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Effects of Different Ventilation Strategies on the Microclimate and Transpiration of a Rose Crop in a Reenhouse

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Research Article

Effects of Different Ventilation Strategies on the Microclimate and Transpiration of a Rose Crop in a Reenhouse

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ABSTRACT

The study was aimed at reducing internal air temperatures of a greenhouse shelter as this is one of the main problems facing greenhouse management in warm climates such as in Zimbabwe. The water vapour balance method was used to evaluate the ventilation rate and the results were employed in calibrating and validating the ventilation sub-model of the greenhouse climate model, the GDGCM model, in a naturally ventilated three span Azrom type greenhouse in Zimbabwe. Two ventilation regimes namely: configuration with roof vents only with closed side vents and configuration with both side vents and roof vents open, were investigated. Crop transpiration was estimated using the Penman-Monteith method. The model was fitted to experimental data for ventilation rates, and the parameters for the model, the discharge and wind effect coefficient were determined using statistical analysis. The results showed that there was a good fit between measured and predicted values ($R^2 = 0.702$ and 0.729) for the model on the two ventilation regimes. The air renewal rate was found to be influenced by the nature of ventilation regime in place. The model simulation revealed that the greenhouse has higher air renewal rates for the configuration with both roof and side vents. The greenhouse internal air temperature was reduced significantly for the latter configuration as it had lower simulated air temperatures than the former.

Keywords: ventilation rate, greenhouse, GDGCM model, air renewal, Zimbabwe.

INTRODUCTION

A greenhouse is a structure where protected farming is carried out and it is partly separated from its surroundings. The roof's transparency is a link between the internal microclimate and outdoor atmospheric conditions. The air exchange between the inside and outside establishes the microclimate and atmospheric conditions (Fucks, 1996). The major challenge faced by many greenhouse users is cooling the greenhouse during periods of higher solar irradiance. The most practised ventilation method is natural ventilation because of its cost effectiveness. A greenhouse provides a controlled and favourable environment for crops to grow and gives yield in all seasons. Since there is climate control in greenhouse, there is higher yield per unit area. Ventilation plays one major role in controlling the internal environment in a greenhouse. Ventilation affects both the energy and mass balance in a greenhouse. The effects of energy balance influence the internal air temperature and humidity. The mass balance is exhibited by the amount of water vapour and constituent gases such as carbon dioxide. The concentration of carbon dioxide has a bearing on the photosynthesis process which affects crops growth. Good ventilation practice in a greenhouse also reduces the prevalence of pests and diseases through its control on humidity.

Despite the fact that ventilation is an important physical process influencing the indoor greenhouse microclimate, it has been poorly investigated in Zimbabwe. The project seeks to benefit the horticulture industry and farmers in vulnerable areas where outdoor environmental conditions is not suitable for crop growth. In Zimbabwe, the widely employed ventilation method is natural ventilation because it is cheaper than forced ventilation which requires large quantity of energy.

The aim of this study was to measure the air exchange rates resulting from natural ventilation in a greenhouse equipped with continuous roof and side vents, to investigate the effect of different ventilation regimes on the microclimate and transpiration of a well watered rose crop in Zimbabwe by measurement and simulation.

The specific objectives of the research are:

- To evaluate the ventilation rates for two ventilation strategies, the configuration with roof vents only and the configuration with both side and roof vents.
- To investigate the effects of these two strategies on the greenhouse microclimate and transpiration rate by use of greenhouse dynamic greenhouse climate model (GDGCM).

LITERATURE REVIEW

Greenhouse microclimate

A microclimate is the local modification of the general climate that is imposed by the special configuration of a small area. It is influenced by topography, the ground surface and plant cover and man made forms such as greenhouse, houses and wind breaks (Jones, 1992). The basic goal of farmers that use greenhouse is to strive to provide environmental conditions which allow photosynthesis and respiration to occur so that plants grow, and that the quality is good and are marketable. Air exchange rate is one of the most important parameters of ventilation systems in a greenhouse. The ventilation systems serves the purpose of optimum control of greenhouse climatic conditions for plant growth through supply of sufficient and uniform air exchange rate, between the inside and the outside of greenhouse environments. A better air exchange rate helps reduce the greenhouse air temperature and improves the evapo-transpiration processes for crops. Ventilation and leakage rates are influenced by environmental factors such as wind speed, wind direction, temperature difference between inside and outside and ventilator aperture (Baptista, et al., 1998).

The thermal environment of the greenhouse arises from the complicated mass and heat exchanges between the various components of the greenhouse and the fluctuating weather conditions which present a dynamically changing greenhouse microclimate. The conditions which define the microclimate of the greenhouse are the inflows and outflows and production of energy and mass as result of interactions between the external and internal of the greenhouse.

The greenhouse structures are used to overcome low temperatures in winter and high temperatures in summer. Thus, it is necessary for modifying the temperature not only for crop protection, but also to provide comfortable working conditions. In Zimbabwe growers overcome the effects of high summer temperatures by practicing good ventilation, shading and evaporative cooling.

Ventilation

The main driving forces of ventilation for a greenhouse with both roof and side vents are:

1. The chimney effect, due to thermal buoyancy forces (Bruce, 1982), aiming at a vertical distribution of pressures between the side and roof openings.
2. The static wind effect due to the mean component of the wind velocity, which induces a spatial distribution of pressures over the envelope of the greenhouse.
3. The turbulent effect of the wind, linked to the pressure fluctuations of the wind velocity along openings (Boulard and Baille, 1995), inducing an influx and out flux within the same opening.

The static wind effect gives rise to a vertical distribution of pressures between the side and roof openings (1978) and to a horizontal distribution of pressures between the upwind and the downwind parts of the greenhouse (Hoxey and Maron, 1991; Boulard et al., 1991) resulting in "side wall effect" already analyzed by several authors (De Jong, 1991; Fernandez and Bailey, 1992).

Method of Determining the Ventilation Rate

The water vapour balance method

Assuming (i) Perfect mixing of water vapour in the volume of the greenhouse, and (ii) that evaporation from the soil and/ or other medium is negligible (justified by the presence of a plastic mulch on the soil surface and the cover offered by the crop); the greenhouse ventilation rate, G can be calculated from mass balance of water vapour of the greenhouse:

$$V \frac{dx_i}{dt} = G(t) \cdot [x_e(t) - x_i(t)] + T_r(t) \quad (1)$$

Where $G(t)$ is the ventilation rate (m^3/s), V is the greenhouse volume (m^3), x_i and x_e is the inside and outside air absolute humidity respectively, (kg/m^3), and $T_r(t)$ is the greenhouse crop transpiration rate (kg/s). For small time steps, Δt Equation (1) can also be expressed as:

$$V \frac{\Delta x_i}{\Delta t} = V \frac{x_i(t + \frac{\Delta t}{2}) - x_i(t - \frac{\Delta t}{2})}{\Delta t} = G(t)[x_e(t) - x_i(t)] + T_r(t) \quad (2)$$

So that:

$$G(t) = \frac{\left[V \frac{x_i(t + \frac{\Delta t}{2}) - x_i(t - \frac{\Delta t}{2})}{\Delta t} - T_r(t) \right]}{[x_e(t) - x_i(t)]} \quad (3)$$

Measured values of air temperature and relative humidity outside and inside the greenhouse (at 30-minute time steps) will be used to calculate the values of outside and inside greenhouse air absolute humidity, respectively. These values and the crop transpiration rate, $T_r(t)$, obtained from measurements of sap flow, leaf area and the leaf area index will then be used to calculate the greenhouse ventilation rate, and hence the air renewal rate. The absolute humidity is evaluated from the relationship as given by Jones (1992)

$$x = \frac{2165}{T} * e \quad (4)$$

Where x is the absolute humidity in kg/m^3 , T is air temperature and e is the actual vapour pressure (kPa).

The areas of the vent openings will be calculated by using the control algorithm of the ventilation control system and compared to a few values measured on selected days and at selected times of the day.

Leakage rates will be calculated as the average value of the ventilation rates when the greenhouse is closed.

Determination of Transpiration Rate

The transpiration rate in a greenhouse can be determined by using many methods which include eddy-correlation, aerodynamic techniques, Bowen approaches and combination or energy balance methods. Fuchs (1973) examined these methods and separated them as to energy balance, mass and heat transport, and turbulent mixing, aerodynamic and the Bowen ratio method. The Penman Monteith can be used to evaluate transpiration rate in a greenhouse and it is formulated from the following basic principles.

Penman in 1948 combined the energy balance with mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed. This is the combination method which was further developed by many researchers and extended to cropped surfaces by introducing resistance factors. The resistances are aerodynamic resistance and surface resistance. The surface resistance, r_s , describes the resistance of vapour flow through the stomata openings, total leaf area and soil surface. The aerodynamic resistance, r_a , describes the resistance from vegetation upward and involves friction from air flowing over the vegetative surface. (Seginer 1984; Stanghellini 1987; Baille *et al.*, 1994c; Kittas *et al.*, 1999).

RESEARCH METHODOLOGY

The investigations were in two parts, namely the empirical and modeling parts and these were designed to address the primary objectives. The former was aimed at evaluating the ventilation rates of the two configurations of roof and side vents. The latter investigation was a desktop type and made use of a greenhouse climate model, the Gembloux Dynamic Greenhouse Climate Model (GDGCM), to explore the effects of the two ventilation configurations on the microclimate and transpiration rate of a rose crop.

Study Area

The experiments were done in Harare, Zimbabwe at approximately 17,8°S, 31.1E and at an altitude of approximately 1483m between September 2007 and April 2007. The greenhouse shelter was for rose crop growers, Floraline Pvt. Ltd in Harare, about 5km from the University of Zimbabwe. The greenhouse was an Azrom type (figure1). Each span of the greenhouse measured 9.6m wide and 44m long, with ridge and gutter heights of

6.5m and 4.1m, respectively. The ridges were oriented north-south, the greenhouse total floor area was 1267m² and the roof sloped at about 26° to the horizontal. The cladding material was 200µm polyethylene film with terrestrial infrared and UV absorbing additives (Ganeiger Co, Israel). The roof vents (one in each span on the west side of the roof) were located along the whole length of the ridge and were 1.4m, wide, with maximum opening angle of 34° with the roof. The polyethylene side could be rolled up from the 2m above the floor to 3.35m on the south wall and to 3.45m on the north wall. The side and roof vents positions were controlled by an automated climate control system (NETAFIM NETAGROW Version 718.3 Priva, Israel) in response to ventilation temperatures (temperature at which ventilation begin) which is calculated on the basis of set ventilation temperatures and a number of influences, such as the measured inside air temperature and relative humidity and outside conditions.

Figure 1: Azrom type greenhouse at Floraline Pvt. Ltd in Harare, Zimbabwe

Two circulation fans, 0.75m in diameter with a rated outflow of 16 00m³/hr at zero static pressure (blowing N-S) were installed under each gutter at a height 3.5m and 12m from the north and south wall respectively. The plants which were planted in the greenhouse included several cultivars of roses, grown in vermiculite medium in slightly raised 20mx0.45mx0.2m containers and were watered through an automated drip system. The total area of the vegetation cover represented about 40% of the total greenhouse floor. The containers were laid parallel to the gutters in twelve 20m rows in each span. The greenhouse roses were a variety of cultivars which included commercial ones line Nectarine, Betsy, King Arthur, Upendo and Symphonica Rosso.

Figure 2: Inside setup of the greenhouse

Empirical Investigations

Two automatic weather stations (AWS) were installed, the internal and the external to monitor greenhouse climate and environmental conditions. Inside the greenhouse was PAR, net radiation, solar radiation, relative humidity, air temperature and wind speed. Agro-meteorology variables measured were soil moisture, leaf temperature and leaf area index. Variables measured outside the greenhouse were all meteorological and these were air temperature and relative humidity were measured at 1.5m above ground by means of temperature and humidity probe of model

RH2nl Delta T Devices, Cambridge, UK. The incoming solar radiation, PAR, wind speed and direction were measured at 2m above ground. Other measurements made were the dimensions of the roof opening area and side openings area.

Internal Measurements

The internal automatic weather station (AWS), Figure 2, was installed approximately at the centre of the greenhouse. The climatic parameters which were measured by the AWS included temperature and relative humidity at above soil heights of 0.4 m and 0.8 m (within the canopy) and on top of the canopy at 1.5 m and 2 m (just below the roof of the greenhouse) in order to investigate possible vertical gradients of air temperature and relative humidity. To test the homogeneity within the greenhouse, the relative humidity and temperature were measured at the centre of the greenhouse and at four other positions at 1.5 m above soil surface (see Figure 2) by temperature humidity probes (model HMP45C, Vaisala Inc, Boston, USA). The greenhouse internal air temperature and humidity were taken as the average of the five sensor positions. The net radiation, PAR, the incoming solar radiation were measured above the canopy and the soil temperature measured at two positions in the vermiculite medium. Leaf temperature was measured at six positions.

The leaf temperature was measured at six positions with fine chromel-alumel thermocouples, type K, 0.2mm in diameter, attached to the lower side of leaf by paper clips.

The leaf temperature was taken as the average of six leaf temperatures. The vermiculite temperature at two positions were measured with soil temperature probes (type STI, Delta T Devices, Cambridge, UK), and the average of the two readings was taken as vermiculite temperature.

All measurements were automatically recorded by the two data loggers, one that was Campbell Scientific data logger CR23X (Campbell Scientific Ltd, Shepshed, UK) that recorded measurements every 5 second and averaged over 30 minutes using a DL2e data logger (Delta T Devices, Cambridge, UK). The leaf temperature was measured at six points in the greenhouse using leaf temperature thermocouples. To check the reliability of thermocouples, infrared radiation thermometer was used on selected days. The soil temperature was measured using soil temperature probes (type STI, Delta T Devices, Cambridge, UK).

Transpiration Rate Estimation

Variables used to determine the transpiration rate inputs are inside air temperature, relative humidity, and solar radiation of crop canopy, net radiation and leaf temperature according to equation (2). The leaf area index was then used to estimate calculation the transpiration rate for all the crops in the greenhouse.

Model Description

In order to evaluate the ventilation rates and the microclimate for different ventilation strategies a model GDGCM was used. The Gembloux Dynamic Greenhouse Climate Model (GDGCM), previously validated for a tomato crop in European greenhouses by Deltour et al. (1985), and Wang and Boulard (2000), was adapted, calibrated and validated to simulate the microclimate for a naturally ventilated Zimbabwean greenhouse containing a rose crop by Mashonjowa et al (2008). The GDGCM is a multiple component semi- one dimensional dynamic greenhouse climate model which calculates eight heat balances for the following greenhouse layers which are the cover, air, vegetation, soil surface and four soil layers as shown in Figure 3.6 (Pieters, 1995; Pieters and Deltour, 1997). The model also takes into account a mass balance for the simulation of the relative humidity of the greenhouse air. The greenhouse microclimate is the result of heat and mass exchanges between these layers.

Figure 3: The schematic diagram showing the heat and mass exchanges between the greenhouse layers (after Pieters and Deltour, 1997)

The model assumes that the greenhouse layers are homogeneous and that all fluxes are vertical. Considering that, the solar radiation absorptance of some layers depends on the angle of incidence, and thus on the sun's position in the sky, the model is not strictly one-dimensional, hence it is said to be semi-one dimensional. The interactions between these layers include heat transfers by conduction, convection, solar radiation and thermal radiation, as well as the latent heat exchanges. The greenhouse cover forms a barrier between the interior and external climate and consequently its outer surface exchanges heat with the sky and outside air, while its inner surface exchanges heat with inside air, the vegetation and the soil surface. The greenhouse surfaces also exchanges mass with the inside and outside air through condensation of water vapour and latent heat is released in the process. The greenhouse air exchanges heat by convection with the cover, the vegetation, the soil and the heating system (if any) and through exchange with the outside air by advection and ventilation. The crop inside the greenhouse absorbs solar radiation; there is also the radiative exchange with the cover, soil and heating system, convective heat exchange with the greenhouse air and latent heat linked with the transpiration from crops and evaporation from the soil surface.

The soil gains and losses energy through the absorption of solar radiation, radiative exchange with the cover, the crop and heating system, convective exchange with the greenhouse air and conductive exchange with the underlying soil surfaces.

To allow the simulation of the effect of control procedures for regulating the inside air, several possibilities of heating and ventilating strategies, among which the user can choose, are built into the model (Bakker et al., 1995; Pieters and Deltour, 1997; Hanan, 1998; Wang and Boulard, 2000).

Ventilation sub-model

Ventilation is a very important tool for greenhouse climate control. Ventilation is mainly used for control of temperature, humidity and concentration of gases, such as CO_2 , in the greenhouse. An efficient ventilation performance is a crucial feature of a greenhouse in hot summer conditions. Besides cooling the greenhouse in summer, ventilation is important for transport of heat and mass in form of water vapour and other gases through replacement of inside air by outside air. Ventilation is characterized by the air renewal rate R_a , which expresses the ratio of the total volume of fresh air supplied in one hour to greenhouse volume.

South-west of the greenhouse indicated consistently lower day-time temperatures than the other four sensors. There were no significant differences between the night-time temperatures and the day-time relative humidities measured at the five positions. The night-time humidity measured by sensor Z5, located near the centre of the greenhouse and at the point at which all climatic measurements were made earlier, was consistently lower than those measured at the other four positions. Since the conditions that are applicable for the use of GDGCM which assumes the eight layers of the homogeneous and the water vapour balance which requires the greenhouse to be perfectly mixed are met which makes the greenhouse to be suitable for the application of the model and the water vapour method.

The water vapour content which results from transpiration of the crops and evaporation from the soil is not readily transferred into the atmosphere as the canopy offers some resistance. In summary these findings were similar to what was found by Demrati et al. (2007). For the diurnal period, the air temperatures gradient increases with height of greenhouse. It is due to the progressive absorption of solar radiation by the crop canopy, together with limitation to the vertical air exchanges between the regions above and below the crop canopy. As a result, air relative humidity at night is higher when measured below the crop cover than above.

RESULTS AND DISCUSSION

Validation of Penman Monteith Method

The ventilation rate was determined using the water vapour balance method; the transpiration term was evaluated using the Penman-Monteith method as was applied by (Katsoulas et al 2001). To validate the Penman Monteith method it was compared with Sap flow measurements using historical data (Mashonjowa et al 2007). Figure 4 shows the correlation between transpiration rates obtained from sap flow and determined by Penman Monteith formula using data from 1 December 2007-31 December 2007.

Figure 4: correlation between transpiration obtained from sap flow and transpiration obtained from Penman-Monteith method on days 1-31 December 2007

The results showed there is a good fit between the measured transpiration rates from sap flow gauges and the calculated transpiration rates from Penman-Monteith, although the sap flow gauges tends to overestimate the crop transpiration in the morning (just after sunrise), and underestimate crop transpiration in the afternoon (just before sunset) as reported by the following authors: (Baker and van Bavel, 1987; Baker and Nieber, 1989; Grime et al., 1995)). This was explained as follows, in the morning when soil temperature exceeds air temperature; there is negative temperature gradient in the sensor as warm sap enters a cooler stem, causing a temporary over-estimation of whole-plant transpiration, if the sensor is near the soil. In the afternoon, when the ambient air temperature is higher than soil temperature, the sensor registers a higher positive gradient in the sensor, resulting in an underestimation of whole plant transpiration. The errors can also be attributed to up scaling of the leaf transpiration that is based on the assumption and the transpiration from the single is uniform throughout the whole canopy.

Determination of stomatal resistance

The version Penman-Monteith formula which was adopted for determining transpiration rates required the measurements and estimation of aerodynamic resistance and canopy stomatal resistance. The aerodynamic resistance for plants in a greenhouse was assumed to be 200sm^{-1} . The stomatal resistance in this study was obtained from the stomatal sub-model in the GDGCM. Before use, the stomatal model was calibrated to obtain the equation parameters by experimental data fitting into a statistical package called Sigma plot. It was then validated by comparing measured stomatal resistance with predicted stomatal obtained from the model. The fig 6 shows the variation of solar radiation and stomatal resistance.

Figure 5: Variation of measured stomatal resistance and solar radiation on 28 November, 2007 -14 December, 2007

Figure 5 presents the variation of stomatal resistance and solar radiation. An increase in solar radiation results in a decrease in the stomatal resistance. Figure 5 can be used to explain why transpiration is high during the day and almost zero at night. During the day, transpiration is high because the incident solar radiation is high and the canopy stomatal resistance is low. During the night, the stomatal resistance is much higher because solar radiation is zero and consequently transpiration is very small because the radiative component is almost equal to zero.

Figure 6: Variation of measured stomatal resistance with vapour pressure deficit (VPD) on 28 November, 2007-December 2007

Figure 6 presents the variation of measured stomatal resistance with vapour pressure deficit. It can be observed that high vapour pressure deficit corresponded to low stomatal resistance, and when the vapour pressure deficit was low, the stomatal was very large. This can be explained as follows: high vapour pressure deficit that occurs when temperature is high and because air can hold more vapour when its temperature rises. The vapour deficit between the leaf and the vapour pressure deficit becomes large and causes stomatal resistance to decrease rapidly. Low temperatures make the air more humid and it also tends to decrease the vapour pressure deficit that tends to increase the stomatal resistance.

Table1, shows the parameters of the stomatal model found by experimental data fitting using a statistical package Sigma plot and what has been found out by other authors; the values obtained in this study was comparable to what has been found out by Kittas et al. (1999). However, there was great difference to what has been found by Baille et al. (1994c), this could be due to different locations of the growing medium of the roses and different cultivars. To test the reliability of the stomatal model it was validated by comparing predicted canopy stomatal resistance and measured stomatal resistance.

Figure7: the correlation between observed stomatal resistance and predicted stomatal resistance on 16 December, 2007

Table 1: Model specific parameters obtained in this study compared to those found by Baille et al. (1994c) and Kittas et al.(1999) for two cultivars of roses (Rosa x Hybrida)

	This study	Baille et al.	Kittas et al.
Cultivar and Substrate	Average of several cultivars in vermiculite	cv Sonia in rockwool	cv First Red in perlite
A	546.9752±93.1	349	566
B	52.3263±17.2	28	90
C	-0.1299±0.1	1.45	0.276

Figure 7, shows there was good fit between the measured canopy stomatal resistance and the simulated canopy stomatal resistance and therefore the stomatal resistance which was required in determination of the transpiration was estimated using the model equation.

Statistically, analysis for stomatal model validation and calibration is shown in Table 2. The t test was used to carry out the significance to test the null hypothesis H_0 that there is no significant difference between the observed stomatal resistance and predicted stomatal resistance. In both calibration and validation (Table 2) we accepted H_0 since $t_{\alpha=0.025} < |t_{stat}|$ and concluded that there was no significant difference between the modeled and the measured stomatal resistance at 5% level of significance.

Table 2: Results of significance test using t-test at 5% level of significance for the observed and predicted stomatal resistance for calibration and validation, including the Root Mean Square Error (RSME)

Process	RSME	Number of observations	t_{stat}	$t_{\alpha=0.025}$
Calibration	478.7	33	1.462	2.037
Validation	232	21	-1.357	2.423

E. Model Results

Introduction

In this section, the results from the simulation of ventilation sub model of the GDGCM are presented for the two ventilation configurations using the same outside weather data and the same greenhouse parameters.

Influence of Ventilation Strategy on Air renewal rates

The simulated air renewal rates for the two configurations were found from model outputs. These rates were then compared to find the effects of ventilation on the air renewal rate. The results are displayed in Figure 7.

The major purpose of ventilation is to reduce the heat load in the greenhouse during periods of high solar irradiance. This would prevent crops from overheating; reduce the risk of disease prevalence as excessive humidity will be carried out of the greenhouse, and increase the rate of photosynthesis. During summer, the aim of greenhouse users will be to keep the difference between internal and external air temperature as low as possible.

The trends for the air renewal rates for the two ventilation configurations were similar as shown in Fig 7(a). Ventilation is vital for cooling the greenhouse in periods of high solar irradiance. From Fig 7, it can be deduced that large difference of air renewal rates occurred during the day. At night, as temperatures are low in the greenhouse, the air renewal rate for the two ventilation regimes were almost equal and corresponded to air exchange rate effected by the leakage of 2.9 hr^{-1} when the greenhouse vents were completely closed. During the day, the air renewal rates projected were high around midday reaching a maximum value of 15.6 hr^{-1} for the configuration with both roof and side vents and 6.5 hr^{-1} for the configuration with roof vents only on 11th September 2007 at 1600hrs. The air renewal rates were high during the day because the greenhouse receives high solar radiation that consequently heats the interior air, crops and the soil that results in sensible and latent heat. The infrared radiation which is emitted by vegetation and soil trapped within the interior of the greenhouse (greenhouse effect). Sensible, latent heat and infrared radiation in a greenhouse result in increase in temperature. since the greenhouse responds to ventilation set

(a)

(b)

Figure 8: The simulated air renewal rate (a) for the period from 11-13 September 2007 and (b) for the period from 16-17 October, 2007.

Temperature, during the day rises because solar radiation is high and so this explains why there is a maximum air renewal rates around midday and also why there is maximum opening of the vents with roofs only. The greenhouse ventilation area is lower than the one with both roof and side vents hence it has lower ventilation rates. The predicted air renewal rates for the ventilation regime with both roof and side vents were higher than those with only roof vents as expected.

Fig 7(a) shows that ventilation rates were higher for the ventilation strategy with both roof and side vents than for the ventilation strategy with roof vents only. As air renewal rate depends on wind speed and internal air temperature, if the opening area is reduced, the wind speed will be reduced hence the reduction in air renewal rate. The greenhouse equipped with roof vents only therefore would have low ventilation as opposed to when greenhouse had both roof and side openings that would have extra opening area of side vents to allow more air movement thereby increasing the ventilation rate. Fig 12 (a) shows that during the night, there was no significant difference between the simulated air renewal rates of the two configurations. As both vents were closed at night therefore, the air renewal rate is the leakage rate of 2.9 hr^{-1} . There was a large difference between the simulated air renewal rates for the two ventilation configurations during the day. The modeled results were as follows: on 16 October, 2007, the maximum air renewal rate of 12.43 hr^{-1} for the configuration with both roof and side vents and 6.96 hr^{-1} for the configuration with roof and side vents and 6.97 hr^{-1} for the configuration with only roof vents at 1030hrs on the 17 October, 2007. The air renewal rates were also high during the day with a maximum of 11.8 hr^{-1} for the ventilation strategy with both vents and 5.6 hr^{-1} for the greenhouse with roof vents only.

The difference in simulated air renewal rates for the different day was found to be dependent on the solar radiation incident on the greenhouse and also on the degree of opening of vents. These findings are similar to what have been found by other authors that the combination of roof and side openings increases air velocity hence the air renewal rate (Bartzanas et al., 2005; Fatnassi et al., 2001; Harmanto et al., 2006).

Effects of ventilation on the microclimate of the greenhouse

The purpose of ventilation in a greenhouse is to control temperature, in order to reduce water stress in plants, increase crop growth as most crops grow well in a temperature range. The results from the GDGCM model were used to investigate the effects of the two ventilation regimes using outside weather data and greenhouse parameters.

Influence of Ventilation on inside air Temperature

The influence of ventilation strategy on the inside air temperature was shown from the results predicted inside air temperature from the two models that was done for the greenhouse for the two configurations: one with roof vents only and the other with both roof and side vents using same weather data and conditions but only different in ventilation strategy. The simulated internal air temperature for the two configurations was compared and the results are displayed in Figure 9.

Temperature is one of the most crucial environmental factors influencing plant growth especially in protected cultivation. The simulated internal air temperature in Figure 9 for the two ventilation regimes was compared on selected hottest days of the month for the entire summer period. Figure 9 shows that the temperatures for the ventilation strategy with roof vents only were higher than the temperatures for the ventilation strategy with both roof and side vents. The trends shown in Figure 9 indicate that there were significant differences during midday.

During the night, early in the morning and late afternoon, the internal air temperatures from the two models were almost equal. The observed temperature difference between the two ventilation regimes during the day shows that air temperature is influenced by the ventilation strategy. Thus the temperature of the configuration with both roof and side vents were lower than the corresponding temperatures for roof vents only which had lower air renewal rates. The results from the model show that the ventilation regime affects the cooling of the greenhouse especially in periods of high solar radiation. Temperatures are lower for the configuration with both roof and side vents as compared to configuration with roof vents only. The difference in temperature for the two configurations can be explained as

Figure 9: The simulated diurnal variation of internal air temperature for the two configurations on 18th October, 2007.

Effects of ventilation strategy on relative humidity

The water vapour content of the greenhouse is highly influenced by the rate at which the greenhouse is capable of exchanging heat and mass transfer which is dependent upon the ventilation rate. The restriction introduced by incorporating the roof vents only would therefore limit the rate of mass transfer and this was observed in the simulated relative humidity obtained for greenhouse configuration with roof vents only and for the configuration with both roof and side vents. The daily variation of relative humidity for the two configurations is presented as shown in Figure 10.

The results indicate that inside air humidity was dependent on the vent opening configuration. On 2nd December, 2007, the simulated relative humidities were similar for both vent configurations and it showed that the

inside relative humidities were very high, over 90% at night until in the morning when humidity for both configurations dropped to 70% and 60% for the configuration with roof vents only and for the configuration with both roof and side vents respectively. During the day, the simulated relative humidity for roof vents only was higher than the corresponding relative follows since the configuration with roof vents has lower air renewal rates than the configuration with a combination of roof and side vents as shown in figure 10 where high air, velocity was found to affect relative humidity. (a)

(b)

Figure 10: The simulated diurnal variation of relative humidity on (a) 18th November, 2007 and b) 2nd December, 2007.

Humidity for both roof and side vents. This can be explained as follows: humidity depends on ventilation rate; the configuration with roof vents only which had lower ventilation rate therefore this configuration had higher humidity than the other configuration that had higher ventilation rates. The observations made from the simulated inside relative humidity are that low ventilation rates tend to make the air more humid because water vapour from transpiring crops will be carried away at a low rate.

From the model it can be observed that the two ventilation regimes show much difference during the day for the two configurations. Differences between the relative humidity were found to be high, about 8%. The difference in airflow rates of the two ventilation strategies is responsible for the difference for the observed differences in humidity.

Effects of ventilation regimes on the transpiration

The modelled results showed that transpiration was affected by the ventilation regime. The transpiration from the simulation for the greenhouse equipped with both roof and side vents were higher than the transpiration for the greenhouse with only roof vents. This effect therefore means that crops in the greenhouse with both roof and side vents have higher growth rate than the crops in the greenhouse with only roof vents provided that water is not

limiting. Figure 11 shows that crop transpiration was high during the day for the two configurations and maximum transpiration occurred at around midday as expected when stomatal resistance is low. This can be explained

Figure 11: Simulated canopy transpiration on 18th October, 2007 for the two ventilation regimes.

thus:: the rate of transfer of humidity from the greenhouse is lower in the case of roof vents and higher in the case with both roof and side vents. Lower ventilation rates result in decrease in vapour pressure deficit that reduces the rate of transpiration. These findings are similar to what has been reported by Baille et al. (2001) and Katsoulas et al. (2001). In their studies, they reported that high rates of air exchange between the inside and outside of the greenhouse keep the vapour pressure deficit high and consequently increase the transpiration rate. Figure 19 shows that maximum transpiration took place around midday since solar radiation is maximal during midday. This agrees with the theory that transpiration is driven by solar irradiance and that the leaves open their stomata apertures widely in high solar irradiance as a physiological mechanism to cool the leaves (Demratti, 2007). The latent heat from transpiring crops will further reduce the heat load in the greenhouse and thus giving the suitability of employing both roof and side vents for cooling the greenhouse in summer.

The rate of transpiration from simulations shows that it depends highly on the ventilation regime on practice. During the night, the transpiration was slightly above zero showing that there might be some nighttime transpiration. The results indicate that the greenhouse with both roof and side vents is well suited for plant growth. Table 6 summarizes the maximum transpiration of the two ventilation configurations on the selected hot days during summer

Table 6: Maximum transpiration for the two ventilation configurations

Date	Maximum canopy transpiration flux density (Wm^{-2}) for roof vents only	Maximum canopy transpiration flux density for both roof and side vents (Wm^{-2})
18 October 2007	153	166.5
18 November 2007	128	139.3
21 January 2008	97.2	123.4
		95.6

Table 6 presents the maximum transpiration for the two configurations and shows that the maximum transpiration on 18th October, 2007 was predicted to be 166.5 Wm^{-2} for the greenhouse with both roof and side vents while it was 153 Wm^{-2} for the configuration with roof vents only. On 18th November, 2007, the predicted maximum transpirations were 139.3 Wm^{-2} and 128 Wm^{-2} for the greenhouse with both roof and side vents and for the greenhouse with only roof vents respectively. The transpirations were lower on 21st January, 2008 with the modelled maximum transpiration for the greenhouse with both roof and side vents opening being 123.4 Wm^{-2} and 97.2 Wm^{-2} for the greenhouse with roof vents only. The lowest predicted maximum transpirations were found on 8th March, 2008. The configuration with both roof and side openings had a transpiration rate of 95.6 Wm^{-2} while the rate was 87 Wm^{-2} for the other configuration. These findings clearly demonstrate that ventilation strategy affects crop transpiration inside a greenhouse.

CONCLUSIONS

In this study, the influence of the two ventilation configurations was investigated for 3-span Azrom type greenhouse rose crop using the GDGCM climate model. The model was calibrated and validated against experimental data. It can also be concluded that the GDGCM climate model can be used to simulate the microclimate and the transpiration rate of crops inside the greenhouse in warm climates, and basing on the model results, the ventilation strategy with both roof and side vents was found to provide the suitable microclimate and transpiration for rose crop growth. Thus the GDGCM can be used as designing tool to monitor greenhouse ventilation system using the climatic parameters and greenhouse construction parameter.

Field measurements were carried out to predict the ventilation rates and crop microclimate in a commercial greenhouse for rose cultivation. The water vapour method was successfully used to determine the greenhouse ventilation rates which were used for calibration and validation of the GDGCM climate model.

Modeled air exchange rates in a 3-span Azrom type showed that the microclimate and transpiration was adversely affected by the ventilation regime on practice. The results indicates that the configuration with both roof and side vents gave the maximum greenhouse ventilation rates during the day. On selected hot day the predicted air renewal rates were 15.6hr^{-1} and 6.5hr^{-1} for the ventilation strategy with roof vents only. These results showed that the configuration with roof vents only gave lower ventilation rates. Basing on these findings, it can be concluded that the most effective vent configuration was the combination of roof and side vents.

The simulated temperatures from the model showed that the configuration with both roof and side vents was more effective in reducing the inside air temperature on selected hot days. The average difference between????????

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