Energy saving potential analysis of the application of Cooling tower cooling technology in Guiyang

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Abstract. We conducted research on the development of cooling tower cooling technology and the trend of wet bulb temperature in Guiyang throughout the year. According to the results, we found that the cumulative number of hours in which the wet bulb temperature of Guiyang was ≤14°C totaled 4327 hours, which accounted for 49.39% of the total. On the one hand, in winter, when the wet bulb temperature is 14°C as the switching temperature, the theoretical cooling hours in winter is 2130 hours. On the other hand, in spring and autumn, the theoretical hours of indirect cooling tower "free" cooling totaled 1904 hours. At the same time, it is worth mentioning that in winter and transitional seasons, the theoretical cooling hours account for 94% of the total free cooling hours available for cooling towers throughout the year. Through further analysis, we believe that the application of this technology in Guiyang has good energy-saving potential and application value. It should be noted that in actual engineering applications, the utilization characteristics of natural cold sources also need to be considered. At the same time, we have to combine the terminal form of the air conditioner and the characteristics of the cooling load to give full play to the energy-saving potential of cooling tower cooling technology.

1. Preface
As we all know, energy, as an important basic resource for people's food, clothing, housing, and transportation, is not only an important material basis for the national economy, but also the basis for the survival and development of modern society. However, as the scale of the building expands and functions overlap, there is a problem of perennial cooling in the inner area of the building. At the same time, cooling tower cooling technology is now an important technology for us to use natural cold sources to achieve energy saving in air conditioning systems, which has attracted the attention and attention of people in the HVAC industry around the world.

2. Development status of cooling tower cooling technology
Cooling tower cooling system, also known as Tower Cooling. This is a concept proposed by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) in the 1980s, namely water-side free cooling [1-2]. In fact, as early as the 1980s, this technology attracted the attention of European and American countries and was put into practical engineering applications. In addition, in the 1990s, this technology has been widely used, and many achievements have been made.
in theoretical research. It is worth mentioning that the cooling tower cooling technology literature included in ASHRAE points out that the cooling tower cooling system has high-efficiency energy saving potential [3].

The cooling tower is an evaporative heat dissipation device that uses water as a circulating coolant. The device can use water and flowing air to exchange cold and heat to produce steam. In this case, steam volatilization can take away heat, so as to meet the needs of life and production. Specifically, in the process of heat and mass transfer between the cooling tower and air, on the one hand, the heat transfer due to the temperature difference between air and water is called contact heat transfer. On the other hand, the heat transfer formed by the difference in the partial pressure of water vapor in the saturated water film on the water surface and the difference in the partial pressure of air vapor is called evaporative heat transfer. The above-mentioned two forms of heat transfer are the main methods of heat exchange in cooling towers. In addition, for a cooling tower with a certain structure, the outlet water temperature is determined by the outdoor atmospheric wet bulb temperature and the cooling load of the building. We know that the outdoor atmospheric wet bulb temperature is the lowest temperature at which water can be cooled, and is also the theoretical limit value of the cooling tower outlet water temperature. In the transition season or early summer, the outdoor temperature is relatively low, the relative humidity drops, the outdoor wet bulb temperature also decreases, and the building cooling load is small. In this case, appropriately increasing the temperature of the chilled water and reducing its dehumidification capacity can fully meet the indoor thermal comfort requirements. At this time, we can turn off the chiller and use the cool outdoor air to directly or indirectly cool the building with the circulating cooling water flowing through the cooling tower, thus becoming a "free" cold source.

Merkel first proposed the heat transfer theory of closed cooling tower, and became the theoretical basis of related research. But what we need to know is that the evaporation loss of water is ignored in Merkel’s theory, and the enthalpy difference is mistakenly used as the driving force of heat transfer between air and water film. At the same time, he thinks that the Lewis number of heat exchange in saturated boundary layer is equal [4], which is not correct. Parker and Treyball studied the heat and mass transfer mechanism of the medium in the tube. They obtained the correlation formula of the heat transfer coefficient through the combined experiment of the fluid inside and outside the tube, and established a more complete mathematical model [5]. Researchers such as Koschenz established a closed cooling tower model, assuming that the spray water temperature in the tower was constant and equal to the outlet water temperature of the cooling tower [6]. In 1997, Zalewski and Gryglaszewski [7] created a mathematical analysis model of heat and mass transfer in a closed cooling tower. Using this model and applying the similarity between heat transfer and mass transfer, he deduced the relationship between the mass transfer coefficient and the heat transfer coefficient when the fluid flows through the tube bundle. Webb [8] used the cooling tower theoretical model to distinguish the heat transfer coefficient of the water film and the mass transfer coefficient of the air flow through the water film according to the correlation coefficient. Maclaine-Cross and Banks [9], Kettleborough and Hsieh [10], Chen et al. [11] studied the indirect evaporative cooling tower model. The research model reasonably reflects the influence of outdoor air, but the cooling effect is overestimated. Pascal Stabat [12] developed a simplified model of a closed cooling tower on the basis of Merkel evaporation theory. At the same time, he also introduced the heat exchanger efficiency unit number method (E-NTU) to evaluate the heat exchange effect. This simplified model can not only be used to evaluate the cooling tower performance under different air volumes and operating conditions, but also to evaluate the water volume of cooling tower. Mansour et al. [13] used CFD to simulate an evaporative cooling tower with suction airflow, and the simulation results can be comparable to the results of the finite difference model. G. Gan and Riffat [14] used Fluent to simulate the cooling capacity and pressure loss characteristics of a closed cooling tower. The results showed that CFD can predict the working characteristics of closed cooling towers, which basically met the requirements of cooling tower design and operation optimization. In view of the fact that the heat transfer performance of a closed cooling tower is affected by its own structure (spray water volume), outdoor environment (air volume,
temperature and humidity) and other factors, there is no mathematical model that can accurately express this heat transfer process. Therefore, at the same time of theoretical analysis, we need to further fit the heat transfer correlation equation based on field measurements or experiments.

Based on the analysis of the cooling tower cooling system and the air-water heat exchange process, Hugh Crowther and Marley proposed suggestions and improvement measures for optimizing the cooling tower cooling system [15,16]. Research on the application of this technology in Europe is also in full swing. In addition, the dry and cold climate characteristics of Northern Europe make the energy-saving effect of this technology more significant. Based on European climatic conditions, Jorge Facao et al. put forward a number of improvement opinions on the development and application of this system [17]. TL White implemented energy-saving transformation for the air-conditioning system of an office laboratory complex in St. Louis, USA by installing plate heat exchangers and using cooling tower cooling technology. Specifically, when the outdoor wet bulb temperature drops to 7.2°C, if you turn off the conventional chiller cooling mode and switch to the cooling tower cooling mode, you can save about 125,000 US dollars in operating costs per year [18]. S.A. Mumma et al. conducted an air conditioning energy consumption analysis on an office building during the transition season. Through research, they found that when the outdoor wet bulb temperature is 7°C, if the cooling tower cooling system is turned on, the chiller can be turned on for 1044 hours throughout the year, and the energy saving effect is significant [19]. It is worth mentioning that with the in-depth research on the application of cooling tower cooling technology in European and American countries, this technology has also changed from a simple air conditioning system transformation to a composite application combined with other air conditioning technologies. For example, if the cooling tower cooling technology is combined with the end device of the radiant top plate, the advantages of the cold radiant plate in terms of thermal comfort can be exerted, while the cooling effect of the cooling water can be maximized. At the same time, this measure can also extend the cooling tower cooling hours, thereby achieving economical and considerable energy-saving effects [20].

3. Cooling capacity and service scope
On the one hand, since the outlet water temperature of the cooling tower has a strong correlation with the outdoor atmospheric wet bulb temperature, the most ideal outlet water temperature is that the cooling tower will be processed by the cooling medium to the atmospheric wet bulb temperature. On the other hand, there is a large amount of sensible heat and latent heat exchange due to the cooling process of cooling water. It is worth mentioning that the cooling mode of the cooling tower is suitable for winter or transition season, and the outdoor wet bulb temperature has been lowered compared with other periods. For this reason, the cooling tower outlet water temperature will drop further at this time. Combining the climate parameters of Guiyang, the current engineering application and the thermal performance of cooling towers, we need to determine not only the technical positioning of the cooling tower cooling system in new buildings and existing building renovations, but also the cooling capacity and service scope that we undertake. 1) As an auxiliary cold source. 2) Operate in winter and transition seasons. 3) Mainly for sensible heat load. 4) Suitable for independent temperature and humidity control system. 5) Air conditioning terminal forms such as cold radiant panels and fan coils (dry surface cooling) should be adopted. 6) It is suitable for public buildings, internal areas, data rooms, clean industrial plants, etc.

Under the realistic conditions that the inner area of the building needs to be cooled all year round, the cooling tower is the best choice to provide the inner area of the cooling. For buildings without inner areas, when the demand for cooling temperature is low, the cooling tower cooling temperature can be appropriately increased to extend the cooling hours in the transition season. In this way, the running time of conventional cold sources can be shortened to a certain extent, thereby achieving certain economic and energy-saving benefits.

4. Energy saving potential analysis
It can be seen from Table 1 that the annual wet bulb temperature in Guiyang is from -3°C to 25°C, and
the maximum number of hours that the wet bulb temperature is 21°C to 22°C is 715 hours. This accounted for 8.16% of the year. Obviously, the two intervals with the largest number of consecutive hours in the whole year are 3~11°C and 13~22°C respectively, and the number of hours in each unit interval is greater than 250h.

Table 1. The frequency table of all levels of wet bulb temperature in Guiyang throughout the year

| Wet bulb temperature range (°C) | -3~2 | -2~1 | -1~0 | 0~1 | 1~2 | 2~3 | 3~4 | 4~5 |
|----------------------------------|------|------|------|-----|-----|-----|-----|-----|
| Hours (h)                        | 21   | 33   | 86   | 140 | 181 | 192 | 276 | 288 |

| Wet bulb temperature range (°C) | 5~6 | 6~7 | 7~8 | 8~9 | 9~10 | 10~11 | 11~12 | 12~13 |
|----------------------------------|-----|-----|-----|-----|------|--------|-------|-------|
| Hours (h)                        | 441 | 501 | 440 | 326 | 256  | 298    | 236   | 219   |

| Wet bulb temperature range (°C) | 13~14 | 14~15 | 15~16 | 16~17 | 17~18 | 18~19 | 19~20 | 20~21 |
|----------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Hours (h)                        | 335   | 447   | 475   | 424   | 534   | 469   | 525   | 714   |

| Wet bulb temperature range (°C) | 21~22 | 22~23 | 23~24 | 24~25 |
|----------------------------------|-------|-------|-------|-------|
| Hours (h)                        | 715   | 186   | 4     | 1     |

Table 2. The cumulative hourly distribution of wet bulb temperatures at all levels in Guiyang throughout the year

| Wet bulb temperature range (°C) | ≤ -2 | ≤ -1 | ≤ 0 | ≤ 1 | ≤ 2 | ≤ 3 | ≤ 4 | ≤ 5 |
|----------------------------------|------|------|-----|-----|-----|-----|-----|-----|
| Hours (h)                        | 21   | 54   | 140 | 280 | 461 | 653 | 929 | 1217|

| Wet bulb temperature range (°C) | ≤ 6 | ≤ 7 | ≤ 8 | ≤ 9 | ≤ 10 | ≤ 11 | ≤ 12 | ≤ 13 |
|----------------------------------|-----|-----|-----|-----|-------|-------|-------|-------|
| Hours (h)                        | 1658 | 2159 | 2599 | 2925 | 3181  | 3479  | 3715  | 3934  |

| Wet bulb temperature range (°C) | ≤ 14 | ≤ 15 | ≤ 16 | ≤ 17 | ≤ 18 | ≤ 19 | ≤ 20 | ≤ 21 |
|----------------------------------|------|------|------|------|------|------|------|------|
| Hours (h)                        | 4269 | 4716 | 5191 | 5615 | 6149  | 6618  | 7143  | 7857  |

| Wet bulb temperature range (°C) | ≤ 22 | ≤ 23 | ≤ 24 | ≤ 25 |
|----------------------------------|------|------|------|------|
| Hours (h)                        | 8572 | 8758 | 8762 | 8763 |

As shown in Figures 1 and Table2, on the one hand, the cumulative number of hours in Guiyang where the wet bulb temperature is ≤14°C totals 4269 hours, accounting for 48.72% of the total. On the other hand, when the switching temperature is 4°C (including 4°C), the cumulative number of indirect "free" cooling towers is 4269h, which only accounts for 10.6% of the annual ratio. By comparison, we found that temperature has a great influence on the cumulative hours of indirect “free” cooling tower cooling. Specifically, the lower the switching temperature setting, the fewer theoretical cooling hours. When the wet bulb temperature is 14°C as the switching temperature, the cooling tower can provide cooling for more than 90% of the cooling hours in Guiyang in winter. First, the theoretical cooling hours in winter (December, January and February) are 2,130 hours. This accounted for 98.61% in winter, 24.32% in the whole year, and 49.23% of the total number of indirect "free" cooling hours that can be used in the whole year. Secondly, in the four months of spring (March and April) and autumn (October and November, the theoretical hours of cooling tower indirect "free" cooling totaled 1904 hours. This accounts for the indirect cooling tower available throughout the year. The proportion of the total hours of free cooling is 44.00%. In addition, between May and September, the cooling tower
indirect “free” cooling theoretical cooling hours is only 271 hours. It can be seen that Guiyang Cooling Tower "Free" cooling technology is applicable in winter and transitional seasons, and the cooling hours are longer. This can be said to have greater energy-saving potential.

![Cumulative distribution of monthly cooling hours under different switching temperatures in Guiyang](image)

Figure 1. Cumulative distribution of monthly cooling hours under different switching temperatures in Guiyang

5. Conclusion
At present, as an engineering technology with energy-saving potential, cooling tower cooling technology has been widely studied and applied at home and abroad. The cumulative number of hours in which the wet bulb temperature of Guiyang was ≤14°C throughout the year totaled 4269 hours, accounting for 48.72% of the total. On the one hand, in winter, when the wet bulb temperature is 14°C as the switching temperature, the theoretical cooling hours in winter is 2130 hours. On the other hand, in spring and autumn, the theoretical hours of indirect cooling tower "free" cooling totaled 1904 hours. In addition, in winter and transitional seasons, the theoretical cooling hours accounted for 94% of the total available cooling tower free cooling hours throughout the year. Through further analysis, we believe that when the switching temperature is set to 14°C, the free cooling technology of cooling towers can be used in Guiyang to solve the sensible heat load in the building and the energy saving potential is greater. Of course, as a form of technology for the utilization of natural cold sources, this technology also needs to combine the terminal form of the central air-conditioning and the characteristics of energy-consuming buildings in order to give full play to the energy-saving advantages of cooling tower cooling technology in winter and transitional seasons. It is worth noting that in the system design, we should also pay attention to the impact of water quality corrosion, air conditioning load fluctuations, climate change, switching operation management and other factors on the cooling tower cooling technology.

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