Applied Energy Symposium 2019: Low carbon cities and urban energy systems
October 16-18, 2019, Xiamen, China
Paper ID: 0092

ANALYSIS OF EFFICIENCY AND EMISSION REDUCTION OF ONLINE WATER TREATMENT TECHNOLOGY

Yaoli Zhang[1*], Pengfei Wang [1], Gang Hong[1]

1College of energy, Xiamen university, Xiamen, Fujian, 361105, China

ABSTRACT

In order to reduce the impact of fouling on the efficiency of central air conditioning chillers, and thus improve the energy efficiency of buildings, we propose a new type of special online water treatment technology (SOWTT). The effects of SOWTT were evaluated by tracking and calculating the operating efficiency, annual electricity consumption, annual electricity expenditure, and carbon dioxide emission reduction of dozens of chillers in Xiamen. The results show that compared with the mechanical cleaning technology, the SOWTT not only reduces the annual power consumption of the refrigeration unit, but also increases the emission reduction of carbon dioxide. At the same time, the COP of the chiller is also greatly improved, and the comprehensive benefits are remarkable.

Keywords: energy conservation in building, dirt thermal resistance, special online water treatment technology, refrigeration coefficient, chiller

1. INTRODUCTION

With the rapid development of the global economy and the huge leap in science and technology, human living standards have been continuously improved, but at the same time energy consumption has increased year by year. The use of a large amount of energy not only exacerbates the energy crisis, but also increases the concentration of greenhouse gases. The resulting global warming problem seriously affects human survival. Therefore, countries should rectify major energy consumption links, improve energy efficiency, reduce carbon emissions, and achieve sustainable human development. Research shows that building energy consumption accounts for about 40% of global energy consumption, accounting for about one-third of global greenhouse gas emissions[1,2]. It is expected that this proportion will increase further in the next few years. The largest energy consumption in buildings is heating and air conditioning systems, which account for 40%-60% of the total energy consumption of buildings [3]. The problem of building energy consumption in China is also very serious. According to relevant data, the annual electricity consumption of large public buildings is about 22% of the total electricity consumption of cities and towns in China, which is 1.5-2 times of the electricity consumption of the same type of buildings in developed countries such as Europe and Japan [4]. The total energy consumption of central air-conditioning systems in China accounts for 40-50% of the energy consumption of large public buildings, and some even reach more than 70% in hot summer areas. It can be seen that the cooling power consumption in the city accounts for a large proportion, and reducing the energy consumption of the chiller is the main way to achieve energy saving in buildings.

At present, water-cooled units used in large-scale shopping malls, hotels, office buildings, etc. in cities are generally wasteful of energy. This is mainly because the water circuit is in contact with the external environment, it is easy to breed bacteria and scale, the heat exchange capacity is deteriorated, the operation efficiency of the chiller is reduced, and the power consumption is increased. Statistics show that the annual heat loss of heat exchangers in developed countries accounts for about 0.25% of GDP. China's industrial technology is relatively backward, the equipment is outdated, and the annual loss due to dirt is more expensive. It is conservatively estimated that the pollution has reduced the efficiency of China's heat exchangers by at least 50% [5]. In southern China, the problem of condenser fouling is particularly serious.

In order to improve the energy efficiency of buildings, alleviate the energy crisis and improve the current situation of global warming, people study the chiller, which is the main energy consumption of buildings, and put forward a variety of methods for scaling, including physical method, chemical method and mechanical method. However, the effect of different cleaning methods varies greatly. Although the chemical method is evenly cleaned and does not leave a dead angle, there is a problem that the pipeline is corroded and the cleaning fluid damages the environment; the physical cleaning requires additional equipment and consumes part of the energy, and the cleaning speed is not as fast as chemical cleaning; the traditional mechanical cleaning operation is complicated. A shutdown is required to open the device for processing. Based on the above deficiencies, we have cooperated with a company to develop a new type of SOWTT that is safe, efficient and environmentally friendly. This paper analyzes the high efficiency of the technology in the anti-scaling of the condenser from the perspective of the unit's energy efficiency. If the technology is promoted, it can effectively improve the cooling efficiency of large public buildings in the city and achieve the goal of building energy conservation.

2. THE FORMATION OF DIRT IN THE CONDENSER

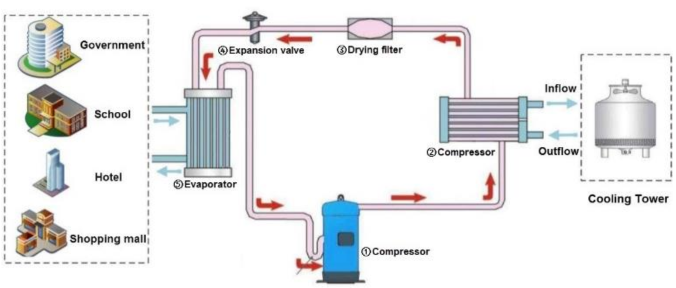

Fig 1 Schematic diagram of the chiller system

In the refrigeration cycle shown in Figure 1, the middle pink portion is a refrigeration cycle that is completely closed. On the left side, the chilled water circulation is also closed. The cooling capacity is generally brought by the wind system to the hotel, shopping malls and other cold users through the heat exchanger. The cooling water circulation on the right side generally uses a cooling tower to transfer heat to the outdoor environment, which is an open system. The condenser is a connection device for the cooling water circulation and the refrigeration cycle. Generally, the cooling water flows in the heat exchange tubes, and the refrigerant flows outside the heat exchange tubes. In practice, the inside of the heat exchange tube is particularly prone to fouling, mainly because the cooling water flows through the cooling tower to bring microorganisms and dust into it. In addition, the cooling water evaporates to increase the concentration of Ca^{2+} and Mg^{2+}, and their solubility decreases with the increase of temperature, so that it precipitates on the inner wall of the condenser at a high temperature to form a scale such as $CaCO_3$ or $MgCO_3$. The thermal conductivity of these materials is very small. For example, the thermal conductivity of $CaCO_3$ is only 0.8W/(m·K) [6], which is 1/60 of the thermal conductivity of carbon steel. Therefore, even if a very thin layer of dirt accumulates, it will have a serious impact on the heat transfer effect. According to the 2000 Handbook of the American Association of Refrigeration, Heating and Air-Conditioning Engineers, when a chiller condenser has a 0.3 mm thick film-type scale, the chiller will increase the energy consumption by 12.4% [7]. It can be seen that the degree of fouling must be strictly controlled.

3. MATHEMATICAL MODEL

If the chiller condenser produces fouling, the condensing temperature and condensing pressure of the chiller rise when the temperature of the cooling water inlet and outlet water and the chilled water inlet and outlet temperature are the same. Since the evaporation temperature does not change much, it is assumed that the state point 1 remains unchanged, and the chiller refrigeration cycle will change from 1-2-3-4-1 to 1→2'→3'→4'→1. As shown in the pressure cycle diagram of the refrigeration cycle in Figure 2.

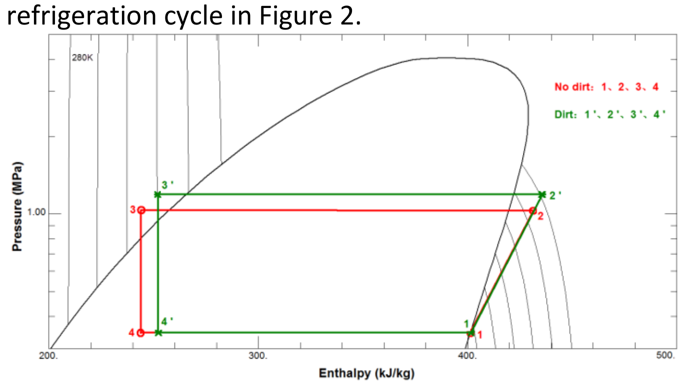

Fig 2 Refrigeration cycle pressure map in the presence of dirt

According to the recorded data, the COP value of the refrigeration unit can be calculated under different fouling heat resistance values. The calculation principle is as follows.

The heat exchange capacity of the condenser can be written as

$$Q_c = \dot{m}_c c_p \left(t_{c,out} - t_{c,in}\right) = K A_i \Delta t_m \quad (1)$$

$\dot{m}_c$, c_P, $t_{c,out}$, $t_{c,in}$, K, A_i denote water mass flow rate, the constant pressure specific heat of water, the cooling water outlet temperature, the cooling water inlet temperature, the heat transfer coefficient and the total internal surface area of the heat exchange tube.

Δt_m in the above equations denotes Logarithmic mean temperature difference, given by

$$\Delta t_m = \frac{\Delta t_{max} - \Delta t_{min}}{\ln \frac{\Delta t_{max}}{\Delta t_{min}}} \quad (2)$$

Where are Δt_{max} and Δt_{min} represent the larger and smaller of the temperature difference between the fluid at the inlet end of the condenser and the temperature difference between the fluids at the outlet end of the condenser, respectively.

The formula for calculating the heat transfer coefficient can be written as

$$\frac{1}{K} = \frac{1}{h_w} + \frac{\delta}{\lambda_p}\frac{A_i}{\bar{A}} + \frac{1}{h_c}\frac{A_i}{A_o} + R_f \quad (3)$$

Where h_w is the convective heat transfer coefficient of the cooling water side, δ is the thickness of the heat exchange tube wall, λ_p is the thermal conductivity of the heat exchange tube, $\bar{A}$ is the average area of the inner and outer surfaces of the heat exchange tube, A_i is the inner surface area of the heat exchange tube, A_o is external surface area of heat pipe.

Ma Shuo et al. [8]summarized the variation of fouling thermal resistance with time through related experiments.

$$R_f = 8.81 \times 10^{-5} t^{0.25} \quad (4)$$

Where t is time.

In the condenser, the cooling water flow rate is generally 1.8-2.5 m/s, and the corresponding Re is in the range of 3.8×10^4-5.38×10^4. Therefore, the flow state of the cooling water in the tube is turbulent, and the convective heat transfer coefficient of the cooling water can be calculated by the following formula.

$$h_w = 0.023\frac{\lambda_w}{d_i}\mathrm{Re}_w^{0.8}\mathrm{Pr}_w^{0.4} \quad (5)$$

Where λ_w is the thermal conductivity of the cooling water, d_i is the inner diameter of the heat exchange tube, Re_w is the Reynolds number of the cooling water, Pr_w is the Prandtl number of the cooling water.

The convective heat transfer coefficient on the refrigerant side can be calculated by an empirical formula.

$$h_c = 0.725\varphi\varepsilon_n\left[\frac{gr\rho_c^3\lambda_c^2}{\mu_c n_m d_o (t_c - t_w)}\right]^{0.25} \quad (6)$$

Where φ is the enhancement factor, ε_n is the tube bundle correction coefficient, g is the gravitational acceleration, r is the latent heat of vaporization, ρ_c is the refrigerant density, λ_c is the refrigerant thermal conductivity, μ_c is the refrigerant dynamic viscosity, n_m is the average number of rows in the vertical direction, d_o is the outer diameter of the heat exchange tube, t_w is the wall temperature.

By calculating the change in the heat exchange amount of the condenser, the value of each state point after the fouling can be obtained. The cooling coefficient COP of the chiller is obtained by the following formula.

$$COP = \frac{h_1 - h_{4'}}{h_{2'} - h_1} \quad (7)$$

Where h1, h2', h4' are the enthalpy of the state points.

In summary, the circulation efficiency of chiller under different fouling thermal resistance can be obtained. In order to further explore the characteristics of the SOWTT, we studied the operating conditions of four chiller units. Unit A uses SOWTT, and the thermal resistance of the dirt is maintained at 0.0001 $m^2\cdot K/W$. Unit B is a mechanical cleaning technology. It is assumed that the cleaning is very clean, and the thermal resistance of dirt is 0 after cleaning. After that, the thermal resistance of dirt meets the variation law of formula (4). Considering that mechanical cleaning is closely related to cycle, it can be divided into monthly cleaning, quarterly cleaning, and semi-annual cleaning, respectively corresponding to unit B1, B2, B3. For these four units, the differences in refrigeration efficiency, annual electricity consumption and carbon dioxide emission reduction can be analyzed.

4. RESULT AND DISCUSSION

The initial state and operating conditions of the four chillers are the same. The state parameters of the refrigeration cycle at the beginning are shown in Table 1 below, and then the chiller is descaled and scaled in four ways, and the effect on the efficiency of the unit is evaluated.

Table 1 Refrigeration cycle status parameters

Working point	Temperature /K	Pressure /MPa	Enthalpy (kJ/kg)
1	281.65	0.394	403.48
2	316.85	0.902	426.24
3	203.25	0.866	241.86
4	283.05	0.414	241.86

4.1 Influence of SOWTT on unit efficiency

In the A unit with SOWTT, the COP of the refrigeration cycle is maintained at 5.505. When the mechanical cleaning technology is used, the thermal resistance of the dirt increases with time during the time interval from descaling to the next descaling, and the heat transfer amount of the condenser decreases, and the COP of the refrigeration cycle continues to decrease. Fig. 3, Fig. 4 and Fig. 5 show the variation of COP over time in the refrigeration cycle using two techniques. It can be found that the mechanical cleaning technology, whether it is cleaned once a month, cleaned once a quarter or once every six months, the refrigeration cycle COP is lower than the SOWTT in almost all time periods, and the heat exchange effect is poor. It is more obvious when it is cleaned once every six months.

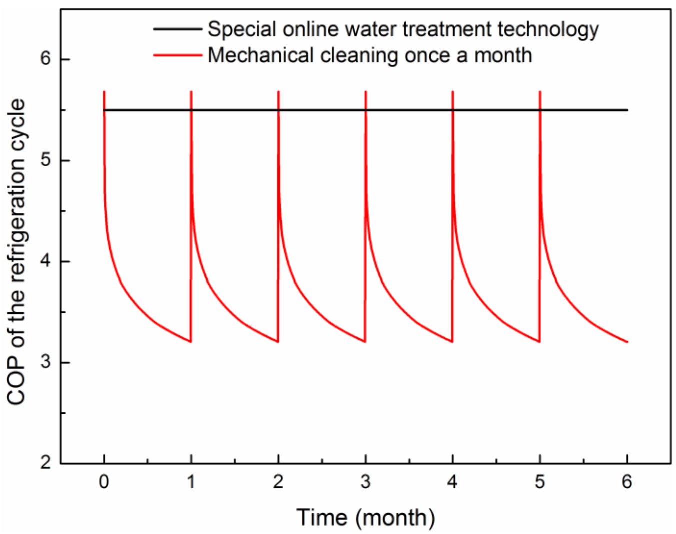

Fig 3 Changes in COP over time with different descaling techniques (1)

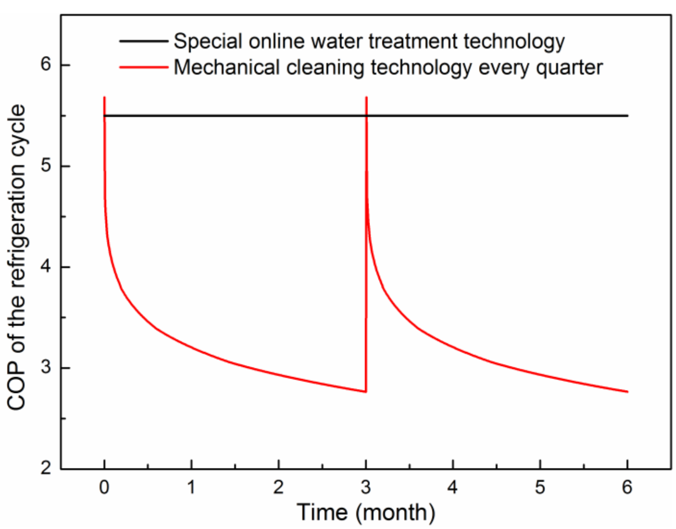

Fig 4 Changes in COP over time with different descaling techniques (2)

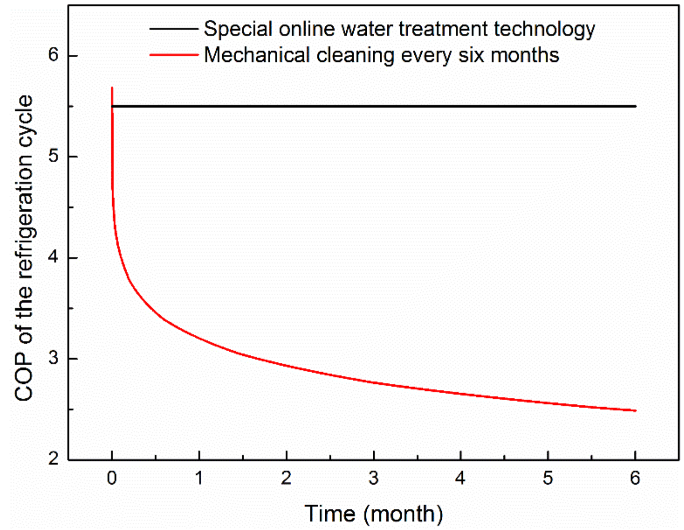

Fig 5 Changes in COP over time with different descaling techniques (3)

4.2 Impact of SOWTT on annual electricity consumption

For the annual electricity consumption of the four units, the case can be analyzed with a screw chiller with cooling capacity of 1000 kW used by a hotel in Xiamen, China. Assume that the screw unit used in the hotel will run for six months in a year. When the SOWTT is adopted, the COP of the refrigeration cycle is kept at 5.505 with high efficiency, and the power consumption of the unit is 181.65 kW, and the power consumption is linear with time. Considering the mechanical cleaning method, the COP changes with time, so the power consumption is obtained by integrating the running power over time.

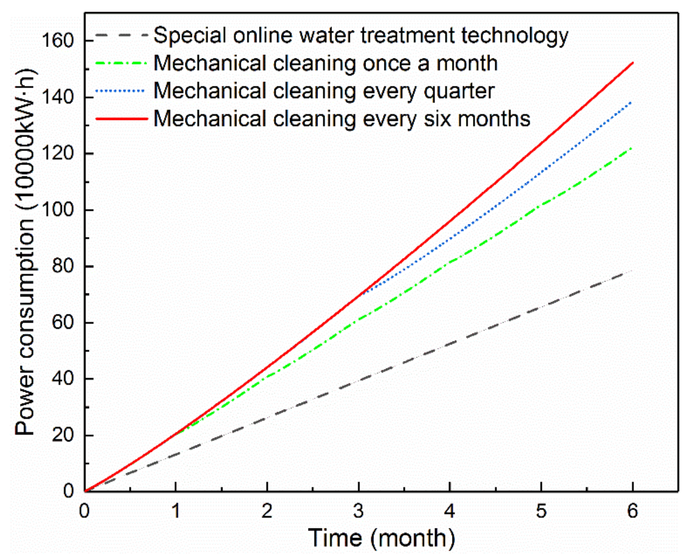

Fig 6 The power consumption of the refrigeration unit changes with time

As shown in Figure 6, it is the curve of the power consumption of four refrigeration units with time. It can be found that the B3 unit that is mechanically cleaned once every six months is the largest, and then the B2 unit that is cleaned once every quarter. The lowest power consumption is the unit using SOWTT, and the difference in power consumption between the three units of unit A and B is increasing with time. If the three units are running at the same time, after one year (the unit runs for 6 months), the cooling units using SOWTT consume 436414 degrees of electricity, 600829 degrees of electricity and 735793 degrees of electricity, respectively, compared with the three units using the mechanical cleaning technology of monthly cleaning, quarterly cleaning and semi-annual cleaning. The energy saving effect is significant.

At present, the price of commercial electricity in Xiamen city is ¥0.6408 per KWh, which can be used to calculate the electricity expense of using SOWTT and mechanical cleaning technology once a month, once a quarter and once a half a year.

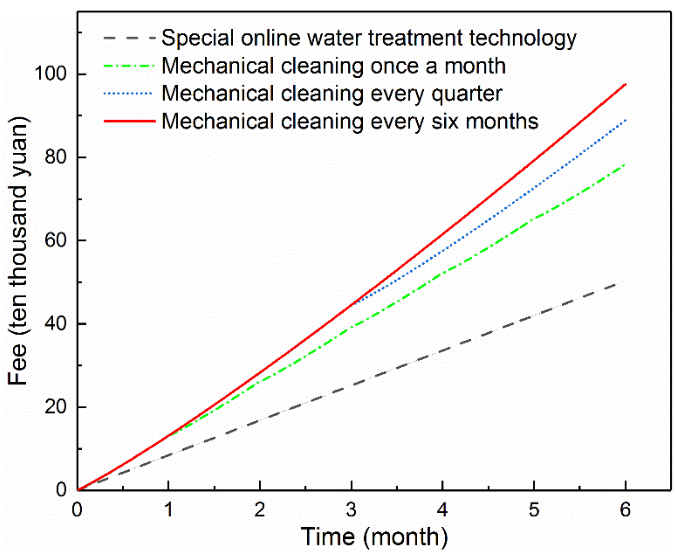

Fig7 The relationship between unit electricity expenditure and time under different

From the relationship between the electricity expenditure and the time of the unit in different descaling modes shown in Figure 7, it can be found that the difference in the electricity expenditure of the unit corresponding to the mechanical cleaning technology is higher than that of the unit corresponding to the SOWTT. The bigger it is, the more prominent it is when it is mechanically cleaned every six months. If the cold water enterprise adopts the SOWTT to descale the refrigeration unit condenser, it saves about ¥279,000 compared with the monthly mechanical cleaning, which saves about ¥385,000 electricity bills compared with the mechanical cleaning every quarter, compared with the mechanical cleaning of semi-annually, saves electricity costs by ¥472,000, greatly reducing the operating costs of enterprises, reflecting the huge economic advantages of SOWTT.

4.3 Impact of SOWTT on carbon dioxide emission reduction

By saving energy, carbon dioxide emissions can be reduced. The data show that saving one kilowatt hour is equivalent to reducing 1 kg of carbon dioxide emissions [9]. According to this value, the amount of carbon dioxide that can be reduced by SOWTT compared to mechanical cleaning technology can be obtained. As can be seen from Fig. 8, the amount of carbon dioxide reduced by using SOWTT rather than mechanical cleaning technology increases with the operation time of the unit. If the unit is operated for six months, the SOWTT can reduce about 436 tons of carbon dioxide compared with the mechanical cleaning technology once a month, about 600 tons of carbon dioxide compared with the mechanical cleaning technology once a quarter, and about 736 tons of carbon dioxide compared with the mechanical cleaning technology once a half year, which has a significant reduction effect.

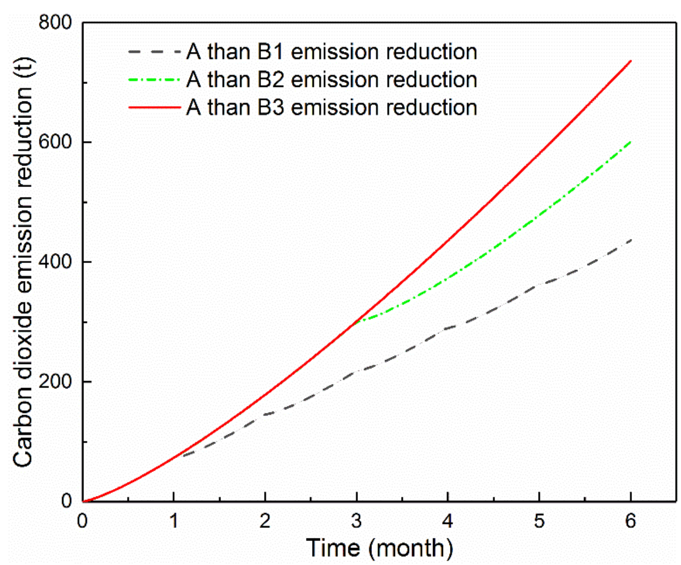

Fig 8 SOWTT more than the mechanical cleaning technology to reduce carbon dioxide emissions over time

4.4 Application of SOWTT in Xiamen

In engineering applications, the condenser heat transfer effect is evaluated by the size of the intuitive data "small temperature difference". "Small temperature difference" is a common name in the industry. The scientific name is "close to temperature difference", which refers to the difference between the saturation temperature of the refrigerant in the condenser and the temperature of the cooling water outlet. The increase of “small temperature difference” means that the heat exchange efficiency of the heat exchanger is reduced. The small temperature difference of the normal condenser operation is generally about 2 °C. Once the condenser starts to scale, the small temperature difference can often reach 4-5 °C, even 6 - 8 °C, severely caused the cold machine over temperature and overpressure alarm shutdown. The study found that for every 1°C increase in the small temperature difference of the condenser of the chiller, the cooling efficiency will decrease by 2-3%, that is to say, the cooling energy consumption will increase by 2-3%, which will seriously affect the unit efficiency.

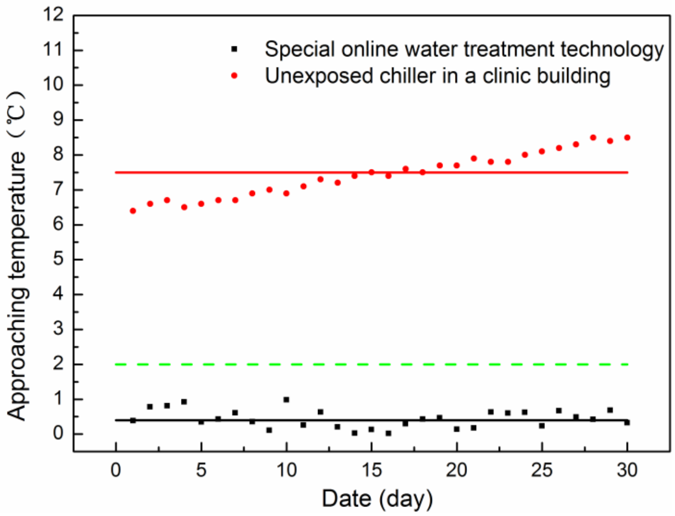

Fig 9 Whether the effect of descaling on small temperature differences

We conducted a one-month follow-up survey of a chiller in a hotel using an SOWTT in Xiamen and a non-descaling chiller in an outpatient building, and obtained the scatter plot shown in Figure 9. It can be found that the small temperature difference of the SOWTT is maintained at about 0.4 °C, which is basically equivalent to the small temperature difference of the new unit, far below the upper limit of the normal range of 2 °C, but if the descaling is not performed, the small temperature difference is continuously increased during the measurement cycle. The internal average small temperature difference has reached 7.5 °C, and the power consumption will be greatly increased under the same conditions. Therefore, the small temperature difference can also reflect the excellent anti-scaling effect of the SOWTT.

5. CONCLUSION

Through the research on SOWTT and mechanical descaling technology in terms of operating efficiency, annual power consumption, carbon dioxide emissions, etc., we can know that SOWTT has an excellent anti-scaling effect, and saves electricity costs of ¥472,000 compared to the mechanical cleaning every six months. In terms of energy saving and emission reduction, the SOWTT has obvious advantages. Compared with the mechanical cleaning every six months, it saves 735,793 kWh and reduces 736 tons of carbon dioxide. Therefore, if the SOWTT technology is widely used in urban public buildings, it will effectively improve the cooling efficiency, reduce the operating costs of the chiller, and significantly reduce greenhouse gas emissions, thereby achieving the goal of building energy efficiency and low carbon cities.

REFERENCE

[1] Yang, L., et al. Thermal comfort and building energy consumption implications – A review. J Applied Energy 2014; 115:164–73.

[2] Goh, T., et al. Quantifying drivers of CO2 emissions from electricity generation current practices and future extensions. J Applied Energy 2018; 231:1191–204

[3] Chaudhuri, T, et al. A feedforward neural network based indoor-climate control framework for thermal comfort and energy saving in buildings. J Applied Energy 2019; 248: 44-53.

[4] ZhouHai, et al. Energy Management in Colleges and Universities: Current Situations and Strategies. J China Population, Resources and Environment2014; 24(S2):95-98.

[5] Xu Z M, Yang S R, Guo S Q, et al. Costs due to utility boiler fouling in China. J Heat Transfer-Asian Research 2005; 34 (2) : 53-63.

[6] Zhanglixin, Li Xin, Gao Ming, et al. Comparison of Descaling Characteristics between High-frequency and Induction-type Electronic Descaling Devices. J Journal of Refrigeration 2018; 39(01): 108-114.

[7] ASHRAE, ASHRAE Handbook 2000 Systems And Equipment. M, America: ASHRAE, 2000.

[8] MaShuo, Liu Wanfu, et al. Influence of rubber ball on-line cleaning device on chiller performance. J Heating Ventilating & Air Conditioning 2019; 49(02): 117-120+32.

[9] Tang Yong. Analysis of thermal efficiency of coal mine gas utilization and recycling ways. J Environmental Protection and Technology 2019, 25(02): 52-55.