ENERGY-SAVING AND EMISSION REDUCTION SYSTEM OF DATA CENTER HEAT PIPE BASED ON LATENT HEAT OF WATER EVAPORATION

by

Jinhui ZHAO, Panle WANG**, Jingshun LI, Tianwei GU, and Jiaxu LU

School of Mechanical and Power Engineering, Zhengzhou University, Zhengzhou, China

Original scientific paper
https://doi.org/10.2298/TSCI2205475Z

To address the current problem of high energy consumption in data centers, this paper proposes a data center heat pipe air-conditioning system based on the latent heat of water evaporation, which uses the latent heat of water evaporation for cooling by creating a low pressure environment to evaporate large amounts of water. In order to verify the effect of the system, a heat pipe test bench based on the latent heat of water evaporation was designed and built. Compared with the traditional heat pipe in the data center for heat dissipation, the performance and economy of the water evaporation latent heat pipe system designed in this paper are analyzed experimentally. A multi-physics coupled model of water evaporation latent heat pipe air-conditioning based on COMSOL Multiphysics was established to simulate and study the temperature field and velocity field distribution of water evaporation latent heat pipe air-conditioning system in data centers. The research shows that:

- *Under the designed test conditions, compared with the traditional heat pipe system, the water evaporation latent heat pipe air conditioner can conduct 2540 kJ more heat in one day in an outdoor environment of 24 °C.*
- *At an ambient temperature of 3 5°C and an indoor temperature of 25.8 °C, the cooling capacity of the heat pipe in the data center water evaporation latent heat pipe air-conditioning system is twice the cooling capacity of the air conditioner, and the heat pipe can work efficiently regardless of the outdoor ambient temperature.*
- *The energy-saving effect of the latent heat pipe of water evaporation in the data center has a significant effect on air conditioners with an energy efficiency rating (EER) lower than 2.5-4.4. It can improve the energy efficiency of level 5 with an EER of 2.5 to level 2 with an EER of 3.22, greatly reducing the power consumption of the data center air-conditioning system. When the EER of the air conditioner exceeds 4.4, the coefficient of performance of the data center water evaporation latent heat pipe air-conditioning system will be lower than that of the air conditioner itself.*

Key words*: data centre, latent heat of water evaporation, heat pipe, energy saving and emission reduction, numerical simulation*

*Corresponding author, e-mail: wang_pl18079944190@163.com

Instruction

The rise and development of the third industrial revolution, represented by the information technology industry, has driven the widespread construction of data centers. Data center is a special type of building used to centrally place and manage all kinds of IT equipment (such as servers, high-performance computers, workstations, *etc.*) and their supporting facilities (power supply, lighting, air-conditioning, *etc.*) to realize the functions of storage, communication and network services for a large amount of data and provide real-time and efficient information processing services for users with different needs. With high heat density per unit area of data center and continuous operation throughout the year, global IT-related carbon emissions reach 1.54 billion tons, accounting for 5% of total global carbon emissions, making it one of the major sources of greenhouse gas emissions. The energy consumption composition of the data center is shown in fig. 1.

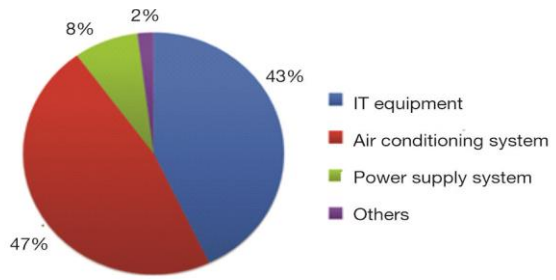

Figure 1. Composition diagram of data center energy consumption

As you can see, data center energy consumption is mainly concentrated on server IT equipment and air-conditioning system, among which electricity consumption of air-conditioning system accounts for about 47% of the total electricity consumption of data center, being the largest auxiliary equipment of data center energy consumption. Such high energy consumption not only increases operating costs, but also leads to unsatisfactory power usage effectiveness (PUE). As of 2019, the average PUE level of large and ultra-large data centers in China is around 1.5. China's *Fourteenth Five-Year Plan* for energy conservation and emission reduction proposes to further promote the substantial improvement of energy utilization efficiency, the continuous reduction of the total discharge of major pollutants, and the realization of a series of carbon peaking and carbon neutrality requirements such as energy conservation, carbon reduction, pollution reduction, synergy and efficiency, and continuous improvement of ecological environment quality. In order to achieve the *Fourteenth Five-Year Plan* energy saving and emission reduction targets, how to reduce data center energy consumption and improve energy use efficiency has been an important direction for data center development. Among them, heat pipe technology has become one of the important technology forms to realize data center air-conditioning system because of its low cost and low energy consumption.

Domestic and international scholars have achieved relatively more research results on application of data center cooling technology and the application of heat pipes. Sun and Qian [1] used heat pipes as heat exchangers between the interior of the server room and the outdoor air to efficiently utilize the natural outdoor cooling source while avoiding the direct entry of outdoor air into the interior of the server room. Jing *et al.* [2] effectively combined the flat micro-heat pipe array with the porous channel parallel flow pipe, and designed the end of a new indoor side micro-heat pipe array type air-water heat exchanger, which uses natural cooling energy to dissipate heat and cool the overall environment of the data room in winter or transitional seasons. Wang *et al*. [3] proposed a new heat pipe type server room air conditioning system, and designed and manufactured a prototype heat pipe type server room air conditioner with a rated cooling capacity of 13 kW. Under the premise of not increasing the cost, the annual energy efficiency of the heat pipe type computer room air conditioner is 40% and 20% higher than that of the fixed speed type and variable frequency computer room air conditioner with the same capacity. He *et al.* [4] elucidated the applicability and energy efficiency of heat pipe air conditioning systems in high heat generation density server rooms. The study shows that the heat pipe air conditioning system can achieve an annual power saving rate of about 20% while ensuring the heat dissipation requirements of the server room. Liu *et al.* [5] established a theoretical analysis model of separated heat pipe cooling system for data rooms, and proposed a method that can be flexibly configured according to the heat load and the actual server room, with low construction cost and effective adaptation to the existing air conditioning system of the server room. Zhang *et al.* [6] explored cold plate liquid cooling technology and its application in data center thermal management. Gan *et al.* [7] constructed a 1-D steady-state model of micro heat pipes (MHP) of equilateral-triangle cross-section has been constructed with the incorporation of a natural convection heat sink surrounding the condenser section. Subsequently, they used the model to address some of the issues associated with a copper-water MHP whose condenser section is immersed in nominally quiescent cooling water. Borodinecs *et al.* [8] studied already-installed air-cooling equipment with a direct evaporative cooling system for the creation of two regression models of electricity consumption representing the *on* and *off* sequences to examine the potential advantages of air-cooled equipment using direct evaporative cooling technology versus cooling equipment not using this technology. The results of the study facilitate further research in this area, particularly in the analysis of various materials for insulated pre-cooling pads, and the possibility of using newly developed metal pre-cooling pads. Yang *et al.* [9] provides an updated review of the research progress for solving problems of indirect evaporative cooling (IEC). Based on the results, IEC is expected to contribute more to the reduction of energy consumption for air conditioning in buildings. The current state of knowledge and research directions of dew-point IEC is presented by Pacak and Worek [10]. It was found that the researchers focused on the development of dew point IEC by improving its design, geometry, water distribution method, and the implementation of new porous materials. Potential directions of evaporation technology are pointed out, such as improving the coefficient of performance of solid dehumidification evaporative cooling systems, developing new geometries, efficient water distribution, including the development of porous materials, *etc*. Tushar and Mandar [11] experimentally tested the performance of three different heat pipe heat exchanger structures using distilled water as the working medium. Deng *et al.* [12] proposed the use of split heat pipe technology to harness the available cold energy from automotive air conditioners. Experiments were conducted to validate the proposal. It was found that it is feasible to use split heat pipes to deliver the cold energy from LNG to MAC. Moreover, the cooling capacity of the MAC increased with the LNG consumption and air flow rate. Tan and Zhang [13] optimized the heat pipe structure of WIHP, optimized the RESL by time period weighted average temperature, and preferred a large diameter heat pipe. The effect law of heat pipe structure on heat transfer coefficient such as operating temperature, evaporation section length ratio (RESL), and heat pipe diameter was analyzed to enhance the heat transfer performance of WIHP. The results show that the average equivalent heat transfer coefficient (EHTC) of WIHP reaches the maximum value of 1.24 W/(m^2°C) at 75% RESL, and the RESL should be optimized based on the weighted average temperature of the time period. A systematic review of existing heat pipe systems for data center applications is presented by Li *et al.* [14]. The heat transfer mechanisms of heat pipe systems are described from the perspective of evaporators and condensers. The effects of the type of work material, work material charge ratio, geometric parameters and operating parameters on the thermal performance of heat pipe systems are further discussed. Energy efficiency and environmental analysis of stand-alone heat pipe systems and heat pipe integrated systems are investigated. Changchun Institute of Technology [15] conducted a study on the heat transfer performance of a new pulsating heat pipe heat sink for CPU cooling. Thermo-siphon and its integrated system have obvious advantages over other free cooling methods and have great potential for application in data center cooling. The current status of research on thermo-siphon and its integrated system is reviewed by Zhang *et al.* [16]. The characteristics of the existing designs are compared and the shortcomings of the existing research are summarized. Salih *et al.* [17] demonstrated the effect of induced CRAH bypass on the optimization of heat dissipation in closed-aisle data centers and used the validated FNM in conjunction with a thermodynamic model of the cooling infrastructure confirmed the existence of an optimal BP fraction that minimizes the combined power consumption of the cooler and CRAH fan. Ikeda *et al.* [18] designed a system for cooling the medium in a high-table culture system using the latent heat of water evaporation. The heat of the medium evaporated the water and thus cooled the medium. The temperature of the medium measured at 5 cm below the surface (medium depth 10 cm) was 5~6 ℃ lower than the control without the cooling system. Moreover, when air was circulated by a fan placed under the bench, the temperature at a depth of 5 cm was more than 10 ℃ lower than the control. Ali *et al.* [19] proposed a new system that meets the comfort conditions by considering both dome and evaporative cooling channel technologies. The results obtained show that the dome diameter and cooling channel size have significant effects on the system performance, and the proposed system can provide the required air change per hour at wind speeds of 0.8~3.2 m/s. Ramy *et al.* [20] present a chronological review and discussion of published patents and describe different configurations of IEC devices. It gives the criteria and evaluation parameters used to characterize the performance of IEC devices. The review shows that convective air heat exchange on the dry side of the IEC heat exchanger is usually a limiting factor for the size of the IEC device to be built.

Evidently, most of the current data center heat pipe air-conditioning systems uses the condensing end of the heat pipe with the natural cooling of the outdoors to take away the heat from the server room. To further strengthen the heat transfer at the condensing end of the heat pipe, a series of auxiliary equipment such as pumps and fans often have to be added, covering a large area and increasing power consumption. More importantly, the heat transfer effect of heat pipe depends on the temperature difference between indoor and outdoor, and the application is subject to the external environment. In view of this, based on the latent heat of water phase change, this paper proposes a new type of data center heat pipe energy-saving and emission reduction system, and designs and builds a new heat pipe heat dissipation test bench. Compared with the heat dissipation capacity of the traditional heat pipe, the advantages of the new heat pipe device are analyzed. Based on the multi-physics coupling method of fluid heat transfer in COMSOL Multiphysics, a new data center heat pipe air conditioner model is established to study the joint operation of the latent heat pipe of water evaporation and air conditioner in the data center. This thesis intends to provide a more energy-efficient, environmentally friendly, economical, efficient and convenient solution for data centers and other environments with high demand for long-term heat dissipation.

Design programme

System operation principle

As can be seen from fig. 2, the water evaporation latent heat pipe device is mainly composed of a heat pipe, a vacuum box, and a water ring vacuum pump. The condensation end of the heat pipe is located in the vacuum box. The principle is to use the vacuum pump to create a low pressure environment so that the water in the vacuum box at room temperature evaporates in large quantities, and the latent heat of evaporation of water accelerates the liquefaction of the condensing end of the heat pipe, thus improving the circulation effect of the heat-conducting mass in the heat pipe.

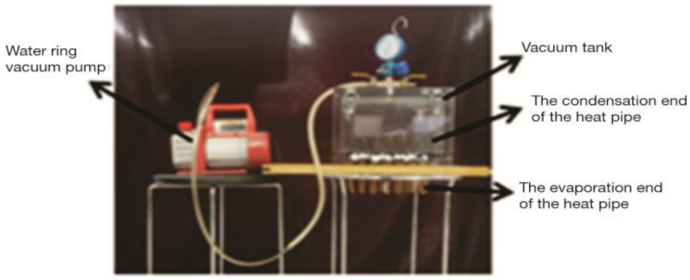

Figure 2. Latent heat pipe device for water evaporation

As can be seen from fig. 3, the working process of the data center water evaporation latent heat pipe air-conditioning system is that part of the heat of the IT equipment (in a closed room) in the data center is cooled by the air conditioner, and the other part is transferred to the outside world through the new heat pipe device. According to the principle of the latent heat pipe system of water evaporation, the water in the vacuum box continues to absorb the heat of the working substance at the condensation end of the heat pipe during the evaporation process. The gaseous mass is cooled and liquefied and then flows back by gravity to the evaporation end of the heat pipe to continue absorbing heat from the chamber. In addition, the fan continuously guides the heat of the heat source to the heat pipe, and ultimately achieves the function of transferring the heat of the data center equipment to the outdoor in order to reduce the use of air-conditioning.

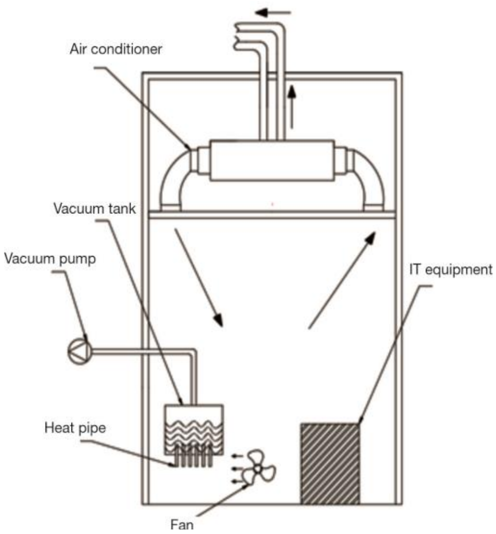

Figure 3. Schematic diagram of the data center water evaporation latent heat pipe air conditioning system

Experiment design

Taking the latent heat pipe system of water evaporation as the experimental group, fig. 4, and the traditional heat pipe as the control, fig. 5, the heat dissipation effect of the two sets of heat pipes on the heat source was studied, respectively. At the same time, set a heat source to naturally cool down as a control, fig. 6, and figs. 4-6 shows the actual test bench built.

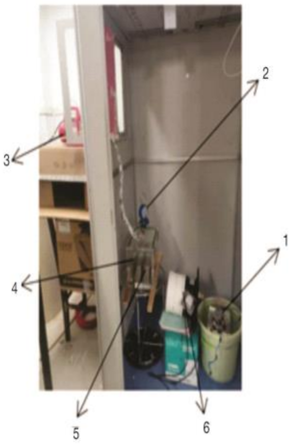

Figure 4. Test bench for water evaporation latent heat pipe

Figure 5. Test bench for traditional heat pipe

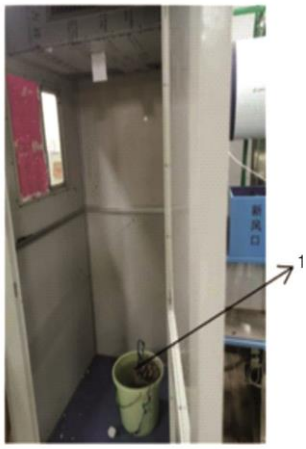

Figure 6. Test bench for natural cooling

The material details of each part are shown in tab. 1.

Table 1. Bill of materials

Item No.	Part	Description	Quantity
1	IT simulation heating equipment	Rated power is 500W	1
2	Vacuum gauge	Measure the vacuum in the vacuum box	1
3	Water ring vacuum pump	Rated power is 145W	1
4	Vacuum tank	Material is PMMA	1
5	Heat pipe	The working substance is ethanol, the boiling point is 20°C	21
6	Fan	Rated power is 80W	1
7	Thermometer (in the laboratory room)	Measure heat pipes, heat sources, indoor and outdoor temperatures	1

System experiment

Experiment programme

In order to compare the heat transfer effect of the water evaporation latent heat pipe and the traditional heat pipe, the following programmed is designed. At an average outdoor temperature of 24 °C, a 500 W heat source was placed into 12 kg of water to simulate an IT cooling device, and the water evaporation latent heat pipe device was used to compare with the traditional heat pipe device for heat dissipation, respectively, to measure the change in water temperature within 1 hour.

Experiment results

The experimental data recording results are shown in tab. 2.

Economic analysis

The heat dissipation effect of the two sets of heat pipes is quantified by the net heat absorption power of the water. The calculation formula is:

$$P = \frac{c_p m \Delta T}{3600} \tag{1}$$

where P – is the net endothermic power of water, c_p – the constant pressure specific heat of water, T – the temperature rises of the water, and m – the mass of the water.

Table 2. Water temperature change table

Time [minute]	Latent heat pipe of water evaporation [℃]	Traditional heat pipe [℃]	Natural cooling [℃]
0	20.2	20.2	20.2
5	22.8	23.6	21.8
10	26	27.2	28.8
15	28.8	29.9	30.7
20	31.4	32.6	35.9
25	33.7	34.5	37.2
30	36	37.2	38.4
35	38.3	40.1	42.5
40	40.5	42	45.5
45	42.6	44.1	46.9
50	44.4	45.8	49.4
55	46.5	47.6	51.4
60	47.9	50	53.2

Put the data of the control group and the experimental group into the previous formula to get: the net heat absorption of water in the latent heat of water evaporation heat pipe P_1 = 387.8 W, net heat absorption of traditional heat pipe water P_2 = 417.2 W, net heat absorption of natural cooling water P_0 = 462 W, heat transfer power of water evaporation heat pipe: $P_s = P_0 - P_1$ = 74.2 W, heat transfer power of conventional heat pipe: $P_c = P_0 - P_2$ = 44.8 W.

Taking 24 hours as the calculation time, the latent heat pipe of water evaporation can conduct more heat than the traditional heat pipe $\Delta E = 24\times60\times60\times(P_s - P_c)$ = 2540 kJ

Numerical simulation

Physical model

The physical model of the water evaporation latent heat pipe system test bench is shown in fig. 7. The set-up a cylindrical heat source with a diameter of 32 cm and a height of 30 cm in a closed room of 97 cm × 97 cm × 210 cm as an IT heating device. There is a fan with a diameter of 17 cm on the upper left of the heat source. The left side of the space is a latent heat pipe device for water evaporation. The size of the vacuum water tank is 29 cm × 19 cm × 20 cm, and the material is PMMA. The upper end surface of the box is connected to the vacuum pump through a conduit. There are 21 heat pipes in the box, with a thickness of 3 mm, a width of 6 mm, and a length of 90 mm. There is an air conditioner above the space, and its outlet size is 45 cm × 12 cm.

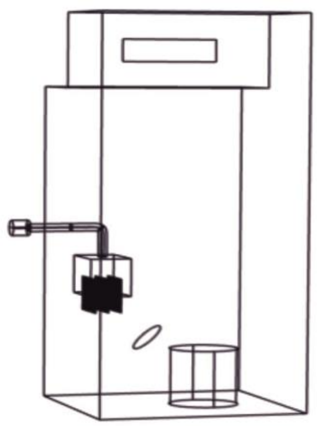

Figure 7. Physical model of water evaporation latent heat pipe

Mathematical model

According to heat transfer and fluid mechanics, the solid-fluid heat transfer and flow interface is selected, and the non-isothermal flow interface is used to couple multi-physics to construct a solid-fluid heat transfer model. Using the transient solver, the velocity field and temperature field are calculated.

For heat transfer to a solid, the governing equation can be obtained from the laws of thermodynamics:

$$\rho c_p u\nabla T + \nabla q = Q + Q_{\text{ted}} \tag{2}$$

$$q = -k\nabla T \tag{3}$$

where ∇ is the Hamiltonian, k – the thermal conductivity, Q_{ted} – the represents the heat source, and u – the velocity vector.

For fluid heat transfer, the governing equation can be obtained:

$$\rho c_p u\nabla T + \nabla q = Q + Q_p + Q_{\text{ed}} \tag{4}$$

$$q = -k\nabla T \tag{5}$$

$$\rho = \frac{p_A}{R_S T} \text{ (in the ideal gas domain)} \tag{6}$$

where Q_p is the pressure function.

For fluid-flow, from fluid mechanics, the governing equations can be obtained:

$$\rho(u\nabla)u = \nabla[-pI + K] + F + \rho \text{g} \tag{7}$$

$$\nabla(\rho u) = 0 \tag{8}$$

where p is the fluid stress tensor, I – the deformation tensor, F – the fluid volume force, and μ – the dynamic viscosity coefficient.

Boundary conditions

In terms of heat transfer, the ambient temperature is 25 °C, the heating power of the heat source is 500 W, the total heat transfer coefficient between the air and the wall is 13.33 W/(m^{2}K), the temperature at the lower end of the heat pipe is set to a constant temperature of 20 °C, and the heating power of the heat source is 500 W. In terms of the flow field, define the air in the space to participate in heat transfer and check the gravity flow, and set the pressure constraint point at the same time, and set the air supply volume of the fan to 0.02 m^3/s.

Verification of simulation results

It can be seen from fig. 8 that the simulation and experimental results are in good agreement. Through the calculation, the mean square error of the heat source temperature within 1 hour is 2.25 °C, and the deviation is 4.6%, which indicates that the established mathematical model has good accuracy.

After increasing the number of meshes from 31697 to 80401, it can be seen from the fig. 9 that the effect of the mesh refinement on the simulation results is not significant, and the error is calculated to be 2.64%, thus verifying the independence of the mesh.

From figs. 10 and 11, it can be seen that after the experiment is carried out for 1 hour, due to the heating of the heat source. The space temperature increases significantly, the average temperature of the heat source is 49.68 °C, and the maximum internal temperature is 69.0 °C. At the same time, the evaporation of water at the condensation end of the heat pipe absorbs heat and the forced convection of the fan accelerates the heat exchange between the heat source and the new heat pipe device, and the new heat pipe system has obvious high thermal conductivity.

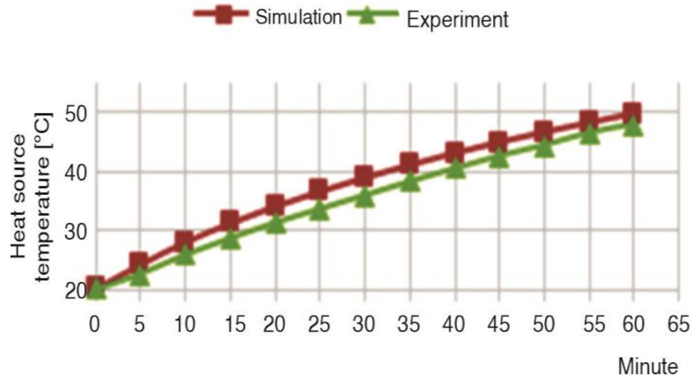

Figure 8. Cross-validation between simulation results and experimental data

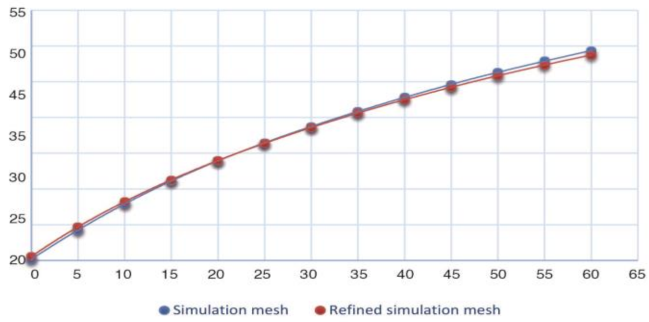

Figure 9. Mesh independence verification

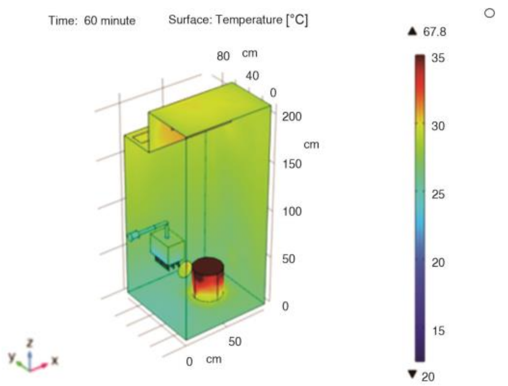

Figure 10. Thermal distribution of indoor heat pipes

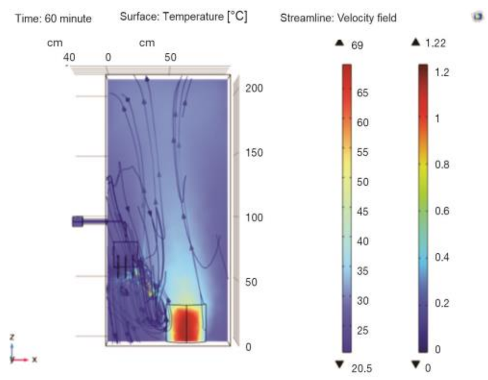

Figure 11. Distribution of heat conduction flow field of indoor heat pipe

Simulation of water evaporation latent heat pipe air-conditioning system in data centre

Physical model

According to fig. 3 in section *System operation principle*, based on the model in section *Physical model*, increase the number of heat pipes in the vacuum box to 63, which is equivalent to three large heat pipes of 18 cm × 5.6 cm × 0.9 cm. The equivalent physical model is shown in fig. 12.

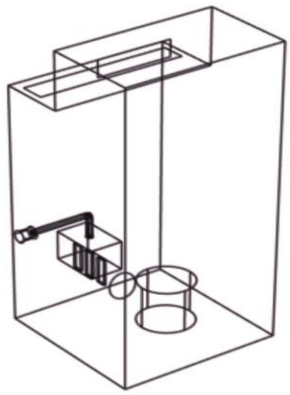

Figure 12. Physical model of data center water evaporation latent heat pipe air conditioning system

Boundary conditions

In terms of heat transfer, the ambient temperature is 35 °C, the heat load of the indoor heat source is assumed to be 1500 W, the total heat transfer coefficient between the air and the wall is 3 W/(m^{2}K), the temperature at the lower end of the heat pipe is set to a constant temperature of 20 °C, and the air supply temperature of the air conditioner is 16 °C. In terms of flow field, define the air inside the space to participate in heat transfer and check the gravity flow, and set the pressure constraint point at the same time. The air supply volume of the fan is set to 0.12 m^3/s, and the air supply speed of the air conditioner is 2.5 m/s.

Simulation results

It can be seen from tab. 3, figs 13, and 14 of the simulation results that when the latent heat pipe air-conditioning system of water evaporation in the data center is running, due to the low pressure environment created by the vacuum pump, the water in the water tank evaporates at

Table 3. Steady-state results of the latent heat pipe air-conditioning system of water evaporation in the data centre

Heat source temperature	Indoor temperature	Outdoor temperature	Cooling power of air conditioner	Heat pipe thermal conductivity
46.0 °C	25.8 °C	35 °C	482 W	968 W

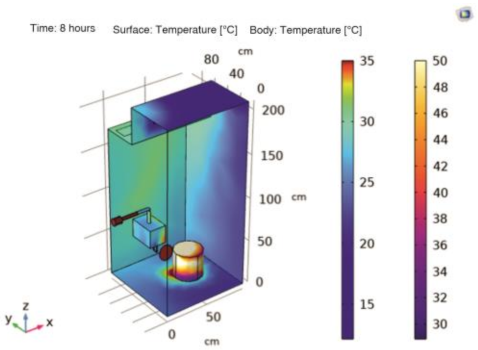

Figure 13. The temperature distribution of the latent heat pipe air-conditioning system of water evaporation in the data centre

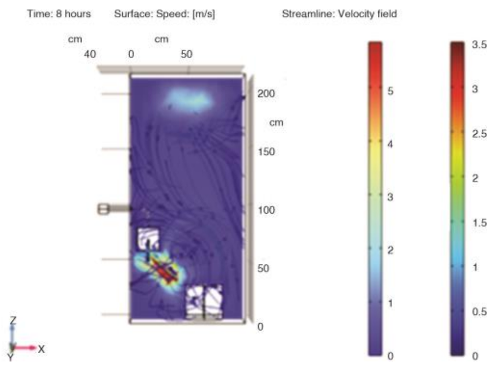

Figure 14. Flow field distribution of latent heat pipe air-conditioning system of water evaporation in data centre

room temperature, absorbing heat from the condensation end of the heat pipe and the wall of the water tank. This speeds up the circulation of working substance of the heat pipe and also cools the walls of the water tank. In addition, due to the local turbulence caused by the fan, the indoor heat is forced to be directed to the new heat pipe device, which increases the heat exchange between the new heat pipe and the heat source. The final steady-state result is that at an outdoor temperature of 35 °C and an indoor temperature of 25.8 °C, the ratio of the heat conduction power of the new heat pipe device to the cooling power of the air conditioner is 2:1. As a result, the new heat pipe device can greatly reduce the energy consumption of the air conditioner in the data center. And at the same time, the heat pipe can operate normally in the outdoor high temperature environment without being affected by the environment.

Performance analysis

Use the software probe results to construct an expression for the coefficient of performance of the latent heat pipe air-conditioning system of water evaporation in the data center:

$$EER = \frac{P_{\text{heater}} - bnd_1 \times S_{\text{boundary}}}{\dfrac{P_{\text{heater}} - bnd_1 \times S_{\text{boundary}} + S_{\text{hotpipe}} \times bnd_2}{EER_0 + P_1 + P_2}}$$

where EER is the coefficient of performance of the data center water evaporation latent heat pipe air-conditioning system, EER_0 – the coefficient of performance of the air conditioner, P_{heater} – the heat source power, bnd_1 – the average heat flux of the wall, bnd_2 – the average heat flux of the heat pipe heat exchange surface, S_{boundary} – the total area of the heat exchange wall, S_{hotpipe} – the total area of the heat exchange surface of the heat pipe, P_1 – the power of the vacuum pump, and P_2 – the power of the fan.

Taking the probe results and each parameter into the aforementioned equation, and the performance coefficient curve of the data center water evaporation latent heat pipe air-conditioning system is drawn with the performance coefficient of the original air conditioner as the independent variable.

As can be seen from fig. 15, the energy saving effect of the water evaporation latent heat pipe system is significant for air conditioners with *EER* below 2.5-4.4, and the system can improve the energy efficiency from *EER* 5 with *EER* 2.5 to *EER* 2 with *EER* 3.22. When the

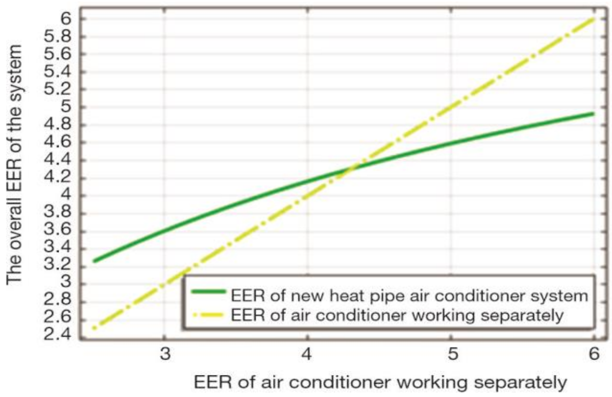

Figure 15. The *EER* curve of energy efficiency of data center water evaporation latent heat pipe air-conditioning system

EER of the air conditioner exceeds 4.4, the coefficient of performance of the data center water evaporation latent heat pipe air-conditioning system will be lower than that of the air conditioner itself. This is resulting from the fact that the performance factor of the new heat pipe unit itself is lower than that of the air conditioner. To extend the energy savings of the system, the following points should be considered:

- Increase the number of heat pipes in the vacuum tank.
- Adjust the relative position of the heat pipe and the heat source reasonably to increase the heat exchange area.
- Use higher flow, more energy-efficient vacuum pumps and fans.
- Add an automatic control system to adjust the cooling ratio of the air conditioner and the heat pipe in real time to achieve the best operating point of the system.

Conclusion

In this paper, a heat pipe test bench based on the latent heat of water evaporation is built, and the thermal conductivity of the latent heat pipe of water evaporation compared with the traditional heat pipe is analyzed. As a result, a system of combined operation of water evaporation latent heat pipe and air conditioner in data center is simulated, and the overall cooling effect of the system is analyzed. The energy-saving effect of the latent heat pipe of water evaporation is studied for the air conditioners with different cooling coefficients in the data center. Based on the experimental and simulation results, the following specific conclusions are made:

- Under the designed test conditions, compared with the traditional heat pipe system, the water evaporation latent heat pipe air conditioner can conduct 2540 kJ more heat in one day in an outdoor environment of 24 °C.
- When the ambient temperature is 35 °C and the indoor temperature is 25.8 °C, the cooling capacity of the heat pipe in the data center water evaporation latent heat pipe air-conditioning system is twice the cooling capacity of the air conditioner, and the heat pipe can work efficiently without being affected by the outdoor ambient temperature.
- The energy-saving effect of the latent heat pipe of water evaporation in the data center has a significant effect on air conditioners with an *EER* lower than 2.5-4.4. It can improve the energy efficiency of level 5 with an *EER* of 2.5 to level 2 with an *EER* of 3.22, which greatly reduces the electricity consumption of data center air-conditioning system. When the *EER* of the air conditioner exceeds 4.4, the coefficient of performance of the data center water evaporation latent heat pipe air-conditioning system will be lower than that of the air conditioner itself.

Fund Project: Major Consulting Research Project of Chinese Academy of Engineering (2020-ZD-18-5)

References

[1] Sun, W., Qian, R., Heat Pipe Air Conditioner Using Natural Energy, *Proceedings*, China Communication Energy Conference Paper Collection, Xi'an, China, 2017, pp. 170-171
[2] Jing, H., *et al*., Research on Performance of Natural Cooling Energy Heat Exchanger Based on Flat Plate Micro Heat Pipe Array, *Data RoomBuilding Science*, 36 (2020), 04, pp. 114-122
[3] Wang, F., *et al*., Design and Analysis of Heat Pipe Type Server Room Air-conditioning System, *Refrigeration and Air-Conditioning, 18* (2018), 05, pp. 4-8
[4] He, Z., *et al*., Application of Heat Pipe Air-conditioning System in High Heat Density Data Room, *Refrigeration, 40* (2021), 03, pp. 54-57

[5] Liu, H., *et al*., Analysis of Operating Characteristics of Separate Heat Pipe Radiator for Data Room, *Building Energy Efficiency, 45* (2017), 10, pp. 6-11

[6] Zhang, Y., *et al*., Discussions of Cold Plate Liquid Cooling Technology and Its Applications in Data Center Thermal Management, *Frontiers in Energy Research, 10* (2022), June, 954718

[7] Gan, T. K., *et al*., Thermal Analysis of Water-Filled Micro Heat Pipes of Natural-Convection Water Heat Sink, *International Journal of Heat and Mass Transfer, 19* (2022), July, 122741

[8] Borodinecs, A., *et al*., Feasibility of Reducing Electricity Consumption of Air-conditioning Equipment by Condenser Direct Evaporative Cooling Technology, Example of Case Study in Dubai, *Atmosphere, 12* (2021), 9, 1205

[9] Yang, H., *et al*., Research Development of Indirect Evaporative Cooling Technology: An Updated Review, *Renewable and Sustainable Energy Reviews, 145* (2021), July, 111082

[10] Pacak, A., Worek, W., Review of Dew Point Evaporative Cooling Technology for Air-conditioning Applications, *Applied Sciences, 11* (2021), 3, 934

[11] Tushar, S.. *et al*.,Experimental Performance and Parametric Analysis of Heat Pipe Heat Exchanger for Air-Conditioning Application Integrated with Evaporative Cooling, *Heat and Mass Transfer, 53* (2017), 11, pp. 3287-3293

[12] Dong, D., *et al*., Theoretical and Experimental Validation Study on Automotive Air-Conditioning Based on Heat Pipe and LNG Cold Energy for LNG-Fueled Heavy Vehicles, *Heat and Mass Transfer, 53* (2017), 11, pp. 2551-2558

[13] Tan, R., Zhang, Z., Heat Pipe Structure on Heat Transfer and Energy Saving Performance of the Wall Implanted with Heat Pipes During the Heating Season, *Applied Thermal Engineering, 102* (2016), June, pp. 633-640

[14] Li, L., *et al*., A State-of-the-Art Review on the Application of Heat Pipe System in Data Centers, *Applied Thermal Engineering, 199* (2021), Nov., 117618

[15] ***, Environment; New Environment Findings from Changchun Institute of Technology Published (An experimental study on heat transfer performance of a pulsating heat pipe radiator for CPU heat dissipation). Ecology, Environment & Conservation, 2020

[16] Zhang, H., *et al*., A Review on Thermosyphon and Its Integrated System with Vapor Compression for Free Cooling of Data Centers, *Renewable and Sustainable Energy Reviews, 81* (2018), Part 1, pp. 789-798

[17] Salih, E. H., *et al*., Experimental Demonstration and Flow Network Model Verification of Induced CRAH Bypass for Cooling Optimization of Enclosed-Aisle Data Centers, *IEEE Transactions on Components, Packaging and Manufacturing Technology, 7* (2017), 11, pp 1795-1803

[18] Ikeda, T., *et al*., Using Latent Heat of Water Evaporation to Cool the Culture Medium for High-Bench Strawberry Culture, *Acta Horticulturae, 708* (2006), 708, pp. 393-396

[19] Ali, M. A., *et al*., A Hybrid Domed Roof and Evaporative Cooling System: Thermal Comfort and Building Energy Evaluation, *Sustainable Cities and Society, 80* (2022), May, 103756

[20] Ramy, M. H., *et al*., Indirect Evaporative Cooling for Buildings: A Comprehensive Patents Review., *Journal of Building Engineering, 50* (2022), June, 104158

Paper submitted: May 18, 2022
Paper revised: July 20, 2022
Paper accepted: August 19, 2022