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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Introduction

This short report briefly summarises the findings and achievements of year 2 of project PC 162 according to the project milestones. The work in year 2 was based on the findings in year 1, when 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 for details). Main conclusion from the work of year 1 was that full size glasshouse modelling was required. This work was subsequently conducted in year 2.

Milestones

The milestones for year 2 were:

(1.1) 2-Dimensional study of empty multi-span glasshouses under summer conditions. Parametric study looking at the internal flow pattern and its dependence on the length of the glasshouse under different wind speeds. This modelling can also be used to indicate first priorities for future modelling.

(1.2) Extending the multi-span models to three dimensions and study the internal flow pattern.

(1.3) 2-Dimensional simulations of multi-span glasshouses with tomato crops inside and study of the internal flow under summer conditions. The crop properties will be resistance to flow and the variation with vertical position.

(1.4) Extending the multi-span models with crops to three dimensions and investigate the internal flow.

(1.5) Conduct simple validation experiments at Cantelo Nurseries. Such experiments will include smoke tracing from smoke injection points and from the layflats to establish general flow patterns and anemometry to establish magnitudes of flow speeds.

As agreed, a review meeting was held between the HDC and the Exeter team on 15/02/01 to discuss the priorities for the work in year 3.

Findings and achievements

The findings and achievements of the work in year 2 are listed below according to the set milestones.

The glasshouse which was used as a reference in all modelling studies is 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 considered with a wind that is normal to the ridges and the simulations are steady state.

(1.1) The full length of 60 spans of the glasshouse was modelled and the behaviour of the internal airflow was studied under different external windspeeds. Windspeeds of 1m/s, 3.5m/s, 5m/s and 8.5m/s at ridge height were chosen. The different windspeeds did not result in changes in internal flow pattern, which was characterised by the existence of a 'dead' zone separating a section of reverse flow at the windward side of the house and a section of flow in the wind direction at the leeward side of the house. The 'dead' zone was located at approximately 60% of the total length of the glasshouse, measured from the windward side and stretched to the top of the house towards the leeward side over a large number of spans. The only influence of the windspeed was the linear increase of internal airflow speed with increasing external windspeed.

(1.2) The extended 3 dimensional model, which was limited to a width of 24.75m due to limitations of computer power, resulted in a similar internal flow pattern but with a lower maximum internal windspeed. This can be attributed to the fact that a 3D model has got a relatively lower percentage of ventilation in the roof than a 2D model, where every single span has got a vent opening.

(1.3) Crops were inserted into the 2D model as discussed under (1.1). The same crop modelling approach was chosen as used in year 1 (see year 1 report). The main feature of this model is its influence on the internal flow due to the canopy density. The main internal flow pattern characteristics remained the same. Only the position of the 'dead' zone changed slightly towards the windward side of the house and its location was more fixed due to the presence of the crops.

(1.4) The model of (1.3) was extended to 3 dimensions, which again did not change the internal flow pattern. Again the maximum internal airflow has decreased due to the reduction in ventilation opening, and the 'dead' zone has moved slightly in the windward direction.

(1.5) Simple smoke tests which confirmed the main flow directions were carried out in year 1. In addition, in year 2 more smoke tests and airflow speed and direction measurements were conducted using sonic anemometry. Two sets of data over two weekends were recorded. However, due to continuous changing windspeed and direction, more data are required to come up with solid conclusions. Only a few links between external windspeed and direction could be made which will have to be proved with further measurements.

Glasshouse length and vent opening

In addition to the agreed milestones some simple parametric studies were carried out with the empty 2 dimensional 60 span glasshouse model. The effect of the glasshouse length (20, 40 or 60 spans), vent opening (50% and 100%) and the influence of a blockage (such as another glasshouse) placed in front of the glasshouse on the internal airflow were investigated. Both the glasshouse length and vent-opening angle did not change the internal flow pattern. Only the maximum internal airflow speed changed with increasing glasshouse length and increasing vent opening. The blockage effect however was considerable.

Blockage effect

Different size blockages were placed in front of the 60 span glasshouse and its effect on the internal flow was studied. First the effect of blockages attached to the glasshouse and of different heights was investigated. With a vent opening of 100% it was observed that reverse flow section decreased with increasing height and if the height was higher than the ridge, no reverse flow was observed. In addition, blockages were placed 5m in front of the glasshouse, according to the configuration at Cantelo where the new block is placed 5m behind the existing glasshouses. The height was chosen as 4.6m, which was the ridge height of the old glasshouse blocks, and the length was changed. The internal airflow with different windspeeds and 50% and 100% vent opening was studied. Under 100% vent opening, the longer the blockage and the higher the windspeed, the smaller the reverse flow section. Under 50% vent opening, it was observed that the reverse flow section disappeared when the height of the blockage exceeded the gutter height.

Temperature effect

Finally a simulation was carried out which included the effect of heating on the internal flow under different windspeeds. The external air temperature was chosen as 15°, the glass temperature assumed to be 20° and the pipe temperature was chosen to be 45° and 60°. Again the internal airflow increased with increasing windspeed and a lower pipe temperature resulted in a higher maximum internal velocity. More swirls were observed, mainly near the ‘dead’ zone, where due to the low local velocity resulting from the wind pressure, the temperature had a dominant influence on the flow pattern. The ‘dead’ zone was observed to be more towards the windward side of the glasshouse for low windspeeds comparing to the situation without the temperature effect but moved in the leeward direction with increasing external windspeed.

Benchmarking and validation

In addition to the validation work that was conducted at Cantelo and described under (1.5) above, benchmark simulations with similar flow characteristics were conducted with the CFD code and a validation of the modelling approach was carried out. The subject of the validation simulations was the comparison with independent pressure distribution measurements on the roof of a closed 52 span glasshouse. This is a valuable validation since the wind pressure is the main driving force of the internal flow and an accurate prediction is an indication that the internal flow is likely to be modelled accurately.

Year 3 (2001) milestones and work plan

The following work plan and milestones were agreed at the HDC review meeting for the project held on 15 February 2001. Nine simulations will be carried out and analysed covering the topics below. All models will have crops (3 layers) and leeward ventilation only. If not mentioned otherwise, the vent-opening angle will be 50%, the windspeed at reference height 3.5m/s and the wind direction may be chosen according to the modeller's preference.

(1.6) Conduct parametric studies to investigate the dependence of the internal flow on vent opening angles.

It was agreed at the review meeting on 15 February 2001 to alter the studies from vent opening angles to analysis of wind direction on internal air flow in the presence of a crop canopy. The effect of wind directions at 0^o, 45^o and 90^o to the ridge of an East-West orientated glasshouse will be analysed.

(1.7) Introduce heat transfer and investigate thermal effects on air flow.

The cooling effect of the plants will be introduced and a situation of extreme radiation load will be studied and compared with the models without radiation. This will be carried out by introduction of a heat source in the floor. Temperature distribution and changes in flow pattern are the focus.

(1.8) Introduce CO_2 injection and absorbance of CO_2 for photosynthesis by the crops and describe CO_2 distributions in the glasshouse atmosphere.

Introduction of CO_2 injection of 49 kg/h/1000m^2 and crop CO_2 absorption. The influence of two different vent openings, 50% and 100%, on the CO_2 dispersal will be investigated under a windspeed of 3.5m/s.

Using the same CO_2 injection rate and a vent opening angle of 50%, the effect of two different windspeeds, 3.5 m/s and 8.5 m/s will be investigated.

Investigate the effect of the CO_2 injection rate for additional injection rates of 24.5 kg/h/1000 m_2 and zero injection; the latter should result in depletion.

Compare findings with the CO_2 optimisation model of Bernard Bailey [see paper presented at workshop in Portugal on 'Management, Identification and Control of Agriculture Buildings, 26 January 2001 and an Excel spreadsheet as part of HDC project PC 110a]. HDC will make the spreadsheet available to Exeter University under licence for experimental purposes.

(1.9) Validate the models with available validation data from previous research.

The comparisons with the findings of HDC project PC 110a on CO_2 optimization should provide some validation. The data collected in Autumn 2000 will be reanalysed for periods where the wind direction was suitable. Further smoke tracer tests will be conducted if feasible at the Cantelo nursery with the presence of a crop canopy.

(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.

The investigations described in 1.6 to 1.8 above account for this work plan.

It is intended that the modelling work will be carried out in 3D but a 2D model will be the starting point of any new modelling process and analysis. If the studied parameter does not have much influence on the transport processes and it can be expected that the 3D model will not provide any new answers, a 3D model will not be developed for such cases.

The proposed windspeed of 3.5m/s will be altered to a minimum of 2.5m/s if an assessment of weather data reveals that the recorded windspeed in the UK is consistently (i.e. more than 20% of the time) lower than 3.5m/s.