The effect of layout of finned tube heat exchangers in a novel cooling system on the thermal environment in data centers

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Abstract. Data centers undertake transfer, calculation, and store of important information, whose suitable thermal environment is necessary for the safe and reliable operation of information technology (IT) equipment. However, in case of the emergency failure or power outage of the air-conditioning system, the inappropriate thermal environment cannot keep the proper operation of IT equipment. Therefore, a novel cooling system is proposed to maintain the thermal environment of server rooms, in which the liquid nitrogen as refrigerant flows into the spiral finned tube heat exchanger (FTHE) by phase changing to take away indoor heat. The effect of horizontal spacings and heights of the FTHE on the thermal environment are investigated numerically. The results display that the indoor air temperature is divided by FTHE. When the height of FTHE is 2.6~2.9 m, the higher the FTHE, the more uniform the indoor temperature distribution. When the FTHE is higher than 3.2 m, the maximum temperature of the heat source is more than 62.6°C, exceeding the temperature tolerance limit. In addition, if space permits, the dislocation layout and the fixed layout can be selected, which perform well in both temperature uniformity and heat source cooling. This investigation provides support for the arrangement of the novel cooling system.

Keywords: Data centers, Finned tube heat exchanger, Thermal environment, Performance analysis

1 Introduction

As a result of the work of data storage, network communications and computing stations, scale and number of data centers have rapidly expanded globally ([1]). Therefore, the amount of data processed has increased exponentially, and data centers have to use redundant power supplies (including emergency generators, uninterruptible power supply (UPS) systems, etc.) to enhance stability ([2]). Cooling is also necessary for information technology (IT) servers ([3]). The Ponemon Institute investigated 63 data centers that had been interrupted unexpectedly. The main reasons for the power outage were failures in the UPS and the cooling system ([4]). The failure of the air conditioning system in data centers will stop the heat transfer from IT equipment, and even paralyze the entire data center, causing huge losses ([5]). How to deal with accidents such as power outages and ensure the uninterrupted operation of data centers has become the focus in recent years.

Lin et al. ([6]) simulated the air temperature rise characteristics of the data center after a power outage, and proposed corresponding temperature control strategies. Nada et al. ([7]) controlled the flow of cold air to limit the possibility of heterogeneous temperature distribution. Qiang et al. ([8]) created a temperature control system based on cloud computing that reduced operating energy consumption by about 10% while ensuring the cooling effect and reliability. Zhu et al. ([9]) made a new model for diagnosing and evaluating the operational risks of air conditioning systems in data centers. It worked well in all situations, and the correct diagnosis rate was as high as 94.17%. Liu et al. ([10]) set a chilled water storage tank as a backup cold source in the event of a grid failure, but they ignored the cooling effect of the cold storage tank and the running time after a power outage.

In summary, regarding the research of cooling systems of data centers, scholars have shifted their focus from energy conservation to reliability in recent years. However, installing redundant cooling equipment that relies on a stable power supply for reliability will increase energy consumption, and once the UPS fails during a power outage, the cooling system cannot operate normally. Therefore, a novel cooling system is proposed to maintain the thermal environment of data centers, in which the liquid nitrogen as refrigerant flows into the spiral finned tube heat exchanger (FTHE) in data centers by phase changing to take away indoor heat. The system is able to maintain a steady cooling capacity while using a little electricity. The effect of horizontal spacings and heights of the FTHE on the thermal environment are investigated numerically.

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2 Methodology

Taking an actual data center as the research object, the model of the server room is established by SolidWorks, as shown in Figure 1. The size of the server room is 20.7 m * 6.85 m * 4 m, and there are cabinets, four air inlets, four air outlets, and FTHE. There are 32 cabinets distributed in the four corners of the server room, whose total heat is 43.76 kW, each with a size of 1 m * 0.8 m * 2.4 m. The wall of FTHE is made of stainless steel, and the material of its fins and the wall of the cabinet are aluminium. The realizable k-ε model and the DO radiation model are adopted.

![Typical data center model](image)

**Fig. 1.** Typical data center model.

In addition, an experimental platform for the novel cooling system is built to verify the accuracy of the simulation model. According to the layout of the experimental platform, a simulation model of the experimental room is built, whose material parameters, boundary conditions and solution model use the same settings as the actual data center simulation model. The total heating power of the experimental platform is 3.46 kW, because the volume of the experimental platform is about 0.078 times that of the actual server room. The experimental platform and its simulation model are shown in Figure 2.

![Experimental platform and its simulation model](image)

**Fig. 2.** Experimental platform and its simulation model of the novel cooling system.

Figure 3 displays the comparison results between the simulation and experimental values of temperature at measuring points, located inside the cabinet, at the cabinet outlet and on the cabinet top. The temperature trends of different measuring points are basically the same, and the deviations are within ±10%, so the model is considered reasonable.

3 Results and discussion

As the main equipment of the novel cooling system, a reasonable arrangement of FTHE can not only upgrade the thermal environment, but also save liquid nitrogen to improve the economy of the system. However, the installation space for FTHE is limited greatly, because the arrangement position of FTHE should exclude the equipment, including fixed cabinets, air ducts, and bridges. When the indoor air is cold, the density will increase and the air will move downward. Therefore, the suspended ceiling layout can save space and promote the downward movement of cold air better. As the liquid nitrogen temperature increases during the heat exchange, the system inlet section should be placed where the heat accumulates. Therefore, the arrangement in which the working fluid flows from the middle of cabinets to both sides can ensure sufficient heat exchange between the working fluid and the indoor air, as shown in Figure 4.

![Inlet position and direction of FTHE](image)

**Fig. 4.** Inlet position and direction of FTHE.

3.1 Influence of the horizontal spacing of FTHE on the thermal environment in the data center

The temperature field of the computer vary with the horizontal distance between FTHE and cabinets. Therefore, the effects of different layout distances with the 2.6 m height on the thermal environment of the server room are studied. According to the relative positions of FTHE with the cabinet, four spacings are proposed as shown in the figure 5.

![Layout of FTHE with different horizontal spacings](image)

**Fig. 5.** Layout of FTHE with different horizontal spacings.
Fig. 6. Temperature variation with height on the axis of the data center at four spacings of FTHE.

Figure 6 depicts the temperature variation with height on the axis of the server room at four spacings. On the whole, the indoor air temperature is divided by FTHE. The temperature below is low and stable, but the temperature above increases rapidly. The overall temperature at Spacing 1 is highest. The temperature polylines for Spacing 3 and 4 almost completely coincide. Compared with them, the temperature of Spacing 2 in the upper part is slightly smaller and that in the lower part is a little higher. The difference between these two parts is 9.3°C, which is feasible.

Fig. 7. Temperature field on the section Y=1.8 m of the data center at four spacings of FTHE.

Figure 7 illuminates the temperature distribution on the Y=1.8 m section at four spacings. The temperature ranges of the heat source surface under four spacings are 20.4~55.3°C, 22.4~40.8°C, 23.4~43.4°C, and 21.5~49.1°C, respectively. At Spacing 3 and 4, the increased distance from FTHE to the cabinet leads to an extension of the cold air supply distance, so the local temperature of the heat source increases, whereas the maximum temperature of the heat source in Spacing 2 is the lowest, and the temperature range is minimal. Thanks to the two sets of FTHE above the cabinet, the hot air in the cabinet directly exchanges heat with them as it flows to the room. After the temperature drops, part of the air continues to flow upward so as to cool the upper part of the room. Although the novel cooling system at Spacing 2 can maintain the ambient temperature within the normal range, there is always a temperature stratification phenomenon of the data center with FTHE as the dividing line.

3.2 Influence of the height of FTHE on the thermal environment in the data center

FTHE are arranged at heights of 2.6 m, 2.9 m, 3.2 m, and 3.5 m based on Spacing 2. Figure 8 indicates the temperature distribution on the X=4.5 m section of the server room at different heights. The increased height of FTHE alleviates temperature stratification, but the heat dissipation of the heat source deteriorates, causing the temperature inside the cabinet to rise. For example, when FTHE are heightened from 3.2 m to 3.5 m, the maximum temperature of the heat source increases from 62.6°C to 79.8°C, which is unacceptable and dangerous.

Fig. 8. Temperature field on the X=4.5 m section of the data center at four heights of FTHE based on Spacing 2.

Fig. 9. Temperature of measuring points at four heights of FTHE based on Spacing 2.

Figure 9 presents the temperature of the points shown in Figure 8(a) at different heights of FTHE. At the same height of FTHE, the temperature near the heat source inside the cabinet is significantly higher than that of the upper and lower parts of the server room where there is no noticeable change of temperature. When the height increases from 2.6 m to 2.9 m, the temperature of the measuring point at 3.4 m decreases from 31.2°C to 23.6°C. The reason is that the higher FTHE results in a longer distance to the upper inlet of the cabinet. The cold air near FTHE no longer flows vertically downward, but
moves closer to the middle of the room, and spreads out. The high temperature and low flow rate of the air entering the cabinet make it impossible for the heat source to cool directly. Therefore, raising height of FTHE helps create the satisfactory thermal environment of the data center, but excessive height may exceed the temperature tolerance limit.

3.3 Influence of other layouts of FTHE on the thermal environment in the data center

Based on the Spacing 2, there are two layouts proposed, as shown in Figure 10. One is the dislocation layout with low in the middle (2.6 m) and high on both sides (3.2 m). The other is the mixed layout, the combination of the upper sides layout and the 2.6 m ceiling layout. The mixed layout appears the temperature stratification with 2.6 m height as the dividing line, whereas that of the dislocation layout appears at 3.3 m.

![Fig. 10. Temperature field on the X=4.5 m section of the data center under the dislocation and mixed layouts based on Spacing 2.](image)

Figure 11 presents a line graph of the temperature variation of the points shown in Figure 10, including the 2.6 m fixed height layout. Overall temperature distribution in the dislocation layout and the mixed layout is more uniform than that at 2.6m fixed height layout. In the cabinet, as the height of the location point increases, the temperature increases in the beginning and then slows down, while the temperature in the upper part of the room remains stable. In the dislocation layout, the temperature trend inside the cabinet is basically the same as that of the 2.6 m fixed height layout, but the temperature in the upper part of the room drops by about 4.5°C. Under the 2.6 m ceiling layout, the temperature in the upper part of the room is the highest, followed by the mixed layout at about 25.5°C. In general, the cooling effects of these three forms are similar, so they can be flexibly adopted according to the actual situation of the server room.

4 Conclusions

This paper mainly simulates the influence of different FTHE arrangements on the thermal environment in the data center through CFD. The conclusions are as follows:

(1) Horizontal layouts of FTHE cannot solve indoor temperature stratification. The temperature of the server room is divided by FTHE. The air temperature in the lower layer of the server room is low and stable, but the air temperature in the upper layer rises sharply. When FTHE are above and on both sides of the cabinet, the temperature distribution is relatively reasonable.

(2) Heightening FTHE appropriately promotes the temperature uniformity, but excessive height may exceed the temperature tolerance limit. When FTHE are heightened from 2.6 m to 2.9 m, the temperature at the upper area of the server room decreased from 31.2°C to 23.6°C. However, when the height rises from 3.2 m to 3.5 m, the maximum temperature of the heat source increases from 62.6°C to 79.8°C, which is unacceptable and dangerous.

(3) When the indoor space allows, the dislocation layout and the mixed layout of FTHE perform well in both temperature uniformity and heat source cooling. The dislocation layout appears the temperature stratification with 3.3 m height as the dividing line, which provides a reference for the flexible layout of FTHE.

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