Journal of Power and Energy Engineering, 2021, 9, 1-20
https://www.scirp.org/journal/jpee
ISSN Online: 2327-5901
ISSN Print: 2327-588X

Energy Saving Model and Calculation Example of Three Cooling Schemes for Data Center in Hot Summer and Cold Winter Area

Feihu Chen[1,2], Xinli Zhou[3], Shuguang Liao[2]

[1]Civil Engineering College, Hunan University, Changsha, China
[2]Changsha Maxxom High-Tech Company Limited, Changsha, China
[3]Hunan Branch of China Mobile's Design Institute, Changsha, China
Email: maxxom121@163.com

How to cite this paper: Chen, F.H., Zhou, X.L. and Liao, S.G. (2021) Energy Saving Model and Calculation Example of Three Cooling Schemes for Data Center in Hot Summer and Cold Winter Area. *Journal of Power and Energy Engineering*, **9**, 1-20.
https://doi.org/10.4236/jpee.2021.912001

Received: June 15, 2021
Accepted: December 25, 2021
Published: December 28, 2021

Abstract

In order to achieve the goal of "carbon peak" in 2030 and "carbon neutralization" in 2060, the task of energy conservation has risen to the national strategic level, and its work is urgent. It focuses on energy saving and energy consumption in data center, 5G network and other fields. The gravity heat pipe double cycle air conditioning is a kind of room air conditioning which uses natural cooling source with high efficiency. According to the outdoor meteorological parameters of ten typical cities in China, the calculation model of unit hybrid refrigeration mode is established by using integral method. A simplified algorithm for statistical summation is proposed. Then it compares with the same type of refrigerant pump air conditioner, water-cooled chiller and natural cooling plate. The results show that the annual operation time of gravity heat pipe double cycle air conditioner is 50.8% longer than that of refrigerant pump air conditioner. Then the calculation model is verified by the annual actual operation data of a data center in Changsha. The results show that the double cycle air conditioner with gravity heat pipe can save about 34% energy compared with the chiller. The accuracy of the calculation model is 17.5%, which meets the engineering accuracy requirements. The application of gravity heat pipe double cycle air conditioning in hot summer and cold winter area is a scheme worthy of popularization and application.

Keywords

Gravity Heat Pipe Double Cycle, Refrigerant Pump, Natural Cooling, Integral Method, Simplified Algorithm for Statistical Summation, Energy Saving Rate

1. Introduction

In 2021, China's NPC and CPPCC clearly proposed to achieve the goals of "carbon peak" in 2030 and "carbon neutral" in 2060. Communication industry focuses on energy saving and energy consumption in data center, 5G network and other fields. Internet Data Center (IDC) is a solution that telecom operators use existing network communication lines, bandwidth, servers and other resources to provide different users such as government internet access, enterprise internet access and enterprise IT management, so that enterprises or individuals can quickly borrow IDC to carry out their own business. With the continuous emergence of e-commerce, Internet of things, artificial intelligence and other Internet industries, the construction demand of IDC continues to grow [1]. Some data show that China will increase 10 million servers in the next five years, and the current power load of each server is about 0.35 kW. By the end of 2020, China's data center power consumption exceeded 200 billion kW·h, accounting for 2.7% of the total social power consumption, and is expected to reach 350 billion kW·h by 2025 [2]. The increasing energy consumption of data center not only brings heavy burden to enterprises, but also brings great challenges to the energy and environment of the whole society.

The energy consumption of data center is mainly composed of IT equipment, power distribution system and air conditioning system. The energy consumption of air conditioning system accounts for about 40% of the total energy consumption of data center [3], which has become the focus of energy saving in data center. At present, the common energy-saving methods of air-conditioning system in data center include efficiency improvement of air-conditioning system, utilization of natural cold source and optimization of air distribution in data center, among which efficiency improvement of air-conditioning system and utilization of natural cold source are the most direct and effective means to reduce energy consumption of air-conditioning system. In order to improve the operation efficiency, the heat pipe cooling technology is a common technical means in the data center. Under the effect of a certain indoor and outdoor temperature difference, the heat in the data center can be quickly removed through the circulating evaporation and condensation process of the working medium in the heat pipe [4] [5]. The operation of the heat pipe cooling system needs to meet certain indoor and outdoor temperature difference conditions. When the outdoor environment temperature is high, it cannot meet the cooling demand in the data center. It needs to combine with the traditional mechanical refrigeration system, which puts forward new requirements for the control and operation of the traditional mechanical refrigeration system.

In order to meet the continuous cooling demand in the data center throughout the year and solve the coupling operation problem between the heat pipe cooling system and the traditional mechanical cooling system, this paper proposes a gravity heat pipe double cycle air conditioning system, which solves the problem of natural cold source utilization through the heat pipe cooling technology and improves the operation efficiency of the air conditioning system in the data center. But the outdoor meteorological parameters vary with seasons and time. Due to the complexity of energy efficiency statistics or calculation methods, there is less research on system energy efficiency analysis.

The energy performance of water cooled multi-spilit heat pipe system (MSHPS) is studied by many scholars. In the heat source and evaporator model: Yue *et al.* developed a complete CFD model for the parallel tubes with simplified louvered fins of the evaporator structure was established to consider the thermal enhancement while reduce the computing costs. The CFD model was validated by comparing the cooling capacity and outlet temperature of MSHPS with experiments [6]. Chen *et al.*, used the thermodynamic simulation software cyclepad to simulate and calculate the thermodynamic properties and energy saving characteristics of 72 backplane heat pipes connected by 6 CDU in a telecommunication room in Changde city. The results show that the annual average energy saving of heat pipe is more than 26% [7]. However, the simulation method is steady-state. There are few researches on the influence of environment on heat pipe system of IDC room and energy efficiency evaluation: A thermodynamic approach for evaluating energy performance (productivity) of information technology (IT) servers and data centers is presented. This approach is based on the first law efficiency to deliver energy performance metrics fined as the ratio of the useful work output (server utilization) to the total energy expanded to support the corresponding computational work. These energy performance metrics will facilitate proper energy evaluation and can be used as indicators to rank and classify IT systems and data centers regardless of their size, capacity or physical location [8]. A distribute parameter annual energy consumption model with considering the effect of the dynamic heat dissipation characteristics of servers, lake water temperature, outdoor weather conditions, and cooling plant thermal performance, will be established to evaluate the performance and energy efficiency of this cooling plant under different load factors [9]. Zou *et al.*, focused on the onsite test about self-adaptive capacity of a MSHPS in a real data center under 25%, 50%, 75% and 100% heating loads and various fan failures. The results show that the MSHPS abnormally operated under low heating loads, but it still met the cooling demands due to its superior self-adaptive capacity [10]. Ling *et al.*, carried out experimental research on the MSHPS, and pointed out that the optimal filling rate of the system is between 33% and 42% [11]. Zeng *et al.*, mainly studies the heat transfer performance of the micro-channel backplane heat pipe air conditioning system and conducts heat transfer performance experiments in a standard enthalpy difference laboratory [12]. Zou had done Experimental investigation on the thermal performance of a water-cooled loop thermosyphon system under fan failure conditions. It is showed that is better to choose a high optimal filling ratio to ensure the good operating performance and anti-failure capability of loop thermosyphon system [13]. Furthermore, many scholars have down many research to check the pipe network characteristics such as liquid separation parameters. A novel multi-branch heat pipe was investigated by experiment. The proposed heat pipe consists of three branches—two with an evaporator and one with a condenser. The optimal working fluid filling ratio and ideal heat load was obtained [14].

Many evaluation model energy saving rate were developed, but the method is complex-ed. An energy reduction of about 30% was resulted due to inserting a wicklessed Heat Pipe Heat Ex-changer (HPHX) in the system. The statistics method was employed to analysis the energy saving potential of pump-driven loop heat pipe (PLHP) system in different climate regions in China [15]. The pump-driven loop heat pipe (PLHP) system provides remarkable energy savings and the indoor temperature is remained at 18˚C to 25˚C. About 74.2% of Chinese cities lie in regions suitable for applications, and the annual energy saving ratio is over 30% [16].

Based on the method of finite time thermodynamics, Hunan University proposed a simple method of subsection discussion and calculation based on outdoor meteorological parameters. The calculation results show that the method can meet the requirements of engineering accuracy and is suitable for system evaluation and decision-making reference [17]. Chen *et al.* used the hourly outdoor air temperature as the input value, and then used the integral model of energy saving rate to better reflect the actual operation of the unit water-cooled multi heat pipe system. The energy saving potential in five typical climatic regions of China is from 25% to 61% respectively [18]. The national standard of direct cooling use the statistical method to evaluate the energy saving rate of different cities, the process is complex, and there are no simple method to evaluate the energy saving rate [19].

In terms of evaluation model, Chen *et al.* Established the evaluation method of condensation heat recovery and energy efficiency by using integral and algebraic accumulation methods. A model of heat recovery period is proposed to solve the problem of rough evaluation of classical thermodynamics [20].

In this paper, to develop a simple method to evaluate the energy saving rate in various climate, the application of gravity heat pipe double cycle air conditioning in data center in hot summer and cold winter area analyzed, according to the outdoor meteorological parameters of ten typical cities in China, the calculation model of unit hybrid refrigeration mode and unit annual energy saving rate is established by using statistical method. And compared with the same type of fluorine pump air conditioning, water-cooled chiller plus natural cooling plate mode. The operation feasibility and energy saving potential of the air conditioning system are proposed and analyzed.

2. The Physical Model of Double Cycle Air Conditioning

Dual cycle air conditioning is a kind of energy-saving air conditioning developed on the traditional precision air conditioning scheme in the computer room in order to use the natural cold source. According to its working principle, it can be divided into gravity heat pipe type double cycle air conditioning and fluorine pump type double cycle air conditioning.

2.1. The Physical Model of Gravity Heat Pipe Type Double Cycle Air Conditioning

Gravity heat pipe type double cycle air conditioner includes mechanical refrigeration cycle system and heat pipe circulation system. The two systems are independent of each other, namely, the evaporator and condenser in two cycles work independently, but the common evaporator fan and condenser fan are shared. The working principle is shown in Figure 1. When the indoor return air temperature (In this cycle, it is set at 35˚C) is higher than the outdoor temperature, the heat pipe circulation system provides cooling capacity, and the mechanical refrigeration cycle system works under other conditions[1]. The specific working modes of gravity heat pipe double cycle air conditioning include mechanical refrigeration cycle mode, natural cooling cycle mode and mixed operation model. The operation model under the different outdoor temperature can be seen in Table 1.

1) Operation model 1#: Mechanical refrigeration cycle: In high temperature season, when the outdoor dry bulb temperature is higher than the indoor return air temperature (35˚C), the compressor will be automatically started to

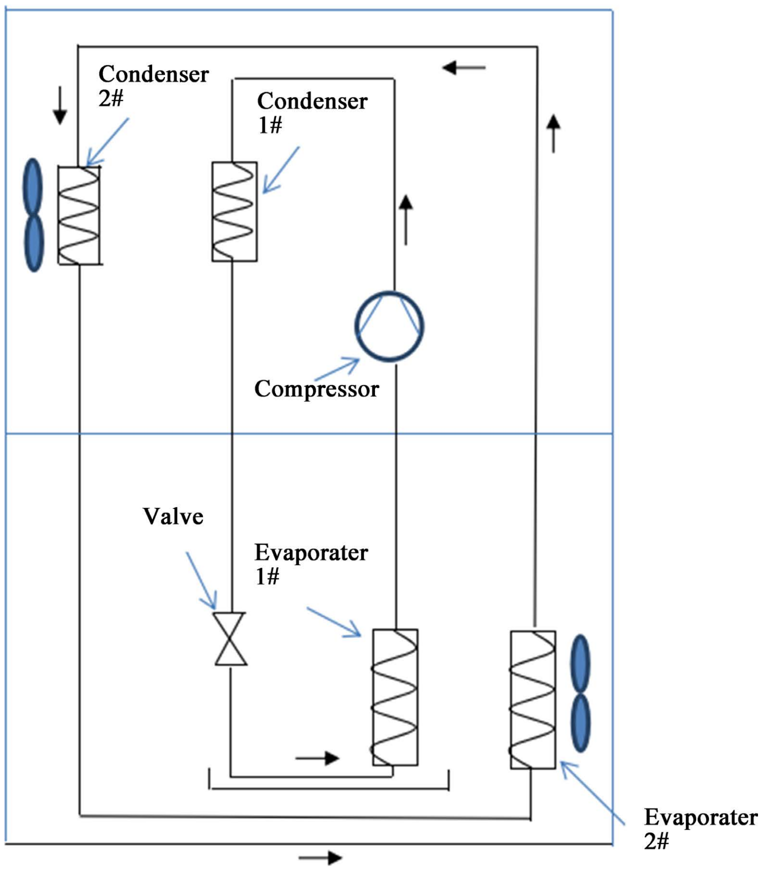

Figure 1. The schematic diagram of gravity heat pipe type double cycle air conditioning.

[1]Code for Design of Data Centers GB50174-2017.

cool the environment in the machine room through the mechanical refrigeration mode.

2) Operation model 2#: Natural cooling cycle: According to the configuration mode of 1:1, the heat exchange capacity of 10˚C temperature difference heat pipe system is rated. When the outdoor dry bulb temperature is lower than the return air temperature of indoor air conditioner than 10˚C (It is 25˚C in this cycle), the cooling capacity of the heat pipe cooling system can reach the refrigeration capacity of compressor cycle. At this time, the compressor stops working and is completely supplied to the machine room by the heat pipe circulation system.

3) Operation model 3#: Mixed (intermediate) mode: In the transitional season, when the outdoor dry bulb temperature is lower than the indoor return air temperature (35˚C), the heat pipe circulation system works to cool down in the data center, but the difference between the outdoor dry bulb temperature(It is between 25˚C to 35˚C) and the indoor air conditioning return air temperature is less than 10˚C, and the heat pipe circulation system cannot fully meet the refrigeration requirements in the data center. Therefore, the mechanical refrigeration cycle system and the heat pipe circulation system are running simultaneously, and the air conditioning machine works in mixed mode. At this time, the heat pipe cycle provides part of the cooling capacity and the compressor provides the rest part of the cooling capacity.

The gravity heat pipe double cycle air conditioner can switch freely between the three working modes. Except for the fan, the two cycles are completely independent. The start and stop of the mechanical refrigeration cycle system is controlled by the return air temperature, which is completely consistent with the ordinary precision air conditioner. When the indoor return air temperature is lower than the outdoor dry bulb temperature, it will automatically be in mixed mode to maximize the use of natural cold source.

2.2. The Physical Model of Double Cycle Air Conditioning with Fluorine Pump

The fluorine pump double cycle air conditioning has two circulation modes, mechanical refrigeration and natural cooling, which are mostly used in cold and cold areas. See in Figure 2.

1) Operation model 1#: Mechanical refrigeration cycle. Refrigerant forms a complete cycle in compressor, condensate tank, liquid reservoir, electromagnetic regulating valve and evaporator. The compressor converts electric energy into mechanical energy, compresses refrigerant gas and maintains refrigerant cycle.

2) Operation model 2#: Natural cooling (refrigerant pump) cycle: Refrigerant forms a complete cycle in condenser, reservoir, refrigerant pump, solenoid valve and evaporator. At this time, the compressor stops working, and the refrigerant circulation is driven by the refrigerant pump, and the flow rate of the refrigerant pump is controlled by the refrigerant level height in the liquid storage tank.

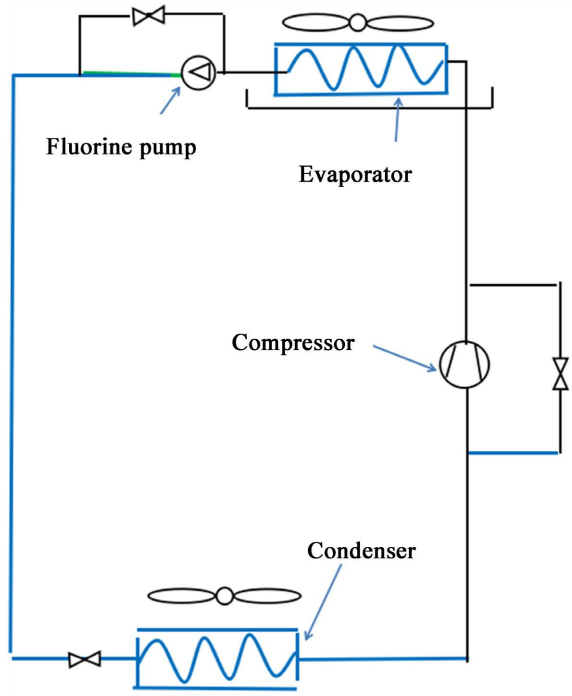

Figure 2. The schematic diagram of fluorine pump double cycle air conditioning.

3) Operation model 3#: Hybrid (intermediate) mode. The Liebert pex4s full time natural cooling precision air conditioning system of Weidi technology realizes the mixing mode by combining the frequency conversion compressor and the frequency conversion fluorine pump. This scheme is rare in the market and the control is relatively complex. When the outdoor air temperature is greater than 20˚C, the compressor of the mechanical refrigeration system will start [21]. When the outdoor air temperature is lower than 20˚C, the frequency conversion mode will be run. When the compressor of the mechanical refrigeration system runs at the lowest frequency, the fluorine pump system will start and run the frequency conversion mode; When the outdoor temperature is lower than 10˚C, the compressor and fluorine pump are closed, and the heat pipe system is operated for refrigeration. See in Table 1.

2.3. The Phsical Model of Replacement of Water-Cooled Chilled Water with Natural Cooling Plate

The system include the water cooled chiller and natural cooling plate, see in Figure 3.

The supply and return water temperature of the water-cooled chilled water system is calculated as 15˚C/21˚C [22].

1) Operation model 1#: Free cooling mode. The cooling water is exchanged through the natural cooling plate to cool the return water of the chilled water. The return water of the chilled water enters the evaporator of the chiller after being partially cooled by the plate heat exchanger, Provide chilled water at 15˚C. When the cooling water temperature is 1˚C lower than the chilled water supply

Table 1. The temperature threshold of three air conditioning schemes under different working modes.

Program	Mechanical refrigeration cycle mode	Mixed cycle mode	Full natural cooling mode
Gravity heat pipe double cycle air conditioner	>35˚C	35˚C - 25˚C	<25˚C
Fluorine pump double circulation air conditioning	>20˚C	20˚C - 10˚C	<10˚C
Replacement of water cooled chilled water with natural cooling plate	>21˚C	21˚C - 16˚C	<16˚C

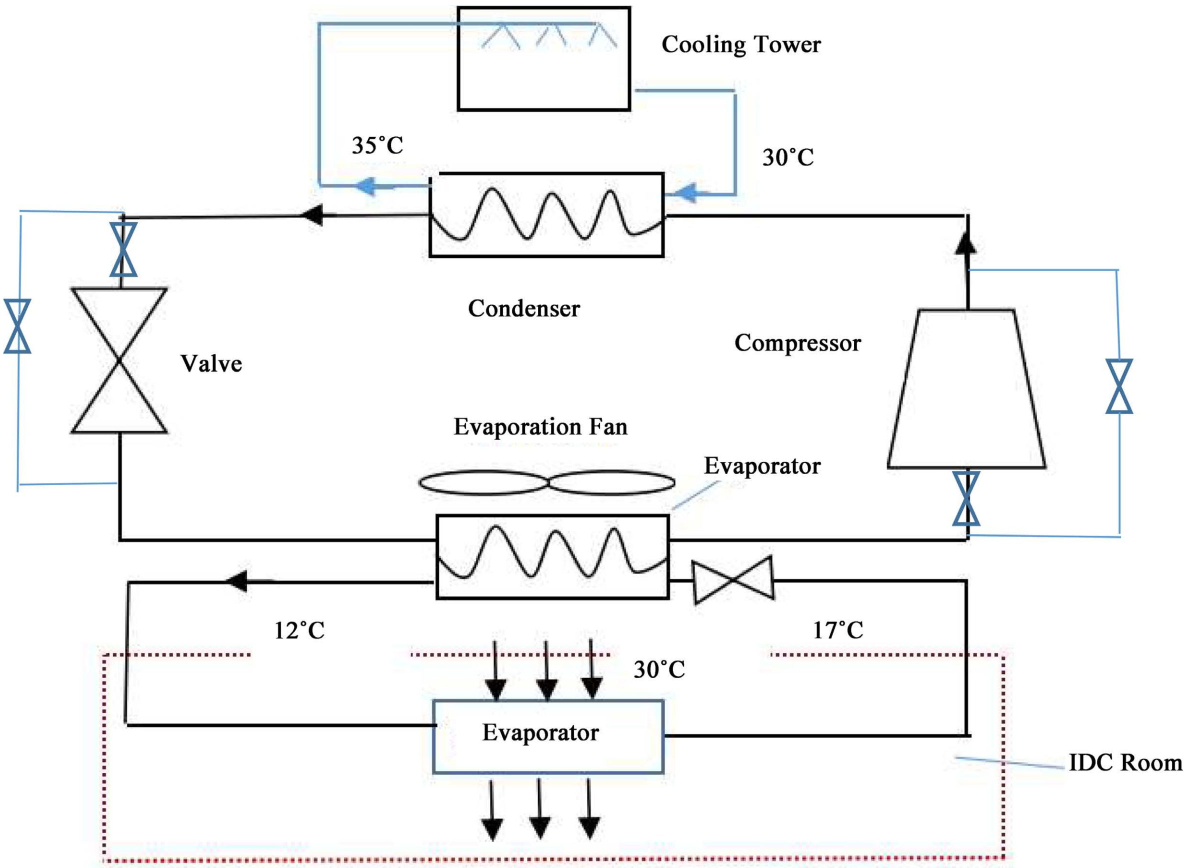

Figure 3. The replacement of water-cooled chilled water with natural cooling plate.

temperature, the cooling water enters the natural cooling mode. At this time, the cooling water temperature is 14˚C, corresponding to the dry bulb temperature of about 16˚C[2]. At this time, the refrigerator stops working, and the chilled water return water is exchanged with the cooling water through the heat plate exchanger to directly provide 15˚C of chilled water.

2) Operation model 1#: Mixed cooling mode. When the cooling water temperature is 2˚C lower than the return water temperature of the chilled water, it enters the mixed cooling condition [23]. At this time, the temperature of the

[2]Enthalpy Diagram.

cooling water is higher than 14˚C and lower than 19˚C, and the corresponding dry bulb temperature is about 21˚C.

3) Operation mode 3#: Mechanical cooling mode. When the temperature of cooling water is higher than 19˚C, it will enter the mechanical cooling mode.

3. The Energy Saving Potential Analysis

The annual outdoor dry bulb temperature distribution of 10 typical representative cities in hot summer and cold winter areas is shown in Figure 4 and Figure 5. The annual average temperature in each area is lower than 25˚C, the lowest is 15.3˚C in Guiyang, and the highest is 17.7˚C in Chongqing. The average temperature of each month in most of the year is lower than 25˚C. The average

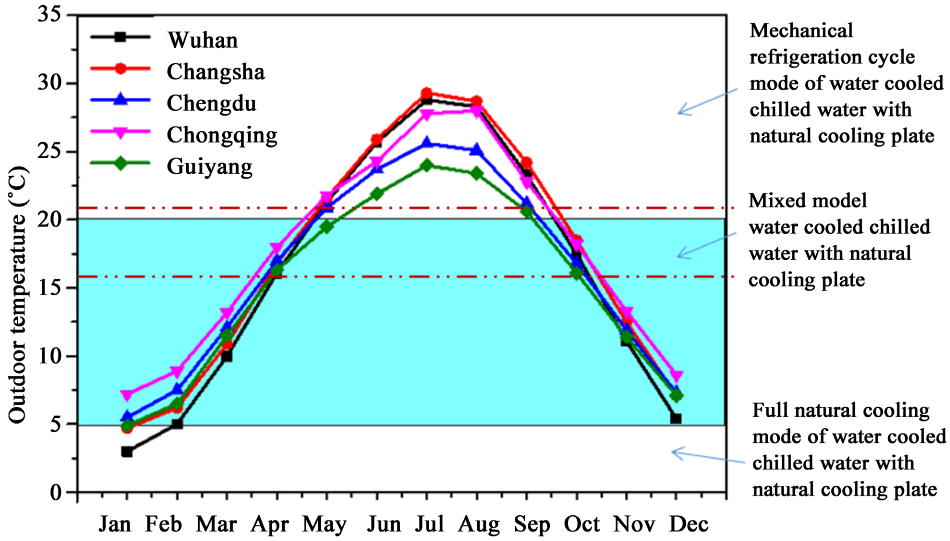

Figure 4. The outdoor air temperature in hot summer and cold winter area (Wuhan, Changsha, Chengdu, Chongqing, Guiyang).

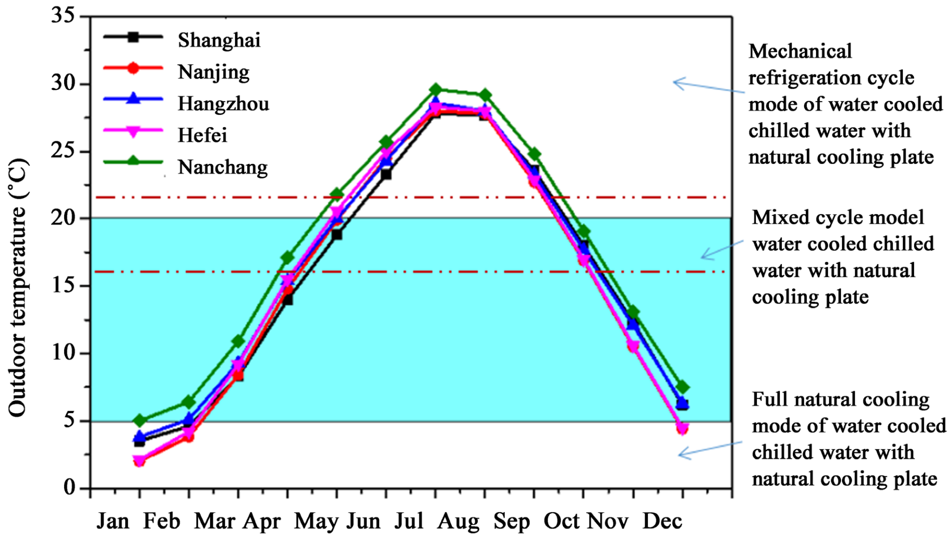

Figure 5. The outdoor air temperature in hot summer and cold winter areas (Shanghai, Nanjing, Hangzhou, Hefei, Nanchang).

temperature of Wuhan, Changsha and Nanchang accounts for 75% of the total time of the year respectively. The average temperature of Shanghai, Nanjing, Hangzhou, Hefei, Chengdu and Chongqing accounts for 83.3% of the total time of the year respectively. The average temperature of Guiyang is lower than 25˚C.

Taking Changsha as an example, the annual distribution of outdoor dry bulb temperature hours is as follows:

3.1. The Energy Efficiency Comparison of Full Natural Cooling

1) Gravity heat pipe double cycle air conditioner

According to Table 2, the annual outdoor dry bulb temperature of Changsha area is below 25˚C for 6753 hours, accounting for 77.09% of the total time of the year. The return air temperature is raised to 35˚C by using the closed heat channel. The gravity heat pipe double cycle air conditioning works in the complete natural cooling mode most of the year. At this time, only the fan is working in the whole air conditioning system. With the further decrease of the outdoor dry bulb temperature, the heat transfer capacity of the heat pipe system increases nonlinearly. The lower the temperature is, the stronger the heat transfer capacity is, and the higher the EER is. In the actual use scenario, the temperature is lower than a certain value, and the maintenance structure is permeated with a lot of cold air. At this time, the return air temperature is less than 35˚C, and the air conditioning system has already stopped working. According to the calculation of outdoor dry bulb temperature in Changsha and the calculation of experimental data, the total natural cooling mode time of gravity heat pipe double cycle air conditioning is 6753 hours.

2) The refrigerant pump type double circulation air conditioner

According to Table 2, the hours of outdoor dry bulb temperature below 10˚C in Changsha reach 2376 hours, accounting for 27.12% of the total time of the whole year. The working time of gravity heat pipe double cycle air conditioning in the full natural cooling mode is much lower than that of gravity heat pipe double cycle air conditioning. At this time, the whole fluorine pump double cycle air conditioning system has refrigerant pump in addition to the fan. According to the samples provided by mature products in the market, combined with the dry bulb temperature in Changsha, the total natural cooling mode time of fluorine pump type double cycle air conditioner is 2376 hours. The COP is higher than that of gravity heat pipe scheme, and the average outdoor dry bulb temperature of complete natural cooling mode is much lower than that of gravity heat pipe scheme.

The time of outdoor environment temperature lower than 10˚C in each area

Table 2. The frequency of annual dry bulb temperature in Changsha.

Dry bulb temperature (˚C)	0≤	0 - 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	≥35
Hours (h)	79	809	1488	1442	1261	1674	1423	526	58

in the whole year was: Wuhan, Shanghai, Nanjing, Hangzhou and Hefei accounted for 33.3% of the total time in the whole year, and Changsha, Chengdu, Chongqing and Guiyang accounted for 25% of the total time in the whole year. By comparing the outdoor environment temperature distribution of each city, the annual proportion time of 10 typical representative cities in hot summer and cold winter areas in the temperature range of 5˚C - 20˚C is 50.8%, that is, the gravity heat pipe double cycle air conditioning can run 50.8% more time than the refrigernt pump air conditioning, which can greatly reduce the energy consumption of the air conditioning system in the data center.

When the outdoor dry bulb temperature is lower than 10˚C, the natural cold source can be fully used in the refrigernt pump type double cycle air conditioner, and the utilization time of the natural cold source is much lower than that of the gravity heat pipe type double cycle air conditioner.

From the above analysis, it can be seen that the gravity heat pipe double cycle air conditioner has high efficiency in using natural cold source, and the application effect in the south of the Yangtze River is very ideal in hot summer and cold winter areas. It can also achieve certain energy-saving effect in the southeast and southern coastal areas where the summer is hot and the winter is warm, and the suitable application area is far larger than that of the Bi refrigernt pump double cycle system.

3) The replacement of water-cooled chilled water with natural cooling plate

According to Table 2, the hours of outdoor dry bulb temperature below 16˚C in Changsha reach 3818 hours, accounting for 43.58% of the total time of the whole year. The time of working in full natural cooling mode is much lower than that of gravity heat pipe double circulation air conditioning, but higher than that of fluorine pump double circulation air conditioning. At this time, the whole chilled water air conditioning system has two sets of cooling water and chilled water pumps and cooling tower in addition to the end fan My fan is working. The energy efficiency ratio of the chilled water system under natural cooling is calculated according to the following model:

According to the calculation model, combined with the dry bulb temperature in Changsha, the total natural cooling time of the scheme of water-cooled chilled water and natural cooling plate is 3818 hours.

3.2. The Energy Efficiency Comparison of Mechanical Refrigeration

1) Gravity heat pipe double cycle air conditioner

According to Table 2, there are only 58 hours of outdoor dry bulb temperature above 35˚C in Changsha, accounting for 0.66% of the total time in the whole year. At this time, the compressor is used for mechanical refrigeration..

2) Refrigerant pump double circulation air conditioner

According to Table 2, the number of hours with outdoor dry bulb temperature above 20˚C in Changsha reaches 3681, accounting for 42% of the total time of the year. At this time, it is completely cooled by the compressor, which is almost the same as the gravity heat pipe double cycle air conditioning.

3) Replacement of water-cooled chilled water with natural cooling plate

By querying the meteorological data, the annual outdoor dry bulb temperature above 21˚C in Changsha area reached 3233 hours, accounting for 36.9% of the total time of the year. At this time, it was completely cooled by the compressor. According to the model in Table 3, the COP was about 4.14.

3.3. The Energy Efficiency Comparison under Mixed Conditions

1) Gravity heat pipe double cycle air conditioner

The mixed operating conditions of gravity heat pipe double cycle air conditioning are: outdoor dry bulb temperature: 35˚C - 25˚C. The number of hours of outdoor dry bulb temperature from 25˚C to 35˚C was 1949 hours, accounting for 22.25% of the total time of the whole year; the number of hours of outdoor dry bulb temperature from 25˚C to 35˚C was 58 hours, accounting for 0.74% of the total time of the whole year.

Taking Changsha area as an example, according to the outdoor meteorological parameter table of Changsha area, the range of outdoor dry bulb temperature 35˚C - 25˚C in Changsha area can be fitted with the "spline function" of MATLAB software.

The energy saving rate of the heat pipe is the proportion of the natural cooling of the heat pipe divided by the time period of the mixed operation [24].

$$\text{Energy saving rate of heat pipe} = \frac{\int_0^{\tau}\left(35-\dot{T}\right)\mathrm{d}t}{\tau} \tag{1}$$

Among them, τ is the time period of mixed operation; 35 is the highest boundary value of mix operation mode, ˚C; $\dot{T}$ is the hourly outdoor dry bulb temperature, ˚C; t is the operation time, s.

2) The refrigerant pump double circulation air conditioner

The mixed operating conditions of fluorine pump double cycle air conditioning are: outdoor dry bulb temperature: 20˚C - 10˚C.

In the same way, the energy saving rate of dual cycle air conditioning with fluorine pump is the energy saving rate of natural cold source minus the power of refrigerant pump

Table 3. The energy consumption of chilled water system under natural cooling mode (1000 racks/5kW).

Equipment	Main technique parameter	Electric power (kW)
Water chilling unit	Cooling capacity Q = 5274 kW	$P_1 = 704$
Cooling tower	Cooling water volume 1265 m^3/h	$P_2 = 50$
Chilled water pump	Flow 960 m^3/h, lift 40 m	$P_3 = 160$
Cooling water pump	Flow 1200 m^3/h, lift 28 m	$P_4 = 160$
Inter row air Conditioning fan	0.2 kW/rack	$P_5 = 200$

$$\text{Energy saving rate of refrigerant pump double cycle air conditioning under mixed operation condition} = \frac{\int_0^{\tau}\left(20-\dot{T}\right)\mathrm{d}t}{\tau} - W_{\text{pump}} \cdot \tau \tag{2}$$

Among them, 20 is the highest boundary value of mixed operation, ˚C; W_{pump} is the power of refrigernt pump, W.

3) The replacement of water-cooled chilled water with natural cooling plate

The mixed operation conditions of water-cooled chilled water and natural cooling plate are: outdoor dry bulb temperature: 21˚C - 16˚C. As show in **Figure 3** and **Figure 4**.

In the same way, the energy-saving rate of water-cooled chilled water plus natural cooling plate is the energy-saving rate of natural cooling source minus the power of water pump.

$$\text{Energy saving rate of water-cooled chilled water with natural cooling plate under mixed condition} = \frac{\int_0^{\tau}\left(21-\dot{T}\right)\mathrm{d}t}{\tau} - W'_{\text{pump}} \cdot \tau \tag{3}$$

Among them, 21 is the highest boundary value of water-cooled chilled water plus natural cooling plate mixed condition, ˚C; W'_{pump} is the power of water pump, W.

4. The Case Analysis and Verification of Energy Saving in a Data Center

At present, the main scheme of air conditioning in data center is to replace chiller with natural cooling plate with air conditioning terminal, and use natural cooling source when the temperature of cooling water supply is lower than that of chilled water return. The maximum return temperature of chilled water is generally set to 21˚C, that is, when the supply temperature of cooling water is lower than 20˚C, the heat exchange starts, and the corresponding outdoor air temperature is lower than 18˚C. It can be seen from **Figure 3** and **Figure 4** that the available time of natural cold source in hot summer and cold winter area is limited, and the temperature fluctuation range in hot summer and cold winter area is often large, resulting in a lot of debris time, which leads to frequent switching operation mode of water chiller, and in order to protect the compressor of water chiller, it is difficult to effectively use the natural cold source in debris time. In addition, two sets of chilled water pumps and two sets of cooling water pumps are needed when using the natural cold source, which further reduces the utilization efficiency of the natural cold source.

4.1. The Operation Energy Consumption of Chillers

There are 1000 cabinets in a data center in Changsha area, and the heating capacity of a single cabinet is 5 kW; the chilled water supply and return water temperature of the chiller is set at 12/17˚C, the cooling water supply and return water temperature is set at 30/35˚C, and the air conditioning return air temperature is set at 35˚C. Then the annual operation energy consumption of the data center is shown in Table 4. The annual total power consumption is 9.59 million kwh, and the annual average COP is 4.5.

When the actual system design cold water supply is 12˚C [25]:

$$\mathrm{COP} = \frac{Q}{W} = \frac{5274}{704} = 7.49 \tag{4}$$

Increase the temperature of cold water supply to 15˚C, the average electric power of the water chilling unit is about 684 kW.

$$\mathrm{COP}' = \frac{Q}{W'} = \frac{5274}{608} = 8.71 \tag{5}$$

Energy saving rate:

$$\frac{8.71 - 7.49}{8.71} = 0.15 \tag{6}$$

After increasing the water supply temperature to 15/21˚C, the annual power consumption of the chiller is about:

$$467 \times (1 - 15\%) = 3.98 \text{ million kW} \tag{7}$$

The calculated energy consumption of the data center is about 8.9 million kW·h.

4.2. The Energy Consumption of Gravity Heat Pipe Double Cycle Air Conditioning

Compared with the data center water-cooled chiller system, the actual time and efficiency of gravity heat pipe double cycle air conditioning using natural cooling source are far greater than the traditional scheme of data center. On one hand, the starting point of heat pipe heat transfer is when the return air temperature of the air conditioning is higher than the air temperature. For example, when the return air temperature is 30˚C, the natural cooling source can be used when the air temperature is 29˚C. When the rated temperature difference is 10˚C, the natural cooling can be realized. On the other hand, there is no additional

Table 4. The operation energy consumption of chillers in a data center in Changsha.

Equipment	Main technique parameter	Electric power(kW)	Annual power consumption (10,000 KWH)
Water chilling unit	Cooling capacity $Q = 5274$ kW	$P_1 = 704$	467
Cooling tower	Cooling water volume 1265 m^3/h	$P_2 = 50$	43
Chilled water pump	Flow 960 m^3/h, lift 40 m	$P_3 = 160$	137
Cooling water pump	Flow 1200 m^3/h, lift 28 m	$P_4 = 160$	137
Inter row air Conditioning fan	0.2 kW/rack	$P_5 = 200$	175
Total			959

energy expenditure when the heat pipe uses the natural cold source.

4.2.1. The Simplified Model and Algorithm of Energy Saving in Transition Season (Hybrid Refrigeration Mode)

According to the statistical method to calculate the energy saving rate, when the average temperature of the month is more than 35˚C, the energy saving rate of the heat pipe is 0; when the average temperature of the month is less than 25˚C, the energy saving rate of the heat pipe is 100% [26].

The energy saving rate is calculated according to the statistical summation method.

Methods: Take the whole year as a calculation and evaluation cycle, because the climate of one year cycle is generally close. According to the outdoor climate parameters of each city, the monthly average value of each month is taken as the input parameter of the calculation model. The difference between the average temperature and the natural cooling temperature 35˚C of the heat pipe is the energy saving effect of the unit. Then the value of each month is accumulated to get the energy saving rate of the whole year [27]. According to **Figure 2**, it can be seen that the months with annual average temperature between 35˚C and 25˚C are July, August and September, and the monthly average temperatures are 26˚C, 30˚C and 28˚C respectively [28].

$$\text{Energy saving rate} = \frac{\sum_{n=1}^{3} \frac{35-\overline{T}_n}{10}}{3} \tag{8}$$

where, T is the outdoor dry bulb temperature of each month in each city, ˚C; "-" is the monthly average temperature, ˚C; "n" is the month. 10 is the temperature range of hybrid refrigeration mode, ˚C.

Taking the outdoor meteorological parameters of Changsha area as input, the energy saving rate of natural cold source in Changsha area is [29]:

$$\text{Energy saving rate} = \frac{(35-26)+(35-30)+(35-28)}{10} = 0.7 \tag{9}$$

Power consumption of double cycle heat pipe.

The power consumption consists of three parts:

1) Natural cooling mode: The operation time is about 6753 hours, and the power consumption is the power consumption of the fan.

2) Mechanical refrigeration mode: Power consumption is about the sum of compressor power consumption and fan power consumption.

The running time is about 58 hours, and the power consumption of the compressor is:

$$58\ \text{h} \times 1750\ \text{kW} = 100000\ \text{kW} \cdot \text{h} \tag{10}$$

3) Hybrid refrigeration mode: The power consumption is about the sum of compressor power consumption and fan power consumption.

The running time is about 1949 hours, and the power consumption is 30% of that when the compressor is fully open.

$$1949\ \text{h} \times 1750\ \text{kW} \times 30\% = 1020000\ \text{kW} \cdot \text{h} \tag{11}$$

$$\text{Power consumption of the fan}: (230 + 200) \times 8760 = 3.72\ \text{million kW} \cdot \text{h} \tag{12}$$

$$\begin{gathered}\text{Annual power consumption of heat pipe double cycle}: \\ 10 + 102 + 372 = 4.84\ \text{million kW} \cdot \text{h}\end{gathered} \tag{13}$$

4.2.2. The Verification of Energy Saving Efficiency in Transition Season (Hybrid Refrigeration Mode)

If a data center in Changsha adopts gravity heat pipe double cycle air conditioning, the return air temperature of the air conditioning is set at 35˚C. The annual energy consumption of the data center with gravity heat pipe double cycle air conditioning is shown in Table 5. The annual total power consumption is 5.87 million kwh, and the annual average COP is 5.28; that is to say, compared with the chiller,

$$\begin{aligned}\text{Energy saving rate} &= \frac{\text{chiller} + \text{natural cooling plate} - \text{grarity het pipe double cycle}}{\text{chiller} + \text{water plate}} \\ &= \frac{890 - 587}{890} = 0.34\end{aligned}$$

So, the annual energy consumption of the air conditioning system can be saved by 34%.

4.2.3. The Error Analysis

The calculation model and test error are calculated as follows [30]:

$$\sigma = \frac{\text{caculation result} - \text{test data}}{\text{testdata}} \times 100\% \tag{14}$$

Input data:

$$\sigma = \frac{484 - 587}{587} \times 100\% = 17.5\% \tag{15}$$

Considering the accuracy and error of the test instrument, the calculation model can meet the requirements of the project. It can meet the requirement of engineering precision.

5. Conclusions and Prospect

1) In order to reduce the energy consumption of air conditioning system in

Table 5. The energy consumption of gravity heat pipe double cycle air conditioning in a data center in Changsha.

Equipment	Main technical parameters	Electric power (kW)	Running time(h)	Annual power consumption (10,000 KWH)
Compressor	Cooling capacity $Q = 5274$ kW	$P = 1750$	1204.5	210.8
Air-cooled condenser fan	Air volume $m = 320 \times 104$ m³/h	$P = 230$	8760	202
Indoor fan	Flow $m = 278 \times 104$ m³/h	$P = 200$	8760	175
Fluorine pump	Flow $m = 20$ m³/h	$P = 100$		51

data center, this paper proposes a gravity heat pipe type double cycle air conditioner. The energy saving effect of the air conditioning system is analyzed by comparing with the fluorine pump air conditioning and the chiller. Because the temperature under 5˚C in the hot summer and cold winter area accounts for very small proportion in the whole year, the energy saving rate of the air conditioner with fluorine pump is very low. The gravity heat pipe type double cycle air conditioner can run 50.8% more time than the fluorine pump air conditioner in the whole year. Taking the climate of Changsha as an example, the energy saving rate of hybrid refrigeration mode is 72.5%. The actual operation results in a data center in Changsha show that the gravity heat pipe type double cycle air conditioner can save about 34% energy than the chiller.

2) For small computer rooms such as edge computer room and medium and small data center, when the power consumption of single stand is no more than 10 kW, the gravity heat pipe type double cycle air conditioner is adopted in the form of inter column, which can close the heat channel, and maximize the air return temperature of air conditioner, which can greatly reduce the PUE value in the data center. In addition, compared with the conventional data center scheme, gravity heat pipe type double cycle air conditioning has certain flexibility in deployment, small particle size, flexible adjustment and high safety and reliability.

3) The integral model and the simplified algorithm for statistical summation are proposed for evaluate the energy saving rate of heat pipe partial cooling. The models are simple and fit for the heat pipe sytems. And they can be used as a reference for energy-saving rate analysis of other similar thermal systems.

4) The average value of the gas temperature outside the chamber is the average value of the month in the calculation model, and the energy saving rate of the computer group in the mixed mode is adopted by algebraic accumulation method. The method can meet the engineering requirements in precision. In fact, the outdoor temperature should be used as the input value, and then the integration model of energy saving rate should be adopted to reflect the actual operation of the system. For specific calculation, please refer to the published papers of this group. This content is also the work to be carried out by the research group in the next step.

Acknowledgements

Thanks for the support of Hunan postdoctoral fund (Number: 198514).

Credit Author Statement

Feihu Chen: Conceptualization; Data curation; Formal analysis; Funding acquisition; Software; Roles/Writing—original draft;
Shuguang Liao: Investigation; Methodology; Project administration; Resources;
Xinli Zhou: Supervision; Validation; Visualization; Writing—review & editing.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Chen, A.S. (2017) Analysis of the Current Situation and Trend of Internet Data Center Industry. *Wireless Internet Technology*, No. 16, 1-5. (In Chinese)

[2] Tang, W. (2020) New Infrastructure: Future Large Power Users. China Energy Report, August 31, 004. (In Chinese)

[3] Gu, L.J., Zhou, F.Q. and Meng, H. (2010) Energy Consumption and Energy Efficiency Level of China Data Center. *China Energy*, **32**, 42-45. (In Chinese)

[4] Wang, F., Shao, S.Q. and Zhang, H.N. (2020) Experimental Study on Power Type Heat Pipe for Cooling in Data Center. *Journal of Refrigeration*, **41**, 89-96. (In Chinese)

[5] Liu, M. and Guo, F. (2020) Application Analysis of Heat Pipe Technology in Data Center. *Science and Information Technology*, **20**, 82-83. (In Chinese)

[6] Yue, C., Zhang, Q., Zhai, Z.Q., *et al.* (2019) Numerical Investigation on Thermal 402 Characteristics and Flow Distribution of a Parallel Micro-Channel Separate Heat Pipe 403 in Data Center. *International Journal of Refrigeration*, **98**, 150-160. https://doi.org/10.1016/j.ijrefrig.2018.10.025

[7] Chen, F.H. and Liao, S.G. (2016) Simulation Research on Heat Pipe Air Conditioning System in Data Center Based on Thermodynamic Simulation Software. *Refrigeration and Energy*, **2**, 28-34. (In Chinese)

[8] Ding, T., *et al.* (2017) Experiment Research on Influence Factors of the Separated Heat Pipe System, Especially the Filling Ratio and Freon Types. *Applied Thermal Engineering*, **118**, 357-364. https://doi.org/10.1016/j.applthermaleng.2017.02.085

[9] Ling, L., Zhang, Q. and Zeng, L.P. (2017) Performance and Energy Efficiency Analysis of Data Center Cooling Plant by Using Lake Water Source. *Procedia Engineering*, **205**, 3096-3103. https://doi.org/10.1016/j.proeng.2017.10.313

[10] Zou, S.K., Zhang, Q., Yu, Y.B., *et al.* (2019) Field Study on the Self-Adaptive Capacity of Multi-Split Heat Pipe System (MSHPS) under Non-Uniform Conditions in Data Center. *Applied Thermal Engineering*, **160**, Article ID: 113999. https://doi.org/10.1016/j.applthermaleng.2019.113999

[11] Li, L., *et al.* (2017) Simulation of a Micro Channel Separate Heat Pipe (MCSHP) under Low Heat Flux and Low Mass Flux. *Applied Thermal Engineering*, **119**, 25-33. https://doi.org/10.1016/j.applthermaleng.2017.03.049

[12] Zeng, L.P., Liu, X., Zhang, Q., *et al.* (2020) Research on Heat Transfer Performance of Micro-Channel Backplane Heat Pipe Air Conditioning System in Data Center. *Applied Science*, **10**, 583-598. https://doi.org/10.3390/app10020583

[13] Zou, S.K., Zhang, Q., Ling, L., *et al.* (2021) Experimental Investigation on the Thermal Performance of a Water-Cooled Loop Thermosyphon System under Fan Failure Conditions. *International Journal of Refrigeration*, **124**, 85-95. https://doi.org/10.1016/j.ijrefrig.2020.12.011

[14] Cai, Y.H., Li, Z.T., Zhai, J.M., *et al.* (2017) Experimental Investigation on a Novel Multi-Branch Heat Pipe for Multi-Heat Source Electronics Channel Heat Exchangers. *International Journal of Heat and Mass Transfer*, **104**, 467-477. https://doi.org/10.1016/j.ijheatmasstransfer.2016.08.080

[15] Abdelaziz, G.B., Abdelbaky, M.A., Kabeel, A.E., *et al.* (2021) Energy Saving via Heat Pipe Heat Exchanger in Air Conditioning Applications "Experimental Study and Economic Analysis". *Journal of Building Engineering*, **35**, 1-12. https://doi.org/10.1016/j.jobe.2020.102053

[16] Zhou, F., Li, C.C., Zhu, W.P., *et al.* (2018) Energy-Saving Analysis of a Case Data Center with a Pump-Driven Loop Heat Pipe System in Different Climate Regions in China. *Energy and Buildings*, **169**, 295-304.

[17] Chen, F.H. (2020) Characteristics and Application Prospects of Unit Water Cooled Multi Connected Heat Pipe System for Data Center. *Refrigeration and Energy*, **7**, 9-12. (In Chinese) https://doi.org/10.1016/j.enbuild.2018.03.081

[18] Chen, F.H., Liao, S.G. and Zhang, Q. (2020) Finite Time Thermodynamic Analysis of Water Cooled Multi-Split Heat Pipe System (MSHPS). *SSRG International Journal of Civil Engineering*, **9**, 7-16. https://doi.org/10.14445/23488352/IJCE-V7I9P102

[19] Zhang, Z.Y. (2019) indirect Evaporative Cooling Air Conditioning Unit for Computer and Data Processing Room. Matlab Edition 6.5, 2003 JB/T, Scientific Publisher, Beijing.

[20] Chen, F.H., Liao, S.G. and Gong, G.C. (2018) Thermodynamic Simulation of CCP in Air-Cooled Heat Pump Unit with HFCs and CO_2 Trans-Critical. *Journal of Power and Energy Engineering*, **6**, 141-164. https://doi.org/10.4236/jpee.2018.69012

[21] Owen, M. (2013) ASHRAE Fundamental Handbook. American Society of Heating. Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

[22] Ling, L., Zhang, Q., Yu, Y.B., *et al.* (2016) Experimental Investigation on the Thermal Performance of Water Cooled Multi-Split Heat Pipe System (MSHPS) for Space Cooling in Modular Data Centers. *Applied Thermal Engineering*, **107**, 591-601. https://doi.org/10.1016/j.applthermaleng.2016.07.006

[23] Cai, Y.H., Li, Z.T. and Zhai, J.M. (2017) Experimental Investigation on a Novel Multi-Branch Heat Pipe for Multi-Heat Source Electronics. *International Journal of Heat and Mass Transfer*, **104**, 467-477. https://doi.org/10.1016/j.ijheatmasstransfer.2016.08.080

[24] Chen, F.H. (2014) Thermodynamic Simulation and Optimization of Compound Condensation Process. Doctoral Dissertation of Hunan University, Changsha. (In Chinese)

[25] Chen, F.H., Liao, S.G. and Zhang, Q. (2019) Finite Time Thermodynamic Model and Energy Efficiency Evaluation of Heat Pipe Evaporator. *Building Thermal Ventilation and Air Conditioning*, **38**, 16-18. (In Chinese)

[26] Chen, F.H., Liao, S.G. and Gong, G.G. (2020) Simulation Research of Heat Pipe Air Conditioning System in Data Center-Based on Thermodynamic Simulation Software. *Clean and Air Conditioning Technology*, No. 4, 28-34. (In Chinese)

[27] Li, L. (2017) Heat Transfer Characteristics and Energy Saving of MicroChannel Separated Heat Pipe Used in Data Room. Doctoral Dissertation of Hunan University, Changsha. (In Chinese)

[28] Todorovica, M.S. and Kimb, J.T. (2014) Data Centre's Energy Efficiency Optimization and Greening—Case Study Methodology and R&D Needs. *Energy and Buildings*, **85**, 564-578. https://doi.org/10.1016/j.enbuild.2014.09.001

[29] AliErsöz, M. and Yıldız, A. (2016) Thermoeconomic Analysis of Thermosyphon Heat Pipes. *Renewable Energy*, **85**, 880-889.

[30] Zhang, X.X., *et al.* (2015) Comparative Study of a Novel Liquid-Vapour Separator Incorporated Gravitational Loop Heat Pipe against the Conventional Gravitational

Straight and Loop Heat Pipes—Part II: Experimental Testing and Simulation Model Validation. *Energy Conversion and Management*, **93**, 228-238.
https://doi.org/10.1016/j.enconman.2015.01.035

Appendix: Nomenclature

Abbreviations

IDC	information Data Center
MSHPS	water cooled multi-spilit heat pipe system
CDU	cooling deliver unit
IT	information technique
HPHX	heat Pipe Heat Ex-changer
COP	coefficient of performance
CFD	calculated fluid design
GPU	general processing unit
SSD	solid state disk
EER	energy efficiency ratio

Symbols

t	time (s)
T	temperature (K)
m	Mass flow (kg/h)
P	power (kW)
Q	heat (J)
W	work input (J)

Green Letters

σ	relative error
τ	period

Subscripts

n	Month
.	hourly
_	average