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CLIMATISATION OF A CLOSED GREENHOUSE IN THE MIDDLE EAST

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Abstract

Cooling is an essential part of greenhouse climate control in warm climates. There are three type of cooling techniques being natural ventilation, evaporative cooling and mechanical cooling. Natural ventilation can only be applied when the outside temperature does not exceed 35 degrees and the average daily temperature is not higher than 22 degrees. Above these temperature ranges the production will be affected negatively. Evaporative cooling can be applied when the dewpoint temperature of the outside air is less than these limits. These method of cooling works effectively in arid regions, though the water consumption is high. The third method of cooling demands a cold surface to remove the latent and sensible heat from the greenhouse. This method has been applied in the current research. This method allows optimal control of the greenhouse climate in temps of temperature and humidity but also in terms of carbon dioxide concentration. The amount of cooling capacity required depends on the amount of solar radiation being absorbed in the greenhouse and the convective heat transfer from outside provided the outside temperature is higher than the greenhouse air temperature. The experiment showed roughly 50% of the solar radiation has to be cooled from the greenhouse in order to maintain its temperature. 60% of the heat being absorbed in the greenhouse is transformed into latent heat through the transpiration of the crop. The system was able to maintain the pre-set temperature and humidity for the greenhouse air.

Keywords: Cooling, condensation, dehumidification, energy use

INTRODUCTION

Inside climate is a critical parameter for the production of greenhouse crops. In moderate climates, temperature and humidity can be regulated sufficiently by ventilation and heating. For tropic and (semi) arid regions climate control is less simple since ventilation is mostly not sufficient for the cooling that is needed to grow a good quality product. A general overview of the cooling methods available for greenhouse is given by Sethi and Sharma (2007) describing ventilation, shading, evaporative cooling, and composite systems where air is cooled using earth-to-air and aquifer coupled heat exchangers. They concluded that none of the currently available technologies can meet all the cooling requirements of the greenhouse crops. The same conclusion was made by Kumar et al. (2009) in view of the needs of greenhouse growers in tropical and subtropical regions. There is a necessity to develop cheap and effective technology, suitable to local climatic conditions to boost the greenhouse industry. Naturally ventilated greenhouses equipped with insect nets are most suitable specially in humid areas where evaporative cooling cannot be applied, though not ideal.

When using evaporative cooling, the inner climate may be good but the water use efficiency is low. Experiments in Arizona(USA) showed a water use efficiency (total of irrigation and pad water evaporation) of 11 kg/m^3 (Sabeh et al., 2011). In even more extreme climates like Saudi Arabia the daily water consumption by the pad and irrigation can be up to

15 l m^{-2} even when the relative humidity in the greenhouse remains below 40% (Al-Helal, 2007).

Mechanical cooling using a heat pump was not considered in these articles though it has been applied in several experiments (Bakker, 2011) and on a commercial scale (Campen and Kempkes, 2011). The advantages of a closed greenhouse on a commercial scale have been reported (Raaphorst, 2011). Not only in the Netherlands the concept of the closed greenhouse is adopted but also in France (Griseya et al., 2011) and Spain (Zaragoza and Buchholz, 2008).

This paper describes the experimental results of a closed greenhouse which was located in Abu Dhabi. The trail was done in the period from October 25, 2015 till February 4, 2016 which a cucumber crop was grown.

MATERIALS AND METHODS

The experimental greenhouse is located on the Abu Dhabi Food Control experimental station in the Baniyas area of Abu Dhabi. The experimental greenhouse is a Venlo type greenhouse consisting of several greenhouse compartments which have an area of 400 m^2 (25 x 16 m) of which 320 m^2 is growing area. The roof cladding of this experimental compartment is tempered Vetrasol diffuse glass with a light transmission of more than 79% and a haze of approximate 70% and a thickness of 4 mm. Window vents with insect netting are present in the cover but not opened during this experiment. The outer wall of the greenhouse compartment consists of double layer polycarbonate 16 mm think with a R-value of 1.8 m^{2}KW^{-1}. The separating wall between the compartments are conventional glass 4mm thick and between the compartment and the technical area sandwich panels are installed with an R value of 2.7 m^{2}KW^{-1}.

Figure 1. Picture of the greenhouse compartment showing the coolers placed above the canopy below the cover and thermal screen, the growing gutters, the air ducts for dehumidification and the heating transport system

The cooling of the greenhouse compartment is done by 5 air coolers which are placed in the center line of the greenhouse below the gutter (Fig 1). The conditioned air is blown sideways. The coolers have a cooling capacity of 57 kW at an air flow of 6650 m^{3}h^{-1} when the greenhouse temperature is 30°C and the relative humidity is 80% and the cooling water has a temperature of 10°C. So around 700 W/m2. The cooling energy is measured with an energy meter based on the cold water flow going into the system and the temperature difference. The condensate is collected for all coolers and measured. The cooling capacity is controlled by the water temperature flowing through the coolers with a minimum temperature of 8 degrees. The heating is a tube rail system of 20 pipes with a diameter of 51 mm which is also used as a transport system for the trolleys. The energy needed for heating is measured.

An air handling unit is used for dehumidification. The air flow of 4000 m^3/h^{-1} is taken from 3 meter high in the greenhouse corner by a vertical pipe before it is passed through a heat exchanger which is fed with water having a temperature of 8 degrees Celsius. After the heat exchanger the air is being distributed evenly in the greenhouse by air ducts hanging under ever other gutter in the greenhouse (6 air ducts in total). The condensate is collected with the condensate from the coolers.

A hanging gutter system for the rock wool slabs is used as planting system including a dripping system. The drain is collected. The compartment is equipped with a high pressure fogging system (120 bar). The compartment is equipped with an automated screen (XLS 30 Harmony Revolux). Pure CO2 is dosed to increase the concentration.

The air temperature and relative humidity are measured at three evenly distibuted locations using aspirated measuring boxes placed just above the canopy. The outside weather conditions including the air temperature and wind speed are measured at a height of 8 m with weather station (Ridder Hortimax S.L., Maasdijk, The Netherlands). The climate control is done by a climate computer. The solar radiation was measured outside and inside the greenhouse compartment at the height of the lower trellies using a pyranometer sensor Kipp Solari (Hortimax S.L.) . The data is recorded every 5 minutes.

THEORY

The heat balance for a closed greenhouse is determined by the solar radiation, the convective heat transfer through the cover and the cooling and heating inside. The solar radiation enters the greenhouse depending on the transmittance of the cover. The radiation is then absorbed or reflected. The radiation on the crop causes the plant to transpire which cools the plant. All the radiation which is absorbed in the greenhouse has to be removed if the temperature is to remain constant. The sides of the greenhouse compartment have a higher insulation, therefore the heat loss or gain are less than through the cover. The heat transfer through the covering (Q) has to be considered:

$$Q = k\left(T_{outside} - T_{greenhouse}\right) \tag{1}$$

With k being the overall transfer coefficient per square meter of greenhouse and T the temperature of the air. The heat transfer coefficient is set to be 7 W/m^2K for the cover and the outer site wall based on the paper by Geoola *et al.* (2009) knowing the average wind speed is around 2 ms^{-1}. When the thermal screen is used the value is set to 3 W/m^2K which corresponds to the energy saving given by the screen manufacturer.

RESULTS

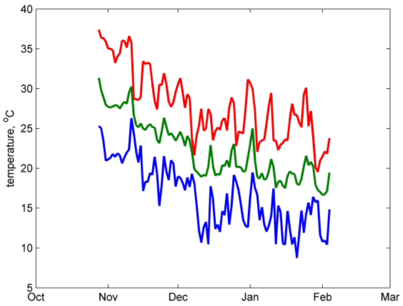

Figure 2. Daily maximum (red), average (green) and minimum (blue) outside air

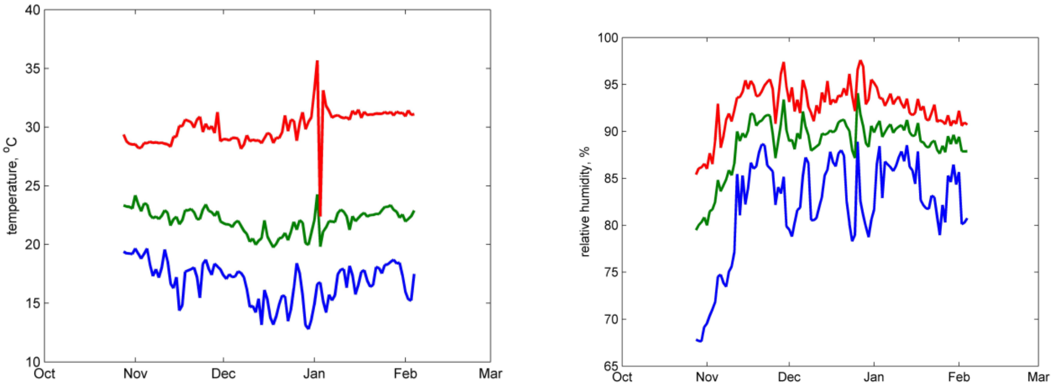

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Figure 3. A: Daily maximum (red), average (green) and minimum (blue) greenhouse air temperature during the experiment. B: Daily maximum (red), average (green) and minimum (blue) relative humidity in the greenhouse during the experiment

The maximum, average, and minimum outside temperature during the experiment are shown in Fig. 2 . During the first weeks of the experiment outside temperatures of more than 35°C are recorded. The air temperature in the greenhouse (Fig. 3A) remained below 32°C except for beginning of January when there was a small power failure. The following day in January was a very cloudy and cold day explaining the low maximum temperature. The minimum temperature in the greenhouse was lower than the setpoint being 15°C since the heat pump was not functioning properly. The cooling capacity of the dehumidification system was not compensated by the heating in this period. As a result, the relative humidity was above 90% (Fig. 3B) specially during night-time.

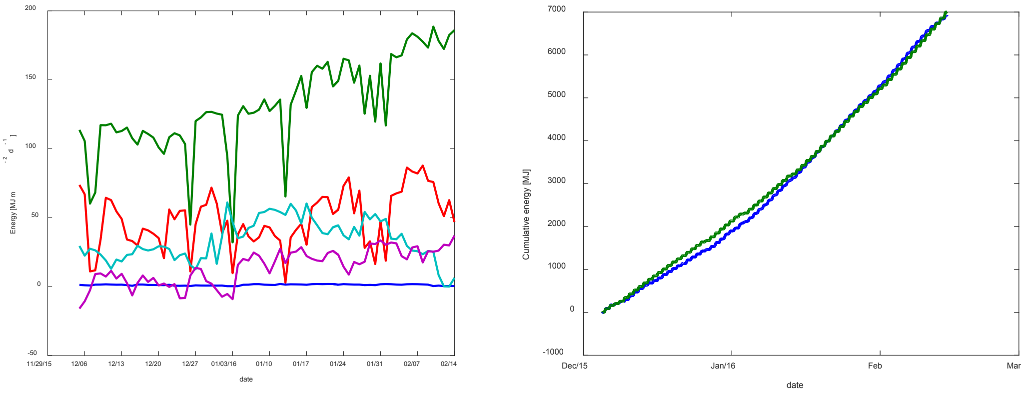

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Figure 4. A: Inside solar radiative energy (green), energy extracted by coolers (red), energy extracted by dehumidifier (light blue), convective heat input (purple), and energy input by heating (dark blue) on a daily base B:Cumulative energy input (solar radiation times the absorption coefficient, the heating) green and the heat extraction by the cooling, dehumidification and convection, blue

The heat balance of the greenhouse is given by the solar radiation and the heating system as source and the cooling and dehumidification system as sink. The convective heat can either be a source or a sink depending on whether the temperature outside is lower or higher than the greenhouse air temperature. Using the estimated values for the convective heat transfer as provided in the theory section, one parameter being the solar radiation absorption inside the greenhouse is not determined. The solar radiation is mainly coming on the canopy where it is absorbed and reflected. The individual heat flows are depicted in Fig. 4A. The total convective heat transfer, both positive and negative as calculated is 18% of the total heat removal by the cooling and dehumidification system which are measured. So the influence of the assumption made for the heat transfer coefficient is limited. The two lines in Fig 4B show the cumulative heat input and output for a specific time frame where the crop was fully developed. The balance between input and output was obtained by assuming 73% of the solar radiation measured inside the greenhouse compartment is absorbed by the canopy and the structure of the greenhouse. The energy flows are not balanced around the first of January. In December more heat enters then is removed and in the first weeks of January it is the opposite. The first weeks the outside temperature is still high resulting in a high cover temperature so the condensation on the cover is minimal. In January there was condensation on the cover resulting in a higher heat transfer through the cover. This can explain the imbalance. Measuring the cover temperature would increase the accuracy.

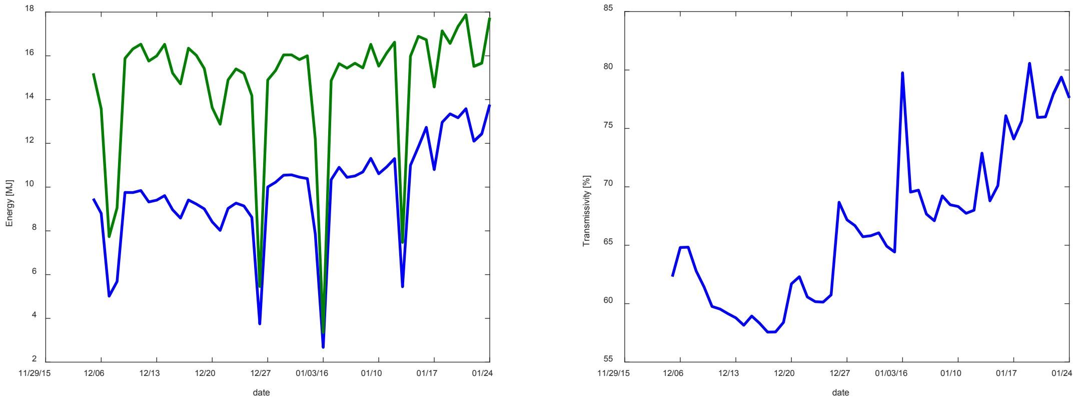

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Figure 5. A: Daily outside solar radiation (green) and inside radiation (blue) B: Transmissivity based on the in and outside measurement in time.

The transmissivity of the cover varies over the year with the angle of the sun. In Fig. 5B it is shown the lowest transmissivity is reached around the 21st of December when the elevation of the sun is lowest. The condensation on the cover in January may also effect the transmissivity.

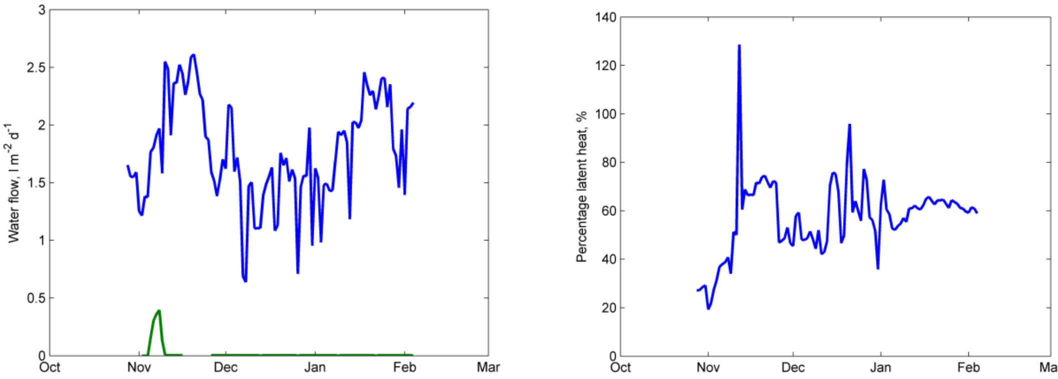

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Figure 6. A: Daily condensate from the coolers and dehumidifier (blue) and water vapour put in the air by the high pressure misting (green) B: Percentage of latent heat over the total heat extracted by the coolers and dehumidifier

Fig 6A. Shows the condensate removal by the coolers and dehumidifiers and the moisture added to the air by the high pressure fogging system. The fogging system was only operation in the first week of the experiment to maintain a relative humidity of 70% when the crop was still small.

Fig. 6B shows the percentage of latent heat, which is calculated by the condense removal multiplied by the evaporation heat (2.4 kJ/l) of water, of the total heat being removed. Roughly 60% is the heat removal is latent heat. During the first weeks of the experiment this percentage was lower since the crop was small. The peaks are caused by pump failure resulting a high flush of water from the system where the pump was fixed again. End of November leaves were removed from the crop which decreased the overall transpiration explaining the lower percentage of latent heat.

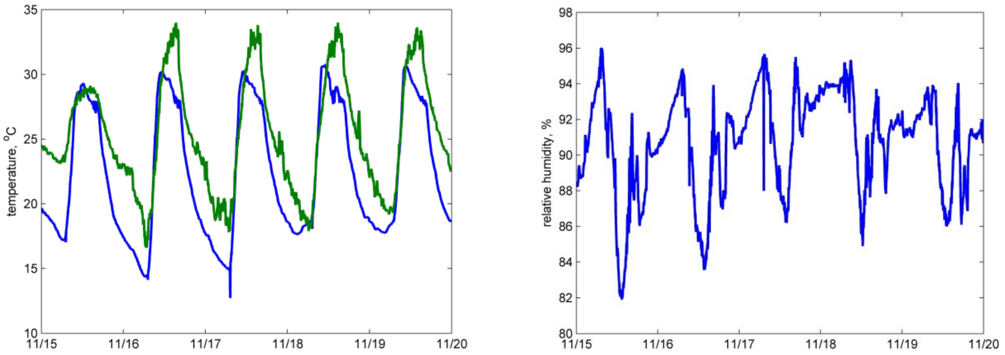

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Figure 7. A: Greenhouse air temperature (blue) and the outside air temperature (green) for a specific period B: Relative humidity of the greenhouse air

Fig. 7A shows the 5 minutes interval data of the outside and greenhouse air temperature for a specific period. It shows the temperature of the greenhouse air follows the temperature of the outside air till the cooling is switch on. Fig. 7B shows the relative humidity for the same period.

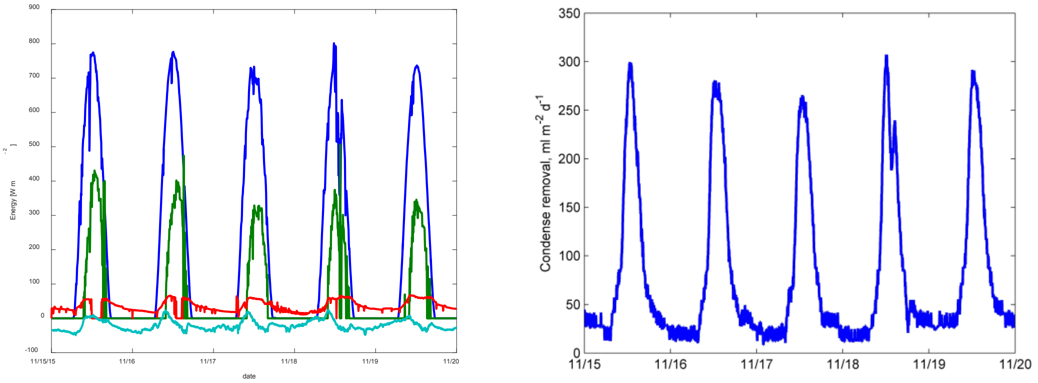

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Figure 8. A: Solar radiation (blue), Cooling energy coolers (green), cooling energy dehumidifier (red), convective heat transfer (light blue) B: Condense removal by the coolers and the dehumidifier

The heat removal by the coolers (Fig. 8A) at the peak solar radiation time approximately 50% of the solar radiative energy at this time, corresponding to the daily average cooling demand in relation to the solar radiation. The convective heat transfer is largest in the night since the greenhouse is cooled by the dehumidifier in this period to remove the moisture but also to lower the daily average temperature and the outside night temperature still being high.

The maximum transpiration by the crop (Fig. 8B) is 300 ml m^{-2} h^{-1}. The night time transpiration is around 20 ml h^{-1} m^{-2}.

DISCUSSION

The system was able to maintain the pre-set temperature and humidity ranges in the greenhouse. The solar radiation is the main source of heat (Fig. 4A). The cooling demand is roughly 50% of the solar radiation due to the transmittance of the cover and the reflection of the crop and structural components. 72% of the solar radiation inside the greenhouse is absorbed by the canopy and structure of the greenhouse. The transmissivity of the greenhouse (Fig. 4B) shows a large dependency on the elevation of the sun. An anti-reflection coating would increase the transmissivity. For countries further from the equators this influence becomes very important.

Dehumidification by condensation not only removes latent heat but also sensible heat. During night-time in combination with lower outside temperatures heating is needed to compensate for this sensible heat loss.

CONCLUSION

The experimental results provided useful information for the cooling demand of a closed greenhouse in relation to the outside conditions. Roughly half of the solar radiation has to be removed from the greenhouse air in order to maintain the temperature. Around 60% of the total heat removed by the cooling system is latent heat. With the results the cooling demand and with that the energy use of a closed greenhouse can be determined based on the outside conditions. This data can be used to analyse the economic feasibility of the system.

ACKNOWLEDGEMENT

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