Characterization of air velocities near greenhouse internal mobile screens using 3D sonic anemometry

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Abstract

In Dutch greenhouses different screen types are used for different purposes (shading, energy saving, black-out, light emission, etc.). In order to quantify the energy and mass transfers through screens, characterization of air permeability through the screens is required. In case of energy saving screens, it is an essential parameter to estimate the energy saving of each screen. Air permeability can be measured under defined conditions in a laboratory. In order to select the appropriate equipment for air velocity measurements, the air velocity vector near screens in a practical situation in a greenhouse needs to be identified by measurements.

Sonic anemometry techniques have been extensively used in different types of greenhouses: a) to study natural ventilation, with and without insect screens, and in different positions; b) to study airflow patterns in greenhouses with mechanical ventilation/pad and fan systems; c) to study airflow patterns induced by different types of heating systems and d) for the estimation of crop evapotranspiration (i.e. eddy covariance). However, no research has been carried out to study the airflow near different types of screens in a greenhouse. Many Dutch growers are increasingly using diverse types of fans with different positions in the greenhouse for dehumidification and improved climate uniformity purposes. The effect of such fans on the air velocity near screens, and therefore effect on energy and mass transfer, is unknown.

For this purpose, air velocities near different types of screens in commercial greenhouses were measured using ultrasonic 3D anemometers. Results show that in absence of fans, air velocity near the screens is affected by vents opening. With vents closed, air velocities are hardly ever above 0.2 m s^{-1}. Therefore, a simple air suction device can be used to characterize permeability of screens at a very low Reynolds range.

Keywords: greenhouse screens, air permeability, vents, fans, wind

INTRODUCTION

In a greenhouse with thermal or shading screens, air exchange takes place between both sides of the screen materials (crop area and roof area) if the screen installation is closed. The air permeability of the screen is important to characterise because air flow causes sensible and latent heat flow through the material and therefore energy and water vapour losses to the top greenhouse compartment (Miguel, 1998). In order to accurately determine how much air is exchanged through a material the air permeability of a material has to be measured under defined conditions in the laboratory. Besides, growers often leave a gap of the screen open expecting that this will increase the airflow exchange between the top and lower compartment.

First the air velocities to be expected to occur in a greenhouse have to be determined. The knowledge of the vertical component of air velocity near the screens under a range of scenarios is important in order to select the appropriate velocity range under which the air permeability of the screens has to be measured in the laboratory. Screens are often used

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under natural convection conditions (greenhouse vents only partially open or fully closed) In order to determine air velocities under natural convection conditions, anemometry techniques can be used to measure air velocities in greenhouses.

Although anemometry techniques have been widely used in different research studies inside different types of greenhouses to characterize natural ventilation mainly (Boulard et al., 1996; Shilo et al., 2004; Teitel et al. 2005), there is no evidence in the scientific literature of their use to characterize air velocities near internal screens in greenhouses. Therefore, an experiment was carried out to characterize the air velocities near different types of screens in a commercial greenhouse by means of ultrasonic 3D anemometers:

MATERIALS AND METHODS

The measurements were performed in a commercial greenhouse in Maasdijk (The Netherlands) (Figure 1). This company (Hofland Freesia B.V., Maasdijk, The Netherlands) has two large glasshouse compartments in which they grow *Freesia sp.* Measurements were carried out in a greenhouse compartment, a standard Venlo glasshouse with 8 m bays. The greenhouse has Venlo roof vents of 3.2 × 1.2 m and two types of screens:

- A shading screen Harmony 5220 O FR (Ludvig Svensson BV, Hellevoetsluis, The Netherlands).
- An energy saving/black-out screen Obscura 9950 FR W (Ludvig Svensson BV, Hellevoetsluis, The Netherlands).

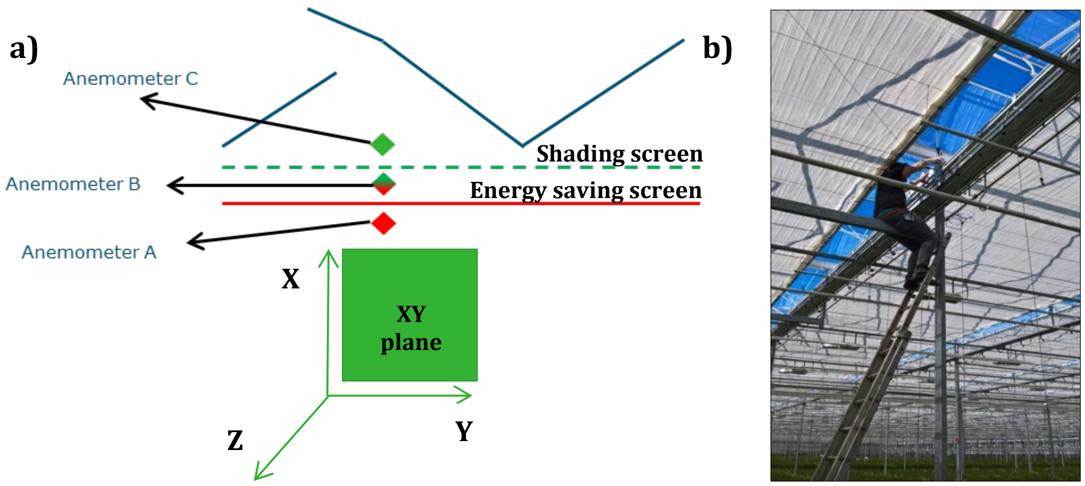

Figure 1. Location of the three sonic 3D anemometers in the commercial greenhouse: a) Scheme of the disposition and location of the sonic anemometers in the commercial greenhouse. b) Placement of the sensors in the greenhouse.

Before installing the 3 ultrasonic 3D anemometers model WindMaster 3-axis ultrasonic anemometer (Gill instruments, Lymington, United Kingdom), with a measurement range 0-50 m s^{-1}, resolution 0.01 m s^{-1} and accuracy lower than 1.5% RMS @12 m s^{-1}. They were calibrated in a simple wind tunnel in Wagenigen University & Research Greenhouse Horticulture laboratory (Figure 2).

a) **b)**

Figure 2. Details of the calibration process of the three ultrasonic 3 D anemometers in the laboratory: a) Wind tunnel and three anemometers and b) Three anemometers inside wind tunnel test section.

For the measurements in the greenhouse, only the vertical component of air velocity vector (that in the XY plane) is of interest as it is the one contributing to the mass and energy exchange through the screens. Therefore, only the components of the air velocity vector in the XY plane were calibrated (from now on, *U* and *V* components) with measurements from a very precise hot wire anemometer VelociCalc Plus multi-parameter ventilation meter 8386 (TSI), with a measurement range of 0-50 m s^{-1} and accuracy of ±3% of reading or ±0.015 m s^{-1}. Results show a very good agreement between the three sensors (named *a*, *b* and *c*) (Figure3), with some minor deviations for the *b* sensor for values higher than 2 m s^{-1}, higher than those expected to be measured inside the greenhouse, which should be in a much lower range (Wang et al., 1999; Molina-Aiz et al., 2009).

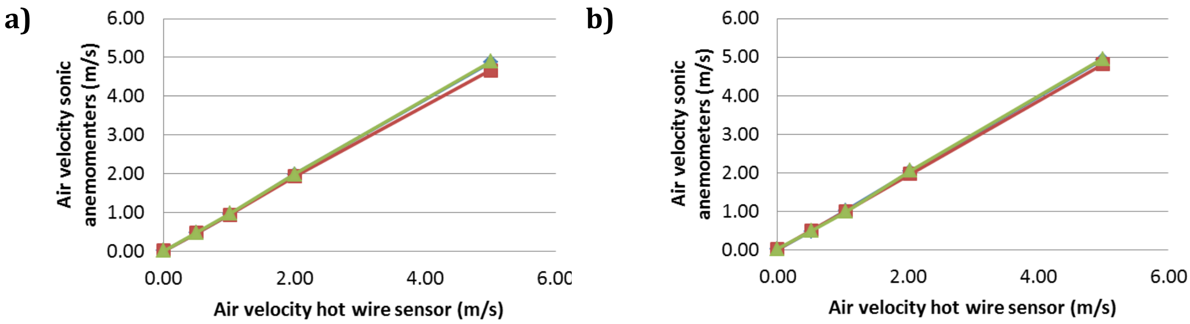

Figure 3. Calibration of air velocity sonic anemometer comparing hot wire *vs* sonic anemometers: a) *U* component air velocity module and b) *V* component air velocity module. Locations *a* (-♦-), b(-■-) and *c* (-▲-).

Once calibrated, sensors were finally installed in the commercial greenhouse following the arrangement that can be seen on Figure 1. The 3 sensors were completely aligned vertically; sensor *c* was located immediately above the top screen (the shading screen); sensor *b* was located in between both screens; and sensor *a* was located below the lower screen (the energy saving/black-out screen). Sensors were located also exactly below the centre of one roof vent, so it can be expected that, when vents were open the air exchange through natural ventilation can be seen in larger air velocity values, with some dependency on external wind speed.

Sensors remained in the greenhouse between September 9 and October 25, 2016. The vertical component of air velocity (in the XY plane) was calculated for each sensor (*a*, *b* and *c*) as:

$$R_{\{a,b,c\}} = \sqrt{U^2 + V^2} \quad (1)$$

In order to account for the effect of the external wind velocity, for the moments when vents were open, the values of normalized air velocity V_{norm} were obtained dividing the resultant in the XY plane by the external wind speed v_{wind} as:

$$V_{norm} = \frac{R_{\{a,b,c\}}}{v_{wind}} \quad (2)$$

The external wind speed v_{wind} was measured at an external metereological station located at 7 m height with a cup anemometer.

RESULTS AND DISCUSSION

In order to determine the air velocities in a greenhouse with and without natural ventilation, measurements have been carried out using 3D anemometer sensors. Figure 4 show the values of the vertical component of the air velocity vector in the XY plane for the three sensors, respectively, together with the external wind velocity values (m/s, divided by 10 for convenience to fit them in the same scale as the rest of parameters), the opening of leeward and windward roof vents (in a 0-1 range, being 0 vents fully closed and 1 vents fully open) and the closing of both the shading and the energy saving/black-out screen (in a 0-1 range, being 0 vents fully closed and 1 vents fully open) for the 25 September 2016.

From Figure 4 we can highlight that during the daytime period, when both screens are not used and vents are open more than 50%, the measured air velocity values are higher, as might be expected. The values measured in the top sensor are consistently higher than those measured in the middle sensor, and those in the middle sensor higher than those in the lower sensor. This suggests that the vent above the sensors is acting as an inlet and therefore, values of the sensor near the vent are the highest with air velocity decreasing as the air flow penetrates lower in the greenhouse. On the other hand, during the night time period, when both screens are used and roof vents are open on a lower percentage, the vertical component of air velocity values are much lower than during the daytime period, as might be expected.

In order to better understand the interaction between the opening and closing of the roof vents and the screens, as well as the external wind speed, with the values of the vertical component of air velocity measured by the 3 sensors, the measurement period has been divided into different scenarios.

Roof vents open more than 50%-Screens not used (0)-Wind velocity>0.5 m s^{-1}

Table 1 shows that when vents are largely open and screens are not used, air velocity values near the vents can be higher than 1 m s^{-1}, for the measured position and for a greenhouse without insect proof screen on the vents. It also shows that for the measured position, air velocity decreases gradually from the top sensor, nearest to the vent to the lower sensor, furthest from the vent. This may suggest that the specific vent where measurements were made could act as an inlet most of the time, but that should be verified analysing the vector direction, which is not relevant for this present work.

Roof vents open less than 50%-Shading screen not used (0)-Energy saving screen closed more than 80%-Wind velocity>0.5 m s^{-1}

In this scenario, we can observe an important decrease in both the mean and maximum values of air velocity. Mean values are lower than 0.1 m s^{-1} in sensors A and B which are located both below and above the energy saving screen. In general, the vertical air velocity profile suggests that air is moving upwards from the crop area due to natural convection, generated by the heating system, and the presence of the screen decreases this air velocity values. The higher peak values on the upper sensor could be a result of incoming airflow from the vents, when they are not fully closed. We can conclude that under these air velocities, Reynolds number is very small (Re<1) and we can apply Darcy's law to characterize the airflow through energy saving screens inside a greenhouse with windows fully or almost fully closed (Miguel, 1998).

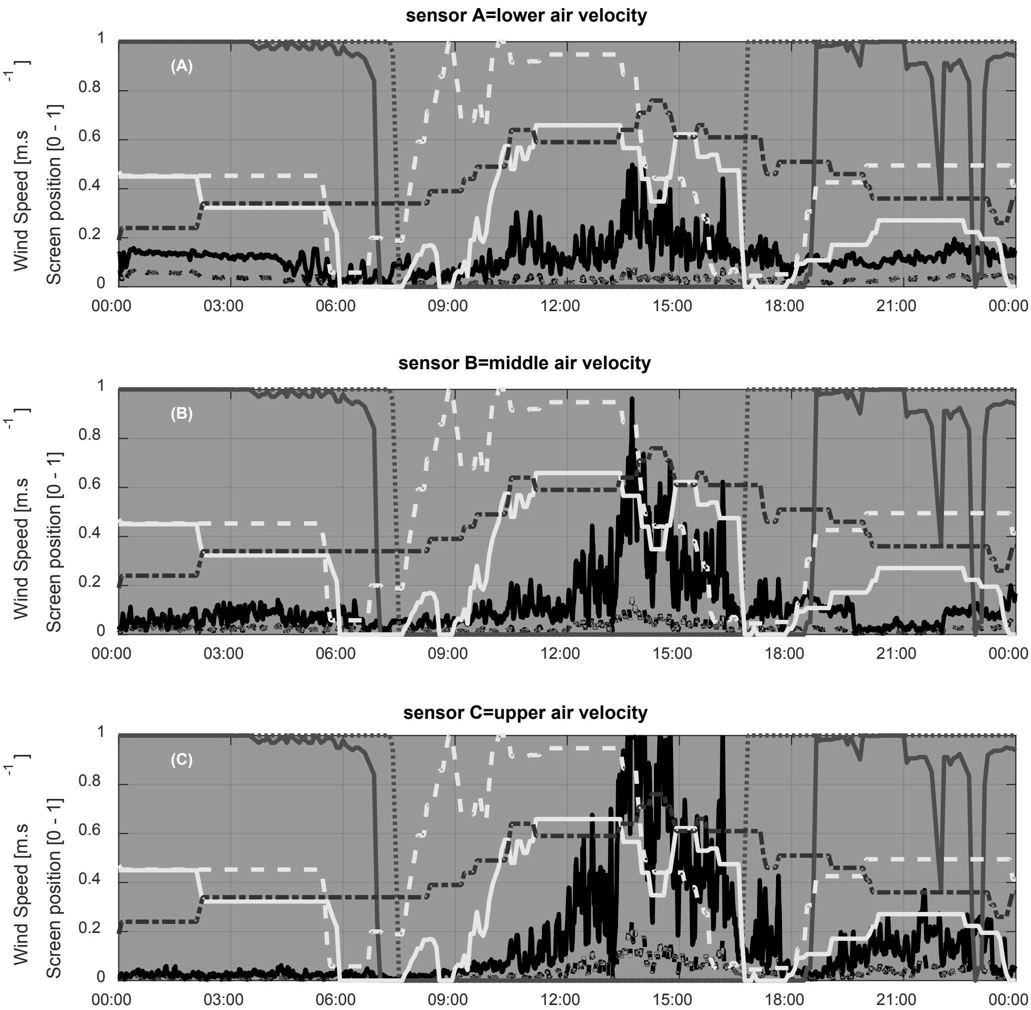

Figure 4. Vertical components of air velocity vector on the top sensor RC (a), on the middle sensor RB (c), on the lower sensor RA (c), and external wind velocity (10% of the value), position of leeward and windward greenhouse vents (0-1) and position of shading and energy saving/darkening screens (0-1) for day 25 September 2016. Resultant velocity( ), normalized velocity( ), shading screen position ( ), blackout screen position ( ), windward vent position ( ), leeward vent position( ), wind velocity*0.1( )

The amount of time for this scenario in which air velocity values measured by the sensors located below and above the energy saving screen (A and B) were higher than 0.1 m s^{-1} was 16.4% and 10.0%, respectively, and values during the measured period sensors never peaked above 0.2 m s^{-1}, as we can see in Figure 4.

Table 1. Mean and maximum values of the vertical component of air velocity measured in the three sensors (A, B and C) as well as for the normalized air velocities for exterior wind speed higher than 0.5 m s^{-1} for different configurations of roof vents and screens.

	Mean / maximum velocity vertical component (m s^{-1})	Mean /maximum normalized air velocity (-)
Greenhouses without screens and roof vents >50% open		
Top sensor (C)	0.18 / 1.77	0.05 / 0.61
Middle sensor(B)	0.15 / 1.09	0.05 / 0.45
Lower sensor(A)	0.14 / 0.70	0.05 / 0.39
Greenhouses with closed energy screens and roof vents >50% open		
Top Sensor (C)	0.06 / 0.25	0.02 / 0.07
Middle sensor(B)	0.07 / 0.18	0.03 / 0.14
Lower sensor(A)	0.08 / 0.18	0.04 / 0.25
Greenhouses with closed energy screens and roof vents ≤50% open		
Top sensor (C)	0.06 / 0.60	0.02 / 0.32
Middle sensor(B)	0.04 / 0.36	0.01 / 0.37
Lower sensor(A)	0.07 / 0.25	0.02 / 0.30

Roof vents open less than 50%-Shading screen closed more than 80%-Energy saving screen closed more than 80%-Wind velocity>0.5 m s^{-1}

In this situation, with both screens used, we can observe that the lowest mean values are obtained in the sensor located between the two screens, which makes sense as this is the most confined sensor, being the upper sensor closer to the vent, and thus, with more influence from the inflows and outflows and the lower sensor being more affected by air moving upwards by buoyancy from the heating system. In this scenario, the percentages of time that the air velocity values were higher than 0.1 m s^{-1} for the three sensors (A, B and C) was 20.4%, 9.2% and 18.7% respectively, and for values higher than 0.2 m s^{-1} was 0.06%, 0.3 % and 2.6%.

CONCLUSIONS

In the experimental greenhouse, and with sonic 3D anemometers located near two screens and below one of the roof vents, values of the vertical component of the air velocity vector have been analysed for different scenarios of vent and screens opening percentages. We can conclude that if energy screens are used and with greenhouse natural ventilation openings usually open at low percentages, the measured values of the vertical resultant of air velocity vector near the screens are below 0.1 m s^{-1} for the majority of time, although at some specific periods they also can reach values between 0.1-0.2 m s^{-1}. Therefore, and for the purpose of characterizing the air permeability values of the different screens, a range of air velocities lower than 0.2 m s^{-1} should be suffice to characterize the screens aerodynamic properties properly. An air suction device, just like the one proposed by Miguel (1998), measuring at low wind speeds is appropriate.

ACKNOWLEDGEMENTS

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