Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 75 (2015) 1255 – 1260

Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

Data Center Energy and Cost Saving Evaluation

Z. Song[a], X. Zhang[b,*], C. Eriksson[a]

[a]*Malardalen University, 72123, Vasteras, Sweden*
[b]*ABB AB, Corporate Research,72178, Vasteras, Sweden*

Abstract

In data centers, about 40% of the total energy is consumed for cooling the IT equipment. Cooling costs are thus one of the major contributors to the total electricity bill of large data centers. This paper studies two factors affecting data center cooling energy consumption, namely air flow management and data center location selection. A unique rack layout with a vertically cooling air flow is proposed. Two cooling systems, computer room air conditioning (CRAC) cooling system and airside economizer (ASE), have been studied. Based on these two cooling systems, four cities have been selected from the worldwide data center locations. A number of energy efficiency metrics are explored for data center cooling, such as power usage effectiveness (PUE), coefficient of performance (COP) and chiller hours. By analyzing the effects of chiller hours and economizer hours, comparative economic results of cooling power consumption are provided in both systems. The results show that the cooling efficiency and operating costs vary significantly with different climate conditions, energy prices and cooling technologies. As climate condition is the major factor which affects the airside economizer, employing the airside economizer in the cold climate yields much lower energy consumption and operation costs.

Peer-review under responsibility of Applied Energy Innovation Institute

Keywords: Data center; Cooling; Energy efficiency

1. Introduction

The worldwide energy consumption of data centers has increased dramatically, now accounting for about 1.3% of the world's electricity usage [1]. The data centers have evolved significantly during the past decades by adopting more efficient technologies and practices in data center infrastructure management (DCIM). It is estimated that the market will grow by about 5 percent yearly to reach $152 billion in 2016 [2]. Meanwhile there is a trend to build mega-data centers with capacities over 40 MW. Energy efficiency is an important issue in the data centers for minimizing environmental impact, lowering costs of energy consumption and optimizing data center operation performance.

* Corresponding author. Tel.: +46-21-323062.
E-mail address: Xiaojing.zhang@se.abb.com.

Peer-review under responsibility of Applied Energy Innovation Institute
doi:10.1016/j.egypro.2015.07.178

A modern data center has a large room with many rows of racks filled with a huge number of servers and other IT equipment used for processing, storing and transmitting digital information. An amount of heat is generated by these thousands of servers and other IT equipment. To maintain reliability of the servers and other IT equipment in the data center, it is of importance to maintain proper temperature and humidity conditions. Fig. 1 reports the results of an investigation of 10 random data centers. It reveals the representative power consumption distribution and the variation, showing a spread between 30% and 55% of the total energy consumed by cooling data center IT equipment. Cooling and ventilation systems consume on average about 40% of the total energy used. Therefore, how to reduce power consumption, power costs and increase cooling efficiency and maximize availability must be taken into account before building up a data center.

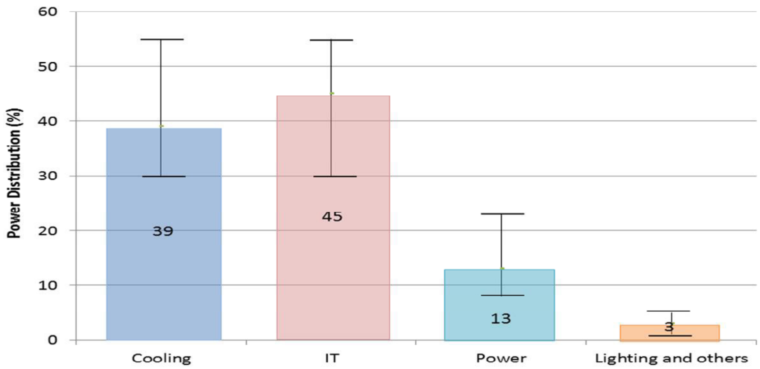


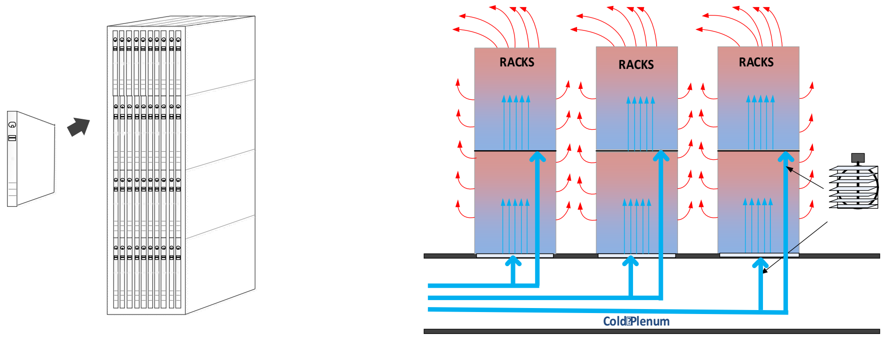
Fig. 1. Data center power consumption distribution and variation.

2. Data center ventilation and air flow management through vertical air flow

A modern data center has a large room with many rows of racks filled with servers and other IT equipment used for processing, storing and transmitting digital information. Typically, servers and other IT equipment are lying down in the racks. In the conventional data center with hot aisle/cold aisle method, cold air generated by the cooling system is supplied through a plenum chamber under the floor of the room. At the sides of the racks, perforated air flow panels are arranged on the floor to let the cold air in. Ideally, the cold air will flow up from the air flow panels, entering the tiny spaces between the servers from one side of the servers and leaving from another side. Thus, the cold air from the one side forms a cold corridor and there is a warm corridor at the other side, in order to isolate cold and hot corridors from each other and to eliminate the possibility that hot air exhausted from one rack would enter the inlet of another rack. It can work because the cold air is heated when flowing between the servers. This arrangement has several disadvantages, mainly because air flow cannot be well controlled. In particular, the cold air and warm air will be mixed on the up side of the racks, since the cold air is much easier flowing up than flowing in between the servers, which makes cooling inefficient. A higher pressure drop is introduced due to horizontally flow through servers and air flow through the arrangement of perforated panels, which results in large flow resistance and limits heat transfer between cooling air and server. This consequently makes for higher energy consumption of the cooling system.

To solve these problems, data center racks with vertically placed servers are proposed as shown in Fig. 2 (a). Instead of the traditional horizontally placed servers, with tiny spaces between servers, all servers are here placed vertically with the optimal space between servers of less than 30 mm. This limitation considers data center space utilization as well as the cooling air channel for heat transfer. Such server racks can be placed either in a closed cabinet or in open space. Natural convection is well utilized through the vertical air flow. The server racks can also be divided into two sections to avoid large temperature differences between bottom servers and the servers on the top of the racks. Instead of air supply though corridors between racks, cooling air is directly supplied from the bottom of racks as shown in Fig. 2 (b). Cold and warm stream mixing is thus avoided. The perforated tiles are no longer needed, which results in reduced flow resistance with lower fan power consumption. Through natural gravity due to air density differences, heat transfer is enhanced by cooling air flowing upwards and ventilation is increased. In order to achieve distributed cooling control, a number of air supplying pipes are provided and placed under the floor of the data center including an inlet adjustable opening in each pipe.

The ventilation system consists of main fans and a number of sun-fans, depending on the size of the data center room that provide cooling air to several rack zones. The flow pattern can be well controlled through sub-fans and the opening adjustment. The fan speeds and the supply cooling air openings are determined to minimize the actual total power used for ventilation while satisfying server temperature and hot spot free demands. The cooling air comes either from outside fresh air, an external cooling station or CRAC units, with a separate control system or a control system integrated to the data center infrastructure management.



(a) Data center rack layout with vertical placed servers. (b) Air flow illustration in data center vertical server rack layout.
Fig. 2. Data center vertical server rack layout with adjustable inlet.

3. Effect on data center location selection

3.1 CRAC and air-side economizer case study scenarios

A typical cooling solution of data center is accomplished by using computer room air conditioning (CRAC) with equipment like air handling units (AHU), chiller and cooling tower, which supply cold air through the plenum under the floor up to each rack and recirculate the expelled hot air to the cooling equipment. An Air-side economizer uses ambient low temperature air from outside directly to cool the internal servers whenever the outside temperature is lower than the set-point temperature of return air in a data center. A computer room air handler (CRAH) is used in the case when outside temperature is not appropriate for cooling. As an air-side economizer does not include humidity control, a dedicated humidification system is needed to stabilize the fluctuation of relative humidity (RH). The Air-side economizer can offer more hours of economization which is more energy efficient and it reduces the cooling load and cooling costs for data centers.

This work covers three scenarios: the baseline; the air-side economizer with COP of 2.1; and the air-side economizer with COP of 4.0. A representative data centre in the US [3] with a conventional CRAC cooling is defined as the cooling solution for the baseline scenario. The data center ventilation layout uses the conventional hot aisle/cold aisle arrangement for all scenarios. Under the airside economizer scenarios, COP was assumed to be 2.1 and 4, respectively [4]. The baseline CRAC fan power is 232 kW and the ASE fan power is 410 kW since the outside air temperature is often higher than CRAC cooling air temperature. To keep sufficient heat transfer, the ASE requires more fan power. Four cities with very different climate conditions are selected as data center locations for comparison.

3.2 Analysis of chiller hour, economizer hour and humidity

A chiller hour is recorded whenever mechanical cooling is required to maintain the maximum allowable IT intake temperature. Economiser hour is collected to determine the number of hours where outside air conditions meet the required data center conditions. Both chiller hour and economizer hour apply to two regions, the region where the data center is cooled entirely by chillers and the transitional region where some of the cooling load is met by the free cooling system and the remainder is met by chillers.

For the baseline scenario, the chiller hours are equal to the annual operation hours since the operation could practically make no use of the outdoor climatic conditions, so the data center is cooled by cooling system all the year round. Based on the ASHRAE thermal environment recommended range [5] for data centers and the analysis of 10 years of climate statistic temperature and humidity data in the four cities, the economizer hour and chiller hour for each data center under the design of ASE scenario are calculated and shown in Table 1 and Table 2. Luleå has special advantage of zero chiller hours. It means that no mechanic cooling equipment is required. Seattle is the ASE favourite city in US because less chiller hours are needed there.

Humidity control is another concern in data center operation. Humidity should be controlled according the most restrictive ASHRAE recommended range, i.e. 5.5°C dew point to 60% relative humidity and 15°C dew point. The baseline uses a water-cooled chiller plant to cool water through heat exchangers, which maintains more constant humidity levels in the data center. The primary disadvantage of airside economization is the lack of humidity control. The extra energy used for humidification may offset a part of the energy savings from ASE and the additional costs for humidification therefor have to be considered in the ASE benefit evaluation.

Table 1. Economizer hours and chiller hours to air-side economizer

	New York City, USA	Seattle, USA	Houston, USA	Luleå, Sweden
Total yearly hours	8760	8760	8760	8760
Economizer hours	8215	8704	7049	8760
Chiller hours (T > 27°C)	551	62	1717	0

Table 2. Humidification costs for ASE system

	New York City, USA	Seattle, USA	Houston, USA	Luleå, Sweden
kW required for humidification [6]	128	128	128	128
Costs of humidification ($/kWh)	0.08	0.08	0.05	0.05
Hours/year for humidification	6048	4704	4704	6046
Annual humidification costs (k$)	62	48	30	39

3.3 Energy consumption comparison of cooling scenarios

The cooling power consumption and the annual operation costs in each design scenario are calculated based on the chiller hours and the PUEs showed in Fig. 3 and Fig. 4. The energy prices in the four cities have been considered. The lower energy price of 0.05 dollar per kWh in Houston and Luleå showed to be an advantage comparing to the energy price of 0.08 dollar per kWh in New York City and Seattle. In the baseline scenario, the performance ratio of total facility energy consumption to server energy consumption was 1.55, which is the same for all of the four data centers. The PUE ratios of the airside economizer scenarios are lower than the baseline, which showed that the airside economizer can reduce energy consumption in most cases. Moreover, minor change in the PUE represented substantial energy savings. Since the cooling system operation in the baseline scenario is assumed to be independent of the climatic conditions, cooling power consumption is the same for all four data centers, which equals to the electric power used for the whole year cooling system operating. Cooling energy consumption is assumed to be proportionally correlated to chiller hours and economization hours. Total electricity consumption for cooling is calculated using the full power load of cooling, and 8760 hours per year. Cooling equipment depreciation and IT downtime were not considered under the operation. The results in Fig. 4 (a) show that airside economization consumed less electric energy than those in the baseline scenario. Airside economization in Luleå provided the largest energy savings due to the cold climate, while that in Houston provided the least energy savings. Table 2 also showed that Luleå has zero chiller hours and the highest economizer hours, while Houston has the most chiller hours and least economizer hours. Thus, the cooling energy consumption in the four data centers are related to the different climate restrictions.

The ASE system reduces cooling costs by taking advantage of cool outdoor air to condition indoor spaces. Among the three cooling design scenarios, the airside economizer could save energy compared to the baseline; the ASE 2 scenario with a higher COP and lower PUE saves even more energy than ASE 1. ASE could save up to 35% of power costs compared to the baseline case.

However, there are a number of factors that affect data center operation costs, notably weather conditions, local electricity prices and operating policies. In Luleå, the cool climate could contribute to the ASE for all hours of the year. Furthermore, since Luleå enjoys the lowest energy price and the lowest industrial tax rate, it is obviously the most cooling efficient site for operating data centers. As the use of ASE brings an associated concern about moisture from humidity, the cost to humidify is also one of the issues should not be neglected. Though the cost of humidification is a significant expense, results from the ASE scenario in Luleå showed that the humidification costs is 27% of total cooling energy saving.

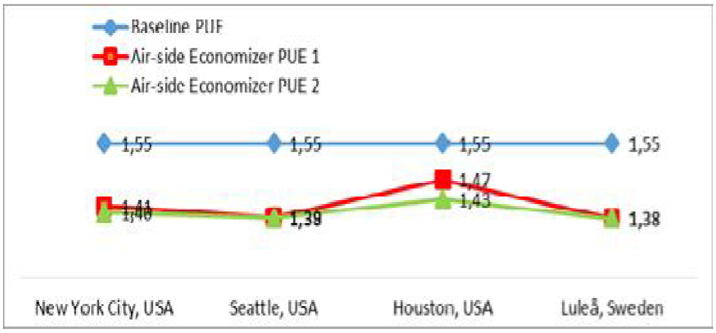
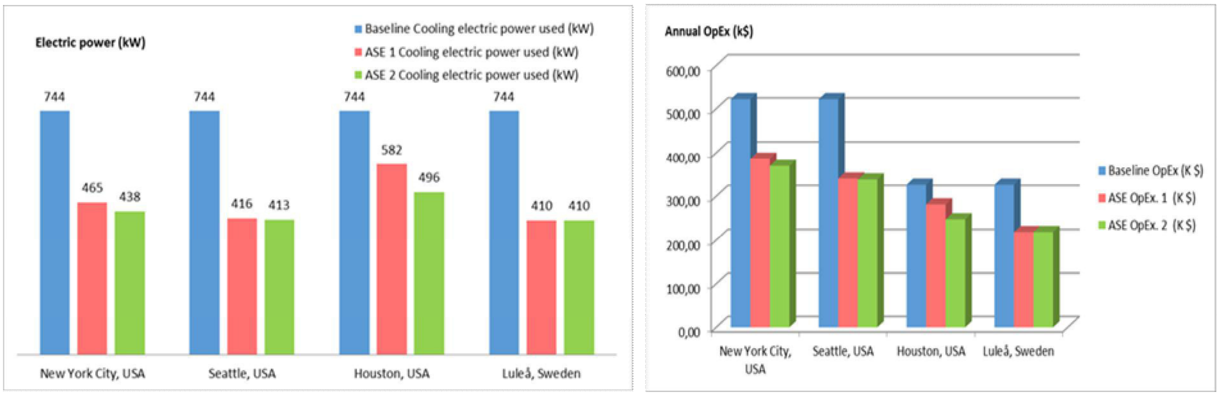


Fig. 3. Case study of data center PUE.



(a) Cooling power consumption. (b) Operation costs.

Fig. 4. Case study of data center cooling power consumption and annual operation costs.

4. Conclusions

Data center ventilation and air flow management with vertically placed server racks provide efficient heat transfer with reduced air flow pressure drop and contribute to data center energy saving.

There are a number of factors affecting data center total energy consumption and costs, in particular weather conditions, local electric prices and operating policies, and the cooling solution design. For an air-side economizer system, the major factor is the climate condition or location selection. Both temperature and humidity have to be considered. Although the cost of humidification is a significant expense, the current study showed that the benefits from the cold climate is much larger than the costs of humidity regulation.

References

[1] Koomey J. G, Growth in data center electricity use 2005 to 2010. *Analytics Press*, Oakland, 2011.

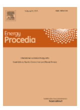
[2] Kovar J. F, The 2014 Data Center 100, *CRN,* 2014.

[3] Shehabi A, Ganguly S, Traber K, Price H, Horvath A, Nazaroff W. W, Gadgil A. J, Energy Implications of Economizer Use in California Data Centers, *ACEEE Conference Proceedings*, Monterey, CA, 2008.

[4] Derrick PE J. Joy D, STULZ Water-Side Economizer Solutions, STULZ Data Center Design Guide, 2014.

[5] ASHRAE TC 9.9, 2011Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. 2011.

[6] Newcombe L, World IT Environmental Range Analysis, The Chartered Institute for IT, 2011.



Biography

Xiaojing Zhang received the M.S. degree in environmental engineering from China in 1983 and Ph.D. degree in energy technology in 1997 at KTH, Stockholm. He joined ABB in 1998 and his career included 15 years of industrial experiences in process industry. Dr. Zhang is currently a principal scientist at ABB AB, Corporate Research, Sweden.