Analysis on the practical use of open-loop surface water source heat pump systems (SWHP)

Yong Wang

Chongqing University

Oklahoma ,USA 06-10-2011

Outline

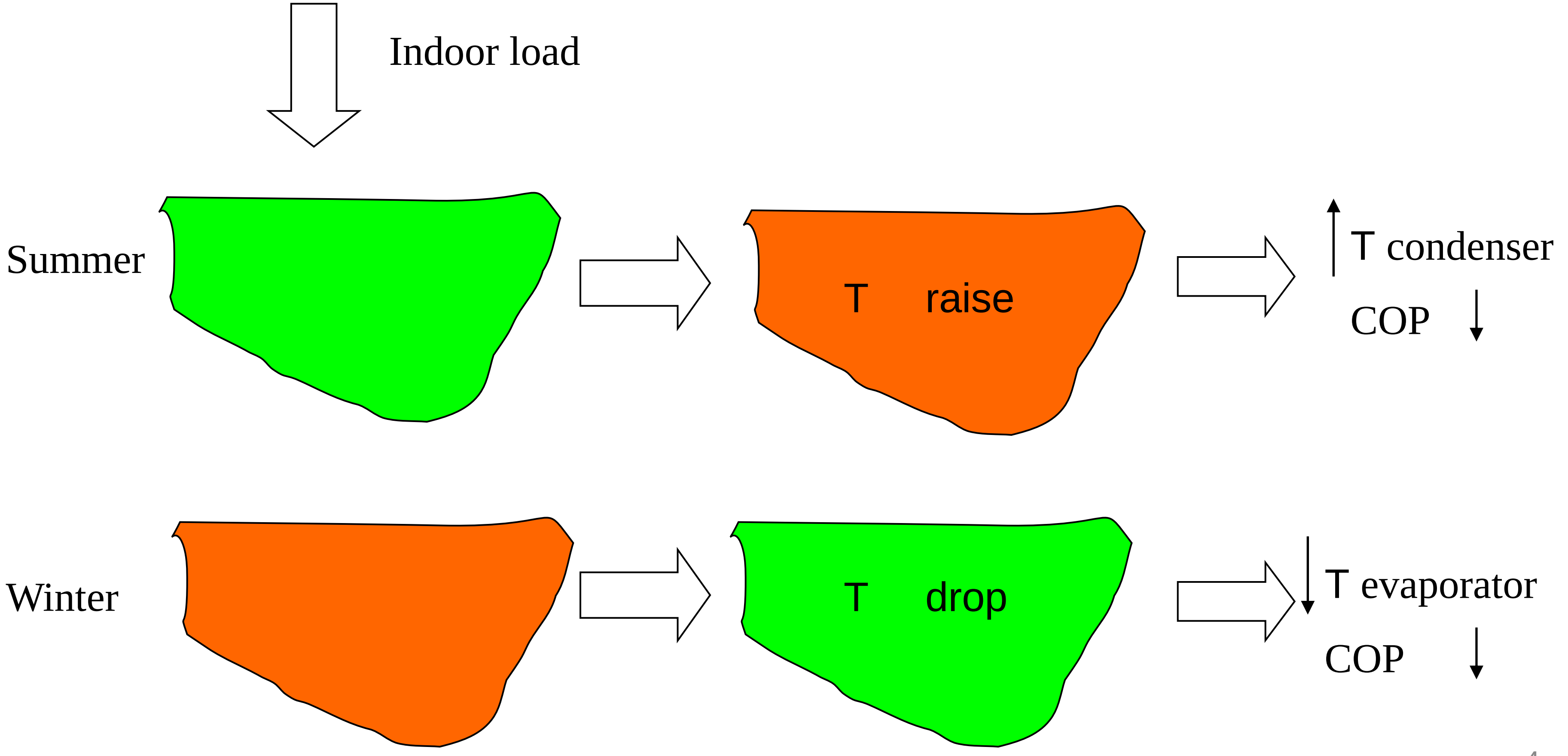
- Research objective
- Analysis of thermal capability of water body
- Scheme of intake water for SWHP
- The method of determining energy consumption for SWHP
- The application in China

Research objective

- Not including sea and sewage source heat pump systems
- Open-loop not closed-loop systems

Analysis of thermal capability of water body

- Conception



Analysis of thermal capability of static water body

- Dynamic variety with time
- COP dropping of the system
- Identifing $T_{limit,}$ which is based on T_{inlet} of cooling tower(in summer) and $T_{stop,}$ when heat pumps stop under various condition (in winter)
- The limited thermal capability absorbed in water body is defined when the T_{mean} of surface water approaches T_{limit}

Calculation method

nature water temperature distribution equation

↓

water temperature distribution equation with load

↓

calculating temperature in water body

↓

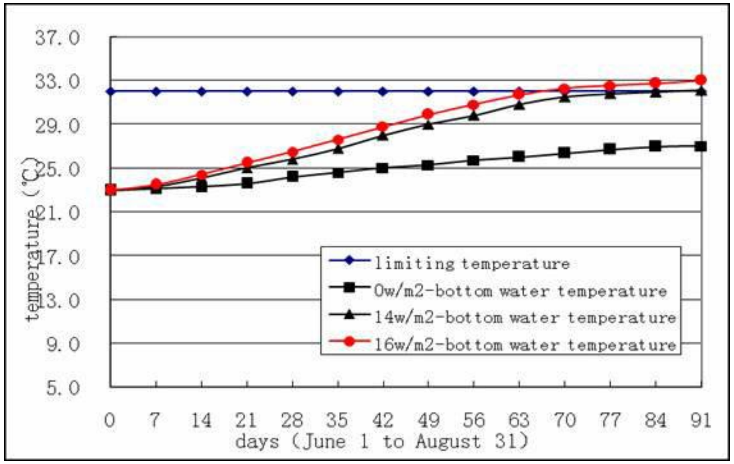
$T_{mean} \fallingdotseq T_{limit}$

↓

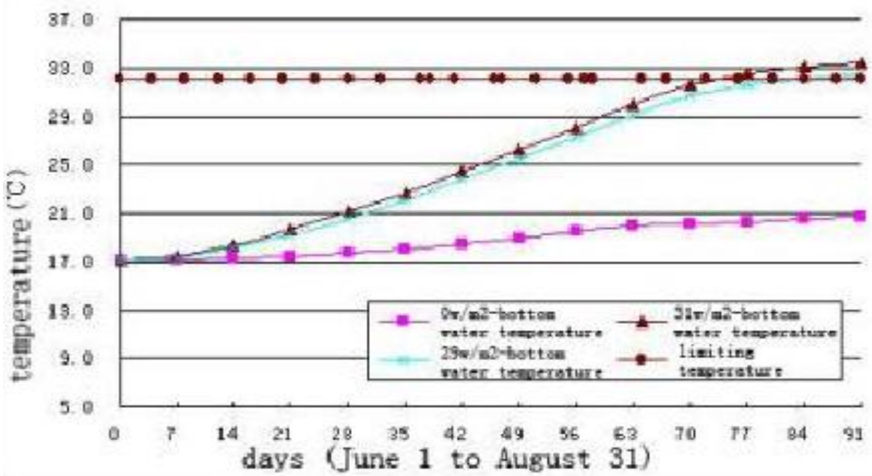
results of heat capability of water body

CHONGQING UNIVERSITY

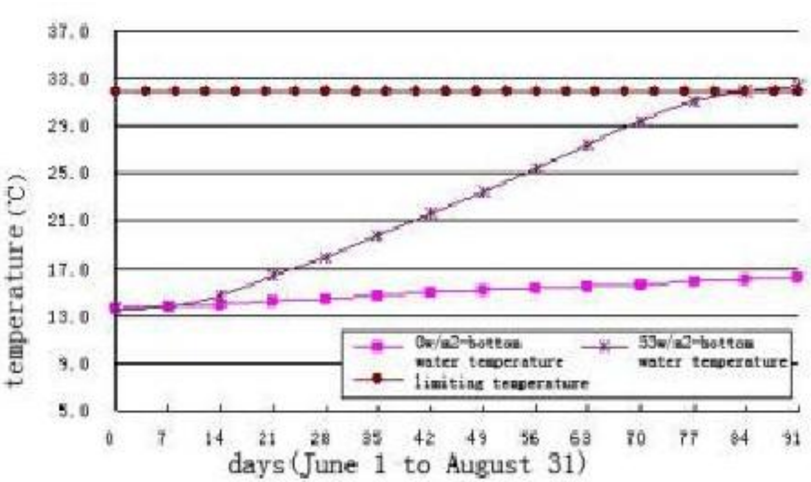
Results of water temperature distribution at different depth and with different inputs in summer



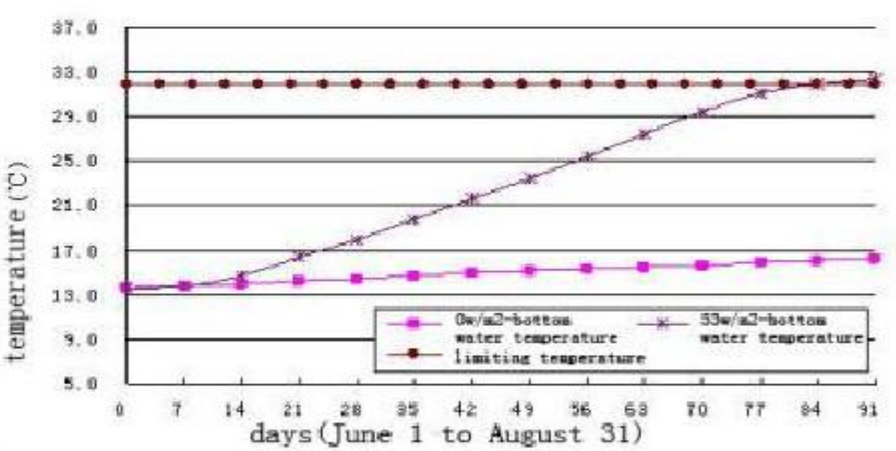
The water temperature changes with time after it bears heat load at the average depth of 4m and the average temperature of 2 6..35℃



The water temperature changes with time after it bears heat load at the average depth of 6m and the average temperature of 2 4.35℃

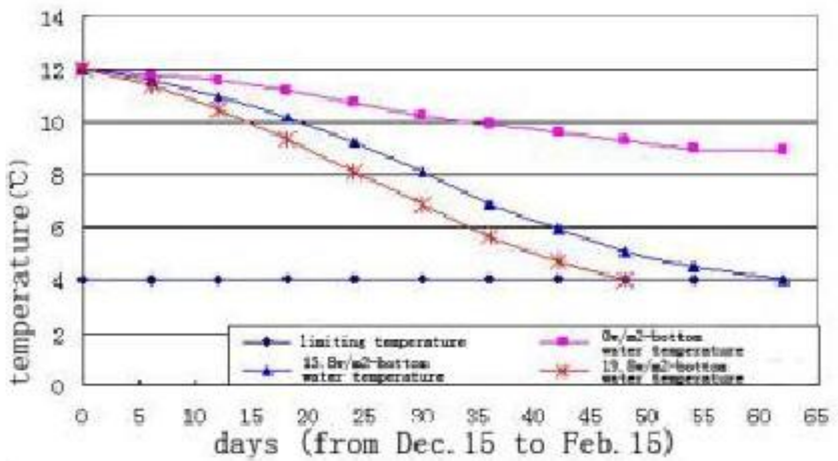


The water temperature changes with time after it bears heat load at the average depth of 8m and the average temperature of 22.31℃

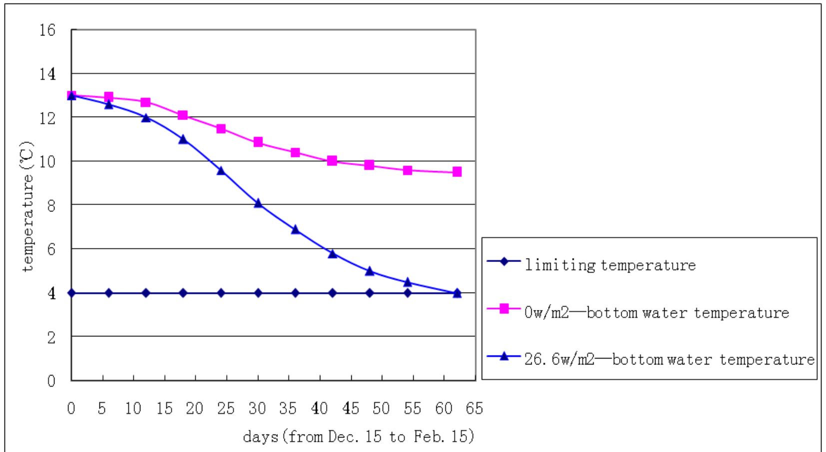


The water temperature changes with time after it bears heat load at the average depth of 10m and the average temperature of 20.53℃

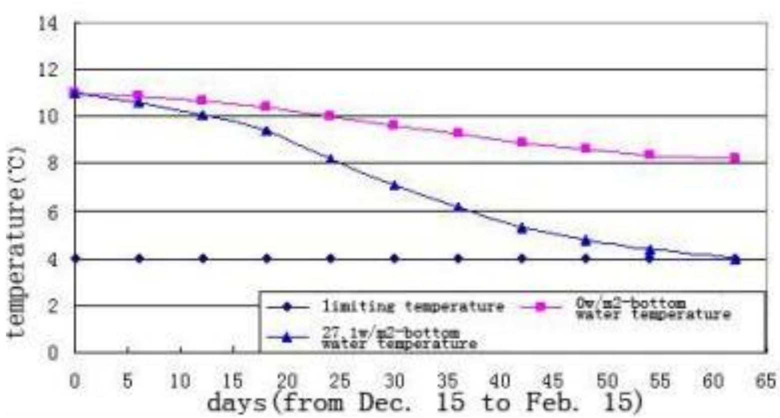
Results of water temperature distribution at different depth and with different inputs in winter



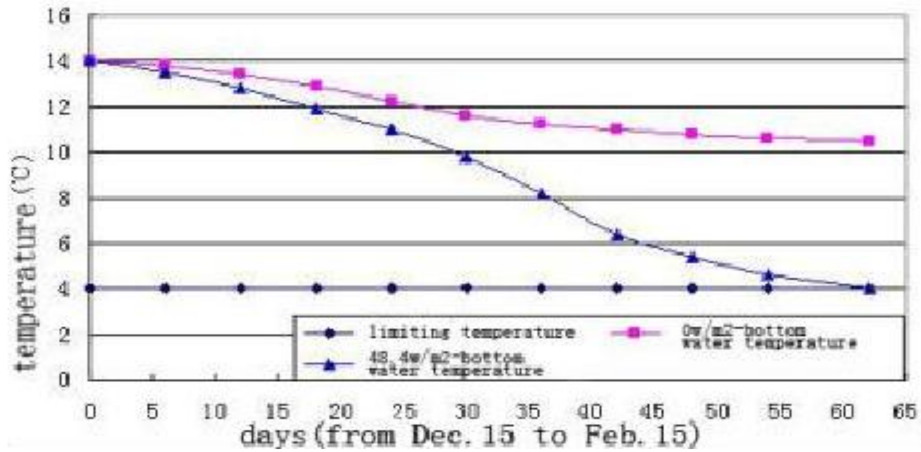
The water temperature changes with time after it bears cool load at the average depth of 4m and the average temperature of 12℃



The water temperature changes with time after it bears cool load at average depth of 6m and the average temperature of 13℃



The water temperature changes with time after it bears cool load at the average depth of 7m and the average temperature of 12℃



The water temperature changes with time after it bears cool load at the average depth of 8m and the average temperature of 11℃

Outcome

- Important parameters: q_{cl} or q_r (KW/m^2)
- q_{cl} or q_r means limited release energy to water in summer or winter
- curve fitting method

In summer

$$q_{cl}=\left(130.7321+1.0025(\bar{h})^{1.7509}-11.8729(\bar{t})^{0.7333}\right)\times\frac{EER}{(EER+1)}\qquad （4m\leqslant\ h\ \leqslant 10m）$$

In winter

$$q_r=\left(-94.2202+9.231(\bar{h})+9.9024(\bar{t})-0.4619(\bar{h})^2-0.2694(\bar{t})^2\right)\times\frac{EER}{(EER-1)}\qquad （4m\leqslant\ h\ \leqslant 10m）$$

Validation

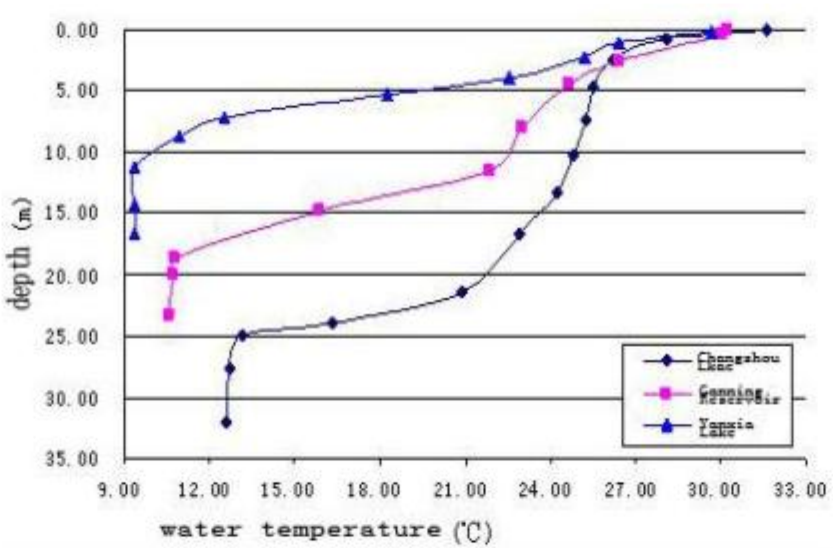
Load w/m^2	Actual input w/m^2	Theoretical limit of temperature ℃	Temperature at the bottom of the water in the end of August ℃
30	33.4	32	31.56

Notice: this project runs with partial and intermittent load. if it is full and continuous load, the temperature will higher than 31.56.

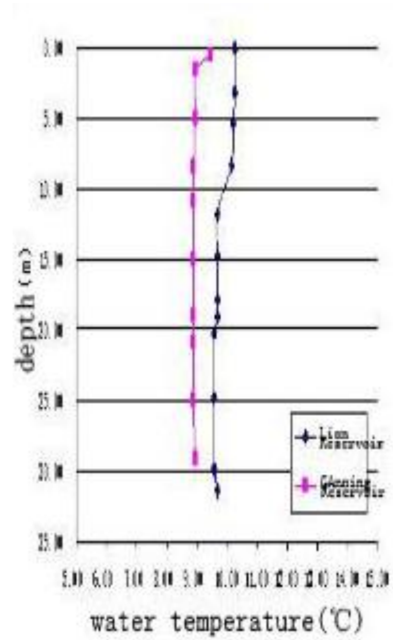
Scheme of intake water for SWHP

If we want to achieve lower temperature water, one intake conduit is not good method

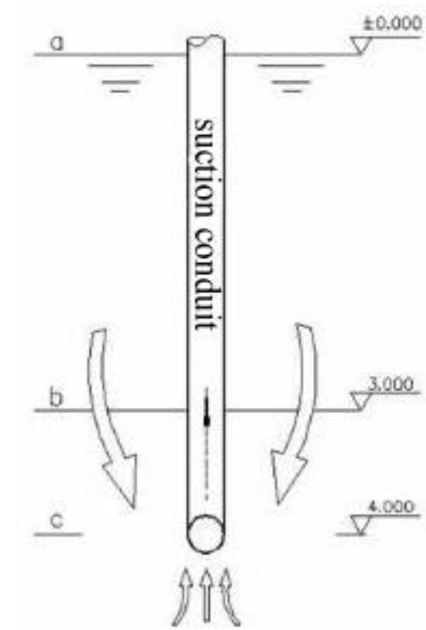
Static water body



summer

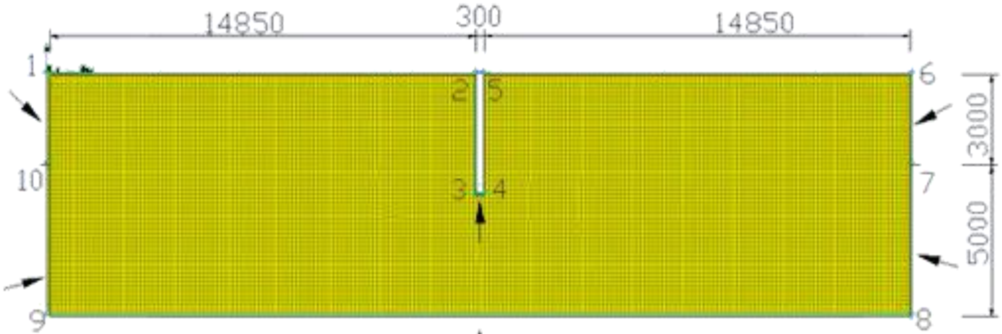


winter

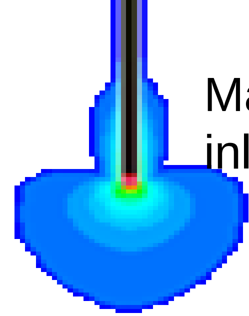


suction caused by the upper water

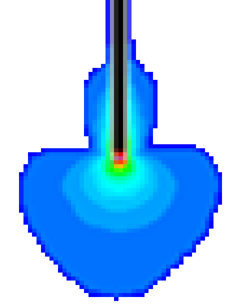
CFD can be used as a prediction tool in design to optimize the water intake system



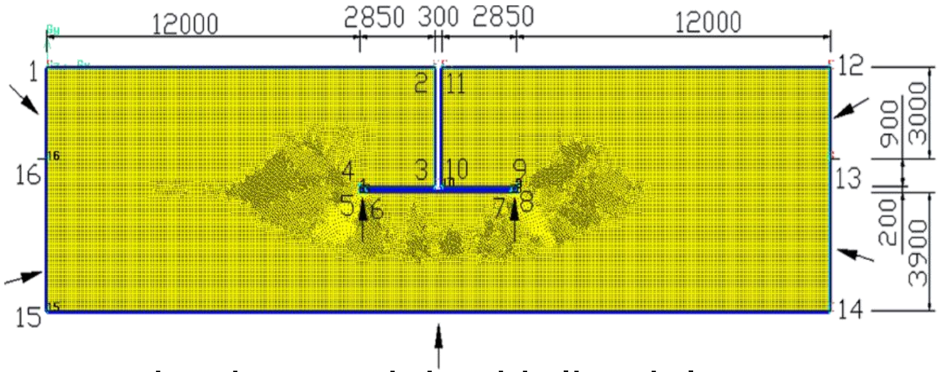
One intake conduit with many little inlet or not



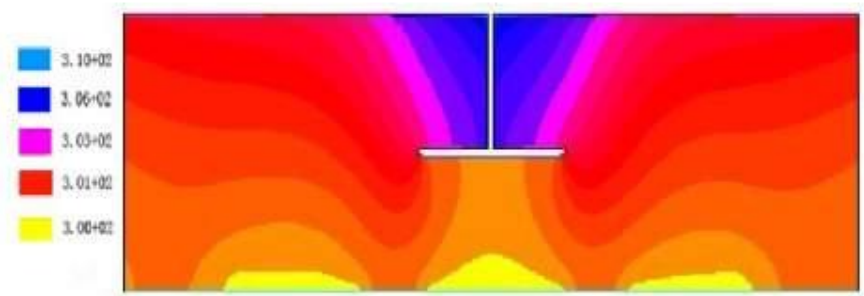
Many little inlets

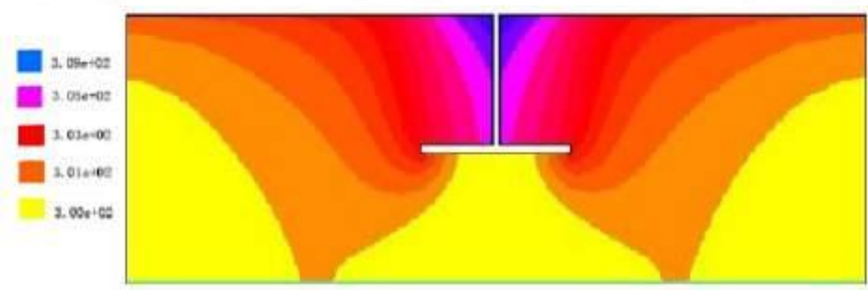


Only one intake conduit



two intake conduit with line inlet or not

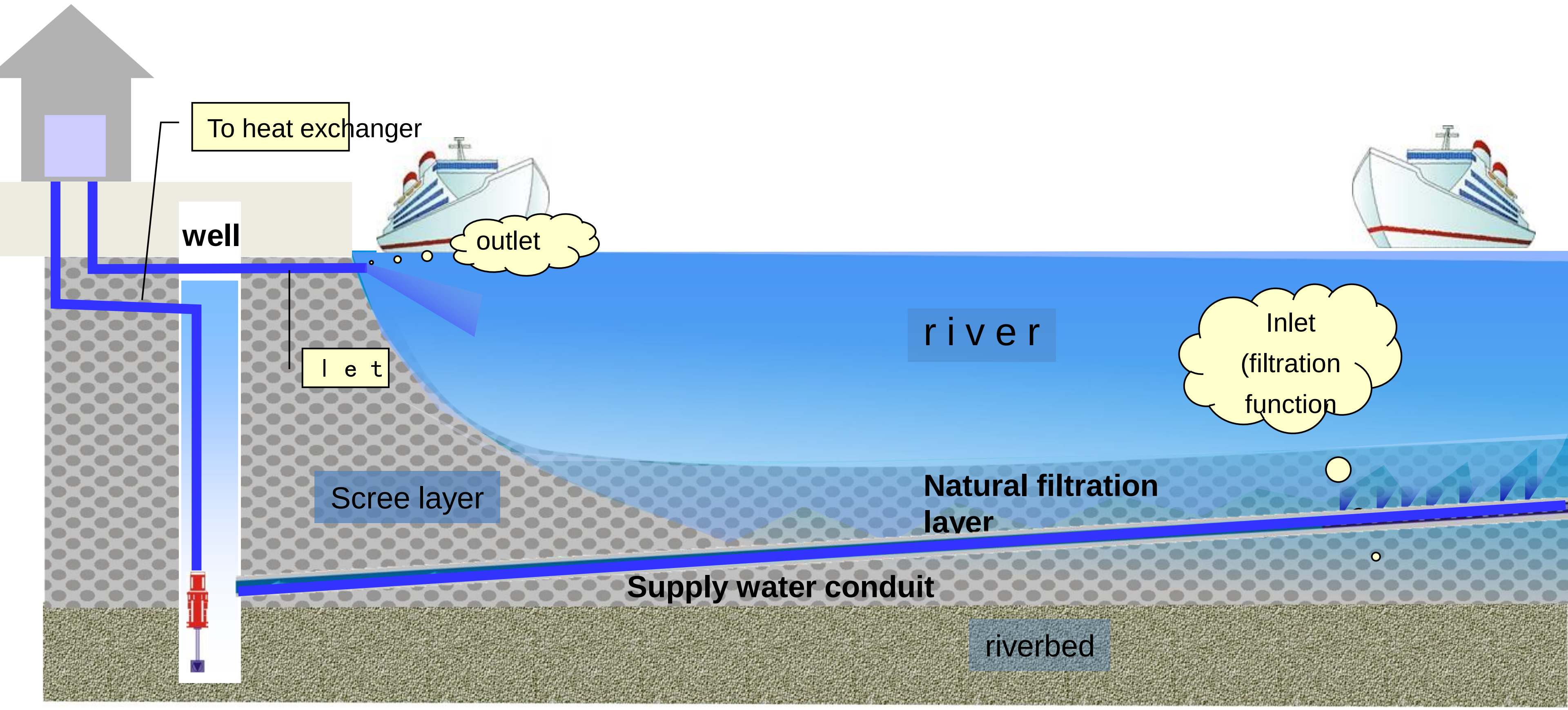




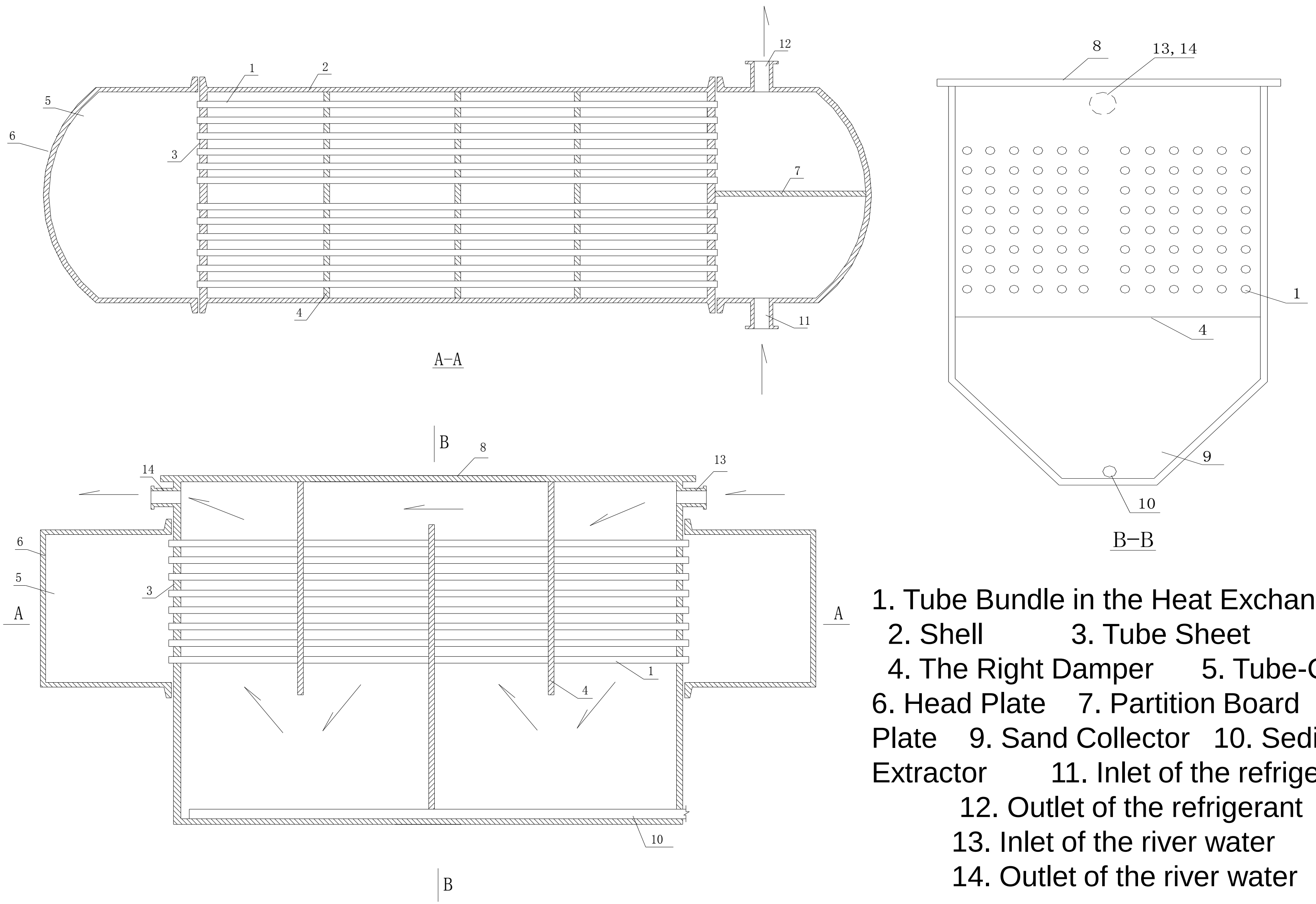
Line inlet at bottom

Effect is distinct

Demonstration of water intake in river (dynamic condition)

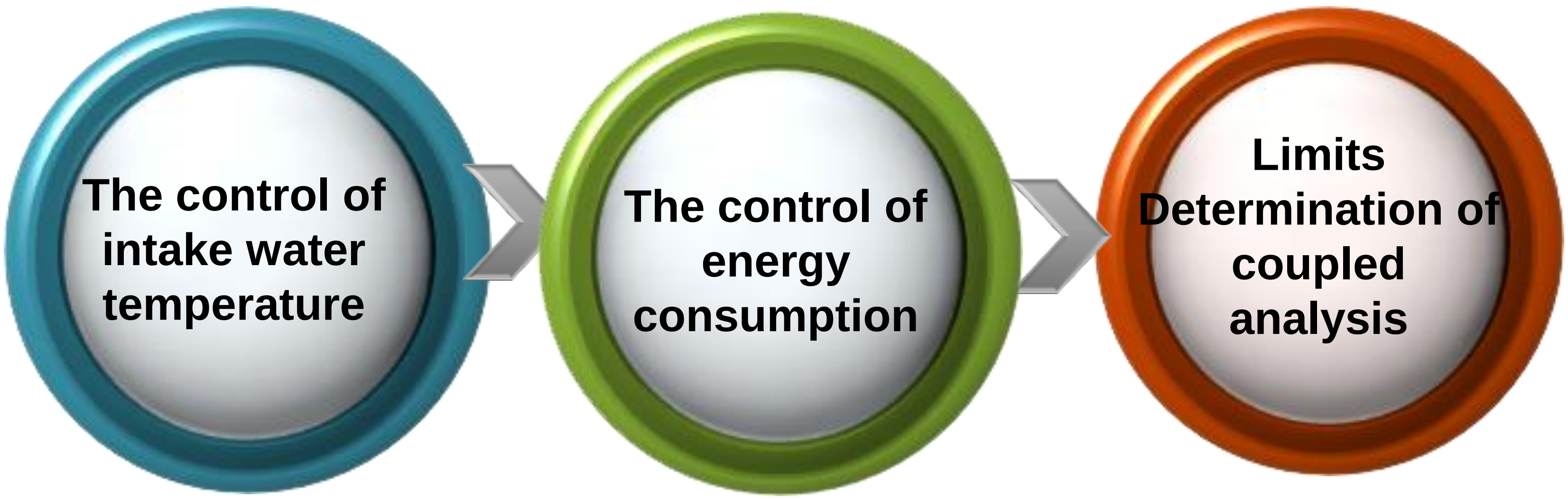


The Design of a Novel Heat Exchanger without Water Treatment (patent number: ZL 2008 1 0069811.1)



1. Tube Bundle in the Heat Exchanger 2. Shell 3. Tube Sheet 4. The Right Damper 5. Tube-Chamber 6. Head Plate 7. Partition Board 8. Cover Plate 9. Sand Collector 10. Sediment Extractor 11. Inlet of the refrigerant 12. Outlet of the refrigerant 13. Inlet of the river water 14. Outlet of the river water

The analysis of limits for intake water temperature coupled with energy consumption



重庆大学 CHONGQING UNIVERSITY

Energy consumption models

Energy consumption model of units

$$f_1 = N\sum_{i=0}^{2}\sum_{j=0}^{2} D_{ij}(T_{c1}-\overline{T}_{c1})^i (T_{e1}-\overline{T}_{e1})^j$$

Energy consumption model of water treatment equipment

$$W_w = constant$$

Energy consumption model of intake water pumps

$$W_i = -2.2 + 0.41G_q + 0.8X10^{-3}G_q^2 + 0.19X10^{-4}G_q^3$$

Energy consumption model of air conditioning water circulation pumps

$$W_C = 0.57\times10^{-4}G^3 - 0.00743G^2 + 0.69G - 14.5$$

Energy consumption model of air conditioning terminals

$$W_t = f\cdot Q$$

Energy consumption model of cooling tower

$$W_l = 1.98\times10^{-5}G_c{}^3 + 8\times10^{-5}G_c{}^2 + 0.143158G_c - 2.168$$

Calculation and analysis method

1）Based on specific parameters of the actual project, energy consumption models of all parts of both water source heat pump systems and traditional air conditioning systems are established.

2）Energy efficiency of water source heat pump system needs to be calculated, under the conditions of different loading rates , different ways of water intake and different intake water temperatures.

3）Energy efficiency of air-conditioning system needs to be calculated under the conditions of different load factors and different water temperature of cooling tower.

4）Taking the energy efficiency of traditional air conditioning system as a benchmark, energy efficiency needs to be compared under these two different conditions to get the operating points with the same energy efficiency, below which point surface water source heat pump systems are just not energy efficient.

5）Under the intake water temperature limits at different operating points, the dynamic water temperature limit curve is gotten by the use of MATLAB.

Benchmark of the intake water head (H)

Considering an idealized water intake situation of open-loop system

Surface water is not too far away from the refrigeration room.

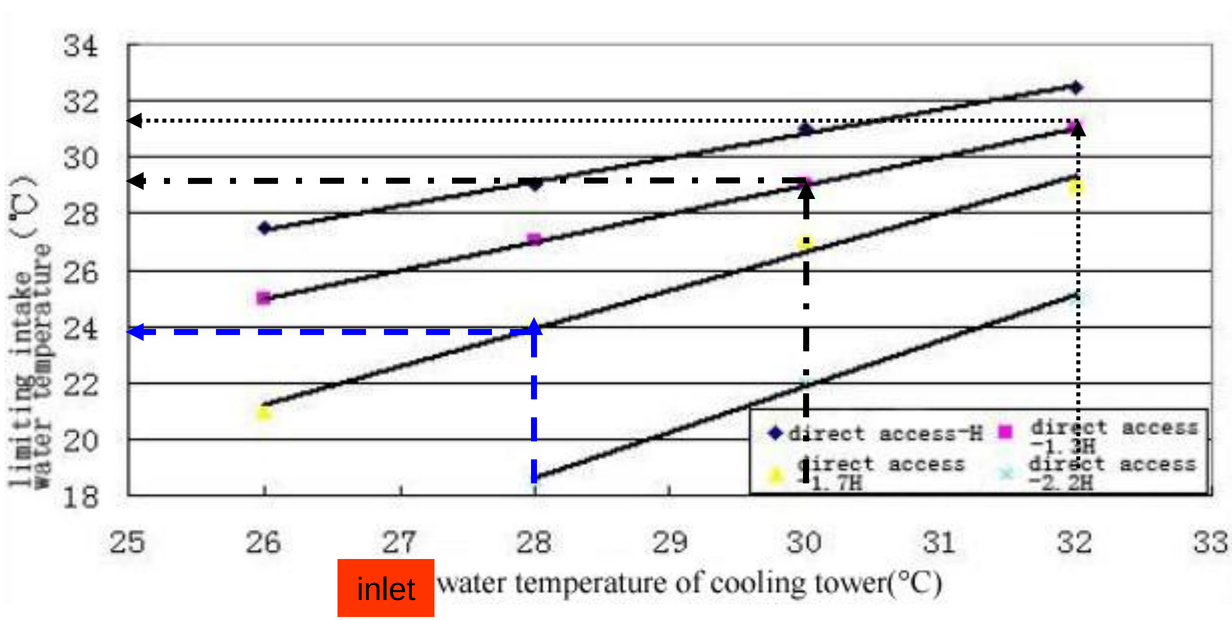
Intake water height is not too large.

Good Water quality and direct water flows into the units through the water pump.

The head of 26 meters is be taken as a benchmark of the intake water pump—H.

Intake water temperature limit (Direct access)

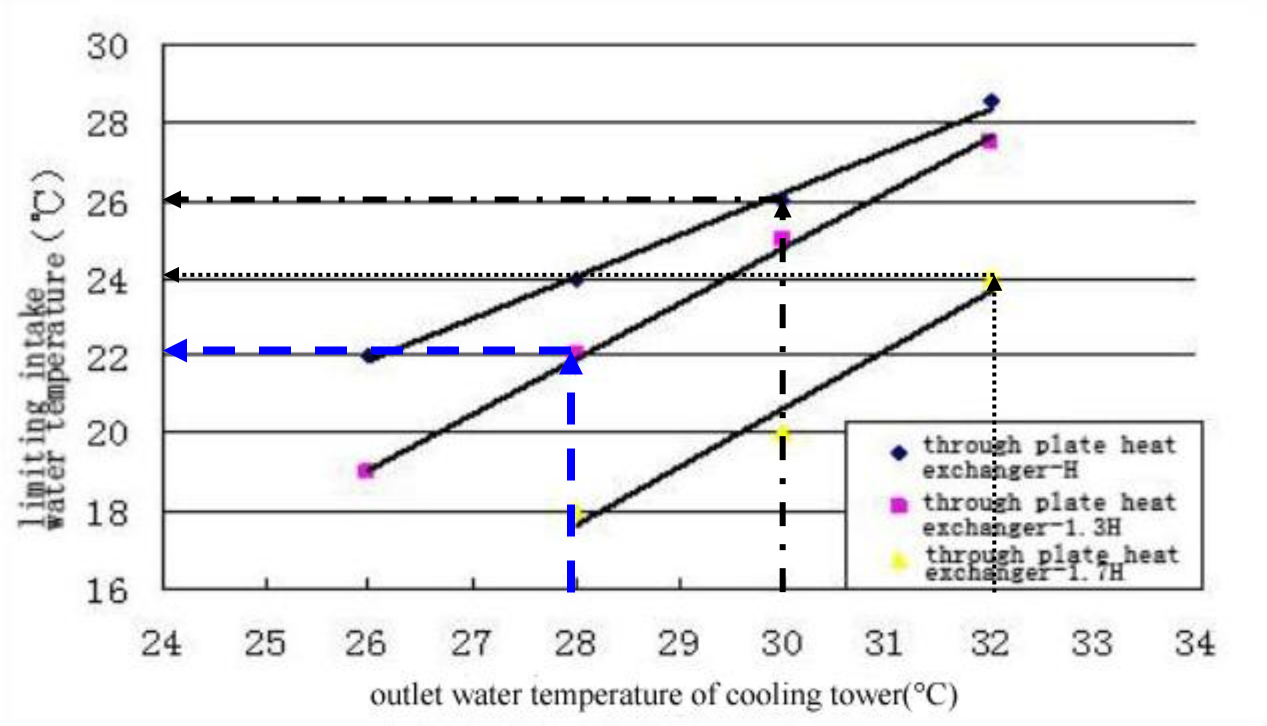
Inlet water temperature of cooling tower ℃	26	28	30	32
Direct access—Intake water temperature limit under program of 1.3H/ ℃	25	27	29	31
Direct access—Intake water temperature limit under program of 1.7H/ ℃	21	24	26.5	29
Direct access—Intake water temperature limit under program of 2.2H/ ℃	/	18.5	22	25



重庆大学 CHONGQING UNIVERSITY

Intake water temperature limit (Through plate heat exchanger)

Plate heat exchanger—program H：y = 1.075x – 6.05 R2 = 0.9968
Plate heat exchanger—program 1.3H：y = 1.425x – 17.95 R2 = 0.9982
Plate heat exchanger—program 1.7H：y = 2x - 40 R2 = 1



Energy saving rate

Directly into unit—program H:Energy saving rate at different intake water temperature and 32℃ of inlet water temperature of cooling tower .

Intake water temperature℃	30	28	26	24	22
EER of the system	3.7612	3.9252	4.085	4.2197	4.425
Energy saving rate%	4.56%	9.15%	13.6%	17.35%	23.05%

Through plate heat exchanger units—program H :Energy saving rate at different intake water temperature and 32℃ of inlet water temperature of cooling tower.

Intake water temperature℃	28	26	25	24	22	20
EER of the system	3.63	3.70	3.78	3.841	3.865	3.925
Energy saving rate %	1%	2.9%	5.1%	6.8%	7.5%	8.4%

Application of the results

The results can be used to calculate the intake water elevation of the surface water source heat pump systems.

Maximum water head at intake water temperature limits

H

$+$

ΣL

Resistance loss

↓

$\triangle H$

The maximum intake water elevation is gained which must match the premise that the system has high energy saving rate.


△H

Project test

Using water heat pump system in which source water flows through the plate heat exchanger for the study:

The head of intake water pump is 1.57H.

Water source heat pump system	Inlet water temperature(℃)	Partial load factor	COP of unit	EER of system
Test data	23.3	0.63	5.17	3.03

Application in China

Provincial distribution of surface water source heat pump applications in China

Province	Quantity	Province	Quantity	Province	Quantity
Heilongjiang	1	Gansu	2	Sichuan	8
Jilin	2	Henan	3	Chongqing	18
Liaoning	4	Jiangsu	5	Hunan	3
Beijing	2	Shanghai	4	Hubei	3
Tianjin	5	Zhejiang	3	Guizhou	1
Hebei	3	Fujian	3	Guangdong	4
Qinghai	1	Jiangxi	1	**Total**	**76**

重庆大学
CHONGQING UNIVERSITY

The distribution of surface water source heat pump in China

Projects of surface water source heat pump application in China

NO.	Region	Project name	Floor area（10^4m^2）	Design cooling capacity （KW）	Design heating capacity（KW）	Surface water source
1	Jiangsu Nanjing	Gulou Service Outsourcing Industrial Park of Nanjing	245.6	90000	43000	Yangtze River
2	Chongqing	The first and second phase of central cooling and heating system supplied by surface water source heat pump in Jiangbei CBD area	145.95	100916	45000	Jialing River
3	Sichuan Fuling	Fuling central business district (CBD)	48	4546.8	2476.4	The junction of Yangtze River and Wu River
4	Shanghai	A part of buildings in World Exhibition or Exposition	46	46000	26000	Huhangpu River
5	Guangdong Guangzhou	Haizhu Square	37.12	4984	2500	Zhujiang

Examples of surface water source heat pump application in China

NO.	Region	Project name	Floor area （$10^4 m^2$）	Design cooling capacity （KW）	Design heating capacity （KW）	Surface water source
6	Anhui	Residential district for workers from Homeland of Science	20.4	6649.6	3324.8	Shushan Lake
7	Shanxi	Mixed Modern City and Mixed City Garden	21	7904.1	6142.3	The lake
8	Henan	Maple's Woods& Water County in Anyang	19.9	4435	2231	The lake
9	Jiangsu	Pioneer International Business Benter in Yancheng	15.62	8276.5	4636.4	Cheng River
10	Guangdong Zhuhai	The Fifth Affiliated Hospital of Zunyi Medical College in Zhuhai	15	5590.3	2796.4	Zhujiang

重庆大学 CHONGQING UNIVERSITY

Examples of surface water source heat pump application in China

NO.	Region	Project name	Floor area（$10^4 m^2$）	Design cooling capacity（KW）	Design heating capacity（KW	Surface water source
11	Hunan Xiangtan	The first phase of construction of Urban Centre of Xiangtan	12.45	7300	4786	Xiang River
12	Fuzhou	Fuzhou Strait International Exhibition Center	12	6360	3184.2	The inner lake of Min River
13	Guang dong Guangzhou	Water source heat pump project of Fangcun Garden	11.96	5367.8	2654.9	The lake
14	Sichuan Chengdu	Qianjiang Platinum Times Square project in Chengdu	10.5	4150.6	2189.3	Pu River

Thanks for your attention！

Email:18908317198@189.cn