Horticultural
Development
Company

Grower summary

PC 278

The development and commercial demonstration of ducted air systems for glasshouse environmental control

Annual Report 2010

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Headlines

The first full year of commercial trials of a fan and duct heating and ventilation system installed in a tomato greenhouse in East Yorkshire delivered:

- a heat energy saving equal to 59kWh/m^2 of gas (12.8%) which is worth £1.53/m^2
- high electricity use of 11kWh/m^2 which costs £0.77/m^2
- a 7.6% yield increase worth £1.85/m^2
- a payback on investment of 7.6 years (assuming that all heat is from boilers). The payback period reduces to 3 years where low-grade heat sources already exist e.g. CHP
- 60% of the total heat demand of the greenhouse using water of 40^{o}C or less and 95% using 50^{o}C or less
- lower disease levels
- minimal impact on the way the crop is managed.

Background and expected deliverables

This report summarises the findings of the second year of commercial trials of a three year project that investigated the performance of a ducted heating and ventilation system installed in a 1Ha tomato greenhouse in Humberside.(Note that the first reported period of the trial was only a part year).

The project follows on from PC 256 which examined the potential for using closed glasshouse technology in the UK. This concluded that ducted air heating and ventilation systems could offer significant advantages over conventional greenhouse design including:

- Reduced energy consumption
- Improved crop yield
- Reduced pest and disease problems
- Increased opportunities to use alternative heat sources.

Objectives
The aims of the project are to investigate the ability of ducted air delivery systems to:

- Reduce energy use in heated glasshouses
- Reduce CO_2 emissions associated with glasshouse production
- Expand the opportunities for glasshouse businesses to use alternative heat sources
- Improve crop yield and quality
- Reduce disease incidence and therefore the use of crop protection chemicals.

Summary of the project and main conclusions to date

Materials and methods

The project comprises three parts:

- Research, development and design of a commercially acceptable ducted air heating and ventilation system for the trial greenhouse at a commercial nursery in the UK
- Installation of the selected system at the trials site
- Commercial trials to investigate system performance and crop response.

The project is being carried out at tomato growers Mill Nursery Ltd in East Yorkshire. Previous reports (PC 278 Interim report, 2008 and PC 278 Annual Report 2008, 2009) cover items 1, 2 and the first part year of commercial trials in 2008. This report details the first full year of commercial trials in 2009.

Trial site and equipment

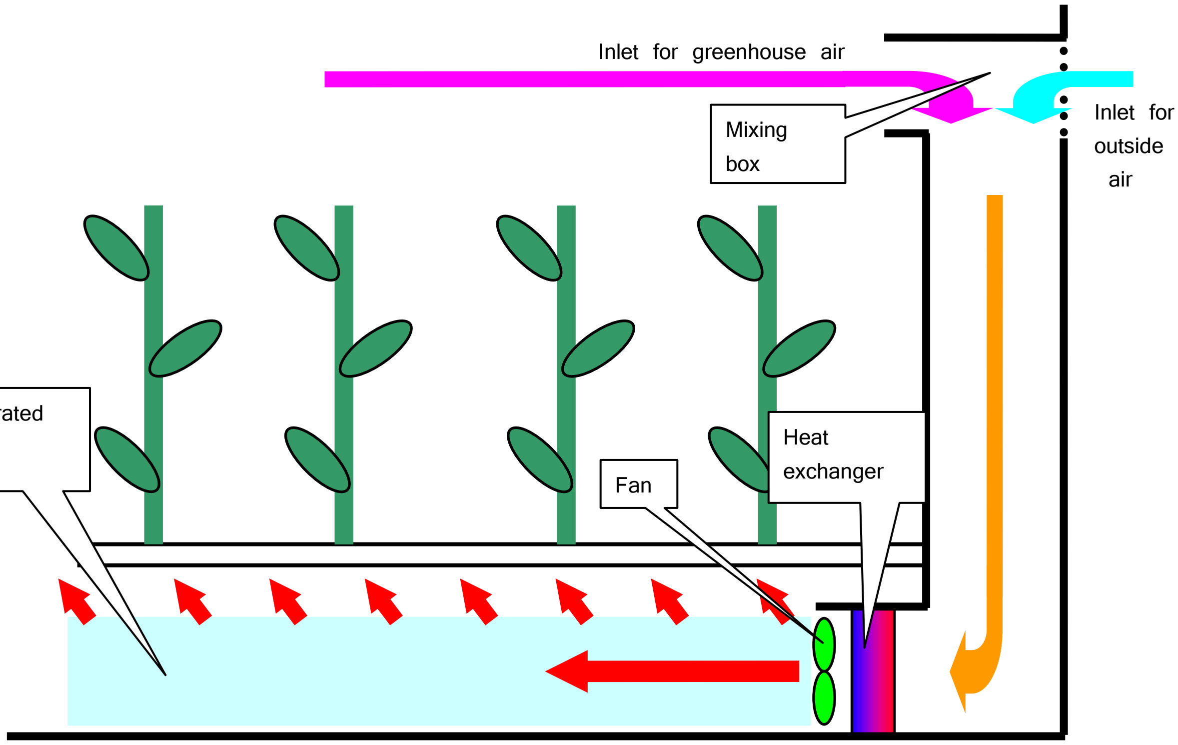
Site

The project is being carried out in two adjacent 1Ha greenhouse compartments. A fan and duct system was installed in one compartment and is being compared with an adjacent and otherwise identical compartment which has a conventional heating and ventilation system.

Equipment

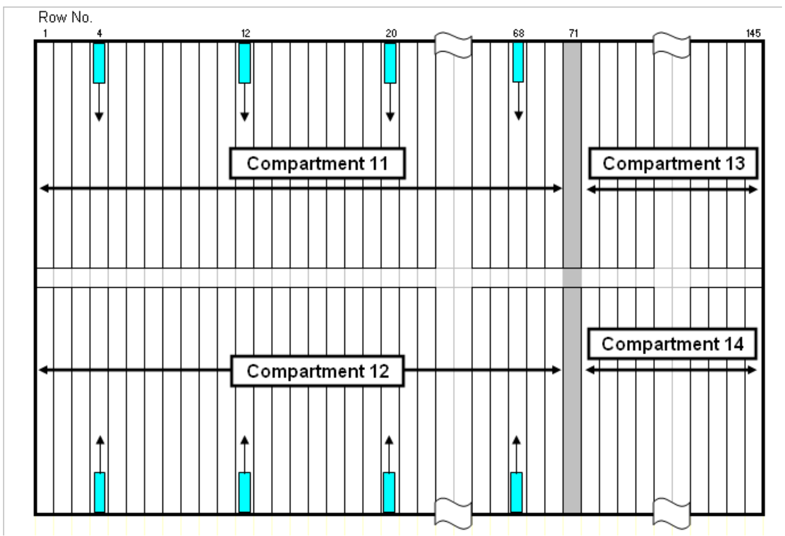
Figure 1 shows a single air handling unit (AHU) of the type installed at Mill Nursery.

Figure 1 – Air handling unit schematic



Collectively these components are called an Air Handling Unit (AHU). Each of the AHUs installed can deliver 6,000m^3/hr and 25kW of heat. The installation at Mill Nursery uses 18 of these AHUs arranged as shown in Figure 2.

Figure 2 – AHU layout



The whole installation has a heating capacity of 450kW/Ha and delivers an airflow of 108,000m^3/hr (2 air changes per hour). It should be noted that the fan and duct installation is not capable of satisfying all the heating and ventilation needs of the greenhouse and the existing pipe rail heating system and roof vents continue to be used.

Results

Temperature uniformity

Figures 3 and 4 show the temperature uniformity achieved in the fan and duct compartment and conventionally heated compartment respectively during January 2009.

Figure 3 – Fan and duct compartment (CMP12)

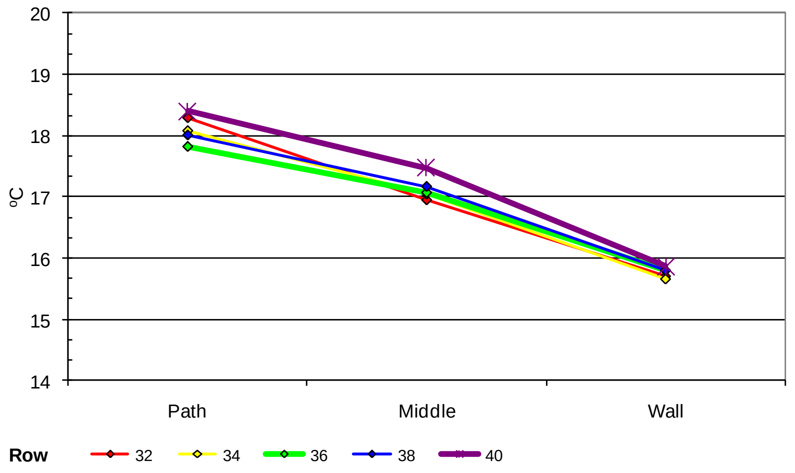
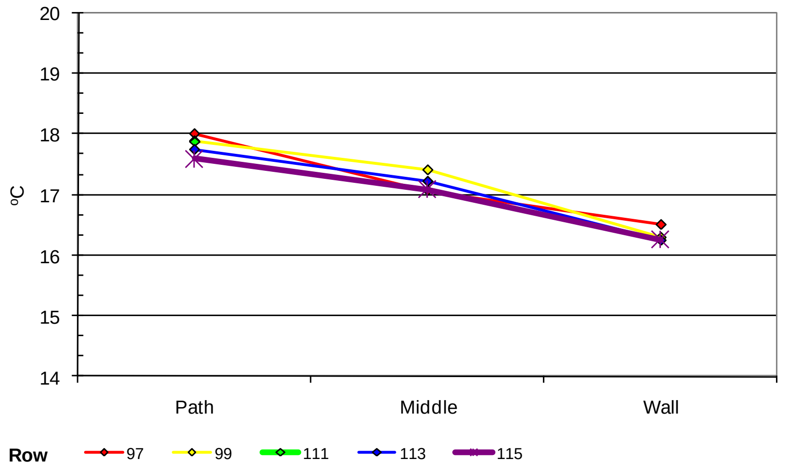


Figure 4 – Conventionally heated compartment (CMP14)

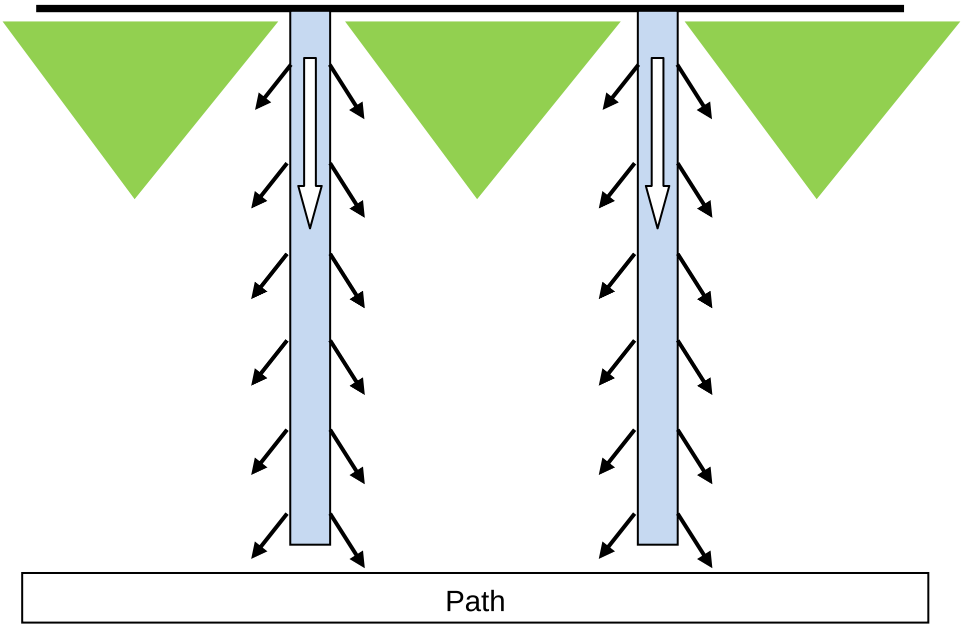


Both compartments were colder close to the wall of the greenhouse than close to the central path. However, the difference between the path and wall in the fan and duct compartment was 2.3^{o}C compared to 1.5^{o}C in the conventionally heated greenhouse. Continued monitoring showed that this trend occurred whenever the greenhouse vents were closed and the heat demand was high. As such it was prevalent from January to late March. This had a significant affect on plant development close to the greenhouse wall in the fan and duct compartment.

Progress in this area was hampered by the limited testing window (requiring cold weather) combined with a modify–test–analyse cycle of 2-3 weeks.

Figure 5 below is a plan view of two ducts as they were originally installed. As the air within the duct is travelling towards the path, it leaves the duct at an acute angle, not at 90° as might be expected intuitively. This left a dead-zone (green triangles).

Figure 5 – Plan view of airflow from the ducts



Further smoke tests showed that there were two dominant air circulation patterns in the greenhouse when the vents were closed (Figure 6). This led to colder air (Circulation 2) accumulating at the wall end of the rows.

Figure 6 – Original air circulation patterns

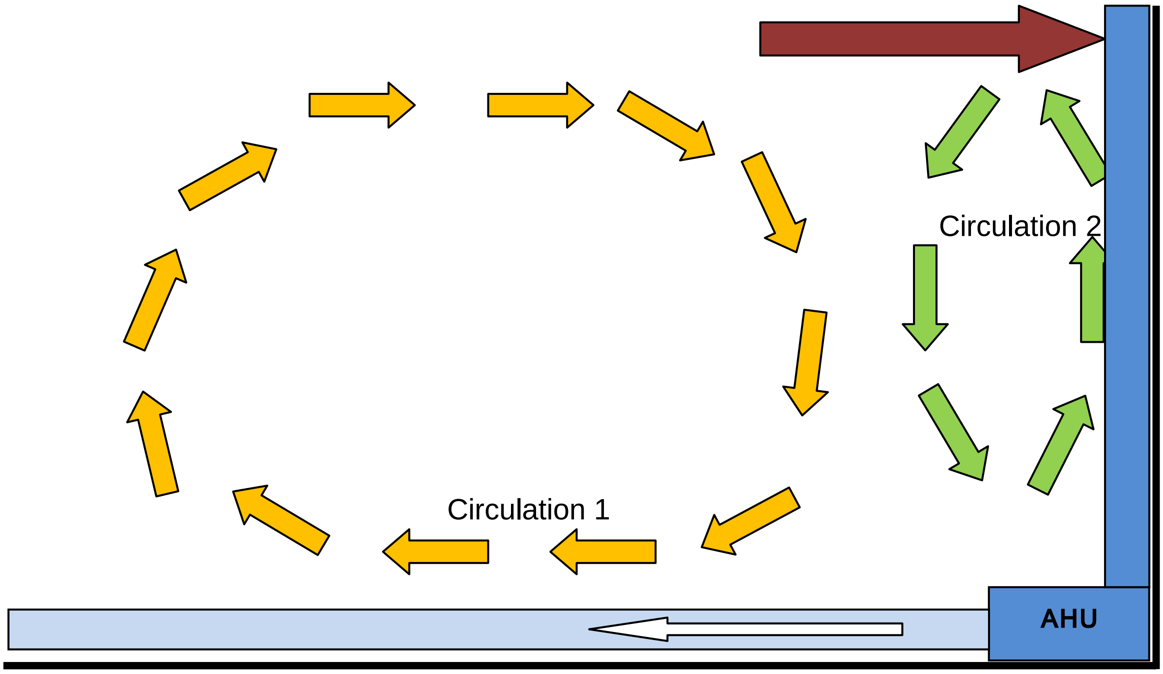


Figure 7 shows the air circulation pattern required. To achieve this:

- Air must leave the outlets at 90^{o} to the duct.
- Additional ducting or outlets should be installed to 'fill the gap' created by the AHU.

These conditions were provided by:

- Fitting a second larger diameter perforated duct over the existing ducts thereby isolating the final air outlets from the air travelling along the inner duct.
- Installing nozzles to blow some air back towards the wall (Figure 8).

Figure 7 – Desired air circulation pattern

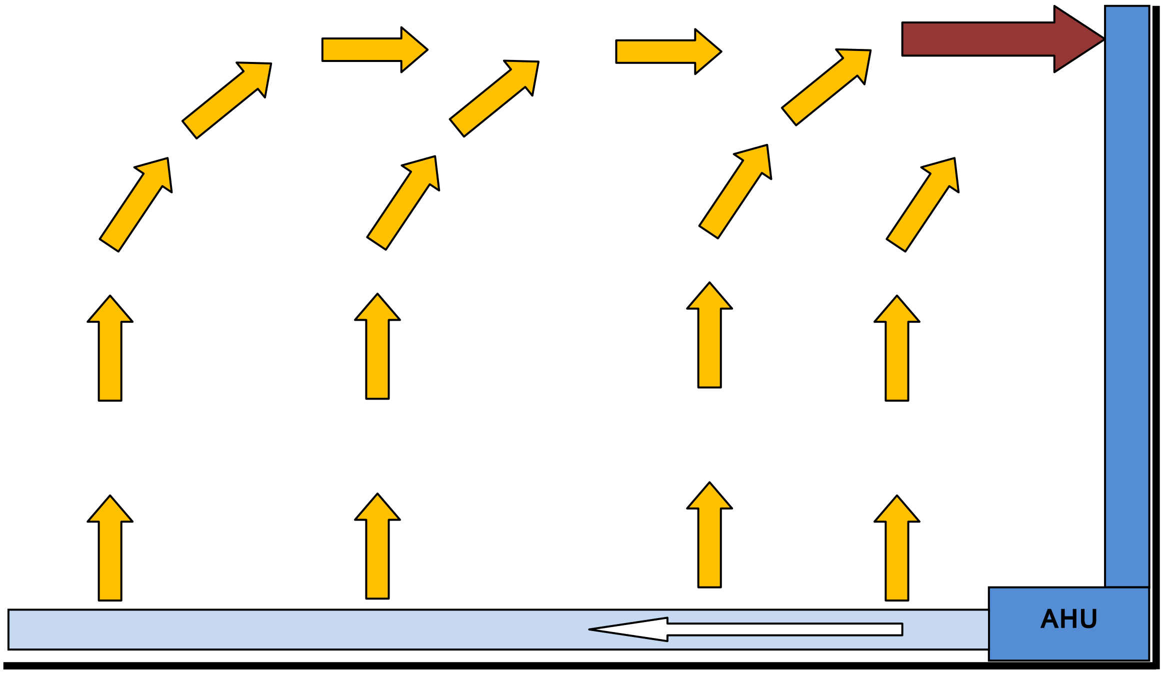
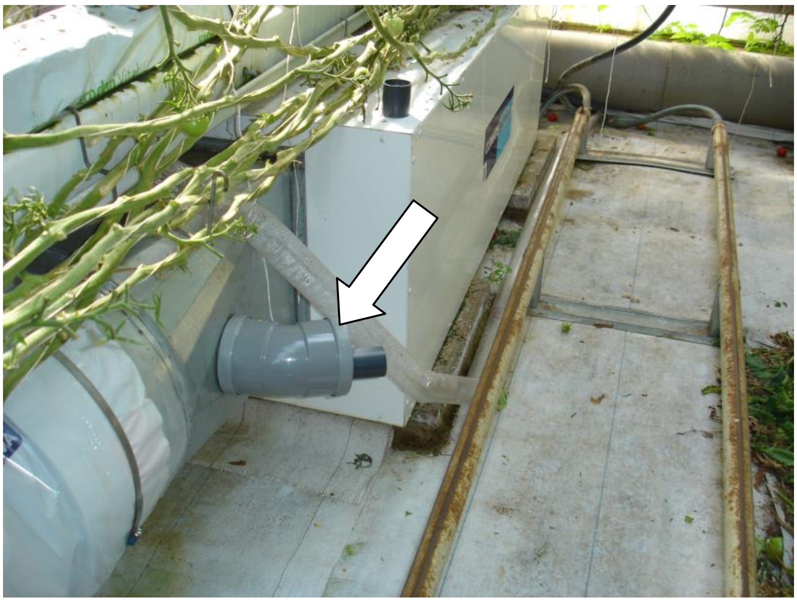


Figure 8 – Nozzle blowing air towards the greenhouse wall



Early work on solving the temperature distribution problem involved a number of modifications to a three duct sample, but this appeared to have little effect. It was concluded that these changes were being overpowered by air movement in the greenhouse as a whole and as such, piecemeal modifications and testing did not yield meaningful results.

The final modifications detailed above were therefore made to the whole installation during August 2009 in an attempt to produce a significant effect.

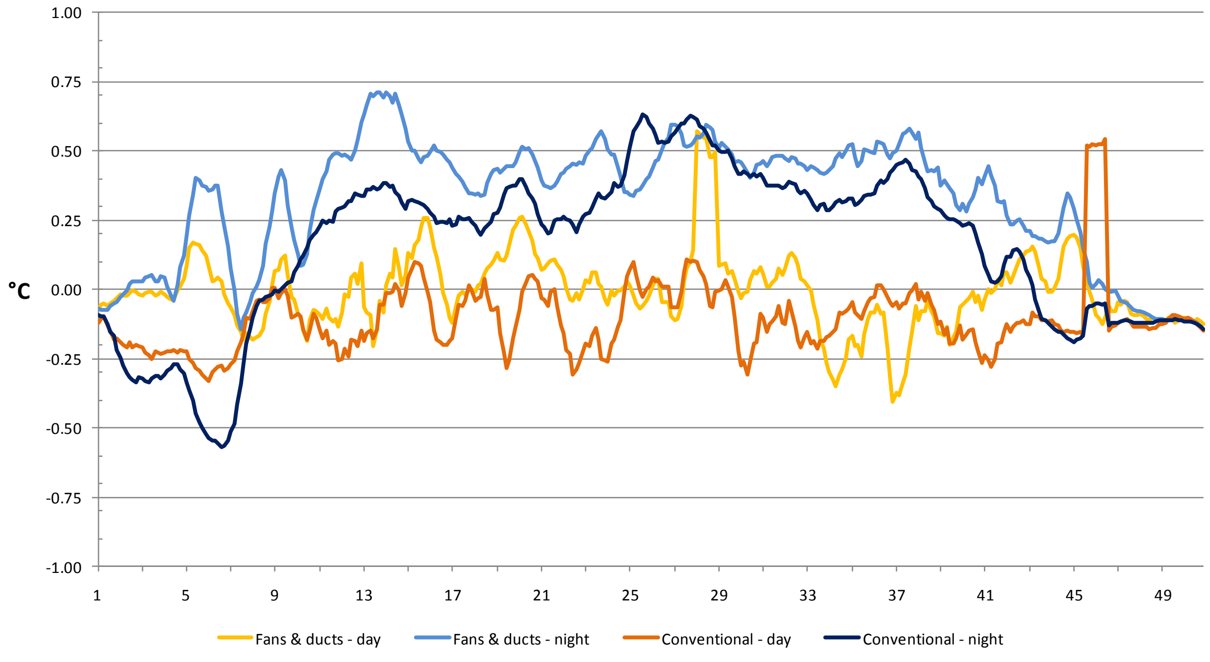
It was not possible to fully prove the effect of these modifications due to a lack of cold weather before the crop was pulled out in early November. However, data from brief periods of high heat demand showed that the difference between the path and wall in each of the compartments was almost the same: 1.0°C in the fan and duct compartment compared to 0.9°C in the conventionally heated greenhouse. There was however a slightly greater row to row variation in the fan and duct compartment.

Greenhouse environment
The climate in the trial and control compartments was managed according to the needs of the individual crop in all cases. This meant there were times when greenhouse temperatures in particular were different across the compartments. In general, a lower humidity deficit (HD) was targeted in CMP 12 (fan and duct) than in CMP 14.

Temperature
From the point of view of crop management via greenhouse climate, temperature continued to be the primary tool in both treatments. The greatest differences in temperature strategies occurred between weeks 4 and 12. However, the same 'rules' of growing (warm day, cold night for a generative effect etc.) were applied in both compartments.

The fan and duct system was expected to have an affect on the vertical temperature profile within the greenhouse. Figure 9 explores this by comparing the temperatures measured at the top of the crop (standard practice on many nurseries) and the bottom of the crop.

Figure 9 – Weekly average vertical temperature difference (bottom minus top)



Key points are:

- Up to the end of February when the crop was small, slight variation in plant growth determined whether the top measuring box was actually within the crop or suspended in free air. Therefore comparisons up to this point are unlikely to be relevant.
- During the night time it was consistently warmer at the bottom of the crop in both compartments. However, the difference was approximately 0.2^{o}C greater in the fan and duct greenhouse than in the conventional compartment.
- During the daytime there was a slight tendency for it to be cooler at the bottom of the crop in the conventional greenhouse (0.1^{o}C over the whole year). Whereas in the fan and duct compartment there was virtually no difference (0.01^{o}C colder over the whole year).

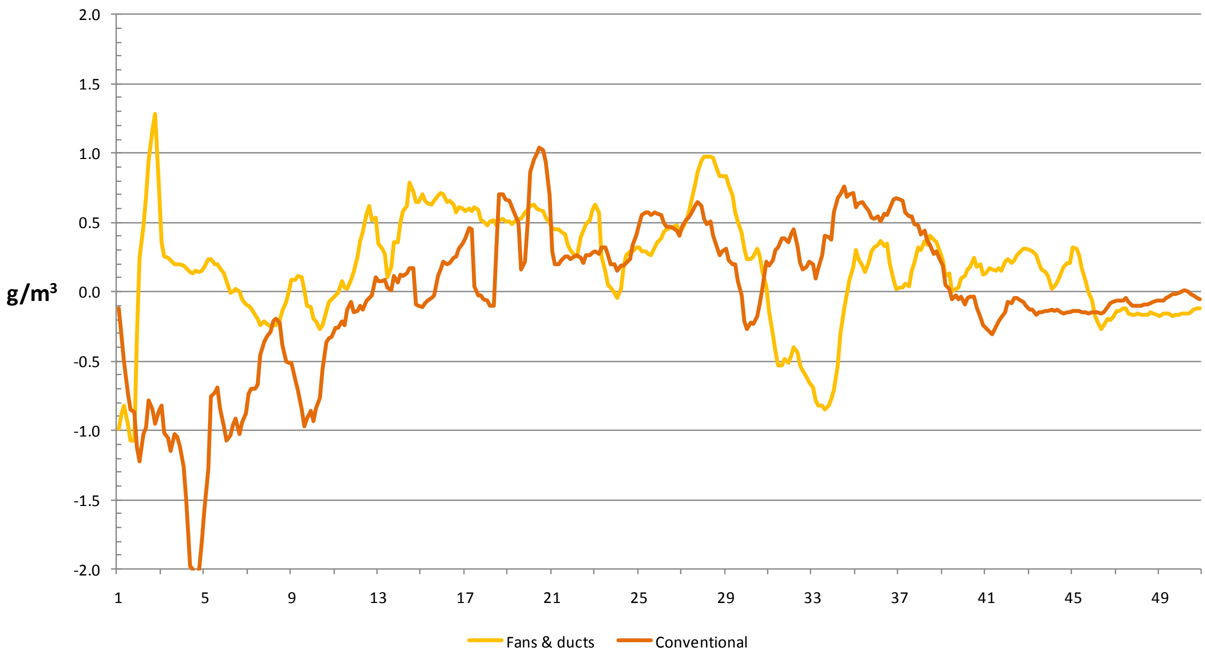
Humidity

At low HDs the grower felt that the environment in the fan and duct compartment was better than in the conventional compartment although the measured HD was almost the same. This provided the grower with the confidence to accept lower HD's in the fan and duct compartment. The target HD in the fan and duct compartment was typically 0.2-0.3g/m^3 lower than in the conventional compartment.

As with temperature, introducing outside air in particular into the bottom of the crop was expected to affect the vertical humidity profile in the greenhouse. Figure 10 shows the difference between the bottom and the top of the plants in each greenhouse during the night time. It is worth noting that:

- There were technical problems for a short period, up to the end of February with the measuring box in CMP14 and in mid-August for measuring box CMP12.
- Up to the end of February the humidity is not generally a significant environmental issue. As a result problems with the bottom measuring box in CMP14 were not noted up to this point.
- A similar and even more subtle problem occurred with the bottom measuring box in CMP12 in mid-August.

Figure 10 – Weekly average daytime vertical HD difference (bottom minus top)



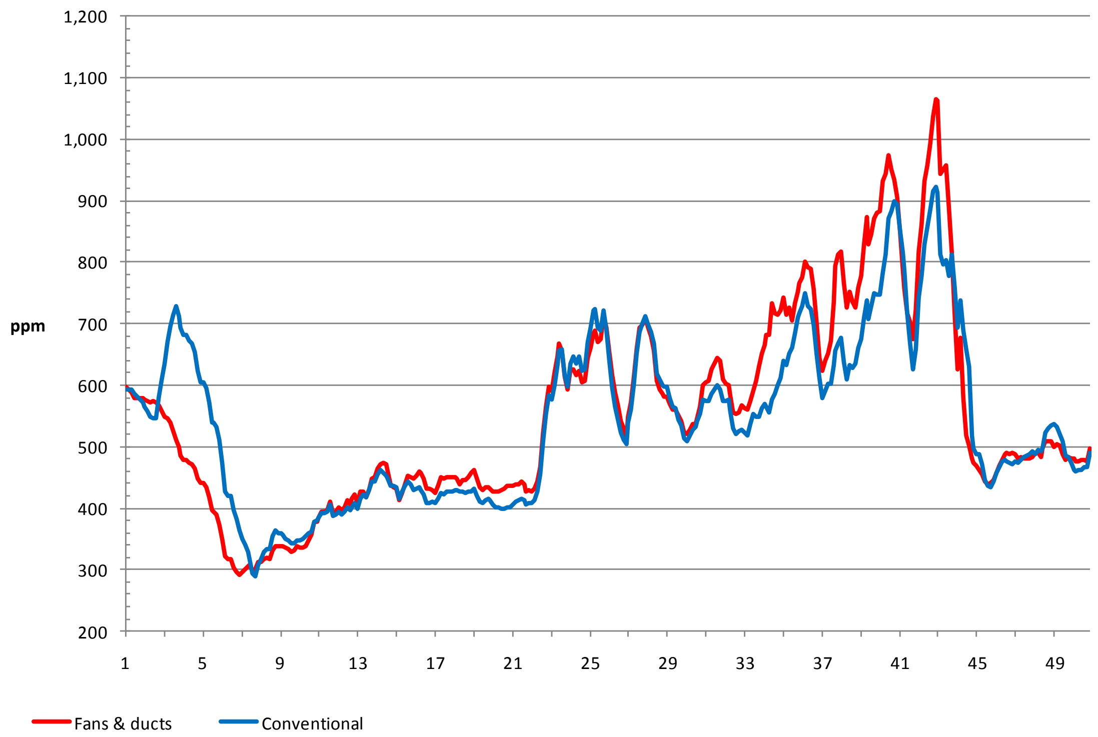
Key points are:

- It was significantly drier at the bottom of the crop, relative to the top, in CMP12 (fan and duct) than in CMP14 during March-April and September-October. This is when the outside air was quite cold which, with the addition of the heat by air delivery system, had good 'drying power' when introduced into the bottom of the crop.
- Through the summer there was little difference between the compartments. In this period the vents were open for most of the time giving good air movement even without fans.

CO_2

Both compartments are served by a single CO_2 enrichment system. This is controlled on the basis of the highest of the two CO_2 measurements taken in the compartments. The availability of CO_2 enrichment was extremely limited until the end of May due to CHP problems on the nursery.

Figure 11 – Daytime CO_2 concentration



Key points are:

- Up to the end of February the measurement equipment in CMP 14 was faulty. During this period similar levels would be expected in both compartments.
- Slightly higher CO_2 levels in CMP12 during April and May.
- Higher CO_2 levels in CMP12 from August to September. This was assumed to be the result of reduced venting at each end of the day due to lower HDs being accepted in CMP 12.

Crop data

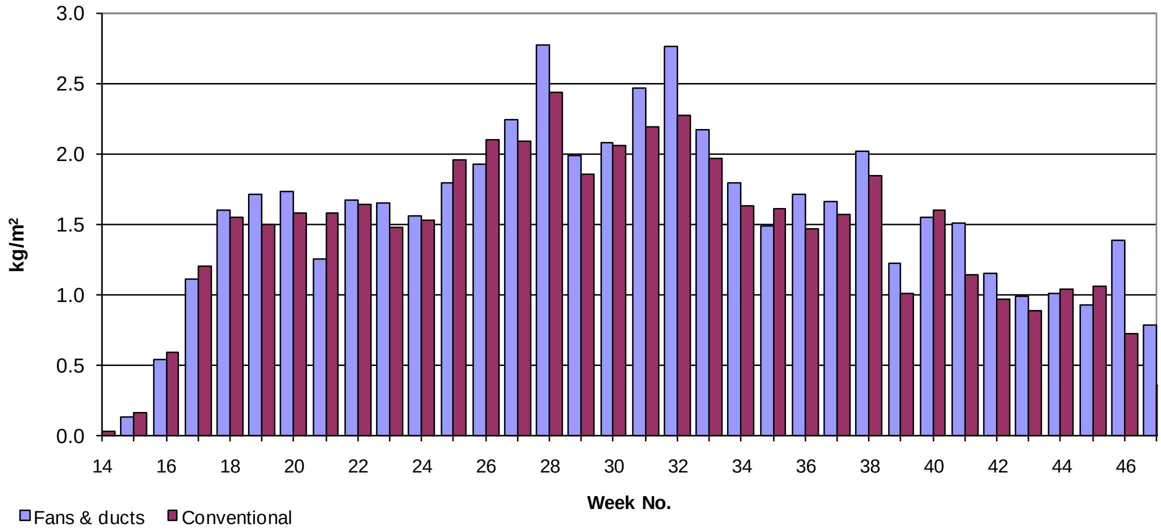
The grower felt that the crop in the fan and duct compartment tended to be more generative than in the conventional compartment. However, there was no clear trend in the crop registration data to confirm this. The data of greatest significance are:

- The total number of trusses produced per plant were almost identical (0.07 difference).

- The fruit load per plant was higher in the fan and duct compartment from week 21 to week 33. This coincided with the oldest truss on the plants in the fan and duct compartment being older than in the conventional compartment suggesting there was a slower speed of fruit ripening in the fan and duct system.

Higher CO_2 levels in the fan and duct greenhouse suggest that the increase in yield was due to higher fruit weight. The total yield in the fan and duct compartment was 52.4kg/m^2 compared to 48.7kg/m^2 in the conventional compartment (7.6% more).

Figure 12 – Weekly yield

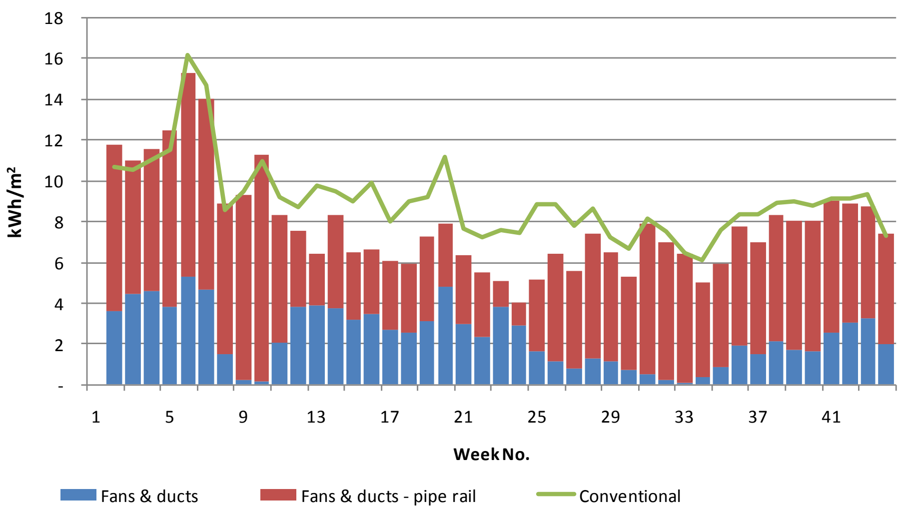


Disease assessments showed that there was less disease (principally Botrytis) in the fan and duct compartment. In the areas monitored there was a smaller number of girdling stem lesions in the fan and duct compartment (99 per 5 rows) than the conventional compartment (166 per 5 rows). The number of leaf Botrytis lesions and missing stem bases was also less and the number of surviving heads was greater.

Energy

Figure 13 shows the weekly heat energy use in each compartment and the contribution of the fan and duct system towards the total heat delivery.

Figure 13 – Weekly heat use



Up to week 10, when the heat demand was dominated by the need to maintain greenhouse temperature, the total amount of heat used in each greenhouse was similar. During this period the fan and duct system provided 26% of the total heat input to the compartment.

The fan and duct system was turned off half way through week 8 due to the temperature uniformity problems and turned on again in week 11.

Energy savings of 20-30% per week were made between weeks 11 and 30 as a result of the relaxation of humidity control set points in the fan and duct compartment. High disease pressure due to poor weather between weeks 30 and 32 required changes to set points which meant little energy was saved during this period. Total delivered heat in terms of gas consumptions (assuming 85% boiler efficiency) was:

- Conventional compartment 458kWh/m^2
- Fan and duct compartment 399kWh/m^2
- Saving 59kWh/m^2 (12.8%).

Further analysis of the data showed that 95% of the heat use in the fan and duct compartment was from water of 50^{o}C or less. In the conventional compartment this proportion was only 60%. The remaining 5% of heat use for CMP 12 still only required a water temperature of less than 60^{o}C. It is important to note that 40^{o}C water satisfied 60% of the heat requirement in the fan and duct compartment.compared to 13% in the conventional compartment. This is of specific interest to those considering the use of low temperature heating systems, like heat pumps.

The fans used 11kWh/m^2 of electricity in 2009 which offsets a significant amount of the heat energy saving. However, it should be noted that the fans ran almost continuously throughout the year, mainly in an attempt to minimise the temperature uniformity problem. It is felt that there is much room for improvement in this area now that the temperature uniformity problem is thought to have been overcome. Reducing electricity consumption will be a major focus in 2010.

Financial benefits

Heat

Assuming the use of a gas fuelled boiler, the energy saving (59kWh/m^2 gas) is worth £1.00/m^2 at current gas prices (1.7p/kWh). Note that gas costs are low at present - 2008 gas costs were closer to 2.6p/kWh (76p/therm) making the energy saving worth £1.53/m^2. There is little doubt that the long term trend will be for higher gas costs.

A major component of this project was to expand the opportunities to use alternative heat sources by enabling lower temperature heating water to be used. With typical heating costs of £10.00/m^2 the value of this could be significant, especially where low-grade waste heat from other industries may be available.

Where CHP is available, as at Mill Nursery, low grade heat is often rejected to heat destroyers in the form of water at 40-45^{o}C. This could be used by the fan and duct system. On the basis that this heat would normally be 'dumped' it could be regarded as free heat. There are also potential savings in electricity used by the fans on the heat destroyers. Subject to the running regime and size of the CHP it may be possible to satisfy up to 30% of the greenhouse heat demand from such sources giving a saving of up to £30,000/Ha.

Electricity
The fans used 11kWh/m^2 of electricity. At current mains electricity prices this would cost £0.77/m^2. Where a nursery has CHP the effective cost of electricity is much less than 'mains price' and is equivalent to the value of electricity sold to the grid at wholesale prices. This would reduce the cost of electricity to around £0.50/m^2.

For a nursery using gas boilers and mains electricity the net value of energy saving in 2009 would be £0.23/m^2.

Maintenance
Maintenance requirements and cost have been minor after the 'teething troubles' which occurred during the first year of commercial trials in 2008. Two fans failed - one required replacement bearings at minimal cost and the other required a motor re-wind. Both fans were on the same side of the greenhouse (CMP11) where there were problems with water ingress in 2008.

The only item that requires ongoing maintenance to date is air filters in the air handling units. Alternative filter media will be tested early in 2010 to try and identify the ones that are: cheaper; that can be cleaned and that do not significantly impede airflow.

Crop
A yield increase of 3.7kg/m^2 (7.6%) was achieved. This occurred from week 27 onwards and as such coincides with typically lower prices for the fruit. As the crop was the loose round variety Encore, additional yield in terms of kilos will deliver additional income.

The same may not be the case with tomatoes on the vine. However, if consistently overweight vines are produced there is the opportunity to either produce more vines by increasing the crop density or reduce levels of CO_2 enrichment and associated energy use.

Taking a notional value of £0.50/kg for the crop the extra yield could be worth £1.85/m^2.

Capital cost
The capital cost of the installation was £15.90/m^2. It should be remembered that this technology is very much in its early adoption stage and costs are expected to come down. Since this installation was completed in March 2008 several other suppliers have brought similar products to the market. Growers are therefore advised to obtain quotes for a fan and duct installation specific to their own circumstances as significant variance is expected.

Taking the specific example discussed above the total financial benefit (net energy saving plus yield increase) was worth £2.08/m^2. This gives a simple payback on investment of 7.6 years. However, if low grade heat from the CHP had been used, which is notionally free, the pay back on investment could be as low as 3 years.

Conclusions

It is commonly believed that any means of increasing air movement will improve the uniformity of the greenhouse environment. Interestingly, this project shows that this is not the case and work needs to be done on the design of forced air distribution systems to ensure that this is not a problem. However, in spite of the temperature uniformity problems encountered, fan and duct installations have been proven to deliver:

- Increased yield (7.6% in 2009) largely due to reduced venting for humidity control leading to higher CO_2 levels in the greenhouse.

- A saving of 59kWh/m^2 of gas used for heating (12.8%) - offset by high electricity use (11kWh/m^2).
- The ability to use low grade heat sources to satisfy the heating demand of greenhouses. With appropriate design it should be possible to heat a greenhouse with a maximum heating water temperature of 40^{o}C.
- Lower disease levels.
- Minimal impact on the way that the crop is managed.

Action points for growers

The results presented in this report are the findings from the first full year of commercial trials of the fan and duct system and this should be borne in mind when considering their possible commercial replication. Nevertheless, growers who have the potential to access sources of low grade heat may well consider this trial as ample evidence to justify adoption of this technology.

Potential adopters of the technology should:

- Determine the amount of heat that is available and the synergy between production and greenhouse heat demands.
- Explore the feasibility and cost of accessing the heat. This could be significant. For example, in the case of CHP this may require additional heat exchangers, pumps and control systems.
- Identify potential suppliers of fan and duct systems.
- Obtain quotes using the specification of the system installed for this project (2 air changes per hour, 450kW heating capacity/Ha).