURE 1
STRUCTURE WATER-COOLED CENTRAL COOLING SYSTEM

AIR COOLING SYSTEM AND TECHNOLOGY

Air-cooling technologies seem to be the most generally used solution in data centers since it is the most typical approach. The main advantages are that it is simple to maintain and has reasonable operating costs [13]. A computer room air conditioner provides the cold supply for the airflow cycle in the terminal cooling subsystem, responsible for accomplishing this task [14]. The terminal cooling and mechanical refrigerating air cooling methods will be discussed in detail in the following subtopics. Due to different equipment densities found in data centers, air-cooling technology implementations can be classified into numerous branches. Each of which is meant to increase power consumption efficiency by increasing the number of cooling terminals [15]. The most complex of these branches is chip-oriented cooling, which has the most sophisticated implementations. However, optimizations applied inside the rack, such as server-level schemes or chip-level schemes, are not viable for some data centers due to the significant rise in costs associated with their implementation and maintenance. As a result, the systems described below are air cooling technologies at the room, row, and rack levels, each with its own set of advantages and problems [16].

I. Room Cooling.

Taniguchi et al. [17] have reported that room-level cooling is concerned with the total heat dissipation of a room, and it is often achieved by using a raised floor arrangement for cold air supply. A typical configuration for air-cooled data center computer rooms includes a plenum beneath the elevated floor and a ceiling vent on the roof. Because the computer room air conditioner operates on a 24-hour cycle, cold air will be continuously supplied. It will be distributed into the indoor environment through perforated tiles on the elevated floor plenum. Different aisles are used in computer rooms to separate the racks that house the servers in rows [18].

Furthermore, the pressure difference between the plenum and the computer room causes cold airflow to be expelled to each row through its cold aisle on one side, caused by the pressure difference between the plenum and the computer room. After absorbing the heat generated by the servers on the other side of the room, warmed airflow will circulate to the ceiling vent on the opposite side, bringing the airflow cycle to completion [19]. The primary source of inefficiency in the airflow mentioned cycle is mixing warmed return air with cold input air, which results in detrimental consequences such as hot air recirculation and cold air bypass [20]. An issue with hot air recirculation is that a fraction of exhausted air is incapable of circulation to the hot aisle and instead mixes with the supplied air in the cold aisle, typically caused by insufficient cold inlet air. The temperature rises within the racks as hot air is recirculated over the information and communications technology equipment. Even worse, hot spots will develop within the shelves, which will harm the overall server performance.

On the other hand, cold air bypass refers to the underutilization of cold air due to an excessive supply of leakage. The cold air is unable to penetrate the racks along the cold aisle but instead flows to the upper space of the room, resulting in an uneven distribution of cooling air throughout the room. Additional cooling capacity must be utilized to resolve these issues, resulting in significant energy waste [21]. Various airflow control approaches have been proposed to mitigate the hot air recirculation and cold air bypass effects, among other things. Hence, one of the most effective of these systems is the air containment system, which prevents airflow intermixing by installing physical barriers to existing buildings [7] [22] [23]. In the case of the hot aisle containment system, this is a physical component developed to lessen the hot air recirculation effect considerably. In a conventional hot aisle configuration, enclosures are installed between the rear racks and the roof's ceiling, sealing off the hot aisle. The hot aisle in this configuration, on the other hand, must be sufficiently wide to prevent excessive pressure rise [24] [25]. The chimneys barrier is a solution for data centers that lack the necessary area for an enclosure solution. It accomplishes separation by placing tiny vertical ducts on top of the racks. Because of the tremendous pressure in the small space of the vertical ducts, the vent must be of sufficient strength. According to Makwana et al. [26], the cold aisle containment system is intended to decrease the cool air bypass impact. By surrounding the cold aisle with partitions between perforated tiles and the airflow inlet on the racks, the cold aisle containment system avoids intermixing, contrasting the traditional structure of the hot aisle cooling system. The hot aisles will be created in all indoor locations other than the cold aisle containment system. It is uncomfortable for technicians to operate for extended periods. The chimneys barrier is a solution for data centers that lack the necessary area for an enclosure solution. It accomplishes separation by placing tiny vertical ducts on top of the racks. Because of the tremendous pressure in the small space of the vertical ducts, the duct must be of sufficient strength [21]. When using room-level cooling, the primary benefit to be gained is the ability to modify the cooling distribution by reconfiguring the perforated tiles. The makes room-level cooling more suitable for data centers with low equipment density. In addition, when room-level cooling is implemented, the computer room air conditioner is typically positioned outside of the computer room, making it easier to maintain the cooling equipment while having little influence on the functioning of information and communications technology devices [25].

On the other hand, several critical cooling components on this level, such as the plenum, are statically coupled to the building structure, making their replacement or alteration prohibitively expensive. In addition, the air containment system partially tackles the problem. The extra effort required to prevent air intermixing remains a significant constraint of room-level cooling. Some form of containment is applied, there remains a great deal of uncertainty about the airflow distribution within the room [27].

II. Rack-Level Cooling.

Rack-level cooling is characterized by the rack coolers being installed within the racks, hence shortening the path of the airflow cycle even further. Typically, an additional enclosure housing a rack cooler is installed with the rack [28]. The inside space of the rack is split into hot and cold aisles using a remote partitioning system. When working remotely, the exhaled warmed air, and the cold supply air can follow the same lanes to complete the cycle. The fans' power consumption that drives the cold air circulation drastically decreases [29].

Furthermore, different information and communications technology (ICT) devices have varying cooling requirements. The ability to configure rack-level cooling on various ICT devices is critical to increasing power consumption efficiency. A one-unit (1U) server, for example, will require more airflow supply than a two-unit (2U) server and vice versa. In addition, blade servers have higher airflow requirements than communication enclosures, directing more airflow [30]. Rack-level cooling allows the distributed cooling capacity to be modified in response to the actual demand of the individual racks, which is advantageous in terms of power savings from the fans when using rack-level cooling. The rack-level cooling level is the most powerful of the levels covered in this section, as it provides the most power to each rack containing ICT devices. Due to the rack's general included internal area, it is possible to significantly minimize mixing of exhausted and supply air, resulting in a more controllable airflow path with a shorter path length. Another advantage of rack-level cooling in terms of space constraints is that modular in-rack coolers may be placed into different racks, allowing for more efficient use of available space [31] [32].

Since dynamical right-sizing approaches are becoming increasingly popular in data center management, active server redistribution based on real-time workload demands necessitates an adaptable cooling solution, which is one of the many advantages of rack-level cooling. In contrast, when the devices in some racks are placed to sleep mode, power waste is unavoidable for room-level or row-level cooling, depending on the configuration. To make up for this trade-off, the cost of rack-level cooling installation is relatively expensive, maybe because the cooling capacity has been over-designed. Another disadvantage of having a cooler in each rack is that maintaining rack-level cooling needs a significant amount of effort [33].

COOLING STRATEGIES OF DATA CENTRE

Preventing local overheating (hot spots), cooling only the server, and separating hot and cold air are essential considerations for server room cooling. Installing an underfloor air distribution system to increase the cooling performance of a data center ensures that cold and hot aisles are always placed close together in the facility. Air movement in the lowest section of a raised floor can help prevent freezing and hot air mixing and create hot spots in an I.T. server room, according to Pantankar [34]. Supportive to the author, airflow is influenced by the increased floor's internal pressure. Other factors that affect how much of an impact higher floors have on airflow include how much-perforated panel there is and how many obstacles are arranged under them. The pressure distribution beneath a raised bed was studied by Karki et al. [35] using an optimized one-dimensional computational model. Variables with no dimensions could control the distribution of airflow. As a comparison variable for a three-dimensional model, the airflow distribution results from the one-dimensional model might be compared to the dimensionless variables. Perforated panels of various sizes were proposed by Wang et al. [36] and used in a data center analysis model. According to their simulations, the perforated panels enhanced the temperature distribution without additional energy.

It is possible to build a cooling system for any facility that can run on emergency power for a lengthy period, notwithstanding recent data center trends. A facility's specific objective may necessitate maximizing runtime while preparing for the eventual shutdown of I.T. equipment in the case of a lengthy outage. The following is a list of three ways to regulate the temperature. Sections on the consequences of each of these three methods will follow.

I. Connect Cooling Equipment to backup Power.

According to Figure 2, Mi Lin et al. [37] discussed the first thermal surge that occurred due to the inability of the CRAH fans.

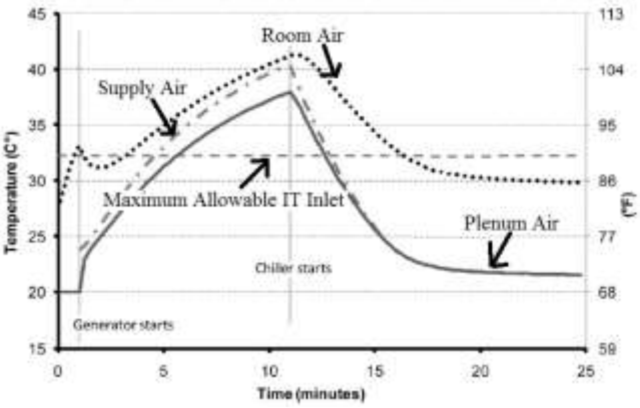

FIGURE 2

FOLLOWING A POWER LOSS, THE TEMPERATURE OF THE SURROUNDING AIR VARIES

It cooled water pumps to operate until the generator takes over the load 1 minute after the power outage begins. The primary cause of this dramatic temperature increase is the ratio of I.T. horsepower to air volume. Directly following the chilling breakdown, even before the heat core of the building (i.e., walls, plenums, servers, etc.) can recover any substantial heat, all of the I.T. power will essentially heat the air. Absent cooling, the highest rate of heat rise might potentially exceed 5 ^{0} C min^{-1} (9 ^{0}F min^{-1}), depending on the density and architecture of the chamber. Except if UPS or the data center protects the CRAH fans and pumps is relatively lightly loaded, the initial temperature surge will almost definitely exceed the thermal transfer limits indicated by tape vendors or the ASHRAE Thermal Standards. Placing just computer room air conditioner or computer room air handler fans on uninterruptible power supplies until the generator begins helps keep appropriate. Cooling airflow reduces recirculation from the I.T. vent to the I.T. inlet and transfers heat to the facility's pre-cooled heat exchange. Pumps help minimize the initial temperature rise before the data-generating process, especially in systems that utilize chilled water computer room air handler units. In this situation, the thermal storage of the chilled water and the piping system by themselves can significantly increase the operating window following a power breakdown. Uninterruptible power supply backup is often unnecessary for glycol-cooled DX systems without a free-cooling coil, as generator power is required to operate the computer room air conditioner. If the compressor plant is located remotely from the data center or if the cooling water system utilizes double-ring pipe loops, a massive amount of chilled water might accumulate in the pipes. Suppose the data center is located in an extensive multi-tenant facility. In that case, the data center will likely be served by a shared chilled water plant, providing ample cooling load. Cooling data center designers and operators should interact with facility workers to ensure the data center has priority when using chilled water for emergency purposes. For the two procedures outlined above, a distinct and separate uninterruptible power supply could be essential to avoid interfering with I.T. systems, regardless of the type of fan, pump, and backup setup. An ideal transformer may handle the structural load if uninterruptible power supply powers the fans, pumps, and I.T. equipment.

II. Use Thermal Storage to Ride Out Chiller-Restart Time.

The chiller can be restarted while the cooling water is still stored in the system. As long as the storage tank is large enough, cooling can be delivered with a slight departure from normal operating conditions when the chilled water pumps and computer room air handler fans in the chilled water system are on an uninterruptible power supply. Chilled water systems can save money by using low-pressure thermal storage tanks rather than installing chillers on an uninterruptible power supply. These tanks can even be composed of plastic. Nestling on the roof or elevated floor will impact tank size and type, as would other issues such as available space and load-bearing capabilities. High-density data centers, where even a short period without cooling might be troublesome, are especially well-suited for their use [38]. Consider the temperature stratification in the tank when calculating thermal storage requirements. The level of the transition region can be lowered for tanks with large diameters by utilizing a water distributor that adjusts the speed at which warm water returns to the tank. Additionally, the chiller's piping and controls should be set up to bypass the storage tank after restarting. Priority is given to delivering water to the data center as quickly as possible, rather than re-cooling the storage tank water.

III. Ensuring Appropriate Reserve Cooling.

For typical operating conditions, the industrial tendency of "right-sizing" cooling makes sense, but even having marginally more cooling capacity than the load can significantly increase the amount of time required to cool a facility that has already become too hot. The key to increasing cooling system efficiency is to scale both bulk cooling (i.e., chillers) and cooling distribution (i.e., CRAH units) in proportion to the rise in I.T [39] load. It could enable sufficient reserve cooling while also increasing data center efficiency. For instance, a data center intended for a maximum I.T. load of 1 M.W. may initially have only a 100 kW I.T. load. While the chilled water plant piping is sized to meet the ultimate data center capacity, the installed chillers may only support around 250 kW of total load or approximately 140 kW of I.T. load. The actual oversizing is determined by the amount of redundancy required and the component's efficiency [40].

CONCLUSION

In conclusion, the information indicated that many configurations are possible, common energy efficiency issues abound, and many factors contribute to energy inefficiencies. The energy inefficiencies commonly observed in the data center are not limited by current technology but due to limited resources, disincentives, and misconceptions. There are many opportunities for efficiency improvements, ranging from simple, low-cost options to more intensive. The solution for each space depends on the specific configuration, which involves room size, I.T. and cooling equipment configuration, and local climate. The operation management of the cooling system should not only focus on the cooling technique itself but also consider the control strategies tailored to the characteristics of the scenarios and the users in the data center services. Eventually, some developing solutions are described, which can potentially improve the cooling performance of data centers in the future.

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