Effects of Shading and Roof Sprinkling in Venlo-Type Greenhouse in Summer

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Abstract: The effects of shading and roof sprinkling based on natural ventilation were experimentally studied in a Venlo-type multi-span greenhouse. Air temperature, humidity and solar radiation inside the greenhouse were measured to compare the cooling effect of shading and roof sprinkling. Under the experimental condition, the mean indoor air temperature was 2.1℃ lower than that outdoor, the largest air temperature difference was 4.4℃. The results showed that the measures of shading and roof sprinkling based on the natural ventilation could effectively cool down the greenhouse in summer. Shading, roof sprinkling and roof opening played different roles in the greenhouse. Different from other evaporative cooling system, the roof sprinkling system did not increase the air humidity inside the greenhouse. The distributions of air temperature and humidity inside the greenhouse were uniform under the experimental conditions. The methods could effectively reduce the air temperature and energy consumption in greenhouses.

Key words: natural ventilation; shading; roof sprinkling; greenhouse

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1 Introduction

Greenhouse ventilation and cooling in summer are the important topics to be addressed in South and Middle China. Air flow through the ventilators can be generated by natural and mechanical ventilation. Natural ventilation is economical in operation but relies on climate conditions[1,2]. For most regions of China, it is very difficult to cool down the multi-span greenhouse just by natural ventilation during the hot seasons, and thereby pad-and-fan or fog-and-fan systems are used for cooling[3]. The energy consumption in greenhouses is increased greatly when operating these systems. In some regions, the energy consumption in the multi-span greenhouse cooling accounts for 30% to 40% of the production cost[4].

In order to solve the problem of greenhouse cooling in an energy-saving measure, several researchers attempted to combine shading and fogging together with natural ventilation. A theoretical study of natural ventilation based on thermal effect using openings on the roof and the side walls in a multi-span greenhouse cooled by fogging system was carried out by Arbel et al (1999)[5]. This study showed that it was possible to establish conditions during most time of the year and in most parts of Israel in a greenhouse combined with fogging and natural ventilation. Dayan et al[6] investigated the effects of several cooling methods on reducing the duration of high temperature exposure in a multi-span greenhouse, which included natural ventilation, with and without shading, and forced ventilation with and without evaporative pad.

Fogging or sprinkling in the greenhouses increases the efficiency of water evaporation, but it also makes the greenhouse a more humid condition which is harmful to some plants. Furthermore, it creates favorable conditions to disease due to the free water accumulated on the leaves. For above reasons, some designers installed the sprinkling system above the roof of the greenhouse[7]. The objectives of this paper were to investigate the effects of roof opening, shading and roof sprinkling on the air temperature and humidity in a naturally ventilated multi-span greenhouse, to explore the cooling method in greenhouse in summer, and to provide reference for greenhouse design in China.

2 Materials and Methods

2.1 Experimental Site and Greenhouse Type

The experiments were carried out in July 2000 in a Venlo type glasshouse imported from the Netherlands by Puyang Shijin Modern Agricultural Limited Company, Henan Province, the central part of China. The large multi-span greenhouse (19353.6 m^2) was orientated S-N, and divided into four parts by glass walls. No. 1 and No. 2 greenhouses located in the southeast and southwest part were selected for

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experiments. The size of two parts was the same, with length 14 bays × 4.5 m bay = 63.0 m, width 8 span × 9.6 m span = 76.8 m. The greenhouse used the improved structures based on Venlo type glasshouse (Fig. 1). The gutter and the ridge were 4.0 m and 5.0 m high, respectively, the roof and wall were made up of horticultural glass with 4 mm thick. The roof vents (3.4 m × 1.0 m) were distributed alternately on the east and west slopes of each span.

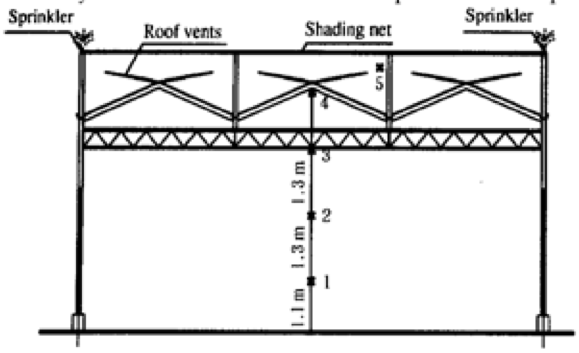

Fig. 1 Schematic diagram of greenhouse and layout of temperature measurement locations

The climate conditions in Puyang are not suitable to natural ventilation. The outside screen and roof sprinkling system were added to the greenhouse. The outside screen (50% transmittance) was placed at 0.4 m higher above the ridge, and dragged by galvanized pipes with motors. The roof sprinkling system was equipped above the screen, and PVC pipe lines were arranged every 9.6 m on one span to supply water. The pipe pressure was under 0.3 MPa and the sprinkler volumetric flux was 5 L min for every 9 m pipe. The sprinklers covered the spraying area of 17 m in diameter. The roof vents, screen and the roof sprinklers were automatically controlled by a computer.

Anthuriums oriented south to north was planted in the greenhouse during measurements. Anthuriums likes the appropriate conditions: solar radiation intensity is less than 300 W m^2, the air temperature is 25℃ in optimum or under 35℃ in general, and the air relative humidity range is 70% ~ 80%.

2.2 Experimental Methods

Air temperature in the greenhouse was measured by PT100 probes. There were five testing points: four of them were arranged from upper canopy to the ridge of greenhouse perpendicularly. The other one was mounted between roof and screen (Fig. 1). Leaf temperatures were measured by infrared thermometer (Raynger ST30, Raytek Co, American). The ventilated thermometer psychrometer measured air relative humidity inside the greenhouse. The solar radiation was measured by radiometers, one outside above the shading net and the other in the middle of the greenhouse. A data logger system (DL3000, Delta-T Devices Co, England) recorded the air temperature and the solar radiation every 5 minutes. The weather station that can measure wind speed and direction, temperature, humidity was located above the south side of the greenhouse (about 6m high).

3 Results and Discussion

3.1 Total Cooling Effect of Shading, Roof Sprinkling in Naturally Ventilated Greenhouse

The air temperature and humidity on July 9, 2001 in No. 1 greenhouse were shown in Fig. 2. The ambient temperature on that day was close to 40℃, the highest temperature in 2001 in Puyang. During the period of experiment, the leeward and windward roof vents were fully opened. Experience showed that the cooling effect with leeward and windward ventilation is better than that with only leeward ventilation[8,9]. Meanwhile, the roof sprinkling system sprayed for 5 min every time, and the greenhouse was all covered by the screen. Under the experimental conditions, the air temperature inside the greenhouse was always lower than the ambient, their mean temperature difference was 2.1℃, the largest difference was 4.4℃. The humidity inside the greenhouse was fluctuated in the range of 70% ~ 85%.

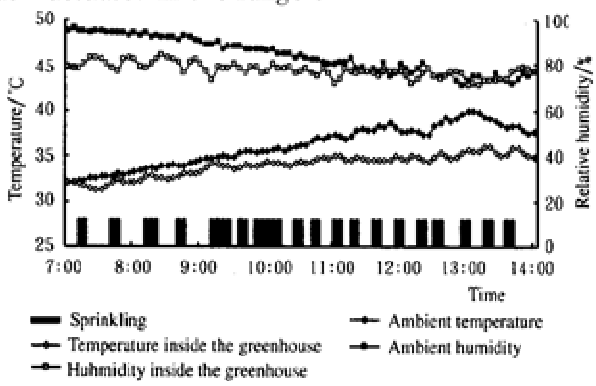

Fig. 2 Air temperature and humidity in the No. 1 greenhouse on July 9, 2001

3.2 Effect of Roof Sprinkling on Air Temperature and Humidity

Different from the sprinkling system inside the greenhouse, the roof sprinkling evaporative cooling system is installed outside the greenhouse. The effect of roof sprinkling on the air temperature and humidity was experimentally investigated in No. 2 greenhouse on July 25, 2001. The sprinkling interval and times were controlled by computer according to the experimental design, the leeward and windward roof vents were fully opened and the screen was covered. The results (Fig. 3) showed that the air temperature inside the greenhouse fell down obviously when the roof sprinkling system ran. After sprinkling stopped, the air temperature began to rise until the next sprinkling. In addition, the air temperature under the screen was higher than that inside the greenhouse gradually before the next sprinkling began, and fell down rapidly when the sprinkling system ran. The reason is that the air under the screen was cooled by evaporated water firstly, then the air was exchanged across the roof vents, the air temperature inside the greenhouse was reduced by convective heat transfer finally.

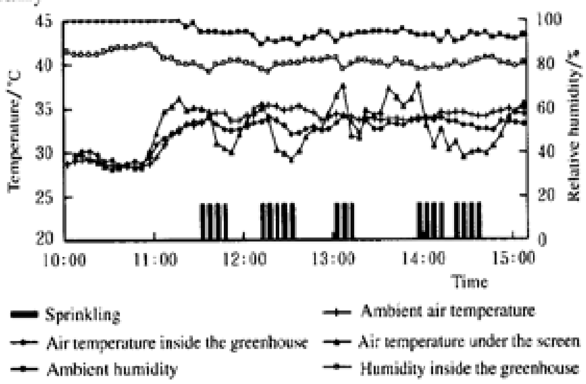

Fig. 3 Air temperature and humidity in No. 2 greenhouse on July 25, 2001

The air humidity inside the greenhouse was also shown in Fig. 3. During the experiment, the air humidity inside the greenhouse fluctuated little. The similar case was also shown in Fig. 2. The experimental results showed that the roof sprinkling system did not make the greenhouse more humid than other systems.

3.3 Effect of Shading on the Greenhouse

The solar radiation environment is crucial to the growth of plant. Shading is a trade-off between greenhouse cooling and radiation. The shading material prevents a part of solar energy into the greenhouse, it is favorable to greenhouse cooling during the hot seasons, while leaves less radiation for photosynthesis. Information is very little on how to compromise between reducing the air temperature and reducing the overall crop yield. The solar radiation of the No. 2 greenhouse at noon of July 26, 2001 was shown in Fig. 4. The solar radiation was low because of the cloud, and the solar radiation into the greenhouse was much lower than that of the outside due to the screen and the roof glass. It was decided by the light transmittance of screen and the cleanness level of roof glass.

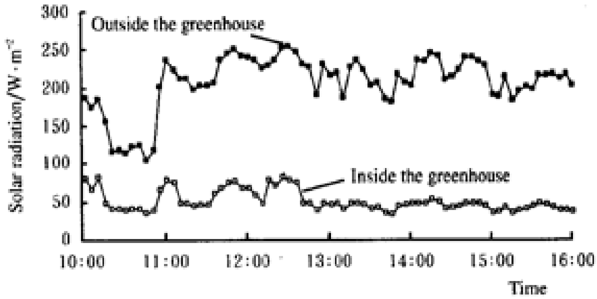

Fig. 4 The solar radiation on July 26, 2001

3.4 Air Temperature and Humidity Distributions Inside the Greenhouse

The uniformity of air temperature and humidity is very important to identical growth of the crops. Fig. 5 and Fig. 6 show the air temperature and humidity distributions in No. 2 greenhouse on July 25, 2001. Considering the structure of the experimental greenhouse and the solar radiation, the test points Ⅰ, Ⅱ, Ⅲ, Ⅳ were equally arranged along south-north direction in the middle of the greenhouse. The test points were 1.2 m high from the ground. During the period of experiment, the differences of air temperature and humidity from the south to north were little. The distributions of air temperature and humidity inside the greenhouse were uniform under the experimental conditions.

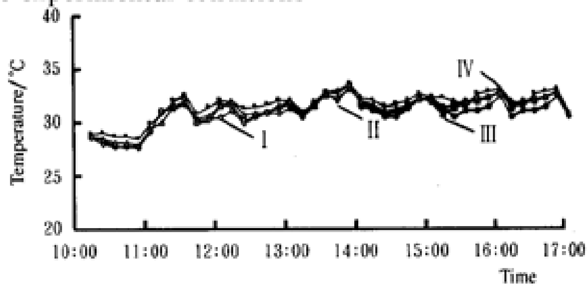

Fig. 5 The distributions of air temperature in No. 2 greenhouse on July 25, 2001.

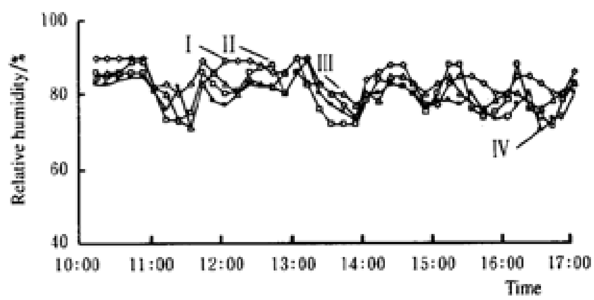

Fig. 6 The distributions of air humidity in No. 2 greenhouse on July 25, 2001.

4 Conclusions

The measures of shading, roof sprinkling based on the natural ventilation can effectively cool down the multi-span greenhouse in summer. The roof opening affects the air temperature inside the greenhouse greatly; the shading net reduces the solar radiation inside the greenhouse; the roof sprinkling system reduces air temperature obviously, while does not increase the air humidity inside the greenhouse. Under the experimental conditions, the distributions of air temperature and humidity inside the greenhouse are uniform. The energy consumption is decreased greatly because fans are not used. The system is suitable for multi-span greenhouse cooling, energy-saving during the hot seasons.

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Venlo 型温室外遮阳和屋顶喷淋系统夏季降温效果

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摘 要: 该文对荷兰 Venlo 型连栋温室夏季采用自然通风并结合遮阳网、室外屋顶喷淋的降温效果进行了实验研究。实验中对温室内空气温、湿度, 太阳辐照度进行了测试, 以比较外遮阳和屋顶喷淋的降温效果。结果表明: Venlo 型温室夏季采用自然通风结合外遮阳和屋顶喷淋的降温措施后能够有效降低室内温度。不同于其它蒸发降温系统, 屋顶喷淋没有造成温室内湿度的显著增加, 室内的温度和湿度分布比较均匀。这种降温措施的能耗小, 可以达到温室降温和降低温室夏季生产成本的双重目的。

关键词: 自然通风; 遮阳; 喷淋; Venlo 型温室