Project title:	A computational fluid dynamics (CFD) study of flow patterns, temperature distributions and CO_2 dispersal in a tomato glasshouse.
Project number:	PC 162
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Summary

The full and final report of this project is the PhD thesis of Sven Reichrath a copy of which is available on CD from the HDC office. Here we summarise the findings and achievements of project PC 162 measured against the project milestones

Introduction

The aim of the project was to use computational fluid dynamics (CFD) to build a computer model of a commercial glasshouse and to use the model to study internal climate behaviour as a function of variables such as external weather, ventilation regime, heating regime and carbon dioxide injection regime. The work in years 2 and 3 was based on the findings of the pilot project undertaken in year 1, during which an evaluation study was carried out on the use of CFD in simulating the internal climate of a tomato glasshouse. See the year 1 report (1999) for details.

The main conclusions from the work of year 1 were that:-

(1) CFD did indeed have the potential to create a better understanding of internal climate behaviour but that

(2) (2) full size glasshouse modelling was required to answer questions raised by growers. This modelling work was subsequently conducted in year 2 (see the year 2 report for details) and continued in year 3.

Summary of the results for year 1 and year 2 (1999-2000)

In year 1, the first step was made in the construction of a computational fluid dynamics (CFD) model which was capable of simulating the internal climate of commercial tomato glasshouses.

The pathfinder “representative slice” model demonstrated the potential of CFD in modelling glasshouse climate behaviour but not surprisingly proved to be inadequate for capturing the full complexity of the flow, temperature and concentration distributions of a large three-dimensional system.

In year 2 a full size, but still two-dimensional model, was developed and used to study effects in a central section of the glasshouse, i.e. the three-dimensional effects created by the sides of the glasshouse and external wind directions diagonal to the building, were neglected. For wind direction normal to the ridges, this model was found to give plausible results. It was validated against experimental data on pressure distributions across the roof of a similar glasshouse. External roof pressure is an important driving force for internal flow when the vents are open.

The model predicted the existence of a "dead" zone and its location, which was found to exist in practice and to be associated with poor production rates.

The model was also used to conduct "what if" parametric studies which revealed the relationship between factors such as external wind speed, heating pipe temperature, CO_2 injection position and rate, ventilation regime and the presence of a crop canopy, on the internal climate characteristics. A limited experimental study of internal flow speeds and directions confirmed some of the model predictions.

Summary of the results for Year 3 (2001)

In year 3, the full-size two-dimensional model was used to model the internal glasshouse climate including carbon dioxide distributions and the sensitivity of changes in the model and boundary conditions was investigated. In addition, a full-size three-dimensional model was developed and the influence of wind direction on the internal airflow was studied.

Milestones

The milestones for year 3 were:

(1.6) Conduct parametric studies to investigate the dependence of the internal flow on vent opening angles.
(1.7) Introduce heat transfer and investigate thermal effects on air flow.
(1.8) Introduce carbon CO_2 injection and absorbance of CO_2 for photosynthesis by the crops and describe CO_2 distributions in the glasshouse atmosphere.
(1.9) Validate the models with available validation data from previous research.
(1.10) Conduct parametric studies with the validated models in which different control schemes (heating, vent control, CO_2 input), external weather conditions and crop heights can be introduced and their effect can be investigated.

Findings and achievements

The findings and achievements of the work in year 3 are listed below according to the agreed milestones.

The glasshouse which was used as a reference in all modelling studies was the new block of Cantelo Nurseries near Taunton. This is a modern Venlo-type glasshouse of approximately 40.000m^2 with a span width of 4m, ridge height of 4.5m, roof angle of 22° and it is orientated in West-East direction. In all studies pure leeward ventilation is assumed and all the simulations were steady state.

(1.6) The dependence on vent opening angle was studied under various boundary condition definitions (i.e. temperature settings, windspeeds) and using a vent opening angle of 50% and 100%. It was observed that the internal windspeed increased linearly with an increase in vent opening angle.

(1.7) When heating was introduced by activating the heating pipes and fixing them at a temperature of 60°C, an effect on the internal airflow was observed. For a reference windspeed at ridge height of 3.5 m/s and 5 m/s, the 'dead' zone moved towards the windward side of the glasshouse. With a windspeed of 8.5 m/s the 'dead' zone was located in the same place as in a situation without heating. In addition, it was predicted that the 'dead' zone was larger. This is due to the dominant effect of the temperature driven airflow when the local air velocity is low. A similar but less striking effect was predicted when the heating pipe temperature was set to 45°C.

(1.8) Introduction of carbon dioxide injection and leaf absorption made the simulation of the dispersal of carbon dioxide inside the glasshouse possible. After adjustment of the crop model a realistic carbon dioxide concentration range of approximately 400-700ppm was predicted with the highest concentrations near the end of the house (leeward side) were the ventilation was less efficient and the internal airflow speeds lower. The model was also used to study the effects of changes in vent opening angle, temperature settings, windspeed, crop density and layflat height. The latter study showed an increased carbon dioxide concentration inside the glasshouse when the layflats were placed higher and while using the same injection rate. This agreed with observations made during the year 1 work using a simple model.

(1.9) Useful data for direct and detailed validation of the numerical simulations is still not available in the literature. However, validations were carried out of the modelling approach and the computational method by comparing experimental data and analytical solutions of closely related and documented processes (see also year 2 report). In addition, the simulations were compared with a new set of recorded data of internal airflow and direction which were taken by the Exeter team at Cantelo Nurseries Ltd. in November 2000. Although the dataset was very limited, good agreement was found between the simulations and measurements.

(1.10) Various parametric studies were conducted during the course of the project. Both numerical parameters and control settings and weather conditions were altered and their effect on the internal climate was simulated and investigated. These parametric studies were conducted throughout the three years and are reported in detail in the year reports and the final report (the PhD thesis). Parameters which were altered were the turbulence model, grid structure, wind profile, wind speed, vent opening angle, temperature settings, carbon dioxide injection and absorption rate, crop density and finally dimensionality.

In addition to the findings which were discussed per milestone above, a full-size three-dimensional model of a glasshouse was developed (240m x 157.5m). Due to the size of the house and the limited amount of computational power available (even on a supercomputer), the degree of detail of these full-size three-dimensional models could not be as great as in the two-dimensional models. The models were used to simulate the effect of wind direction on the internal airflow. Both a normal wind (normal to the ridges) and a parallel wind (parallel to the ridges) produced a symmetric internal airflow pattern with mainly reversed flow. In such cases a less computationally expensive two-dimensional model yields satisfactory results. A diagonal wind resulted in a much more complex airflow pattern but it was observed that the main bulk of the flow moved towards the windward side of the glasshouse.

Relevance to growers

The results of the project which were discussed in the annual reports and in more detail in the resulting PhD thesis, have given some good practical pointers for growers. The main finding was the observation of the existence of reversed airflow and a 'dead' zone in the glasshouse. Although not confirmed by detailed validation and measurements, which would be very expensive and time consuming, verification of the existence of the 'dead' zone was made by grower's observations.

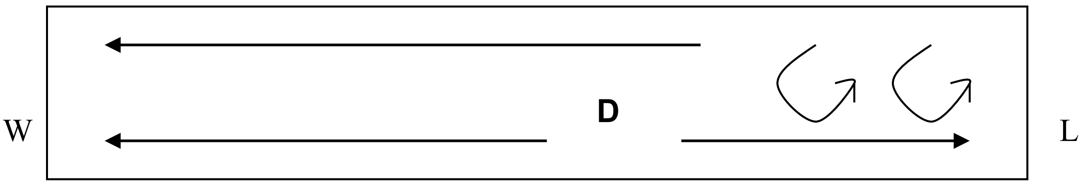

Figure 1: *Typical flow pattern in a multi span glasshouse. Arrows indicate flow direction. Left side is windward side (W), right side is leeward side (L). The 'dead' zone (D) is in the empty region at approximately 0.6 X length of the glasshouse from the windward side. The circular arrows at the windward side represent a swirling airflow.*

Where the 'dead' zone was located, by finding a consistent glasshouse area around 55% from the windward side with a lower production, lower growth rate and higher disease incidence, growers have reported to be able to reduce losses by using fans to increase local air mixing. On this subject one grower quoted: 'The project has already saved me more money than it has cost in total'. Another important finding from the predictions was the improved carbon dioxide distribution when layflats were placed at a higher location in the glasshouse.

- If a consistent area of low production is located, this could be due to the existence of a 'dead' zone. Increasing air mixing could be a solution and it is important to make sure that monitoring points for the climate control computer are not located in or near such area.
- The use of internal screens or differential vent openings could help produce more uniform climate and eliminate stagnant regions.
- Injecting carbon dioxide at above floor level could be beneficial for the dispersal. However, testing may be required before commercial deployment.