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Determination the installation efficiency of the evaporative air cooling in the greenhouse by temperature-moisture regime

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Abstract. The results of theoretical studies and experiments of the developed exhaust ventilation system with direct evaporative air- cooling with using “wet mats” are given. It has shown sufficient efficiency with increasing quality of flower cutting in the summer months. The effect of moisture on the operation of this system was studied. It is established that the heat absorption capacity of air directly depends on its temperature and relative humidity. It is also determined that the temperature of leaves and flowers in summer is usually 2 ÷ 7 °C greater than the air temperature in the greenhouses. In an experimental greenhouse, according to the results of experiments, the effectiveness of the developed installation for evaporative cooling of its operation was determined.

1. Introduction

In climatic zones where the maximum summer temperature is stably above 35^0C, and the internal temperature of the greenhouse for a long period of time exceeds the mark of 30^0C, it is advisable to combine the exhaust ventilation system with evaporative air cooling systems [1, 2]. The use of evaporative cooling with wet mats increases the quality and, consequently, the price of cutting flowers in the summer months [3].

Modern methods of growing cut flowers of roses include, on the one aspect, effective regulation of the microclimate in greenhouses throughout the year [4], and on the other aspect, technical re-equipment of greenhouses for low energy-intensive technology [5]. At the same time, during the blooming of the buds, the temperature needs to be slightly lowered, during the flowering period – increased [6]. The humidity level should be around 70 percent [7]. Additional lighting is required in winter [8]. In summer, on the contrary, it is necessary to slightly shade the bushes with curtains [9]. Among other things, regular

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ventilation is required. The problem with cooling greenhouses is that at high summer air temperatures in greenhouses, the length of the shoots and the diameter of the flowers of roses are sharply reduced [10].
The system of wet mats (the so-called "wet mattresses") is a new technical direction for reducing the air temperature in greenhouses in the summer. The mats are installed in special openings in the side glazing of greenhouses, facing the direction of the prevailing winds in the summer [11]. On the opposite side of the greenhouse, in the openings of the side fence, low-speed fans with a blade diameter of up to one meter and low-power electric motors are installed [12].
The fans work to exhaust air from the greenhouse. Moisture is sprayed onto the mats and cooled air is supplied to the greenhouse by lowering the temperature of the air passing through the wet mats. Despite certain energy costs, such a system effectively reduces the air temperature in greenhouses. During this process, the greenhouse vents are in a closed position [13].
For the roses, the air temperature in greenhouses in summer up to 27 ° C allows you to get high-quality cut flowers. In conditions of high summer temperatures greater 40^0 and low air humidity, a system of additional air humidification is used on the rose crop [14].
Fog-forming nozzles (foggers) spray water to particles with a diameter of less than 100 microns [15], which does not lead to the formation of drip moisture on the leaves and, as a result, the leaf surface of the roses. The use of such nozzles allows not only to effectively reduce the temperature of the leaves due to the evaporation of moisture from their surface, but also saves the energy expended by plants to evaporate water to cool the leaves. The temperature of leaves and flowers in summer is usually 2-7 ° C greater than the air temperature in greenhouses [16].

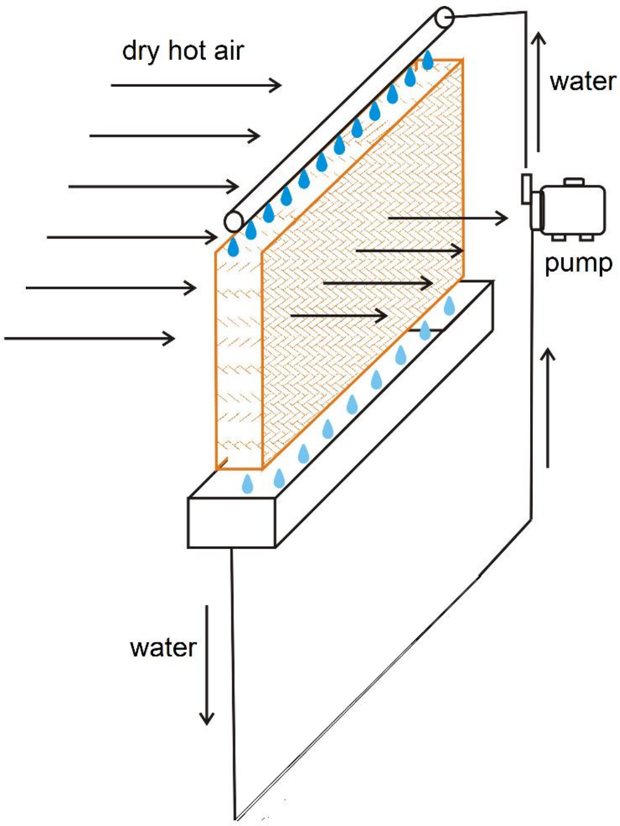

Figure 1. The construction of wet mats using energy-saving technology of indirect evaporative cooling in poultry farm

The efficiency of the exhaust fans is significantly affected by the degree of wear of the drive belts, as well as the presence of a large amount of dust on the fan blades and shutters.

A worn-out belt, while consuming the same (with a new belt) amount of energy, is not able to provide 100% fan performance. And even a 10% loss in capacity "costs" the 3^0C cooling effect of evaporative cooling exhaust ventilation based on evaporative cooling. Dust adhering to the blades during operation can change the aerodynamic characteristics of the blades and reduce air exchange by 30% [17].

An evaporative cooling unit was installed and investigated in a greenhouse located in the village of Tinchlik k.f.j., district - Yukori Chirchik, Tashkent region with an area of 47 × 64 m^2 (flower farm LLC "Xamro-Mirodil").

2. Materials and Methods

Evaporative cooling is based on the principle of heat by evaporated liquid, the so-called adiabatic cooling [18].

With an increase in the absolute moisture content, the air temperature rises, as a result of which, simultaneously with humidification, excess heat is assimilated without artificial cold.

At the same time, the air humidity in the greenhouse has a very strong effect on the operation of any cooling system.

The heat absorption capacity of air is directly related to its temperature and relative humidity. The higher it is, the more difficult it is to achieve the desired effect [19-23].

During the hot season, tap water is supplied to the trays of the evaporative apparatus, which moistens hygroscopic material (wet mats) in the facade section.

The supplied outside air in the amount of 2500 m^3 per hour passes through the moist material and enters to the greenhouse.

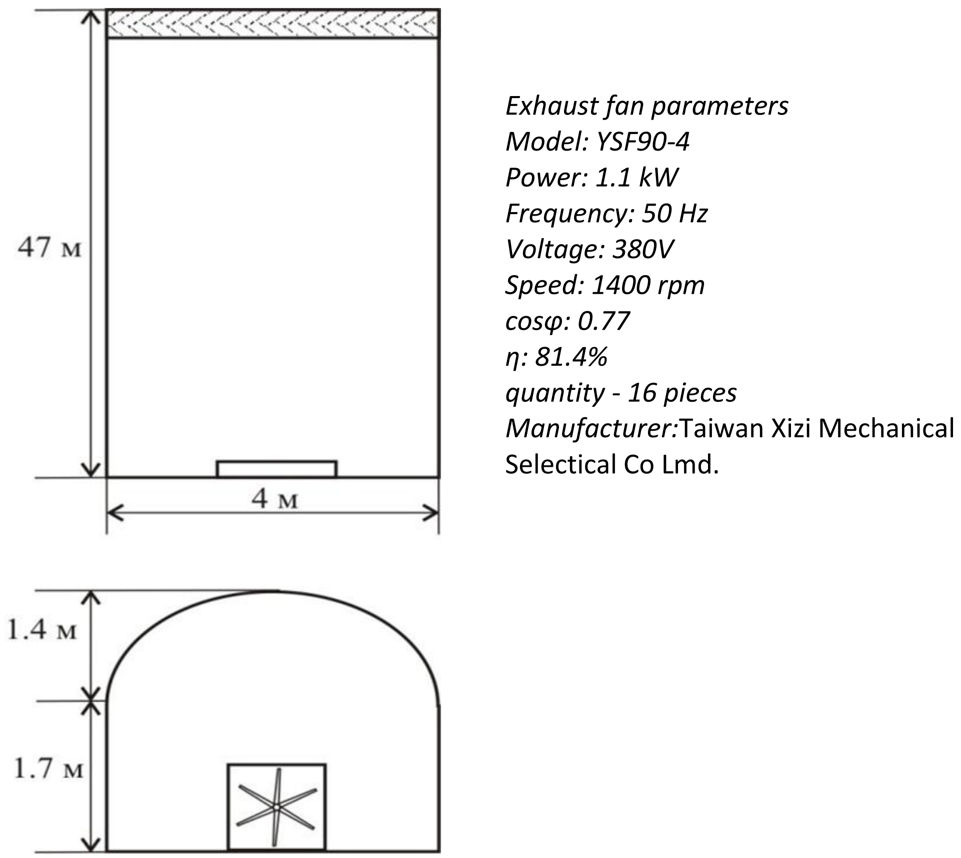

Figure 2. Installation of evaporative cooling in the experimental greenhouse of LLC "Xamro-Mirodil"

For the installation of direct evaporative cooling system devices, the territory is divided into 16 sections 4 m wide with a total area of the flower farm of 47 × 64 m^2.

One of the main characteristics of a wet mat evaporative cooler is its efficiency *E* [24-26].
As for other heat and mass transfer installations, the value of *E* for the coolers of the type under consideration is determined from the ratio

$$E = \frac{t_{air_{inlet}} - t_{air_{outlet}}}{t_{air_{inlet}} - t_m} \quad (1)$$

For an ideal evaporative cooler, E should be one. In the process of ideal adiabatic evaporation of water, the air temperature at the outlet of the cooler is equal to its adiabatic wet bulb temperature, i.e $t_{air_{out}} = t_m^{ad}$,, and hence the relative humidity φ = 1, while the analytical formula for the specific enthalpy of humid air at the outlet from the evaporative cooler

$$I_{out}^{ad} = 1{,}0048 \cdot t_{м}^{ad} + \left(1555{,}75 + 1{,}146 \cdot t_{м}^{ad}\right)\left(\frac{P_б}{4{,}579 \cdot 10^{\frac{7{,}45 t_{м}^{ad}}{235 + t_{м}^{ad}}}} - 1\right)^{-1} \quad (2)$$

Based on the calculated data according to (2), an approximation dependence was determined at a given value of P_b = 715 mm Hg. st., typical for the Tashkent region.

$$t_m^{ad} = A \cdot \ln I_{out}^{ad} - B \quad (3)$$

here *A* and *B* are coefficients depending on P_b. According to the results of calculations with P_b = 715 mm Hg: st. *A* = 18.853 and *B* = 57.25.
At numerically calculating the maximum possible temperature value of wet mats cooled in evaporative coolers, it is required to determine the values $t_m = t_m^{ad}$ at the outside air temperature t'_{air}=35 ^{0}C, φ_0= 70% P_b= 715 mm Hg.st.
By equation (2), it is determined the enthalpy of humid air at the outlet from the evaporative cooler of wet mats

$$I_{out}^{ad} = 1{,}0048 \cdot 35 + \left(1555{,}75 + 1{,}146 \cdot 35\right)\left(\frac{715}{4{,}579 \cdot 10^{\frac{7{,}45 \cdot 35}{235+35}}} - 1\right)^{-} = 68.92 \text{ kJ / kg dry air}$$

By equation (3), we determine the adiabatic temperature of a wet thermometer

$$t_m^{ad} = 18.853 \cdot \ln 68.92 - 57.25 = 22.55\ ^0\text{C}$$

The following formula allows you to define the influence of the irrigation coefficient (μ) of wet mats on the temperature of the cooled air

$$t_{air_{out}} = t_m + \left(t'_{air} - t_m\right) \cdot e^{-\frac{(\alpha_k + \beta_p \cdot r) \cdot a \cdot \delta}{\mu \cdot \vartheta_{wa} \cdot \rho_{wa} \cdot Cp_{air}}} \quad (4)$$

The values of $\alpha_к$ and β_p for the irrigated layer of the wet mats system with a diameter of 0.135 mm, a length of 200 mm, a = F_{HE}/V=16000 m^2/ m^3 can be selected respectively 58.15W/(m^2 ^{0}C), 120 kg/(m^{2}h) [3].

According to the results of the calculations performed to determine $t_{air_{out}}$ = 58 W / (m^2 ^{0}C), $\beta_p r$ = 120 W/(m^2 ^{0}C), a = 16000 m^2 / m^3, δ = 0.002m, μ = 0.1, density humid ρ_{wa} = 1.25kg / m^3 and heat capacity Cp_{air} = 4186.8 the value of t_m^{ad} at t'_{air}= 35^{0}C and t_m = 22.55^{0}C is

$$t_{air_{out}} = 22{,}5 + (35 - 22{,}55) \cdot e^{-\frac{178 \cdot 16000 \cdot 0{,}002}{0{,}1 \cdot 2{,}0 \cdot 1{,}25 \cdot 4186{,}8}} = 22{,}55 + 12{,}45 \cdot e^{-2{,}0407} = 24{,}19\ ^0C$$

The value of the thermal efficiency of the evaporative water cooler, determined by (4), is

$$E = \frac{35 - 24{,}19}{35 - 22{,}55} = 0{,}79$$

3. Results and Discussions

Measurements were made of the temperature and humidity parameters of the air inside the greenhouse during the operation of the evaporative air cooling system, as well as the relative humidity of the air.

Figure 3 shows the temperatures and humidity inside the greenhouse when the evaporative cooling unit is operating, cyclical changes in the daily average temperature versus the cyclical changes in relative humidity.

Obviously, during the hottest hours of the day, the relative humidity drops to below 50%. Under such conditions, the developed evaporative-type coolers consistently increase their efficiency by lowering and lowering the air temperature in the greenhouse, or maintaining it at the desired level throughout the day using sensors installed in the greenhouse.

However, the relative humidity decreases as the temperature rises. The absolute amount of water vapor in the air changes insignificantly with temperature changes.

Considering that the absolute humidity remains approximately constant throughout the day, measurements show that as the outside temperature rises, the temperature indicated by the wet bulb thermometer decreases significantly [23]. For example, with an absolute humidity of 0.015 kg / kg of air and a relative humidity of 75%, the outdoor temperature drops to 25 ° C. At 36 ^{0}C the relative humidity will be 40%.

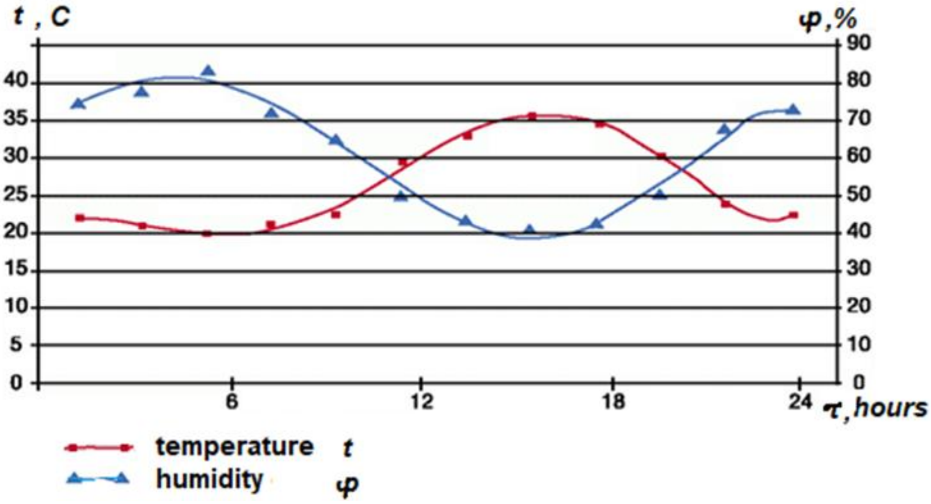

Figure 3. The cycle of temperature and humidity during the summer day inside the experimental greenhouse during the operation of the evaporative cooling unit

4. Conclusions

The thermal efficiency of the evaporative water cooler is 0.79.

At the same time, during the operation of the evaporative air cooling system, it was possible to achieve the optimal values of temperature (up to 27^{0}C) and relative humidity (about 70%) when growing roses in a greenhouse.

The tests carried out have shown sufficient efficiency of the developed direct evaporative cooling unit for use at farm facilities.

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