Study on load forecasting to data centers of high power density based on power usage effectiveness

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Abstract. There is usually considerable energy consumption in data centers. Load forecasting to data centers is in favor of formulating regional load density indexes and of great benefit to getting regional spatial load forecasting more accurately. The building structure and the other influential factors, i.e. equipment, geographic and climatic conditions, are considered for the data centers, and a method to forecast the load of the data centers based on power usage effectiveness is proposed. The cooling capacity of a data center and the index of the power usage effectiveness are used to forecast the power load of the data center in the method. The cooling capacity is obtained by calculating the heat load of the data center. The index is estimated using the group decision-making method of mixed language information. An example is given to prove the applicability and accuracy of this method.

1. Introduction

Currently, data centers are becoming more and more important and their load density is much more centralized than ever with the rapid innovation of Information Technology (IT) and the development trend of energy Internet [1]. The accuracy of load forecasting to the data centers has a significant impact on Spatial Load Forecasting (SLF). There are some methods of SLF [2-8], which can be divided into 4 groups in accordance with the principle of prediction [9]: local simulation method, load density index method, the method of multivariable variants, and trend method. The methods mostly focus on a wide range of power supply area and need a large amount of historical data or sample data. However, there are little methods to forecast the load of the data center for the power density being very concentrated.

A load forecasting method of the data center of high power density on the basis of Power Usage Effectiveness (PUE) is proposed using a combination of energy consumption indexes and group decision-making of mixed-language information for SLF in the paper. The load density index of the data center can be established according to the method with data center architectures, equipment condition, geographic and climatic factors.

2. PUE Index

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The concept of PUE can be indicated in Equation (1) [10], the lower a data center’s PUE is, the better green environment performance it is.

\[ PUE = \frac{P_{TF}}{P_{IT}} \]  

where \( P_{TF} \) refers to Total Facility Power (TFP) and \( P_{IT} \) is IT Equipment Power.

TFP consists of IT Equipment Power and non-IT equipment power \( P_{NIT} \), and non-IT equipment is usually made up of infrastructures[11]. Therefore, Equation (1) can be changed into Equation (2).

\[ PUE = 1 + \frac{P_{NIT}}{P_{IT}} \]  

3. Thermal load calculation of data centers

The computer room at a data center often includes more than one thermal source, which are as follows[12]: 1) Thermal conduction of building envelopes; 2) Solar heat; 3) Thermal dissipation of IT and other equipment; 4) Heat and moisture dissipation of human bodies; 5) Thermal dissipation of illumination device; 6) Ventilation loads.

The requirements for air conditioning’s capacity can be estimated after the above thermal loads are given. Aside from eliminating the heat in a data center, the air conditioning also controls humidity. The rise of humidity adds an extra heat load to the air conditioning, and then the refrigerating capacity need to be expanded. The expansion range of the refrigeration system is typically not more than 30%, 30% mainly refers to the systems containing a huge number of mixed gases in a data center, while the smaller range is mainly for the small systems to return gas through the pipeline.

3.1. Thermal conduction of building envelopes

There are 3 ways of thermal transfer: conduction, convection and radiation. Heat that goes into a data center by its building envelopes such as roofs, walls and partitions has a lot to do with climatic factors like the season, time, locations and irradiation angle of the sun.

Heat conducted to the computer room by planar walls \( Q_C \) (kcal/h) is calculated as in Equation (3) when air temperatures inside and outside the door are stable.

\[ Q_C = K_C F_C (t_{zp} - t_n) \]  

where \( K_C \) is thermal conduction factor, kcal/(m²•h•℃); \( F_C \) is the building envelopes area, m²; \( t_{zp} \) is the temperature indoor, ℃; \( t_n \) is the temperature outdoor, ℃.

3.2. Solar heat going through windows

Some of the heat, \( Q_s \) (kcal/h), absorbed penetrated into from window glass becomes the thermal loads of the computer room because of convection, which can be calculated as in Equation (4).

\[ Q_s = K_s F_s q_s \]  

where \( K_s \) is the penetration factor of solar heat that depends on the types of the glass, and it goes between 0.36–0.4; \( F_s \) is the area of the glass, m²; \( q_s \) is the level of solar heat, kcal/(m²•h).

3.3. Heat of servers

Servers are the major equipment in a data center, and their power consumption can be equal to the maximum power consumption provided in the server brochures.

3.4. Heat and moisture dissipation of human bodies

Human bodies release heat, which contains moisture. And corresponding thermal loads include real and potential heat. When the indoor temperature is 24 ℃, the real thermal load is 70W, and the potential thermal load is 112W; or if the indoor temperature is 21 ℃, the real thermal load is 87W, and the potential thermal load is 94W. In both occasions, the overall thermal loads are near the same. Thermal loads from human bodies can’t be overlooked if there are a lot of persons in the room.

3.5. Thermal dissipation of illumination device

Electric power consumed by the illumination device in the computer room transfers into light as well as heat. Light will eventually turn into heat after it is absorbed by the building and the equipment.
Consequently, light needs to be taken into account as a thermal load, too. The heat generated by the illumination device is generally calculated according to the floor area of the room.

3.6. Thermal loads brought in by outdoor air

The requirements of new air for a computer room in a data center are \(40 \text{ m}^3/\text{h}\) per person and air volumes required to maintain the positive pressure of the room. The thermal load of ventilation, \(Q_v\) (kcal/h), can be calculated as in Equation (5).

\[
Q_v = G_v (h_{nw} - h_{in})
\]

where \(G_v\) refers to fresh air, kg/h, while per cubic meter of air is regarded 1.2 kg; \(h_{nw}\) and \(h_{in}\) are respectively outdoor and indoor air enthalpy.

4. Load Forecasting Method Based on PUE

4.1. Group decision-making of mixed language information

After the investigations to several data centers of a city in northern China, it is found that four main kinds of factors influence PUE of a data center such as geographical, structural, equipment and management factors. Every type of factors involves in several indexes, as shown in Figure 1.

![Figure 1. Influence factor index system of PUE](image)

In Figure 1, some indexes are numerical such as solar radiation, equipment power, number of persons and so on, which are convenient for calculation. However, some indexes are qualitative such as location, energy management, thermal structure and so on. These indexes need to be quantized.

A zero-symmetrical assessment scale is used as shown in Equation (6) [13].

\[
S_a = \begin{cases} 
S_a & \alpha = -(\tau - 1), -\frac{2}{3} (\tau - 2), \cdots, \frac{2}{3} (\tau - 2), (\tau - 1) 
\end{cases}
\]

where \(S_a\) stands for language term, and when its subscript is above 0, it can be calculated as in Equation (7). When subscript comes down 0, \(S_a\) can be calculated as in Equation (8).

\[
S_0 = \begin{cases} 
S_a & \alpha = \frac{2(i - 1)}{\tau + 2 - i}, i = 2, 1, \tau - 1, \tau 
\end{cases}
\]

\[
S_{-i} = \begin{cases} 
S_a & \alpha = -\frac{2(i - 1)}{\tau + 2 - i}, i = \tau, \tau - 1, \cdots, 2 
\end{cases}
\]

Besides, there are some calculation rules: 1) if \(\alpha > \beta\), then \(S_\alpha > S_\beta\); 2) \(S_\alpha + S_\beta = S_{\alpha + \beta}\); 3) \(\lambda S_\alpha = S_{\lambda \alpha}\).

A specific situation in Figure 2 shows when \(\tau\) stands for 4 where \(S_3\) stands for "extremely bad", \(S_{-4/3}\) stands for "very bad", \(S_{-1/2}\) stands for "bad", \(S_0\) stands for "not bad", \(S_{1/2}\) stands for "good", \(S_{4/3}\) stands for "very good", and \(S_3\) stands for "extremely good".

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It can be seen in Figure 2 that this language assessment scale is not balanced, and the closer to 5, the more intensive scales.

![Figure 2. Language assessment scale of \( \tau = 4 \)](image)

There are two integrated operators, OWA operator and LHA operator. OWA operator is defined as in Equation (9).

\[
\text{OWA}(S_{a_1}, S_{a_2}, \cdots, S_{a_n}) = v_1S_{\beta_1} \oplus v_2S_{\beta_2} \oplus \cdots \oplus v_nS_{\beta_n}
\]

where \( v=(v_1, v_2, \cdots, v_n) \) stands for weighted vector, and it satisfies that \( v_i \geq 0 \) (\( i=1, 2, \cdots, n \)), \( \sum v_i = 1 \); \( S_{\beta_j} \) (\( j=1, 2, \cdots, n \)) stands for the \( j \)th number in language information; \( n \) stands for the number of attributes.

The essence of OWA operator is to arrange data from large to small, and the weight \( v_i \) reflects the importance of data position. The effects of subjective evaluations can be eliminated using OWA operator to assess language information, but the importance of data themselves may be ignored at the same time. Then LHA operator is defined as in Eq.(10) for this reason.

\[
\text{LHA}(S_{a_1}, S_{a_2}, \cdots, S_{a_n}) = v_1S_{x_1} \oplus v_2S_{x_2} \oplus \cdots \oplus v_nS_{x_n}
\]

where \( S_{x_j} (j=1, 2, \cdots, n) \) stands for the \( j \)th number among \((nw_1S_{a_1}, nw_2S_{a_2}, \cdots, nw_nS_{a_n}); w=(w_1, w_2, \cdots, w_n) \) stands for another weighted vector, which reflects the importance of data themselves and is independent of their location, for which it is called as the data weight.

4.2. Load forecasting of data centers

The process of load forecasting to a data center is as follows: 1) Data collecting; 2) To build up factor index system; 3) To calculate the two kinds of weight, \( v \) and \( w \), and then group decision-making of mixed language information is applied to PUE estimation [5]; 4) To calculate heat load of the data center; 5) To forecast the total power load of the data center according to PUE.

5. Case study

5.1. Case 1

A data center named A in northern China for example is taken to prove the applicability and accuracy of this method. Data center A mainly serves for science research and education, and the construction area is 17000 m\(^2\), which includes 8500 m\(^2\) of the server room. There are three experts who take part in the evaluation. The equipment factors are taken as an example to explain the detail process. The experts take the \( \tau = 4 \) language assessment scale. The results of the evaluation are shown in Table 1.

| Expert | Equipment power capacity | Thermal performance | Function |
|--------|--------------------------|---------------------|----------|
| 1      | \( S_3 \)                | \( S_0 \)           | \( S_3 \) |
| 2      | \( S_3 \)                | \( S_{1/2} \)       | \( S_3 \) |
| 3      | \( S_3 \)                | \( S_{4/3} \)       | \( S_3 \) |

Table 2. Final evaluation on the targets of equipment factors by 3 experts

| Expert | Equipment factors |
|--------|-------------------|
| 1      | \( S_{1.5} \)     |
| 2      | \( S_{2.13} \)    |
| 3      | \( S_{2.20} \)    |

Using Equation (10) and Equation (11), the two kinds of weight can be calculated: \( v_1=v_2=v_3=(0.25, 0.5, 0.25) \); \( w_1=(0.3333, 0, 0.3333), w_2=(0.4615, 0.0769, 0.4616), w_3=(0.4091, 0.1818, 0.4091) \). Then LHA operator is used, the two weights and evaluation result in Table 2, the final evaluation of
equipment factors comes out as shown in Table 2. As the process above, other evaluations can be assessed in this way. After getting all evaluations of each kind of factor, the PUE can be computed using OWA operator. PUE of data center A is 2.06.

The total heat load of data center A is 4111 kW. When 30% margin is considered, the cooling capacity of data center A is 5344.3 kW. According to PUE, the total power load of data center A is 10386.1 kW. The actual maximum load of this data center is 10513.5 kW on June 25th, 2015, which means the error is 1.21% and it can be accepted.

5.2. Case 2
Another data center named B is also in northern China, but it is an industrial data center whose scale is smaller than data center A. The construction area of data center B is 2500 m$^2$, which includes 1300 m$^2$ of the server room. Calculating process is just like that in subsection 5.1, and as a result, PUE of data center B is 2.58.

The total heat load of data center B is 847 kW. When 30% margin is considered, the cooling capacity of data center B is 1101 kW. According to PUE, the total power load of data center A is 1797 kW. The actual maximum load of this data center is 1823.1 kW on July 13th, 2015, which means the error is 1.45% and it is acceptable.

5.3. Comparison and Discussion
Comparing the two cases above, it can be seen that two data centers, A and B, have similar climatic conditions but different scales. For one thing, the equipment in data center A is newer than B. Therefore the radiating performance of the equipment in A is much better. Moreover, the building structure of A is better designed than B, and the larger scale allows more scientific arrangement for cooling system in A. These features lead to the result that PUE of A is better. It can be easily calculated that load density in data center A is smaller than B. Besides the different functions, the development of the two data centers also contributes to this result. Data center A is a new one, which means it can contain more severs in the future and the power load of A may increase rapidly. On the other hand, data center B has operated for 8 years, and its power load has already been saturated.

6. Conclusion
A load forecasting method of data centers based on PUE is proposed. The scientific basis for power network planning can be provided by quantifying qualitative language information with geographical factors, structural factors, equipment factors, and so on. And the applicability and accuracy of this method is proved according to the application and the comparison of two cases.

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