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Numerical study on the thermal environment of UFAD system with solar chimney for the data center

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Abstract

To improve the thermal environment in the data center, a solar chimney was integrated with Under-floor Air Distribution (UFAD) system in the Computational Fluid Dynamics (CFD) software Airpak. By using the validated model, three types of solar chimney, such as solar chimney transversely over the hot and cold aisles, solar chimney lengthways above the cold or hot aisles, were simulated. The comparison between the model calculation result shows that all types of solar chimneys used in this paper has great potential in providing a better temperature and airflow distribution. Especially in the case of the solar chimney above the cold aisle, the temperature in upper zone of cold aisle can be decreased by 13°C, and the temperature field inside the rack is improved greatly without any additional power.

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Keywords: UFAD; data center; solar chimney; Airpak

1. Introduction

The power consumption of air-conditioning in data center usually accounts for a large proportion of the total energy consumption [1, 2]. A completely filled equipment rack in data center can generate 3kW heat or more, releasing within a relative small area unevenly [3, 4]. The characteristic of high heat and uneven distribution in data

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center requires air-conditioning running in cold mode throughout the year [5], and putting forward higher requirement to the air-conditioning system.

UFAD system is widely used in office building and data center [6]. Compared with the conventional overhead (OH) system, UFAD system adopts a warmer supply air temperature, an under floor supply air plenum, localized air distribution (with or without individual control), the solutions used for perimeter systems, and floor-to-ceiling airflow pattern, etc [7]. Instead of the deep study in the office building [8-10], still few papers focus on the methods to improve the thermal environment and energy saving in data center though increasing rapidly [11]. Indeed, the temperature in many data center exceeds the limit value specified in the standards [12-14]. To resolve this problem, the common approach is to increase the cooling load. But the fact of higher temperature in data center is because the poor discharge of the hot air cycling in the upper zone deteriorating the indoor thermal environment. More cooling load results in a huge waste of energy and increased burden of power system.

Solar chimney is an ideal way to enhance natural ventilation and discharge hot air [15]. In this paper, three kinds of typical solar chimney [16-18] were employed in the model separately, which can not only provide the power to exhaust hot air in the upper zone but also realize a more reasonable distribution of temperature and airflow in both the room and racks.

Nomenclature

ρ	density vector
υ	velocity vector
p	static pressure
τ	stress tensor
ρg	gravitational body force
F	other source terms that may arise from resistances, sources, etc
h	sensible enthalpy
S_h	the source term that includes any volumetric heat sources defined
k	molecular conductivity
k_t	the conductivity due to turbulent transport ($k_t=c_p\mu_t/Pr_t$)

2. Data center description

A data center (10m × 6m × 3.45m) with 10 racks (0.6m× 1.1m × 2.2m) evenly placed in two parallel rows spaced by 1.4m in it was constructed. Every rack was divided into 6 layers with perforated thin plate (separators), and both the front and back doors of racks were also made of perforated thin plate. To discharge the heated air effectively, three exhaust fans were installed evenly along the lengthwise direction on the top of the each rack. The space between the back doors of the racks and walls were the hot aisles, and cold aisle was the space between the front doors of racks. Ten grill vents (0.6m × 0.6m) were placed in the floor. In order to adjust the air balance of the grill vents conveniently, a rectifying plate was installed in the air supply plenum. The schematic diagram and the top view of the data center were shown in Fig.1 and Fig.2.

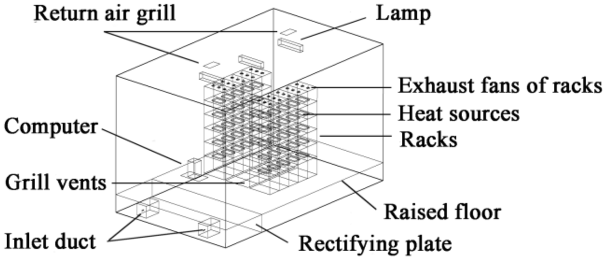


Fig. 1. The schematic of the data center.

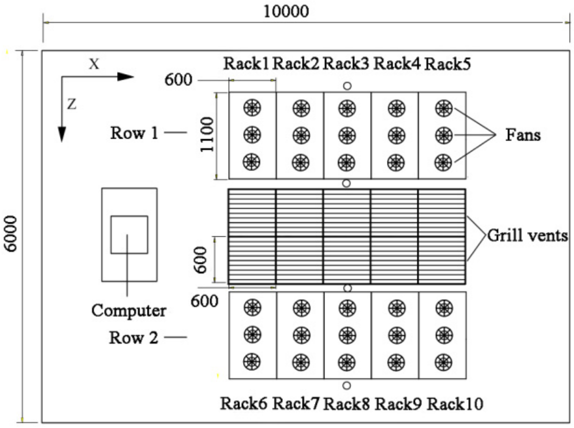


Fig. 2. Top view of the data center.

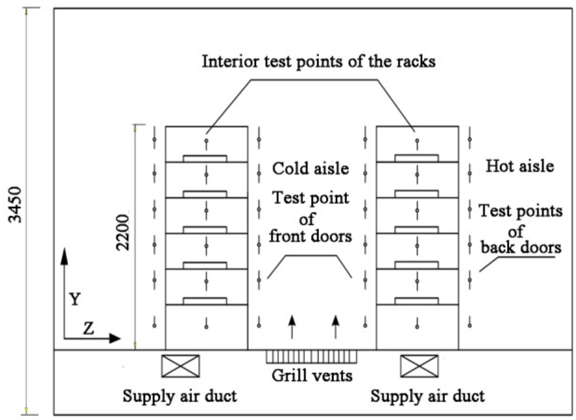


Fig. 3. The distribution of the test points.

The temperature inside the rack 1 and the rack 10, and the temperature located near the front and back doors of rack 3 were selected to study the thermal environment both in the interior and exterior of the racks. Heat sources were used to simulate the heating equipment in the data center, and every rack was configured with four experimental and one candidate 0.75kW heat sources. Each layer of racks was configured with one thermocouple. The interior test points of the racks were at the horizontal center of cross section with individual vertical heights of 0.27m, 0.62m, 0.97m, 1.40m, 1.67m, and 2.02m at each layer. The test points in the exterior of the racks were 0.15m away from the front and back doors. The distribution of the test points can be seen in Fig.3. The distribution of temperature in this data center was tested by the thermocouples located near the front and back doors of the central racks in each row (x=5.7m).

3. Numerical simulation

According to the description of the data center, a model was established in the CFD software Airpak. The indoor zero-equation model, RNG *k-ε* turbulence model, *k-ε* two-equation model and other turbulence models were included in the Airpak [19, 20]. For the ideal effect to calculate as well as the better stability and convergence, indoor zero-equation and SIMPLE algorithm were applied in this model [21, 22]. Four assumptions are proposed to simplify the matter.

- Air flow conforming to the Bossinesq hypothesis is incompressible flow, and steady turbulence.
- The heat dissipation caused by viscous force, and the heat storage by the wall of chimney can be ignored.
- Air leakage is negligible in this model.
- Environmental parameters of outdoor, such as outdoor temperature and solar radiation are constants.

The governing equations are given below according to the assumptions [23].
Momentum equation:

$$\frac{\partial}{\partial t}(\rho \upsilon) + \nabla \cdot (\rho \upsilon \upsilon) = -\nabla p + \nabla \cdot (\tau) + \rho g + F \tag{1}$$

Energy conservation equation:

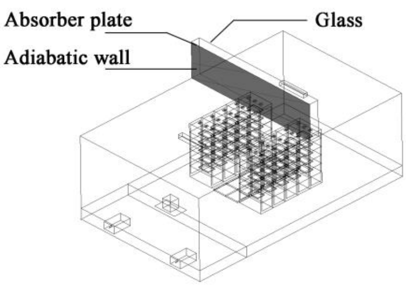
$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot (\rho h \upsilon) = \nabla \cdot [(k + k_t)\nabla T] + S_h \tag{2}$$

The parameters of the discretization solution were shown in Table 1.

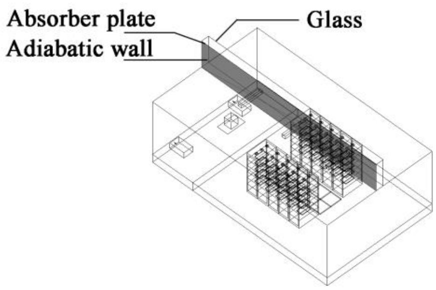
Table 1. The parameters of the discretization solution.

Convergence criteria	Solution	Variables		
		Pressure	Temperature	Momentum
Flow: 1×10^{-3}	Discretization scheme	Second	Second	Second
	Under-relaxation	0.7	0.3	0.3
Power: 1×10^{-6}	Solving format	AMG	AMG	AMG
	Type of the linear solver	V	Flex	Flex

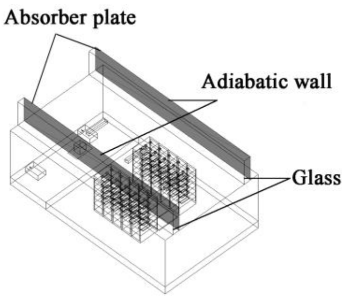
The air temperature of supply and return were 17°C and 35°C respectively. The air volume flowrate of total supply and one exhaust fan on the top of racks were 8000m^3/h and 220m^3/h separately. The three types of solar chimney shown in Fig.4 (a) to Fig.4 (c) were employed in this model. Fig.4 (a) was the model with solar chimney transversely over the hot and cold aisles along the Z direction. From the Fig.4 (b) and Fig.4 (c), we can see that the solar chimney was installed above the cold and hot aisles along the X direction separately. All these types of solar chimneys have the same dimension (0.4m × 1.5m) in the scale of width and height. The heat flux in these models is 400W/m^2.



(a)



(b)



(c)

Fig. 4. (a) Solar chimney transversely over the hot and cold aisles; (b) Solar chimney above the cold aisle; (c) Solar chimneys above the hot aisles.

4. Results and discussion

Case 1 is the result without solar chimney while case 2 to case 4 are the results with the different types of solar chimney, and the details are below:

- Case 1: Without solar chimney
- Case 2: Solar chimney transversely over the hot and cold aisles
- Case 3: Solar chimney above the cold aisle

- Case 4: Solar chimney above the hot aisles

The simulation results of the temperature and airflow field were shown below, and the details are given as follows:

Case 1: Fig.5 (b) and Fig.5 (d) show that some of the supply air vent from back doors of the racks, and others exhausted by the fans on the top of the racks with higher temperature after cooling the heat sources. Then, part of hot air returns to the Air Handing Units (AHU) from the ceiling, and others go back to the lower zone to mix with the cold air, which deteriorates the cooling ability of supply air especially for the racks at higher layers. Therefore, the poor distribution and higher temperature are produced both inside and outside the higher layers of racks (Fig.5 (a) and Fig.5 (c)).

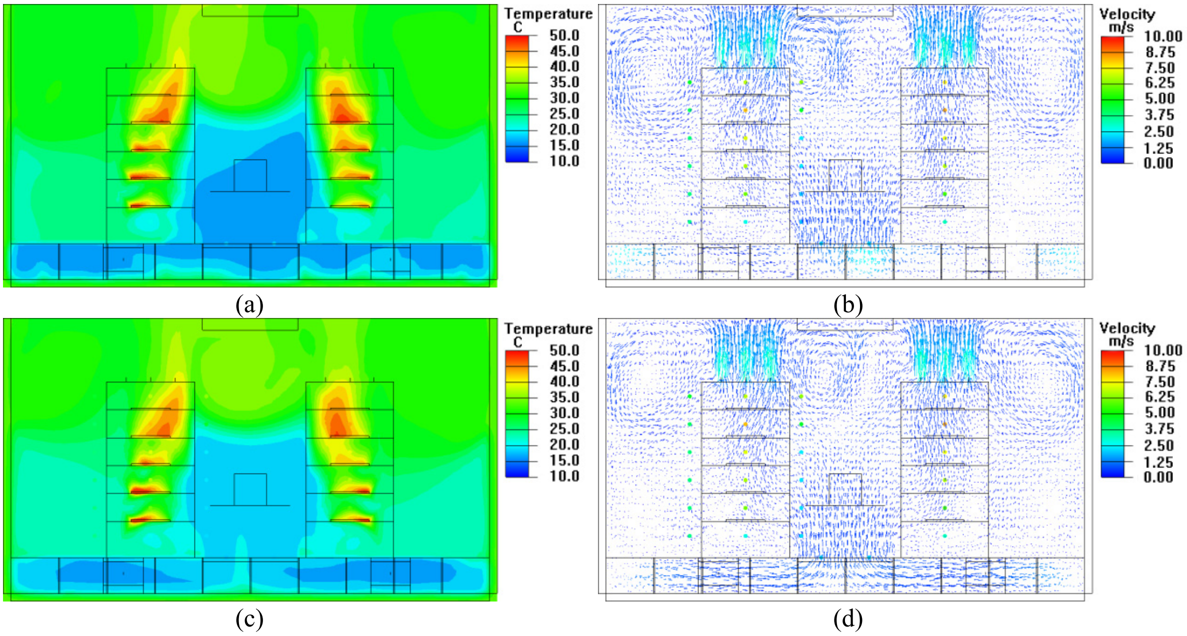
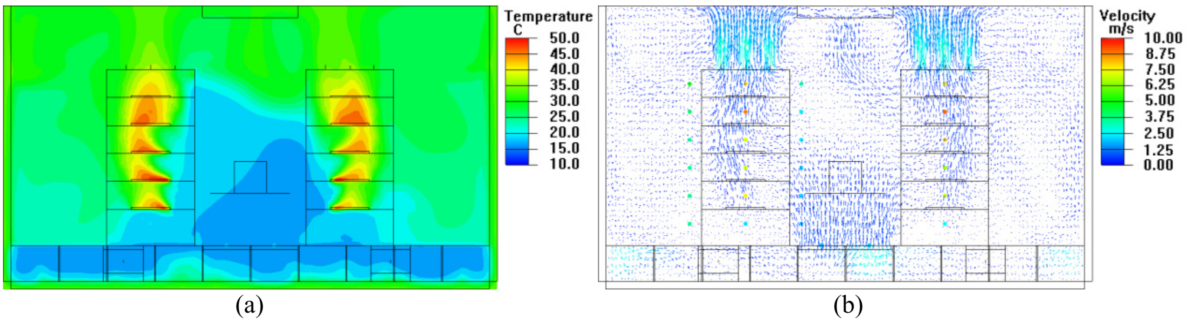
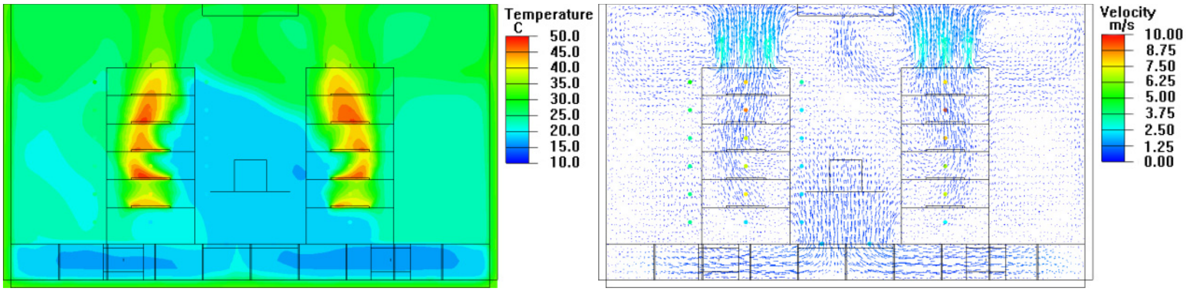


Fig. 5. (a) Case 1: Temperature field in rack1; (b) Case 1: Airflow field in rack 1; (c) Case 1: Temperature field in rack 10; (d) Case 1: Airflow field in rack 10.

Case 2: From the Fig.6 (b) and Fig.6 (d), the distribution of airflow as well as the height of stratification was largely improved both in the cold and hot aisles. But as is shown in Fig.6 (a) and Fig.6 (c), the temperature field for the higher layer inside the racks obtains little improvement while the distribution of temperature for the lower layer is deteriorated. The results also show that the serious imbalance of supply air was caused by this type of solar chimney.

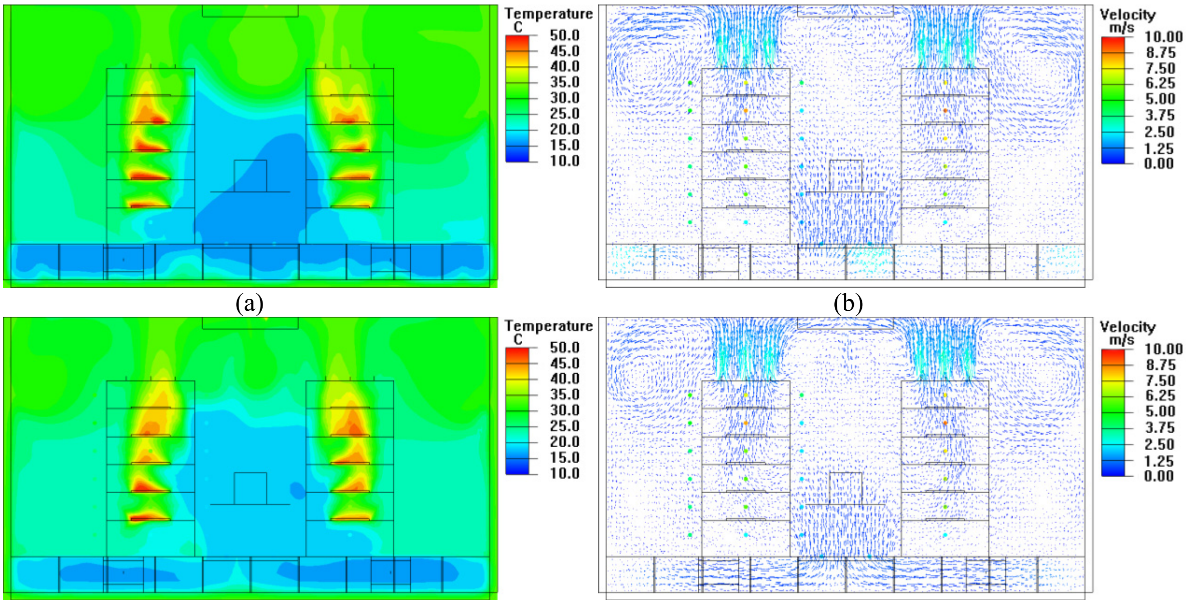




(c) (d)

Fig. 6. (a) Case 2: Temperature field in rack 1; (b) Case 2: Airflow field in rack 1; (c) Case 2: Temperature field in rack 10; (d) Case 2: Airflow field in rack 10.

Case 3: Hot air cycling in the upper zone is discharged from the solar chimney effectively so as to the height of stratification is lifted greatly, which is shown in Fig.7 (b) and Fig.7 (d). From the Fig.7 (a) and Fig.7 (c), the exhaust from the top of the racks is strengthened by the thermal pressure in order that more cold air can enter the racks. Therefore, the cooling effect inside the racks is largely improved without any additional power by using this type solar chimney.



(a) (b)

(c) (d)

Fig. 7. (a) Case 3: Temperature field in rack 1; (b) Case 3: Airflow field in rack 1; (c) Case 3: Temperature field in rack 10; (d) Case 3: Airflow field in rack 10.

Case 4: Instead of the lifting the height of stratification in the hot aisles, the distribution of airflow shown in Fig.8 (b) and Fig.8 (d) were nearly the same as the model without solar chimney in the cold aisle. Due to the effect of thermal pressure, the thermal environment inside the racks is superior to the model without solar chimney obviously. But the poor temperature field in the upper zone of cold aisle still weakens the cooling effect in the higher layer of racks (Fig.8 (a) and Fig.8 (c)).

From the analysis of case 1 to case 4, all the types of models with solar chimney can improved the distribution of temperature and airflow. Case 3 and case 4 are advantageous to others for the temperature inside the racks. The temperature in the front of the rack doors in case 2 and case 3 were lower than others in the upper zone by 13°C to 15°C (Fig.9 (a)). The temperatures in the back of the rack doors shown in Fig.9 (b) were similar to each other for all of the cases. From what has been discussed above, we may reasonably arrive at the conclusion that case 3 is the optimal way to improve the thermal environment in the data center.

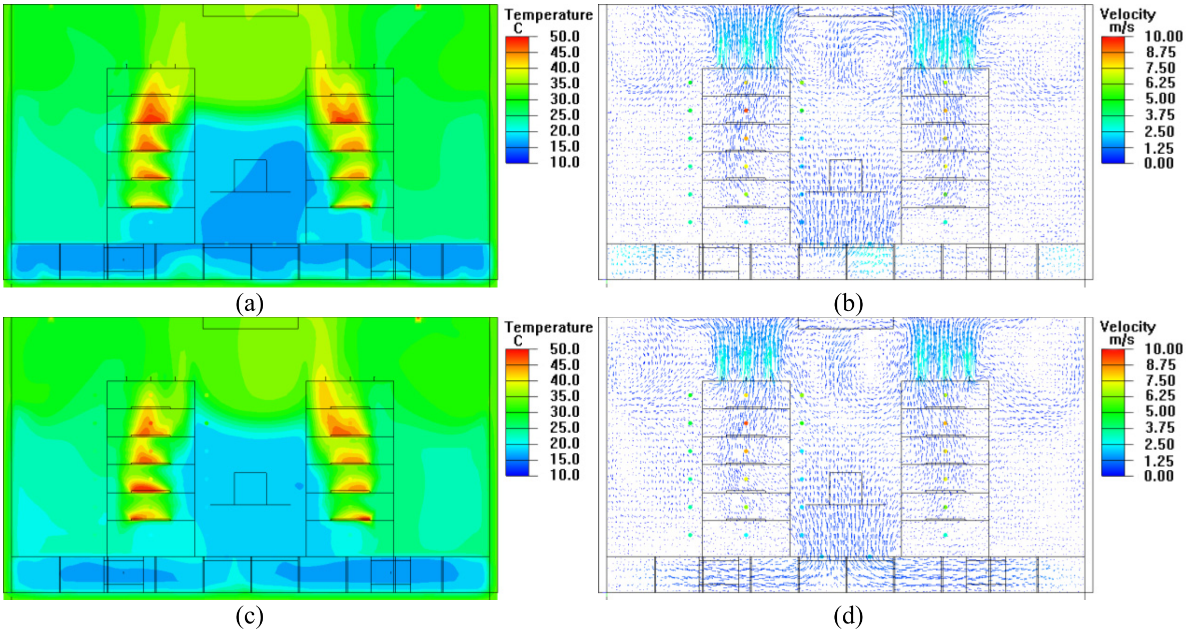


Fig. 8. (a) Case 4: Temperature field in rack 1; (b) Case 4: Airflow field in rack 1; (c) Case 4: Temperature field in rack 10; (d) Case 4: Airflow field in rack 10.

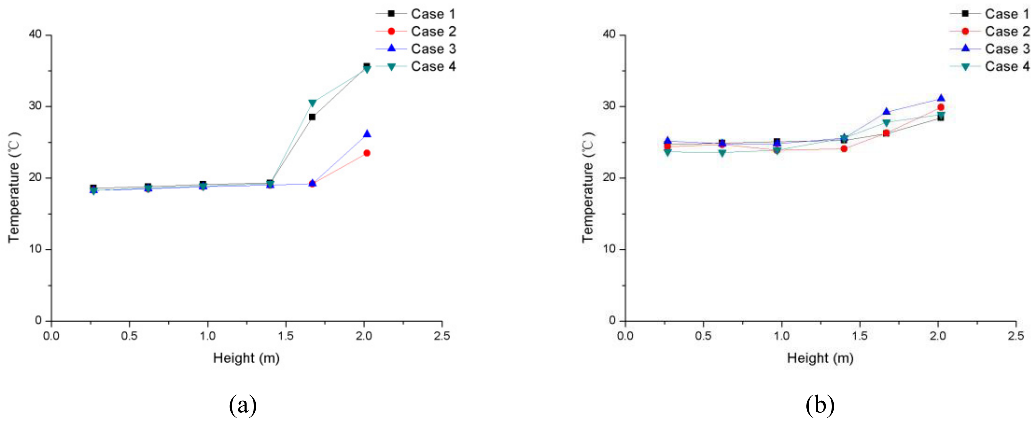


Fig. 9. (a) The temperature in the front of the rack doors; (b) The temperature in the back of the rack doors.

5. Conclusions

Solar chimney is an ideal way to improve the thermal environment of the data center with UFAD system. By using the validated model, three kinds of typical solar chimney were employed separately, which can not only provide the power to exhaust air but also realize a more reasonable distribution of temperature and airflow in both the room and racks.

The comparison between the model calculation result shows that the solar chimney installed above the cold aisle is more effective to this system, in which the temperature in upper zone of cold aisle can be decreased by 13^{o}C, and the temperature field inside the rack is improved greatly without any addition power.

The application of solar chimney in data center with UFAD system can acquire a better cooling effect by the way of improving the distribution of temperature and airflow rather than increasing cooling load, subsequently decreasing the waste of energy and the burden of power system.

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