Studies on cooling hours and switch temperature of cooling-tower cooling supply in Guizhou typical climate district

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Abstract: According to the meteorological parameters of Guizhou Province and the feasibility of developing cooling tower cooling in 4 typical cities and towns in thermal engineering districts, we found the following situation. First of all, if calculated according to the accumulated hours of 8,760 hours of wet bulb temperature below 14°C (including 14°C), Guiyang City (moderate area) has a total of 4327 hours, accounting for 49.39% of the total. Zunyi City (a region with hot summer and cold winter) has a total of 4469 hours, accounting for 51.02% of the whole year. For areas with hot summer and warm winter, such as Xingyi City (a hot winter and warm area), a total of 4404 hours, accounting for 50.27% of the whole year. Weining County (an area with cool summer and cold winter) has a total of 6792 hours, accounting for 77.53% of the total. In addition, if it is in winter (December, January and February), when the wet bulb temperature is 14°C, the cooling hours for Guiyang, Xingyi, Zunyi and Weining are 2152h, 2159h, 2130h, 2160h, which accounting for 97.46%, 99.95%, 98.61% and 100% of the cooling hours in winter. With the help of the above data, we can find that, first of all, these cities have little difference in the number of cooling hours in different climate zones in winter, and they all have the possibility of adopting cooling tower cooling technology. Secondly, in the transitional season, when the wet bulb temperature is 14°C as the switching temperature, the cooling hours of Guiyang, Xingyi, Zunyi and Weining are 2175h, 2232h, 2339h, 3858h, respectively. It can be said that these cities have the possibility of adopting cooling tower cooling technology. It is worth mentioning that in the transitional season, the cool summer and cold winter areas represented by Weining have more obvious advantages in climate and energy saving using cooling tower cooling technology.

1. Introduction

As we all know, 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]. Guizhou is located in the hinterland of southwestern China, within the Yunnan-Guizhou Plateau. There are 9 prefecture-level administrative divisions in the province. In addition, Guizhou is located in the monsoon zone of the subtropical East Asian continent, which actually has a subtropical plateau monsoon humid climate. The climate of Guizhou has the following characteristics. First, most parts of the province have a mild climate, with the highest monthly average temperature of 20°C~26°C, and the lowest monthly average temperature of 4°C~8°C. It is worth mentioning that Guizhou has no severe cold in winter and scorching heat in...
summer, and the four seasons are distinct. Secondly, Guizhou has a typical Yunnan-Guizhou plateau climate. Based on the specific geographical location of Guizhou Province and the special climatic characteristics of the Yunnan-Guizhou Plateau, related studies divided the thermal design climate zones of civil buildings in Guizhou into four regions: hot summer and cold winter, hot summer and warm winter, temperate and cool summer and cold winter. Now for four typical cities in four climate zones, we use cooling towers plus plate heat exchangers to conduct a comprehensive and in-depth analysis of the theoretical cooling hours of the indirect cooling system. This can lay a theoretical foundation for the use of cooling tower free cooling systems in this area.

2. Analysis of theoretical cooling hours and switching temperature in Guiyang
As we all know, Guiyang is a moderate area [3]. First of all, as shown in Figure 1, the Guiyang area provides indirect cooling for cooling towers “free of charge”. The reason for this is that Guiyang's 8,760 hours of wet bulb temperature in the whole year is below 14°C (including 14°C) in total 4327 hours, accounting for 49.39% of the whole year. Second, when the switching temperature is 4°C (including 4°C), the cumulative number of hours of indirect “free” cooling of the cooling tower is 954 hours, which only accounts for 10.89% of the entire year. In addition, if an intermediate value of 9°C is taken between 4°C and 14°C as the switching temperature, the cumulative number of hours of indirect "free" cooling of the cooling tower is 2970 hours, which accounts for 33.90% of the whole year. It can be seen that the temperature has a very obvious influence on the cumulative hours of indirect "free" cooling tower cooling. 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[4].

![Figure 1 Cumulative hourly distribution curve of wet bulb temperature throughout the year in Guiyang](image)

As shown in Figure 2, if the switching temperature is 14°C, the proportion of the cooling tower's indirect “free” cooling hours in each month is greater than 4°C and 9°C. From this we can know that the lower the switching temperature is selected, the fewer theoretical cooling hours. That is, the switching temperature is directly related to the length of the theoretical cooling hours. Therefore, under the premise of meeting the building load, a relatively high switching temperature should be selected as far as possible. In order to extend the cooling hours, this can save more energy.
As shown in Table 1, when the switching temperature is 14°C, more than 90% of the Guiyang area can realize the indirect “free” cooling of the cooling tower in winter, which has achieved the goal of energy saving\(^5\). On the one hand, the theoretical cooling hours in winter (January, February, and December) are 2,152 hours. This accounted for 97.46% in winter, 24.57% of the whole year, and 49.73% of the total hours of indirect “free” cooling that can be used for cooling towers throughout the year. It can be seen that the theoretical cooling hours of indirect “free” cooling by cooling towers in winter account for nearly half of the total indirect “free” cooling hours available for cooling towers throughout the year, and 97.46% of the total winter time. On the other hand, in the four months of March and April in the spring and October and November in the fall, the theoretical hours of indirect “free” cooling towers totaled 1,904 hours. This accounts for 44.00% of the total number of indirect “free” cooling hours that can be used for cooling towers throughout the year. In addition, between May and September in summer, the cooling tower indirect "free" cooling theoretical cooling hours is only 271 hours.

### Table 1 Cooling hours and their proportions when the switching temperature is 14°C in Guiyang

| Month | Season | Accumulated cooling hours (h) | Percentage of the whole month | Percentage of the whole year |
|-------|--------|-------------------------------|-------------------------------|-------------------------------|
| 1     | Winter | 744                           | 100%                          | 8.49%                         |
| 2     | Winter | 664                           | 98.81%                        | 7.58%                         |
| 3     | Spring | 624                           | 83.87%                        | 7.12%                         |
| 4     | Spring | 428                           | 59.44%                        | 4.89%                         |
| 5     | Spring | 212                           | 28.49%                        | 2.42%                         |
| 6     | Summer | 0                             | 0.00%                         | 0.00%                         |
| 7     | Summer | 0                             | 0.00%                         | 0.00%                         |
| 8     | Summer | 0                             | 0.00%                         | 0.00%                         |
| 9     | Autumn | 59                            | 8.19%                         | 0.67%                         |
| 10    | Autumn | 211                           | 28.36%                        | 2.41%                         |
| 11    | Autumn | 641                           | 89.03%                        | 7.32%                         |
| 12    | Winter | 744                           | 100%                          | 8.49%                         |

3. Analysis of theoretical cooling hours and switching temperature in Zunyi area
As we all know, Zunyi belongs to an area with hot summer and cold winter. As shown in Figure 3, in the Zunyi area, the cooling tower is indirectly supplied with “free” cooling. First of all, for Zunyi, on the one hand, the total number of accumulated hours when the wet bulb temperature is below 14°C (including 14°C) for 8,760 hours in the whole year is 4469 hours, which accounts for 51.02% of the whole year. On the other hand, when the switching temperature is 4°C (including 4°C), the cumulative number of hours of indirect “free” cooling of the cooling tower is 1,191 hours, which is only 13.60%
of the whole year. In addition, when an intermediate value of 9°C is directly taken at 4°C and 14°C as the switching temperature, the cumulative number of hours of indirect “free” cooling of the cooling tower is 2710 hours, which accounts for 30.94% of the annual ratio.

As shown in Figure 4 and Table 2, when the switching temperature is 14°C, when the Zunyi area is more than 95% in winter, it can achieve the goal of energy saving indirectly "free" cooling towers. On the one hand, the theoretical cooling hours in winter (January, February, and December) are 2,130 hours. This accounted for 98.61% in winter, 24.32% in the whole year, and 47.66% in the total number of indirect “free” cooling hours that can be used in the whole year. Obviously, the theoretical cooling hours of indirect "free" cooling by cooling towers in winter account for nearly half of the total number of indirect "free" cooling hours that can be used by cooling towers throughout the year, and 98.61% of the total winter time. On the other hand, in the four months of March and April in the spring and October and November in the fall, the theoretical hours of indirect "free" cooling towers totaled 2,178 hours. This accounts for 48.74% of the total number of hours of indirect “free” cooling that can be used for cooling towers throughout the year. In addition, between May and September in the summer, the total number of theoretical cooling hours of indirect "free" cooling tower cooling is only 161 hours. This accounts for 3.60% of the total number of hours of indirect “free” cooling that can be used for
cooling towers throughout the year. Therefore, in Zunyi area in summer, when the switching
temperature is 14 °C, the indirect cooling tower "free" cooling cannot be realized.

Table 2 Cooling hours and their proportions when the switching temperature is 14°C in Zunyi

| Month | Accumulated cooling hours (h) | Percentage of the whole month | Percentage of the whole year |
|-------|------------------------------|-------------------------------|------------------------------|
| 1     | 744                          | 100%                          | 8.49%                        |
| 2     | 655                          | 97.47%                        | 7.48%                        |
| 3     | 710                          | 95.43%                        | 8.11%                        |
| 4     | 511                          | 70.97%                        | 5.83%                        |
| 5     | 153                          | 20.56%                        | 1.75%                        |
| 6     | 0                            | 0.00%                         | 0.00%                        |
| 7     | 0                            | 0.00%                         | 0.00%                        |
| 8     | 0                            | 0.00%                         | 0.00%                        |
| 9     | 8                            | 1.11%                         | 0.09%                        |
| 10    | 391                          | 52.55%                        | 4.46%                        |
| 11    | 566                          | 78.61%                        | 6.46%                        |
| 12    | 731                          | 98.25%                        | 8.34%                        |

4. Theoretical cooling hours and switching temperature analysis in Weining area

As we all know, Weining belongs to a region with cool summer and cold winter. As shown in Figure 5, it is obvious that in the Weining area, cooling towers are indirectly supplied with “free” cooling. For Weining, first of all, the total number of accumulated hours when the wet bulb temperature is below 14°C (including 14°C) for 8,760 hours throughout the year totals 6,792 hours. This accounted for 77.53% of the whole year. Secondly, when the switching temperature is 4°C (including 4°C), the cumulative number of hours of indirect “free” cooling of the cooling tower is 2365 hours. This accounted for 27.0% of the whole year. In addition, when the wet bulb temperature is 9°C as the switching temperature, the cumulative hours of indirect "free" cooling of the cooling tower is 4373 hours. This accounted for 49.92% of the whole year.

Figure 5 The cumulative hourly distribution of wet bulb temperatures at all levels throughout the year in Weining

As shown in Figure 6, when 4°C, 9°C and 14°C are used as the switching temperature and 14°C is the switching temperature respectively, the proportion of indirect “free” cooling tower hours in each month is greater than that of 4°C and 14°C. 9°C. Obviously, the theoretical energy saving potential of cooling towers is greater.
As shown in Table 3, it is obvious that when the switching temperature is 14°C, in the Weining area, 100% of the indirect cooling towers can provide “free” cooling in winter to achieve the purpose of energy saving. On the one hand, the theoretical cooling hours in winter (January, February, and December) are 2,160 hours. This accounted for 100% in winter, 24.66% of the whole year, and 31.80% of the total hours of indirect “free” cooling that can be used for cooling towers throughout the year. It is worth mentioning that the theoretical cooling hours of indirect “free” cooling by cooling towers in winter account for nearly 1/3 of the total indirect “free” cooling hours that can be used by cooling towers throughout the year, and it also accounts for the total winter time. On the other hand, in the four months of March and April in the spring and October and November in the fall, the theoretical hours of indirect “free” cooling by the cooling tower totaled 2,875 hours. This accounts for 42.33% of the total number of hours of indirect “free” cooling that can be used throughout the year. In addition, between May and September, the total number of theoretical cooling hours of indirect “free” cooling tower cooling is 1,757 hours. This accounts for 25.87% of the total number of hours of indirect “free” cooling that can be used for cooling towers throughout the year. In general, when the switching temperature is set at 14°C throughout the year, the total number of “free” cooling theoretical cooling hours is 6792 hours, accounting for 77.53% of the year. If it is in winter and transitional seasons (January to April, October to December), the theoretical cooling hours of "free" cooling is 5,035 hours, accounting for 57.48% of the whole year.

Table 3 The number of cooling hours and their proportion in Weining area when the switching temperature is 14°C

| Month | Season | Accumulated cooling hours (h) | Percentage of the whole month | Percentage of the whole year |
|-------|--------|-------------------------------|-------------------------------|-------------------------------|
| 1     | Winter | 744                           | 100%                          | 8.49%                         |
| 2     | Winter | 672                           | 100%                          | 7.67%                         |
| 3     | Spring | 744                           | 100%                          | 8.49%                         |
| 4     | Spring | 720                           | 100%                          | 8.22%                         |
| 5     | Spring | 543                           | 72.98%                        | 6.20%                         |
| 6     | Summer | 376                           | 52.22%                        | 4.29%                         |
| 7     | Summer | 132                           | 17.74%                        | 1.51%                         |
| 8     | Summer | 266                           | 35.75%                        | 3.04%                         |
| 9     | Autumn | 440                           | 61.11%                        | 5.02%                         |
| 10    | Autumn | 691                           | 92.88%                        | 7.89%                         |
| 11    | Autumn | 720                           | 100%                          | 8.22%                         |
| 1     | Winter | 744                           | 100%                          | 8.49%                         |
5. Analysis of theoretical cooling hours and switching temperature in Xingyi area

As we all know, Xingyi belongs to a region with hot summer and warm winter. As shown in Figure 7, it is obvious that in the Xingyi area, for the cooling tower indirect "free" cooling, the total number of accumulated hours when the wet bulb temperature is below 14°C (including 14°C) for 8,760 hours in a year totals 4404 hours. This accounted for 50.27% of the whole year. Among them, when the switching temperature is 4°C (including 4°C), the cumulative hours of indirect “free” cooling of the cooling tower is 696 hours. This only accounts for 7.95% of the whole year. In addition, when the switching temperature is set to 9°C, the cumulative number of hours of indirect "free" cooling of the cooling tower is 2,339 hours. This accounted for 26.70% of the whole year.

As shown in Figure 8, by comparing 4°C, 9°C and 14°C as the switching temperature, we obviously find that when 14°C is the switching temperature, the proportion of indirect “free” cooling hours of the cooling tower in each month is greater than 4°C and 9°C, the theoretical energy saving potential in this case is greater.

As shown in Table 4, it is obvious that when the switching temperature is 14°C, more than 95% of the Xingyi area can realize the indirect "free" cooling of the cooling tower in winter, which has achieved the goal of energy saving. On the one hand, the theoretical cooling hours in winter (January, February, and December) are 2,159 hours. This accounted for 99.95% in winter, 24.65% of the whole year, and 49.02% of the total number of indirect “free” cooling hours that can be used in the whole year.

![Figure 7](image_url)

**Figure 7** The cumulative hourly distribution of the annual wet bulb temperature in Xingyi area

![Figure 8](image_url)

**Figure 8** Cumulative distribution of monthly cooling hours under different switching temperatures in Xingyi

As shown in Table 4, it is obvious that when the switching temperature is 14°C, more than 95% of the Xingyi area can realize the indirect "free" cooling of the cooling tower in winter, which has achieved the goal of energy saving. On the one hand, the theoretical cooling hours in winter (January, February, and December) are 2,159 hours. This accounted for 99.95% in winter, 24.65% of the whole year, and 49.02% of the total number of indirect “free” cooling hours that can be used in the whole year.
It can be seen that the theoretical cooling hours of indirect “free” cooling by cooling towers in winter account for nearly half of the total indirect “free” cooling hours that can be used by cooling towers throughout the year, and even 99.95% of the total winter time. On the other hand, in the four months of March and April in the spring and October and November in the fall, the theoretical hours of indirect "free" cooling by the cooling tower totaled 2,104 hours. This accounts for 47.78% of the total number of indirect “free” cooling hours that can be used for cooling towers throughout the year. In addition, between May and September, the total number of indirect "free" cooling tower theoretical cooling hours was only 141 hours. This only accounts for 3.20% of the total number of hours of indirect “free” cooling that can be used throughout the year. In other words, in Xingyi area in summer, when the switching temperature is 14 °C, the cooling tower cannot provide indirect "free" cooling.

| Month | Season | Accumulated cooling hours (h) | Percentage of the whole month | Percentage of the whole year |
|-------|--------|------------------------------|------------------------------|-----------------------------|
| 1     | Winter | 744                          | 100%                         | 8.49%                       |
| 2     | Winter | 672                          | 100%                         | 7.67%                       |
| 3     | Spring | 660                          | 88.71%                       | 7.53%                       |
| 4     | Spring | 394                          | 54.72%                       | 4.50%                       |
| 5     | Spring | 92                           | 12.37%                       | 1.05%                       |
| 6     | Summer | 13                           | 1.81%                        | 0.15%                       |
| 7     | Summer | 0                            | 0.00%                        | 0.00%                       |
| 8     | Summer | 0                            | 0.00%                        | 0.00%                       |
| 9     | Autumn | 36                           | 5.00%                        | 0.41%                       |
| 10    | Autumn | 425                          | 57.12%                       | 4.85%                       |
| 11    | Autumn | 625                          | 86.81%                       | 7.13%                       |
| 12    | Winter | 743                          | 99.87%                       | 8.48%                       |

6. Comparison of theoretical cooling hours for typical climate zones
As shown in Figure 9, it is obvious that when the switching temperature is 14°C, during the transition season, the cooling hours for the four cities of Guiyang, Xingyi, Zunyi, and Weining are 2175h, 2232h, 2339h, and 3858h, respectively. We can see that the overall change trends of the four cities are consistent, of which Weining has an absolute advantage.

Figure 9 Distribution of cooling hours in the four cities of Guiyang, Zunyi, Weining and Xingyi

7. Conclusion
To sum up, we found that for Guizhou, on the one hand, in winter, when the 14°C wet bulb temperature is used as the switching temperature, there is no significant difference in the number of cooling hours between the thermal zones. At the same time, these cities have the possibility of
adopting cooling tower indirect cooling technology. On the other hand, in the transition season, when the 14°C wet bulb temperature is used as the switching temperature, the cooling hours in Guiyang, Xingyi, Zunyi and Weining are 2175h, 2232h, 2339h, and 3858h, respectively. In other words, these cities all have the possibility of adopting cooling tower indirect cooling technology. Among them, it is worth mentioning that the climate and energy-saving advantages of using cooling tower cooling technology in cold summer and cold winter areas represented by Weining are more obvious.

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