Greenhouse Characteristics and Climatic Conditions Using 3D Computational Fluid Dynamics Calculations

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Abstract

The proper greenhouse climate depends mainly on ventilation. A lot of experimental work is done describing the ventilation in a mathematical model based on greenhouse geometry and surrounding conditions. Some computational fluid dynamics (CFD) studies are done in this field but they were all two-dimensional. In this presentation, a three-dimensional CFD study on the wind driven ventilation of a Venlo-type greenhouse is given. The calculations are verified by experimental results from tracer gas measurements. From the study it is concluded that the ventilation has a strong three-dimensional character due to the wind direction and the geometry of the greenhouse. The microclimate, hence the temperature distribution in the greenhouse subscribes this as well.

INTRODUCTION

Ventilation is essential for a good climate in a greenhouse and great effort has been made enabling the determination of ventilation as a function of relevant parameters. Determination of the ventilation by experiments is a difficult task. Numerous 'tracer gas' experiments for small compartments (De Jong, 1990) and using the energy balance method for larger commercial greenhouses (Demrati et al, 2001) are done. Varying environmental factors causes the inaccuracy of the ventilation experiments. The wind direction and wind speed, the solar radiation, the outside temperature etc. vary during the measurement. This source of inaccuracy causes uncertainty in the derived ventilation models.

Computational Fluid Dynamics (CFD) calculations open the possibility to determine the ventilation based on steady surrounding conditions. All CFD calculations in literature were based on two-dimensional models (Montero et al, 2001) thus ignoring the three-dimensional characteristics of flow and temperature distribution in the greenhouse. Ventilation resulting from wind especially has a three-dimensional character. Baptista et al. (1999) detected some influence of wind direction but he could not draw any conclusions due to insufficient data. De Jong (1990) made discrimination between leeward and windward windows and stated this was sufficient for small openings.

The purpose of this work is to: (1) verify three-dimensional computational fluid dynamics calculations with experimental results and theory on ventilation to check if 3-D CFD can be used to determine greenhouse dependent ventilation characteristics; (2) determine the influence of wind direction on the ventilation rate.

MATERIALS AND METHODS

Computational fluid dynamics (CFD) becomes a widely used tool to determine flow field and temperature distributions in and around geometries. As computers get faster and cheaper and the CFD software becomes more user friendly, more comprehensive cases can be studied using this technique. A general description of CFD is given by Mistriotis et al. (1997). In a CFD program a system is modelled by discretising space and time (finite volume method) and by solving the conservation equations for the discretised parts for the relevant quantities considered. The conservation equation reads:

$$\frac{\partial \vec{\varphi}}{\partial t} + \vec{\nabla} \cdot \vec{\varphi}\vec{v} = \vec{\nabla} \cdot \left(\Gamma_\varphi \vec{\nabla} \vec{\varphi} \right) + S_\varphi \qquad (1)$$

where $\vec{v}$ is the velocity vector in m/s, Γ_φ is the diffusion coefficient in m^2/s and S_φ is the source term. The symbol $\vec{\phi}$ represents the concentration of the quantity considered. Solving this provides transport between the parts of the model, thus the flow field for heat and mass can be determined. Separate models describing the fluctuating part of the flow account for turbulence. The k-ε model is widely used as a turbulence model. (Launder & Spalding, 1974).

De Jong (1990) performed extensive research on the ventilation of an airtight compartment of 6m by 9.6m within a larger Venlo-type greenhouse of 33m by 70m. The theory derived from these measurements is used to verify the CFD calculations. The CFD model of the experimental greenhouse is constructed by means of the commercially available CFD-program Fluent v.5.2 (Fluent, 1998). The model of the Venlo-type greenhouse used in CFD is depicted in figure 1. From the roof surrounding the greenhouse 6 m is incorporated in the model. Above the greenhouse 11m of air is included. Extending these dimensions does not alter the solution. The dimensions of the roof windows are 1.5 by 0.81 m (L_o *x* W_o).
The ventilation flux ϕ_v in m^3/s is calculated by

$$\phi_v = \frac{H_{input}}{\left(\overline{T}_{greenhouse} - T_{outside}\right) \cdot C_{p,air} \cdot \rho_{air}} \tag{2}$$

where H_{input} is the heat released in the greenhouse in W; $\overline{T}_{greenhouse}$ is the average temperature of the greenhouse air in ^oC; $T_{outside}$ is the outside temperature in ^oC; $C_{p,air}$ is the specific heat of air in J/kg K; and ρ_{air} is the density of air in kg/m^3. Considering only the ventilation due to the wind, the gravity is considered zero and the density of the air is considered constant. The heat input H_{input} for this situation can be set to any value not influencing the ventilation rate.
The function $G(\theta)$ describes the relation between the ventilation flux per unit window area of the cover surface A_o (=$L_o x W_o$) and the average wind speed at reference level $\overline{u}$, in dependence of the opening angle θ. (De Jong, 1990)

$$G(\theta) = \frac{\phi_v}{\overline{u}\ A_o} \tag{3}$$

De Jong made a distinction between windward G_w and leeward G_l side ventilation.

$$G_l(\theta) = 2.29 \cdot 10^{-2}\left[1 - \exp\left(-\frac{\theta}{21.1}\right)\right] \tag{4}$$

$$G_w(\theta) = 0.0019\theta \exp\left(-\frac{\theta}{211.1}\right) \tag{5}$$

RESULTS AND DISCUSSION

In figure 2 the relation between the wind speed and the $G(\theta)$ is depicted for three window opening angles for a leeward wind. The linear relation corresponds with the theory. For the same window openings, 10, 20 and 30 degrees, the ventilation is calculated for every wind direction around the greenhouse (Fig. 3,4, and 5). The figures also show the theory formulated by De Jong based on experiments.

The leeward ventilation with a window opening of 10^o agrees with theory within 15 % in the range of 90^o around the perpendicular to the ridge. For a wind direction more parallel to the ridge the ventilation increases and has a local minimum when the wind is exactly parallel to the ridge. The ventilation increases, as the wind direction becomes windward. Similar conclusions can be drawn for the 20^o window opening (Fig. 4). The theory shows less ventilation than the CFD results for leeward side ventilation with a 30^o window opening. The theory for larger window opening angles is based on less experimental data. Tracer gas experiments with a large window opening are difficult and less accurate due to the large ventilation. The average ventilation for the windward case calculated with CFD is equal to the value from theory.

CONCLUSIONS

It can be concluded that the wind direction does have a major influence on the ventilation of a greenhouse. This three-dimensional character was also found in a previous study on ventilation of a Spanish parral greenhouse (Campen & Bot, 2002). During these measurements the wind direction was measured clearly showing a wind direction dependency confirmed by the CFD calculations.

ACKNOWLEDGEMENTS

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Figures

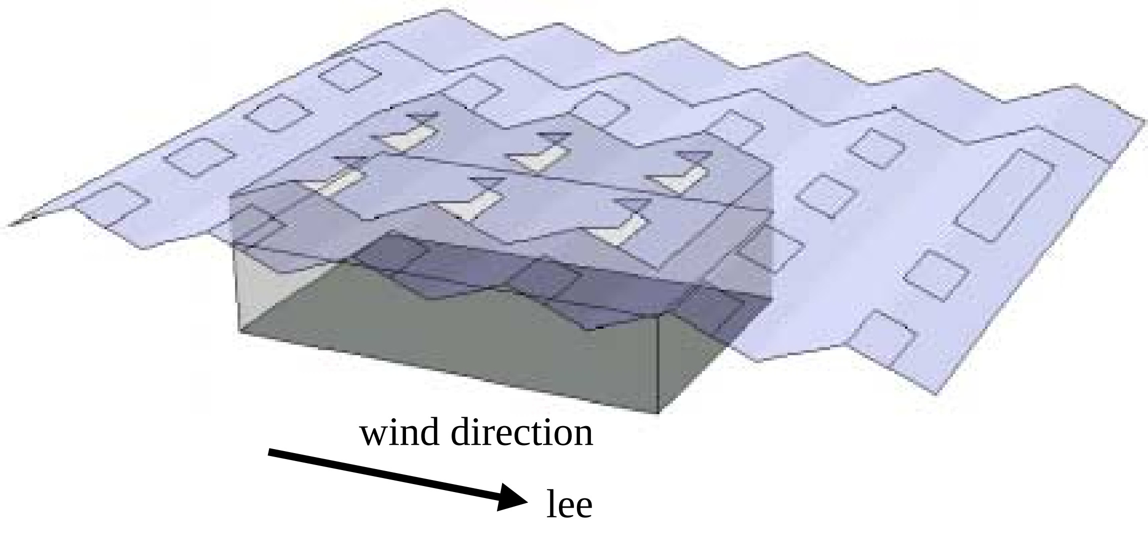

Fig. 1. The model used in the CFD calculations and the definition of the wind direction.

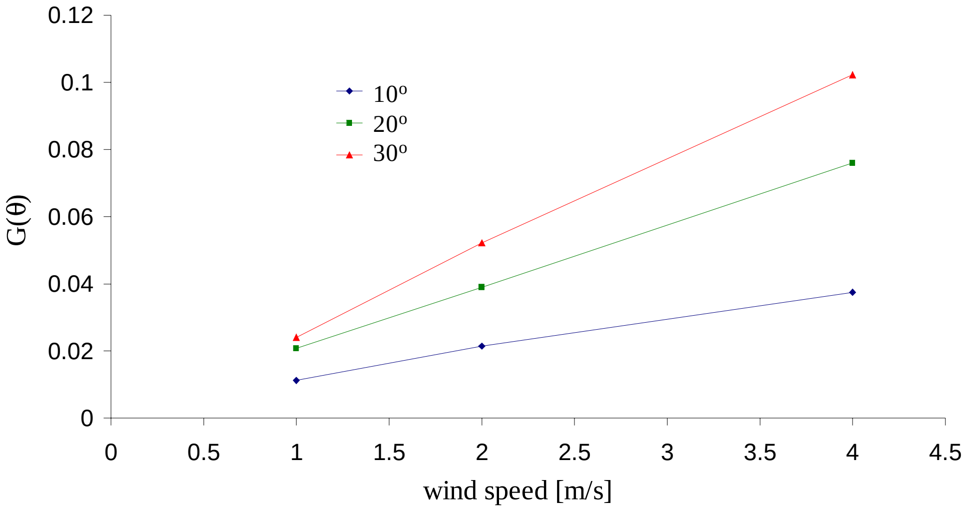

Fig. 2. The function $G(\theta)$ as a function of the wind speed for different window opening angles.

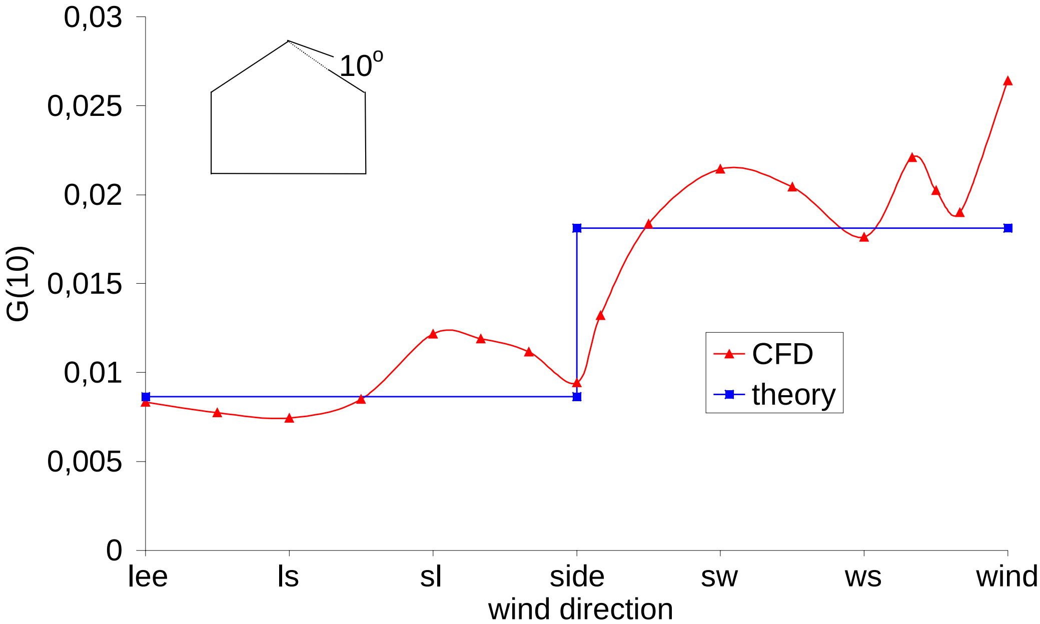

Fig. 3. The function $G(\theta)$ as a function of the wind speed for a window opening of 10^o.

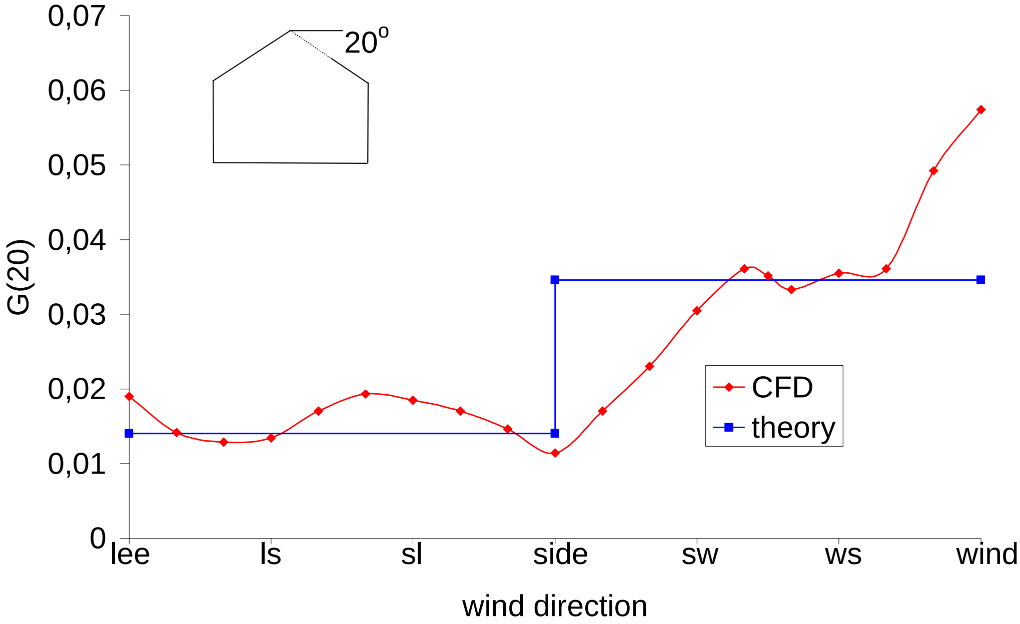

Fig. 4. The function *G(θ)* as a function of the wind direction for a window opening of 20^o.

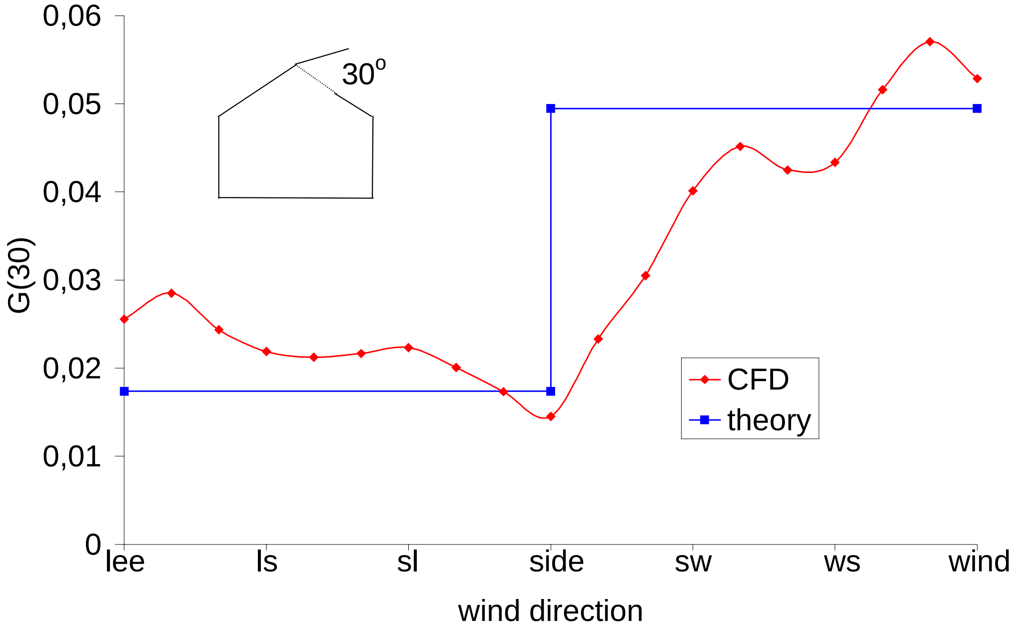

Fig. 5. The function *G(θ)* as a function of the wind direction for a window opening of 30^o.