Cooling dehumidification characteristics of two cooling systems applied in natural light plant factory in the rainy summer

Zhonghua Zhang1,*, Yuqi Zhong2, Xiangzhen Meng1, Xiaocheng Shi3, Gukun Yang1, Wenting An1, Qinyu Tian1, Huixian Shi1,*
1New rural development institute of Tongji University, National Engineering Research Center of Protected Agriculture, Shanghai, China
2Shanghai Tieling middle school, Shanghai, China
3Shanghai BaoYe Group. (Cambodia)Corp. Ltd. Shanghai, China
*Corresponding author e-mail: huixian_shi@tongji.edu.cn, *190293816@qq.com

Abstract. In summer, it is easy to cause the plant to die in the natural light plant factory due to high temperature and high humidity. It is studied for the cooling dehumidification characteristics among various ways of cooling and dehumidification - water Energy-saving groundwater source heat pump cooling air treatment unit (ATU), wet curtain fan, mechanical ventilation, etc. in the semi-enclosed natural light plant factory in typical plum rain weather. The results show that, during the rainy season, the external environment is relatively low temperature. On a typical day, the average temperature is 28.10°C from 9:15 to 17:00 in daytime in the natural light plant factory with only mechanical ventilation. The indoor temperature is 31.1°C, and the average relative humidity is 81.61%, which can meet the needs of suitable temperature and humidity for cultivated crops. Compared with the normal opening of ATU, only the A area can save the operating cost of 337.34 yuan per day. Between 0:00 and 6:40 in the morning and 20:40 to 24:00 in the evening, the average relative humidity of the natural light plant with both mechanical and natural ventilation is 87.03%. Only mechanical ventilation is opened, and the relative humidity is 95.44%. Therefore, natural ventilation should be strengthened from night to next morning.

1. Introduction
The natural light plant dehumidification measures reported by domestic and foreign research mainly include sunshade (shading net, thin film photovoltaic shading, spraying) [1, 2], Ventilation (mechanical, natural) [3, 4], evaporation (distributed fan mat, wet curtain fan, spray) [5, 6], spray and combinations [7, 8], etc. Chen Chuanyan et al. [9] introduced a liquid cooling and dehumidification system, which is an improvement of the current wet curtain-fan cooling system. Before the outdoor air enters the natural light plant factory, it is sprayed and dehumidified by calcium chloride solution to reduce its relative humidity. After dehumidification, the air passes through the wet curtain and enters the natural light plant factory for evaporation and cooling. Zhao Chunqing et al [10] proposed that the key technology of the dehumidification and cooling system lies in the degree of dehumidification treatment of the dehumidification chamber.
The traditional evaporative cooling system has problems such as high humidity in the facility and single measures such as mechanical ventilation. Some scholars have studied the horizontal light pipe system using geothermal energy in the natural light plant cooling system [7], but its cooling and dehumidification characteristics need to be further explored. This paper aims at Shanghai Chongming semi-enclosed natural light plant factory, a variety of cooling and dehumidification methods - groundwater source heat pump cooling air treatment unit (ATU), wet curtain-fan, mechanical ventilation cooling and dehumidification characteristics in typical plum rain weather in summer.

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 18.4 m long and 2 m 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.
is 32.9kw, and the fan air volume is 4500m$^3$/h. According to the match 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 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. Natural light plant factory, rainy season, typical daily cooling and dehumidification characteristics

The crops planted by the natural light plant are generally melons, fruits and vegetables. For example, cucumbers have an optimum growth temperature of 10 to 32°C, a relative humidity of 60% to 90%, and a relative humidity of 75% to 85%. The photosynthetic rate is maximized. Usually, if the relative humidity reaches 90% or higher, the transpiration of the crop is inhibited, and the absorption and transportation of nutrients in the roots are affected, resulting in a decrease in the photosynthesis intensity. Therefore, it is very important to cool and dehumidify the plant in the summer rainy season.

Under the combined effect of the outdoor environment and various cooling methods, the indoor temperature and humidity conditions of the natural light plant factories A7 and A9 on July 6, 2018 are shown in Fig. 2 and Fig. 3. Natural light plant factory A9 indoor relative humidity and absolute humidity at any time. The change between them is shown in Fig. 4.

![Figure 2](image_url)

**Figure 2.** Indoor temperature change chart of natural light plant factory A7 and A9 on July 6
Figure 3. Indoor relative humidity of natural light plant factory A7 with time

Figure 4. Relative humidity and absolute humidity in natural light plant factory A9 with time

Seen from Fig. 3 and Fig. 4, the relative humidity is low in the natural light plant factory during the day and low at night, and the absolute humidity is opposite, and the daytime is high and the night is low. The relative humidity of the natural light plant factory A9 is higher than A7, the relative humidity of the natural light plant factory A7 is about 88%, and the relative humidity during the day is between 75% and 87%. During the period from 0:00 to 6:40 and 20:40 to 24:00, the natural light plant factory A7 is open for mechanical ventilation and natural ventilation. The natural light plant factory A9 is only mechanically ventilated, during 9:15~17:00, it is only mechanically ventilated for the natural light plants Factory A7, and A9 is for ATU cooling and mechanical ventilation. Table 1 is calculated based on the data.
Table 1. Comparison of indoor average temperature and relative humidity between greenhouse A7 and A9 in each period

| Time          | Average temperature /°C | Average relative humidity/% |
|---------------|--------------------------|-----------------------------|
| 0:00~24:0     | 0                        | 0                           |
| 0:00~6:40,20:40~24:0 | 0                        | 0                           |
| 9:15~17:0     | 0                        | 0                           |
| 0:00~24:0     | 0                        | 0                           |
| 0:00~6:40,20:40~24:0 | 0                        | 0                           |
| 9:15~17:0     | 0                        | 0                           |

| Time       | Average temperature /°C | Average relative humidity/% |
|------------|--------------------------|-----------------------------|
| Outdoors   | 25.94                    | 27.74                       |
| A7         | 26.97                    | 28.10                       |
| A9         | 26.22                    | 26.93                       |

Table 2. Operating costs for water storage type groundwater source heat pump cooling system on July 6

| Energy consuming component | period          | operation hours | Power consumption / kWh | Total price / yuan |
|----------------------------|-----------------|-----------------|-------------------------|--------------------|
| Heat pump unit             | Low valley      | 2.4             | 364.72                  | 132.76             |
| Cold storage pump          | Low valley      | 4.5             | 5.41                    | 1.97               |
| Water source side circulation pump | Average segment | 4               | 6.40                    | 4.82               |
| Water source side circulation pump | Peak section | 2               | 12.80                   | 15.64              |
| Submersible pump           | Average segment | 4               | 96                      | 72.19              |
| Submersible pump           | Peak section    | 2               | 48                      | 58.66              |
| User side circulation pump | Average segment | 6.5             | 20.03                   | 15.06              |
| User side circulation pump | Peak section    | 7.7             | 29.65                   | 36.24              |

By analyzing Table 1 and Table 2, we can see that:

(1) In daytime, from 9:15 to 17:00, the average indoor temperature of the natural light plant factory A7 and A9 were 28.10°C and 26.93°C, respectively, and the maximum temperatures were 31.1°C and 28.3°C, respectively. The relative humidity of the natural light plant factory A7 and A9 were 81.61% and 89.95%, respectively. It shows that in the case of not opening the air treatment unit on the typical day of the rainy season, the temperature and humidity can meet the growth demand of cucumber only by mechanical ventilation. By controlling the opening and closing of the air handling unit refrigeration system, reducing humidity, saving energy and operating costs. According to the operation of the equipment and the Shanghai electricity price policy, the cost savings of the air handling unit when the cooling mode is not opened are shown in Table 2 without affecting the normal growth of the crop. On the same day, the operating cost can be saved at 337.34 yuan.

(2) At 0:00~6:40 and 20:40~24:00 during the night, the average indoor temperature of the natural light plant factories A7 and A9 are 26.97 °C and 26.22 °C, respectively. The average temperature of A9 is lower than the average temperature of A7 because of the A9 air treatment during the day. After the unit is cooled, the indoor temperature is low. A7 is to open mechanical ventilation and natural ventilation, while the A9 has no natural ventilation and the cooling loss is slower. Cucumbers have an optimum temperature of 15~18°C at night, and natural light plant factories A7 and A9 have not reached the optimal temperature level. Nighttime low temperature can inhibit the respiration of crops and reduce the consumption of photosynthesis products during the day, thus improving crop quality and yield. The relative humidity of natural light plant factories A7 and A9 were 87.03% and 95.44%, respectively, and the maximum relative humidity was 89% and 97%, respectively. Indoor relative humidity of more than 90% is prone to cause various diseases. Therefore, natural ventilation should be strengthened when the
outdoor relative humidity is 57.11% at night, and the relative humidity in the natural light plant factory should be reduced.

4. Conclusion
For the actual operation of the natural light plant factory in the past two years, the typical day of the rainy season is 9:15~17:00 in daytime. The average indoor temperature of the natural light plant factory with mechanical ventilation is 28.10 °C, the highest indoor temperature is 31.1 °C, and the average relative humidity is 81.61%, for the typical day. In the case of not opening the air treatment unit cooling, only the mechanical ventilation can meet the suitable temperature and humidity requirements of the cultivated crops. By calculating, under the premise of not affecting the normal growth of crops, area a can save operating costs of 337, 34 yuan on the same day. According to statistics, there are 12 days in this typical rainy weather during the plum rain period in 2018, and it can be saved by 4040.08 yuan of the operating cost in Zone A in summer. Therefore, it is obvious that the operating mode of the cooling system may be adjusted for obvious economic benefits.

Acknowledgments
This work was financially supported by National High Technology Research and Development Program (863 Program).

References
[1] U. N. Mutwiwa, H.B. Von Elsner, Cooling Naturally Ventilated Greenhouses in the Tropics by Near-Infra Red Reflection [J]. Acta Hortic, 2008, 801: 259 - 266.
[2] X. Z. Meng, H.X. Shi, D.T. Xu, Research on Application Form of Photovoltaic Power Generation Technology in Greenhouse[J]. Anhui Agricultural Sciences, 2017, 45 (27): 219 - 222.
[3] D. H. Willits, Cooling Fan-ventilated Greenhouses: a Modelling Study [J]. Biosystems Engineering, 2003, 84 (3): 315 - 329.
[4] O. Labban, T.Y. Chen, AF.Ghoniem, Next-generation HVAC: Prospects for and limitations of desiccant and membrane-based dehumidification and cooling [J]. Applied Energy, 2017, 200: 330 - 346.
[5] M. Fuchs, E. Dayan, E.Presnov, Evaporative cooling of a ventilated greenhouse rose crop [J]. Agricultural and Forest Meteorology, 2006, 138 (1-4): 203 - 215.
[6] P. Banik A. Ganguly. Thermal Modeling and Economical Analysis of a Solar Desiccant Assisted Distributed Fan-Pad Ventilated Greenhouse: the World Congress on Engineering, 2014 [C].
[7] V.F. Sethi, S. K. Sharma, Survey of cooling technologies for worldwide agricultural greenhouse applications [J]. Solar Energy, 2007, 81 (12): 1447 - 1459.
[8] W. T. Sun, Y. Zhang, Q.C. Yang, Summer night cooling test of solar greenhouse based on water source heat pump [J]. Journal of Agricultural Modernization Research, 2017, 38 (05): 885 - 892.
[9] C. Y. Chen, Y. L. Zhang, P. Ai, Orthogonal Experimental Analysis of Multi-factors in Greenhouse Dehumidification and Cooling System [J]. Journal of Huazhong Normal University(Natural Science), 2010, 44 (01): 96 – 100.
[10] Zhao Chunqing, Zhang Jiyuan, Ding Shufang. Feasibility Exploration of Dehumidification and Cooling System for Greenhouse Cooling [J]. Journal of Agricultural Mechanization Research, 2004 (5): 77 - 78.