TEMPERATURE CONTROL TECHNIQUES FOR AN AZROM TYPE GREENHOUSE SHELTER IN ZIMBABWE.

Chayangira Juwawa and Simba Farai Malvern

Department of Physics, Geography and Environmental Science, Great Zimbabwe University

Zimbabwe has Savannah type of climate which has average daily maximum temperatures of 28 ^{o}C and may cause greenhouse internal temperatures to soar to unproductive heights. The study sought to regulate internal air temperatures of a greenhouse shelter 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. Methods used include the water vapour balance method to evaluate the ventilation rate and the results were employed in calibrating and validating the ventilation sub-model of the greenhouse climate model called the GDGCM model, in a naturally ventilated three span Azrom type greenhouse in Zimbabwe. 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 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 : temperature, greenhouse, ventilation, transpiration, Zimbabwe

I. INTRODUCTION

Agriculture is the mainstay of Zimbabwean economy and horticulture in particular is key to bringing foreign currency to the country (Simba *et. al* 2012). Commercial farmers and private companies grow different crops in from vegetables, fruits to flowers and greenhouse shelters come in handy in this regard. Some advantages of greenhouses include regulating temperatures, water supply, fertilizer application, relative humidity etc and these can easily be optimized. Different types of greenhouse shelters are available from plastic type to glass types. These variations determine durability and costs. 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 pactised ventilation method is natural ventilation because of its cost effectiveness. A greenhouse provides a controlled and favourable environment for crops to grow and give 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 affect crops growth. Good ventilation practice in a greenhouse also reduces the prevalence of pests and diseases through its control on humidity.

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).

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.

Objectives

To investigate the regulation of temperature by measuring the air exchange rates resulting from natural ventilation in a greenhouse equipped with continous 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.

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^{o}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 1267m^{2} and the roof sloped at about 26^{o} 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^{o} 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 are 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.

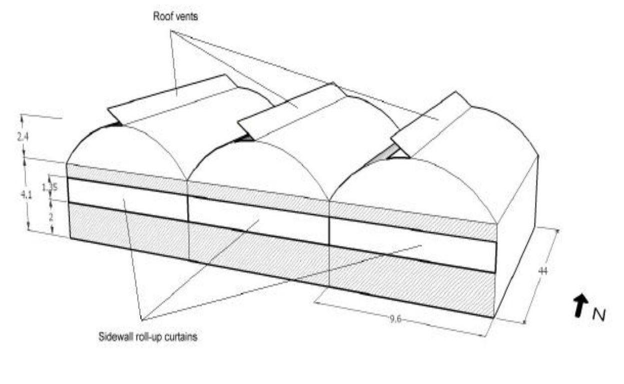


Figure 1: Azrom type greenhouse at Floraline Pvt. Ltd in Harare, Zimbabwe

Two circulation fans, 0.75m in diameter with a rated outflow of 16 00m^3/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 were planted in the greenhouse included several cultivars of roses, grown in vermiculite medium in slightly raised 20mx0.45mx0.2m containers which 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.

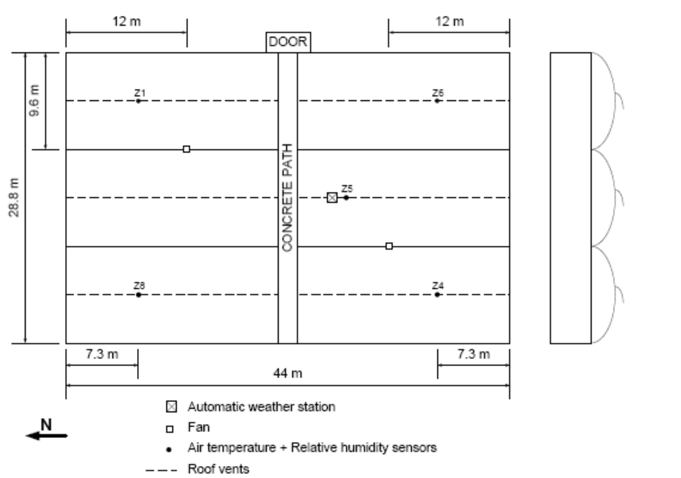


Figure 2: Inside setup of the greenhouse

A. Empirical investigations

Two automatic weather stations (AWS) were installed, the inernal and the other one outside to monitor greenhouse climate and environmental conditions. The iside the greenhouse were 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.

B. 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 by 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 an infrared radition 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 (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.

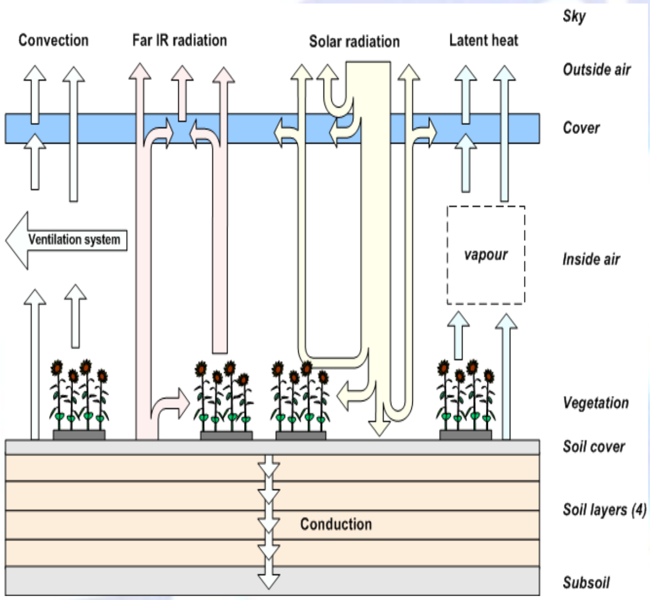


Figure 3: The schematic diagram showing the heat and mass exchanges between the greenhouse layers (after Pieters and Deltour, 1997)

II. Results and Discussion

A. 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.

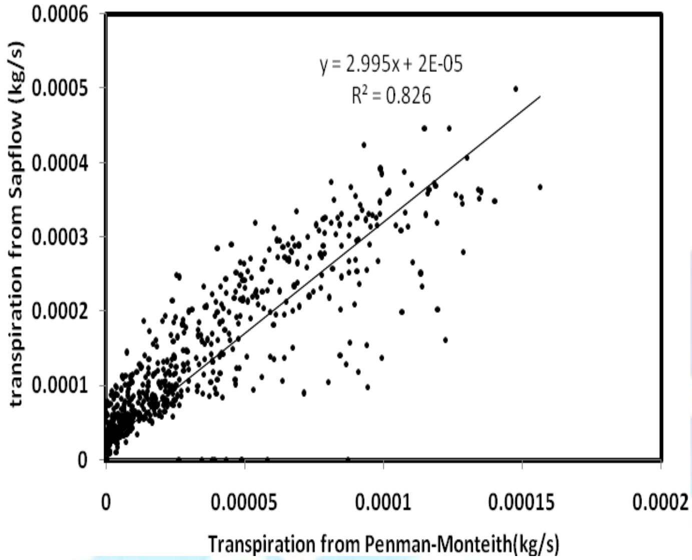


Figure 4: correlation between transpiration obtained from sap flow and transpiration obtained from Penman-Monteith method on days 1-31 December 2007

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 overestimate the crop transpiration in the morning (just after sunrise), and underestimate of crop transpiration in the afternoon (just before sunset) as reported by the following authors (Baker and van Bavel, 1987; Baker and Nieber, 1989 and 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 the transpiration from the single is uniform throughout the whole canopy.

Statistically analysis for stomatal model validation and calibration is shown in Table2. 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 $<$ $t_{\alpha=0.025}$ and concluded that there was no significant difference between $|t_{sat}|$ 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

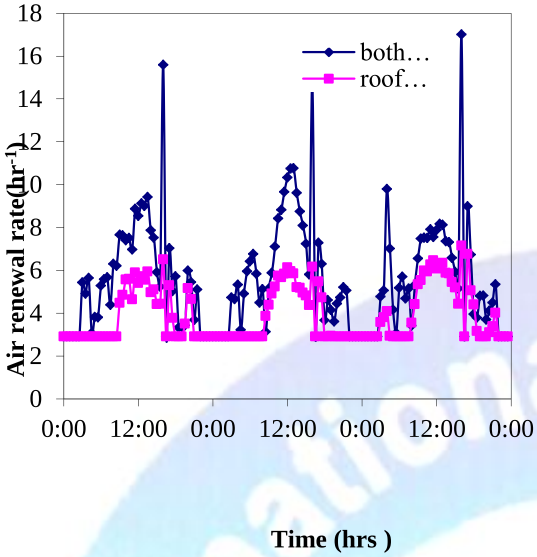
In this section the results from the simulation of ventilation sub model of the GDGCM are presented for the two ventilation configurations using the same outside weather data and the same greenhouse parameters.

Influence of Ventilation Strategy on Air renewal rates

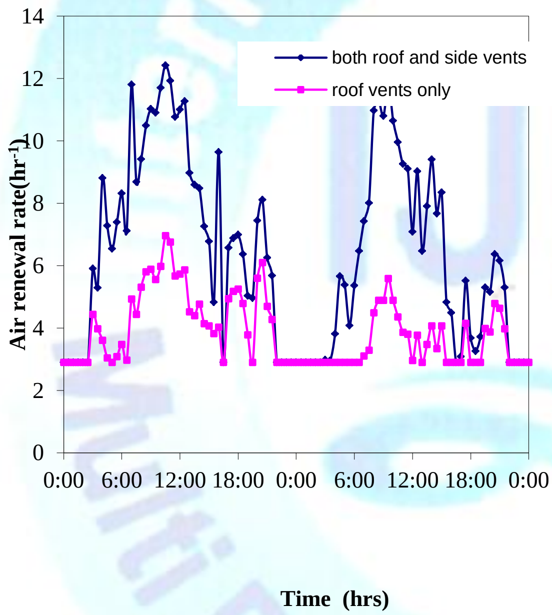
The simulated air renewal rates for the two configurations were found from model outputs. These rates were then compared to find the effects of ventilation on the air renewal rate. The results are displayed in Figure 7.

he major purpose of ventilation is to reduce the heat load in the greenhouse during period 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 11 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 increases. 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 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 roof vents 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, there fore the air renewal rates 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

$hr^{-1}$for the configuration with roof and side vents and 6.97hr $^{-1}$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 11.8hr^{-1} for the ventilation strategy with both vents and 5.6hr^{-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 finding 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 and Harmanto et al., 2006)

F. Effects of ventilation on the microclimate of the greenhouse

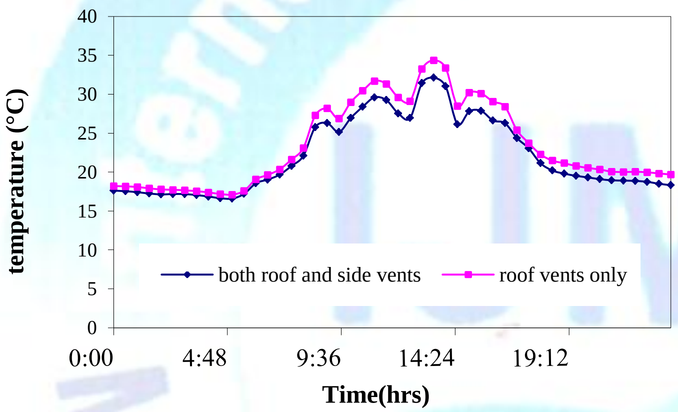
The purpose of ventilation in a greenhouse is to control temperature, in order to reduce water stress in plants, increase crop growth as most crops grow well in a temperature range. The results from the GDGCM model were used to investigate the effects of the two ventilation regimes using outside weather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

G. Influence of Ventilation on inside air Temperature

The influence of ventilation strategy on the inside air temperature was shown from the results of 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 with the only difference in ventilation strategy. The simulated internal air temperature for the two configurations were 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 Figure9 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 inside 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



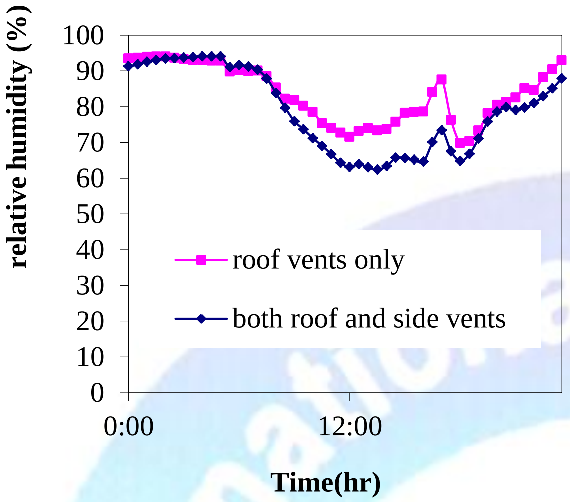
(b)

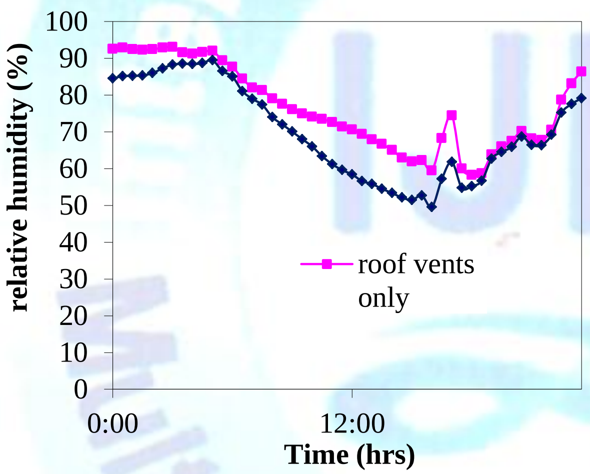
Figure 9: The simulated diurnal variation of internal air temperature for the two configurations on 18 October 2007.

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 are presented as shown in Figure 10.

The results indicate that inside air humidity was dependent on the vent opening configuration. On 2 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 high air, velocity where found to be to affect relative humidity (a)





(b)

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

humidit 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.

H. 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

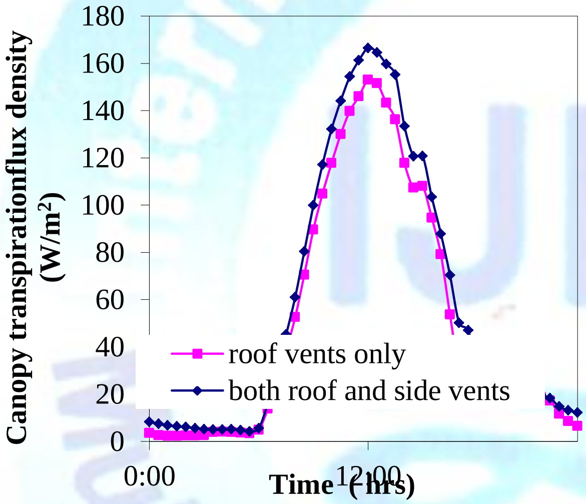


Figure 11: Simulated canopy transpiration on 18 October 2007 for the two ventilation regimes

as follows: 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 a 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 maximum during midday. This agrees with theory that transpiration is driven by solar irradiance and that the leaves opens 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 some nighttime transpiration. The results indicate that the greenhouse with both roof and side vents is well suited for plant growth. Table 6summarizes 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 densityfor 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 18 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 18 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 21 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 8 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 parameters

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

III. References

American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) ,2005. ASHRAE Handbook of Fundamentals, **Chapter 27**: Ventilation and Infiltration. Atlanta, GA.

Baille, A., 1992. Thermique of Energetique des serres, Cours de Diplome d'Agronomie Approfondie, de Gẽnie Agronomique40, Montpellier, France, E.N.S.A.

Baille, A., Kittas, C. and Katsoulas, N., 2001. Influencing of whitening on greenhouse microclimate and crop energy portioning.

Bakker, J.C., Bot, G.P.A., Challa, H., N.J. van de Braak (Editors). 1995. Greenhouse Climate Control: An Integrated Approach. Wageningen, The Netherlands. Wageningen Pers Publisher.

Baptista, F.J., Bailey, B.J., Randall, J.M. and Meneses, J.F., 1998. Greenhouse Ventilation Rate: Theory and Measurement with Tracer Gas Techniques. Journal Agricultural Engineering Res (1999)**72,** pg363-374

Bartzanas, T., Katsoulas, N., Kittas, C., Boulard, T., Mermier, M., 2005. Effect of vent configuration and insect screen on greenhouse microclimate. International Conference "Passive and Low Energy Cooling for the Built Environment", Santorini, Greece.

Bot, G.P.A., 1983. Greenhouse Climate from physical processes to a dynamic model. Ph.D. Thesis, University of Wageningen, Wageningen, The Netherlands.

Boulard, T., 1993. Experimental and modeling study on greenhouse natural ventilation; recapitulative of the 1988-1992 experiments. Note interne I.N.R.A. **93-1**, Station de ^Bioclimatologie de Montfavet, France.

Boulard, T., Baille, A., 1995. Modeling of air exchange rate in a greenhouse equipped with continuous roof vents. Journal Agricultural Engineering, Research **61**, pg 37-48.

Boulard, T., Wang, S. 2000. Greenhouse crop transpiration simulation from external climate conditions. Agricultural and Forestry Meteorology **100**, pg25-34.

Bruce, J.M., 1982. Ventilation of a model livestock building by thermal buoyancy. Transactions of the ASAE, **25161,** pg1724-1726.

Chou, S.K., Chua*, K.J., Ho, J.C., Ooi, C.L., 2004. On the study of an energy-efficient greenhouse for heating, cooling and humidification applications. Applied Energy 77, pg 355-373

De Jong, T., 1990. Natural ventilation of large multi-span greenhouses. Ph.D. Thesis, University of Wageningen, Wageningen, The Netherlands.

Demrati, H., Boulard, T., Bekkaoui, A. and Bouirden, L., 2001. Natural ventilation and microclimatic performance of a large-scale banana greenhouse. J.agric.Engng Res., **80(3)**: 261-271

Demrati, H., Boulard, T., Bekkaoui, A., Fatnassi, H., Majdoubi, H., Elattir and Bouirden, L., 2007. Microclimate and transpiration of a greenhouse. Biosystems Engineering 98(2007) 66-78)

Dynamax Inc. (2005) Dynagage Sapflow sensor user manual. Dynamax Inc., 10808 Fallstone Rd. Houston TX77099, USA (http://www.dynamax.com)Fatnassi, H., Boulard, T. and Bouirden, L., 2003. Simulation of climatic conditions in full-scale greenhouse fitted with insect-proof screens. Agric. For.Meteorol., **118**: 97-111

Fatnassi, H., Boulard,T., Demrati, H., Bouirden, L., Seppe, G., 2001. Ventilation Performance of a large Canarian-Type Greenhouse equipped with insect- proof nets. Biosystems Engineering, **82(1),** 97-105.

Fernandez, J.E., Bailey, B.J., 1992. Measurement and Prediction of greenhouse ventilation rates. Agricultural and Forestry **58**, pg229-245.

Fuchs, M., Dayan, E., Shmuel, D., Zipori,I., 1997. Effects of ventilation on the energy balance of a greenhouse with bare soil. Agricultural and Forestry Meteorology **(86).,** 273-282.

Fuchs, M., Segal. Dayan, E., Jordan, K., 1996. Improving greenhouse microclimate control with help of plant temperature measurements. BARD project No IS- 1816-90R. Final report 2.

Gandemer, J. and Bietry, J.1989, Cours d'aẽrodynamique.REEF, **vol2**, Sciences du Batiment - CTBS Nantes Hanan, J.J., 1998. Greenhouses: Advanced technology for protected horticulture. CRC Press. London. 684pp

Harmanto, Tantau, H.J and Salonke, V.M., 2006. Microclimate and air exchange rates in greenhouses covered with different nets in the humid tropics. Biosystems Engineering, **94(2):**239-253

Jarvis, P.G., 1985. Coupling of transpiration to the atmosphere of horticultural crops. Acta Horticulturae.**171**: 187-205

Jones, H.G., 1992. Plants and microclimate. Cambridge University Press, UK

Katsoulas, N., Bartzanas, T., Boulard, T., Mermier, M. and Kittas, C., 2006. Effect of vent openings and insect screens on greenhouse ventilation. Biosystems Engineering, **93(4):** 427 – 436

Kittas, C. Katsoulas, N., and Baille, A., 1999. Transpiration and Canopy Resistance of Greenhouse Soilless Roses: Measurements and Modelling. Acta. Hort. **507**:61-68

Kittas, C., Boulard, T. and Papadakis, G., 1997. Natural ventilation of a greenhouse with ridge and side openings: Sensitivity to temperature and wind effects. Transactions of the ASAE, **45(4)**: 415-425

Klein,S.A., Beckham, W.A., Cooper, P.I., Dufie, N.A., Freeman, T.L., Mitchel, J.C., Beekman, D.M., Oonk, R.L.,Hughes, P.J., Eberlein, M.E.,Karman, V.D., Pawelski, M.J., Utzinger,D.M., Duffie, J.A., Brandemuehl, M.J., Arny, M.D., Theilacker, J.C., Morrison, G.L., Clark, D.A., Braun, J.E., Evans, B.L.& J.P.Kummer.1988. TRNSYS: A transient system simulation program. Engineering experiment station report **38-12**, Solar Energy Laboratory, University of Wisconsin-Madison, USA.

Mashonjowa, E., Ronse F., Milford, J.R, Lemeur, R., J.G., 2010b. Measurement and simulation of the ventilation rates in a naturally greenhouse in Zimbabwe. Applied Engineering in Agriculture, in press

Mashonjowa, E., Ronse, F., Milford, J.R., Lemeur,R., Pieters,J.G., 2010a. Calibration and validation of a dynamic model in Zimbabwe. Submitted to Agricultural and Forestry Meteorology

Mashonjowa, E., Ronse, F., Pieters, J.G., Lemeur, R., 2007b. Modelling heat and mass transfer in naturally ventilated greenhouse in Zimbabwe. Applied Engineering in Agriculture, in press

Monteith, J.L., 1973. Principles of Environmental Physics, Arnold, Paris

Monteith, J.L., Unsworth. 1990 Principles of Environmental Physics, Edward and Arnold, UK

Papadakis, G., Frangoudakis, A. and Kyritsis, S., 1994. Experimental investigation and modeling of heat and mass transfer between a tomato crop and the greenhouseenvironment. J. Agriculture Engineering. Res., **57**: 217-227

Pasian, C.C. and Lieth, J.H., 1989. Analysis of response of net photosynthesis of rose leaves of varying ages to photosynthetic active radiation and temperature. Journal American Society Horticulture Science **114(4):** 581-586

Pieters, J.G., and Deltour, J.M., 1997. Performances of greenhouses with the presence of condensation on cladding materials. J.Agriculture Engineering. Res., **68(2),** 125-137.

Rosenberg, N.J., Blad, B.L. and Verma, S.B., 1983. Microclimate: Biological environment. Second Edition. John Wiley &Sons, New York

Roy, J.C., Boulard, T., Kittas, C. and Wang, S., 2002. Convective and ventilation transfers ingreenhouses, part 1: the greenhouse considered as a perfectly stirred tank. Biosystems Engineering, **83(1):** 1 – 20

Seginer, L., 1984.Transpirational cooling of a greenhouse crop with partial ground cover. Agricultural and Forestry Meteorology **100**, pg 265-281.

Stanghellini, C., 1987. Transpiration of greenhouse crops; An aid to climate management. Ph.D.Thesis, University of Wageningen, Wageningen, The Netherlands.

Simba FM, Chikodzi D, Murwendo T (2012) Climate Change Scenarios,Perceptions and Crop Production: A Case Study of Semi-Arid Masvingo Provincein Zimbabwe. J Earth Sci Climate Change 3:124. doi:10.4172/2157-7617.1000124