Cooling characteristics of two cooling systems applied in natural light plant factory in high temperature summer

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Abstract. In view of the extreme high temperature in the summer when the natural light plant factory runs, it is easy to cause the plant to die due to high temperature. The actual operation of the Shanghai Chongming Natural Light Plant Factory in the past two years is studied to explore various ways of cooling - water Energy-saving groundwater source heat pump cooling air treatment unit (ATU), wet curtain fan, etc. cooling characteristics in the semi-enclosed natural light plant factory in the summer high temperature weather. The results show that the typical high temperature typical day, the natural light plant factory of the water storage type groundwater source heat pump cooling ATU cooling system is 13.88°C lower than the average temperature of the natural light plant without the system. In high temperature weather, the natural light plant factory wet curtain fan system and water storage type groundwater source heat pump cooling ATU cooling system have better cooling effect, but the latter cooling effect is better, such as only the wet curtain fan cooling system the average indoor temperature of the natural light plant factory A5 is 30.88°C; the average temperature of the natural light plant factory A2 of the natural light plant factory A28 with only the water storage type groundwater source heat pump cooling ATU cooling system is 28.64°C, the average temperature of the natural light plant factory A2 without taking any cooling measures is 40.19°C.

1. Introduction
At present, China's facility agriculture area has accounted for more than 90% of the world's facility agriculture area. As one of the facilities agricultural production methods that are less affected by seasonal changes, the application of large-scale natural light plant plants in agricultural production is increasingly important. [1-3]. The control of temperature in natural light plant plants is crucial for crop growth, which not only affects the photosynthesis and respiration of crops, but also has a significant impact on the transport of photosynthesis products and the absorption of nutrients. [4]. The optimum temperature for crops is generally 20°C ~ 30°C, and the maximum temperature during the day should not exceed 35°C. The temperature in the summer high-temperature natural light plant factory is close to or even exceeds the high temperature limit of crop growth, which will seriously restrict the normal growth and development of crops. [5, 6]
Therefore, it is necessary to control the temperature and humidity in the natural light plant factory to meet the optimum conditions for crop growth. The traditional evaporative cooling system has problems such as high humidity in the facility and single measures such as mechanical ventilation [7, 8]. Therefore, some scholars have studied the horizontal light pipe system using geothermal energy in the natural light plant cooling system [9-12], but the cooling characteristics of various cooling methods need to be further studied. This paper aims at the characteristics of two cooling systems such as groundwater source heat pump cooling air treatment unit (ATU), wet curtain-fan applied in semi-enclosed natural light plant factory in Shanghai Chongming in summer hot weather.

2. Two cooling systems applied in the natural light plant factory

The natural light plant factory is in Shanghai Chongming, which has a large natural light plant factory with an area of 21,000 m², divided into three zones A, B and C. There are 10 greenhouse planting areas in Area A, which are represented as A1~A10, A2, A4, A6, A7, A8, A9, A10, which can be cooled by a kind of water storage type groundwater source heat pump system with each 7 air handling units shown in Fig. 1; A3, A5, A7, A9 are equipped with another kind of wet curtain fan cooling system. The wind turbine used in the greenhouse has a power of 1.1 kW, an air flow of 44,500 m³/h, and a propeller diameter of 50 inches. There are 6 fans in each greenhouse, and the wet curtain has 6 parts. The wet curtain is 18.4m long and 2m wide. A total of 6 spans, each span is 4 m. Each greenhouse planting areas, the length is 35 m, the width is 24 m, the shoulder height is 6.5 m, and the top height is 7.5 m. The outer protective structure is a single-layer float glass with a thickness of 5 mm and is supported by a metal frame.

![Diagram of the natural light plant factory water storage type groundwater source heat pump cooling system](image)

**Figure 1.** Natural light plant factory water storage type groundwater source heat pump cooling system

In Fig. 1, Natural light plant factory water storage type groundwater source heat pump cooling system includes groundwater heat exchange system, heat pump unit, energy storage system and air handling unit. The basic parameters of the groundwater source heat pump are: the cooling load of the seven greenhouses is 1345.4KW, the heat load is 762kw, and a heat pump unit with a rated calorific value of 799kw, model 30HXC200-PH3opt150, and a cool storage tank of 600m³ are used. The basic parameters
of the terminal air handling unit are: each unit needs 26.7kw of heat supply, the required cooling capacity is 32.9kw, and the fan air volume is 4500m$^3$/h. According to the matching of the system capacity and demand and the local electricity price peak-valley period, the control valve switch determines that the system has five operating modes. When the electricity price is low and the heat pump unit heat (cold) is greater than the plant plant load, the unit is stored in the heat (cold) side heating (cold) mode; when the heat pump unit is heating (cold) and heat storage When the (cold) water tank is used for heat (cold) volume less than the load required by the plant, the regenerative (cold) tank and the unit heating (cold) mode are used; when the electricity price is high, the regenerative (cold) tank is used. Heating (cold) mode; when the heat pump unit stops running, the cold water well storage mode is adopted; in the summer, when the cold water well ground temperature is less than 12°C, the cold water well direct supply cooling mode is adopted.

3. Summer high temperature typical day natural light plant factory water storage type groundwater source heat pump ATU cooling characteristics

Select the summer high temperature typical week from July 21st to July 27th, 2017, the natural light plant factory A4 operation data to study the summer cooling characteristics of the energy storage type groundwater source heat pump cooling ATU. The comparison between the indoor temperature and the outdoor ambient temperature during normal operation of the ATU is shown in Fig. 2.

![Figure 2. Comparison of indoor temperature and outdoor ambient temperature of natural light plant factory A4 during normal working of ATU](image)

It can be seen from Fig. 2 that, under the normal operation of the air treatment unit from July 21 to 25, the indoor temperature of the natural light plant is always lower than the outdoor ambient temperature, the outdoor average temperature is 32.90°C, and the average temperature of the natural light plant is 27.72°C. When the outdoor ambient temperature is above 38°C from 12:00 to 14:00, the air treatment unit can reduce the indoor temperature by 5~7°C, and the cooling effect is remarkable. The ATU can achieve a reduction in the temperature of the natural light plant factory in 30 minutes after stable operation. The ATU runs intermittently on July 26th and 27th, but the effect is not as good as the ATU works normally.

On July 22, 2017, from 9:00 to 17:00, the outdoor ambient temperature is higher than 35°C, which is used to further study the cooling effect of ATU during the high temperature period in summer. The ATU of the natural light plant factory A4 is normally turned on, and the cooling system of A9 is turned off. It can be seen from Fig. 3. In the absence of solar radiation, the indoor temperature and outdoor temperature of A4 and A7 are 28.63°C, 26.43°C, 28.84°C, respectively; on the 22nd, the average temperature of the outdoor environment is 36.97°C from 9:00 to 17:00. The average indoor temperature of A9 is 44.97°C, and the optimum temperature for photosynthesis of general crops is 20–30°C. If it is...
in high temperature for a long time, it will cause serious physiological obstacles to stop growing or even die. The average indoor temperature of A4 is 31.09°C, and the highest indoor temperature can be controlled at about 32°C. The indoor temperature of A4 can ensure that the average crop is safe in the summer extreme temperature. When the solar radiation intensity is strong during the day and the ATU is cooled, the indoor temperature can be reduced by 5.88 °C, which is 13.88°C lower than the natural light plant without ATU cooling. The ATU cooling effect is good, which can ensure the general crop growth.

![Figure 3. Comparison of indoor temperature of natural light plant factory A4 and indoor temperature of A9](image)

**4. Cooling characteristics of natural light plant factory wet curtain fan system in summer high temperature typical day**

The wet curtain fan is mainly opened during the day when the solar radiation is strong and the temperature is high. Therefore, in order to study the cooling effect of the wet curtain fan at the extreme high temperature, on July 27, 2018, for example, the outdoor ambient temperature is selected to be higher than 30 °C. The data is analysed from 7:00 to 19:00. The actual cooling power and fan operation of the ATU of the natural light plant factory A9 on July 27 is shown in Figure 4. The natural light plant factory A2 has no ATU cooling, no wet curtain fan cooling, natural light plant factory A5 without ATU cooling, wet curtain fan Cooling, natural light plant factory A9 has ATU cooling, no wet curtain fan cooling, three natural light plant factories are normal use of external sunshade and skylight natural ventilation, 7:00~19:00 outdoor ambient temperature and natural light plant factory A2, A5 and The indoor temperature of A9 is shown in Figure 5.
Figure 4. Comparison of indoor temperature and outdoor temperature of A2, A5 and A9 on July 27, 2018

Figure 5. ATU operation of the Natural Light Plant Factory A9 on July 27, 2018

As is shown in Fig. 5, the natural light plant factory A5 rapidly drops the indoor temperature after the wet curtain fan is turned on at about 8:25. And it can be clearly seen from Fig. 7 that the indoor temperature of the natural light plant factory A9 with ATU cooling is always lower than that of the natural light plant factory A5, the indoor average temperature of A5 is 30.88 °C, while the indoor average temperature of A9 is 28.64 °C, and the indoor average temperature difference is 2.24 °C. It shows that the cooling effect of the wet curtain fan in this natural light plant factory is weaker than the ATU. On the same day, from 7:00 to 19:00, the average temperature of the outdoor environment is 32.30 °C, and the average temperature of the natural light plant A2 without ATU cooling is 40.19 °C, indicating that the wet curtain fan cooling system can cool down 9.31 compared to the uncooled natural light plant factory.

5. Conclusion
High temperature weather, the natural light plant factory with ATU cooling on typical days is 13.88°C lower than the average light plant factory without ATU cooling. Through the typical indoor temperature comparison of natural light plant factories with ATU cooling, cooling with wet curtain fan, no ATU and cooling of the wet curtain fan, the weather is obtained from 7:00 to 19:00 and the average temperature
of the outdoor environment is 32.30°C. Compared with the natural light plant factory without ATU and wet curtain fan cooling, the wet curtain fan can reduce the temperature by 9.31°C, and the ATU can cool down to 11.55°C. It shows that the wet curtain fan cooling system and ATU have better cooling effect in the natural light plant factory in high temperature weather, and the ATU has better cooling effect than the wet curtain fan cooling system.

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