International Journal of Scientific & Engineering Research, Volume 14, Issue 3, March-2023
ISSN 2229-5518

Best Practices for Energy Efficiency in Data Center Heating, Ventilation, and Air Conditioning Systems

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Abstract—The steady increase in data center energy consumption, the growing energy supply crisis on a global scale, and concerns about climate change are bringing to the forefront the need for energy conservation and more rational use of energy. The increased energy consumption is due to the increased capacity of data processing and telecommunications (datacom) equipment, which contributes to the increased energy demand of the heating, ventilation and air conditioning (HVAC) systems whose job it is to achieve and maintain the prescribed criteria for temperature, humidity and cleanliness in the rooms in which they are located. The average energy consumption of HVAC systems installed in data centers is about 31% of the total energy consumption in data centers. This paper explores opportunities to improve the energy efficiency of HVAC systems by integrating proven best solutions, focusing on mechanical cooling equipment and cooling distribution equipment, as parts of HVAC systems that are significant energy consumers.

Index Terms—Cooling equipment, distribution equipment, data center, energy efficiency, HVAC systems.

1 Introduction

MOST financial and industrial companies operate their data processing in data centers. Industry trends show a steady growth in the number of data centers and an increasing concentration of financial institutions and Internet companies in large data centers. Today, data centers have an average cooling load density of 500 W/m² to 2500W/m², with the tendency that it is constantly increasing. They have defined air parameters (temperature, humidity, cleanliness), operate continuously 24 hours a day, seven days a week, 365 days a year.

The requirements for the characteristics of the environment in the room where the datacom equipment is placed vary depending on the type of equipment and manufacturer, and correspond to [1] four standardized conditions (classes 1 to 4) and the fifth class NEBS, which defines the conditions of telecommunications equipment.

The HVAC systems provide the defined characteristics of the environment in which the data communications equipment is located in the data centers. The tests conducted for twelve data centers [2] show that the cooling systems have an energy consumption of about 23%, while the HVAC fans account for about 8% of the total energy consumption in the data center, so that the HVAC systems account for about 31% of the total energy consumption of data centers, Fig. 1. While most data centers have an average energy consumption by HVAC systems of about 31%, the most efficient HVAC systems have an average energy consumption of 20% and the least efficient HVAC systems have an average energy consumption of 54% [3], which shows that it is necessary to take more care in designing HVAC systems to minimize the energy consumption of data centers.

HVAC systems consist of several components and can be divided into three major groups: mechanical cooling equipment, cooling distribution equipment, and heat rejection equipment, Fig. 2. In this paper, the mechanical cooling equipments and the cooling distribution equipments are studied, i.e., recommendations are made to reduce their energy consumption, i.e., to optimize their operation and increase their energy efficiency.

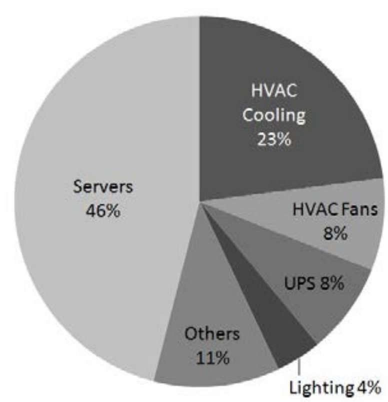

Fig. 1. Distribution of energy consumption in average data centers

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International Journal of Scientific & Engineering Research, Volume 14, Issue 3, March-2023
ISSN 2229-5518

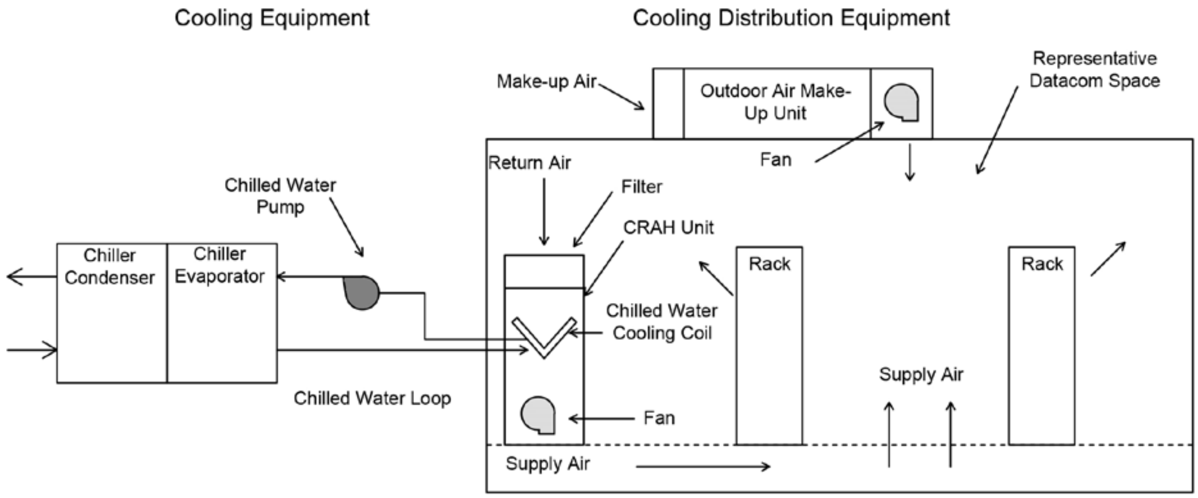

Fig.2 Schematic diagram of mechanical cooling and distribution equipment as parts of the HVAC system [3]

2 ENERGY SAVING MEASURES FOR MECHANICAL COOLING EQUIPMENT

Cooling equipment is the largest energy consumer of all data center HVAC equipment. Since data centers consume large amounts of energy for cooling, the cooling equipment used should be highly energy efficient. The choice of equipment depends on several factors, but two types of chillers are commonly used in data centers: Water chillers and refrigerant compressors.

There are many different types (centrifugal, reciprocating, absorption, scroll, etc.) and sizes of chillers. Absorption chillers are considered a separate class of chiller because they use a heat source instead of a compressor, making them particularly suitable when a free heat source is available. Chillers can use different types of refrigerants that have different characteristics in terms of safety and environmental impact [4].

When choosing chillers for data centers, the operating environment in which they will operate should be considered. Consideration should be given to the operation of duplicated chillers (if there are five chillers, one will have a redundancy function and serve the four fully loaded chillers) and the fact that the chillers may operate at a low capacity from the start, even though they are sized for future data center growth.

To maintain the prescribed working conditions of Datacom equipment, various alternatives for cooling equipment can be used: water-cooled chiller, direct expansion compressor, air-cooled chiller and heat exchanger for free cooling.

Cooling systems that use direct expansion units are most often used in smaller data centers. These units reject heat from the refrigerant to the outside air through an air-cooled condenser. There are several ways to reduce the energy consumption of cooling systems that use direct expansion units. The energy efficiency of the chiller at part load can be optimized by using variable frequency drive compressors. Chillers with motors with frequency regulation, high evaporator temperatures and low water inlet temperatures in the condenser can have an operating efficiency at part load of 0.01 kW/per kW of cooling capacity or less [5]. The direct expansion system with air-side economizer helps to increase the energy efficiency of the cooling system. For a wide range of outdoor air temperatures, the application of variable speed condenser fan control lowers energy consumption by reducing condenser fan energy compared to standard fan phase control.

High-efficiency water-cooled chillers equipped with a variable-frequency driven compressor and appropriate condenser water matching are typically the most efficient cooling option for large data centers. Water-cooled chillers typically require less maintenance, are more efficient, provide less variation in data center air temperature, and are easier to operate with waste heat compared to direct expansion systems.

The thermodynamic efficiency of the chiller depends primarily on the temperature difference between the chilled water and the condenser water. The efficiency of the chiller can be significantly increased if this temperature difference is reduced. Tests conducted in several data centers show that the projected chilled water in the data centers is usually at a temperature of about 7^{o}C, and when combined with a cooling coil start-up temperature of about 4oC, the supply air temperature is about 11^{o}C and the temperature in the rooms with data communication equipment is about 22^{o}C. Chilled water temperatures greater than 7^{o}C allow for an increase in the energy efficiency of the chiller and, at the same time, the supplied air temperatures allow the data communication equipment to operate within the recommended operating range [3].

Energy efficiency, reliability, and reserve should be considered when selecting pumps and pumping systems for condenser and chilled water. Variable speed pumps should be used so that the standby pump can operate simultaneously. Loading to maximum speed occurs when one of the pumps fails. The relative energy efficiency of the primary pumping systems in relation to the secondary pumping systems should also be considered when optimizing energy consumption.

Significant energy savings in air conditioning can be achieved by using natural cooling (free cooling option). Depending on the conditions of the external environment of the data center, three types of economizers can be used that can reduce the working hours of the cooling unit: water-side economizers, air-side economizers, and combined water and air-side economizers.

If we take into account the fact that data centers operate 24 hours a day, then climatic conditions allow us to use the option of free cooling - Air Economizer - to save energy. If we take into account that there are many hours of the year when the outdoor temperature is in the range of 13 - 16°C (i.e. from 16 - 20°C, if the recommendations for a higher temperature of cold air distributed to datacom equipment are accepted), then the application of natural cooling using air contributes to significant energy savings. The air economizer takes advantage of the times of the year when the enthalpy of the outside air is lower than the enthalpy of the return air. For given outdoor conditions, using outside air reduces the load on the cooling unit compared to using return air flow. A properly designed data center cooling system and its controls will ensure that cooling savings are not lost due to the need for additional humidification and filtration.

Although opinions are divided on the risks this strategy may pose, it is a common practice to implement it in data centers. Adequate control solutions successfully manage temperature and humidity fluctuations, regardless of the fact that large amounts of outside air are introduced into a data center. Issues related to the possible introduction of particles or gaseous pollutants through outside air into data centers are successfully addressed. Lawrence Berkeley National Laboratory has found slightly higher particle concentrations in data centers using outside air economizers compared to data centers with 100% recirculation systems.

The free cooling option reduces the chiller's hours of operation or the operation of the compressor in the cooling unit and provides the cooling unit with savings of 30 to 50 %, depending on the average temperature and humidity of the environment [6], considering that the data center should operate continuously 24 hours/day, or 8760 hours/year.

Water-side economizers use cooling towers to provide chilled water for data center cooling. This takes advantage of times of the year when the outdoor wet bulb temperature is sufficiently lower than the set point for the cooling water supplied. Free cooling is generally best suited for climates where the wet bulb temperature is below (13°C) for 3,000 or more hours per year [7]. Instead of running the chiller during these periods, water from the cooling tower is routed past the chiller and into the heat exchangers to cool the chilled water directly.

The water-side economizers most commonly used in data centers are integrated economizers (modular and integral with the mechanical plant) and parallel economizers (with the mechanical plant only). In some cases, both water-side and air-side economizers are used in the same center. Integrated economizers are used to reduce the load on the cooling device, when conditions are not suitable for full economizer operation. In this case, the water-side economizers provide pre-cooling of the return water to reduce the load on the chiller.

Parallel water economizers are used to bypass the chiller when outdoor wet bulb conditions allow full operation of the economizer. The parallel economizer can start after the cooling tower has lowered the temperature of the incoming condensate water enough to directly or indirectly achieve the designed chilled water temperatures.

Integrated economizers are more efficient than parallel economizers [7], and to meet ASHRAE Standard 90.1 [8], the integrated economizer must be used when designing cooling systems.

However, to assess whether this is the case for a particular data center, a proper technical assessment of local climate conditions must be made. Natural cooling, however, is used in many data centers and results in energy-efficient operation. Combined water- and air-side economizers are a good option for climates with low wet bulb temperatures that can use wet economizers during the many hot hours of the year, with a transition to an air-side economizer during the winter months.

3 Energy saving measures for cooling distribution equipment

The fans that distribute the air consume a considerable amount of energy. Therefore, it is particularly important to increase their energy efficiency, that is, to optimize their work from various aspects.

Matching the cooling capacity to datacom equipment can be achieved by using a variable airflow distribution system (VAV), which is a particularly important step in reducing the energy consumption of the fans. Compared to systems operating at constant airflow (CAV), variable airflow systems can provide additional capacity but always operate at temperature and airflow levels suitable to regulate the optimal temperature and humidity in the conditioned space, reducing energy consumption for fan operation and the need for supplemental heating. Increasing the efficiency of the fans also increases the efficiency of the data center air conditioning system.

The frequency- driven fan motor of a chiller allows fan speed and energy consumption to be reduced when the cooling load is reduced. A 10% reduction in fan speed results in a 27% reduction in energy consumption, and a 20% reduction in fan speed results in a 49% reduction in energy consumption. [10].

By using high-efficiency fans that match the expected working conditions, by using energy-efficient motors, and by using filters with low pressure drop, they help reduce energy costs.

Pumps typically operate 24 hours a day, so increasing their energy efficiency is of particular importance. Energy efficiency, reliability and reserve should be considered when selecting pumps and pumping systems. Variable speed pumps should be used so that the standby pump can operate simultaneously. Loading to maximum speed occurs when one of the pumps fails. The relative energy efficiency of the primary pumping systems in relation to the secondary pumping systems should also be considered when optimizing energy consumption. To reduce pump energy consumption, it is particularly important to optimize the Δt of the child water, which contributes to lower pump power.

Different types of humidifiers can be used in data centers, but they should be adjustable and easy to maintain. The humidity sensor should be placed so that it regulates the humidity of the air at the entrance to the datacom equipment.

Equipment used for computer room air conditioning comes in a variety of configurations, but the most common are computer room air conditioners and central air handler systems. Central air handler systems compared to computer room air conditioners have several advantages. The advantage of such equipment is the conditioning of conditioned air to the project size at a central location. In the central climate chamber can be used a variety of heat exchangers for heating and cooling, but it is ideal if each of them can be modulating control. Various types of humidification systems can be used in a central station, differing in steam quality, degree of control, and energy consumption. The use of a variable airflow distribution system optimizes their operation and, in particular, increases energy efficiency at partial load.

4 CONCLUSION

Data centers are large consumers of energy with a tendency to further increase energy consumption due to the need to provide large computing capacity. Globally, special attention is being paid to the potential reduction of energy consumption in data centers, as they can consume 100 to 200 times more electricity than normal office space. There are significant opportunities to reduce energy consumption in data centers, and it is estimated that energy consumption in centers can be reduced by up to 40% [10].

Although reliable operation and functionality are priorities for most data centers, energy consumption can be significantly reduced without disrupting the operation of data communications equipment if proven, field-tested solutions are incorporated into the HVAC system design. A well-designed and maintained HVAC system requires improved performance, newer technologies, and increased efficiency of cooling equipment and cooling distribution equipment. Cooling equipment and cooling distribution systems have many parameters that lend themselves to energy optimization: chillers, compressors, pumps, fans, humidifiers, chilled water supply and differential temperature, etc. When this is added to the implementation of best practices, HVAC systems can be optimized and significantly reduce energy consumption.

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