Grower Summary

PC 278

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

Final Report 2011

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The results and conclusions in this report may be based on an investigation conducted over one year. Therefore, care must be taken with the interpretation of the results.

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Before using all pesticides check the approval status and conditions of use.

Read the label before use: use pesticides safely.

Further information

If you would like a copy of the full report, please email the HDC office (hdc@hdc.ahdb.org.uk), quoting your HDC number, alternatively contact the HDC at the address below.

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Headline

Water at 50^{o}C or less satisfied 95% of the total greenhouse heat demand, this compares with 60% of heat demand with a conventional heating system.

Background and Expected Deliverables

This report summarises the findings of the second year of commercial trials of a three year project. The purpose of the project was to investigate the performance of a ducted heating and ventilation system installed in a 1Ha tomato greenhouse in E. Yorks.

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 through:

- 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 and costs 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 comprised three parts:

- Researching, developing and designing a commercially acceptable ducted air heating and ventilation system for a trial greenhouse at a commercial nursery.
- Installing the selected system at the trial site.
- Carrying out commercial trials to investigate system performance and crop response.

Trial Site and Equipment

Site

The project was carried out in two adjacent 1Ha greenhouse compartments at Mill Nurseries Ltd in East Yorkshire. A fan and duct system installed in one compartment was 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 of the type installed at Mill Nurseries Ltd.

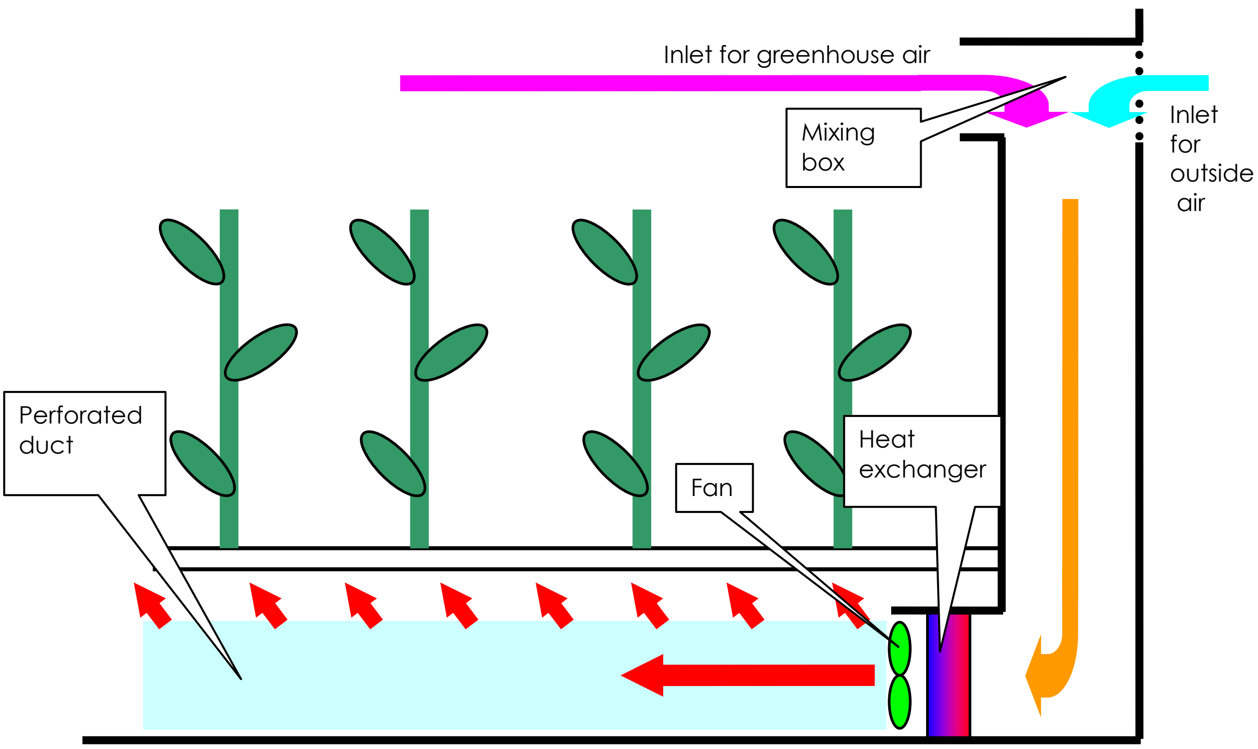

Figure 1. Air handling unit schematic

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

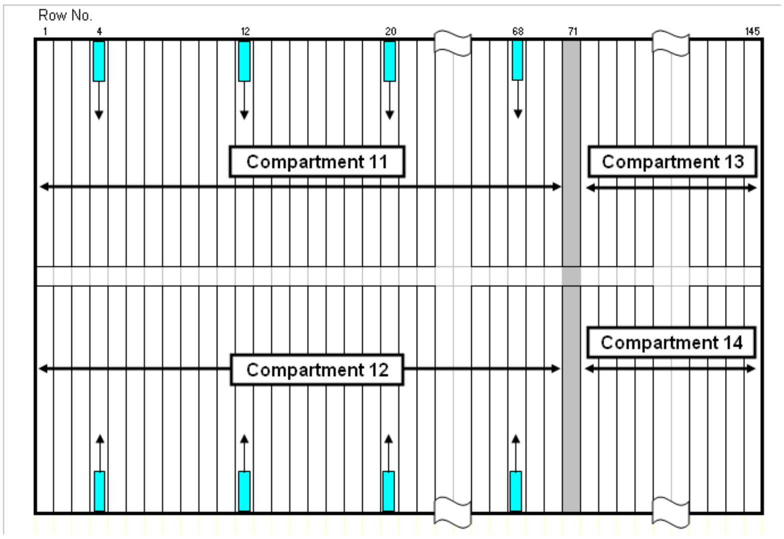

Figure 2: AHU layout

The whole installation has a heating capacity of 450kW/Ha and delivers an airflow of 108,000m^3/hr (2 air changes per hour). 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

It was anticipated at the design stage that increased air movement delivered by a fan and duct system would result in improved uniformity of temperature. During the initial operation phase this did not prove to be the case. In fact it made the temperature uniformity worse during the winter when the heat demand was high and there was no venting.

Extensive trials and subsequent modifications were required before a satisfactory solution was proven in January 2010. Figures 3 and 4 below show the temperature uniformity measured between 11th and 26th January 2010.

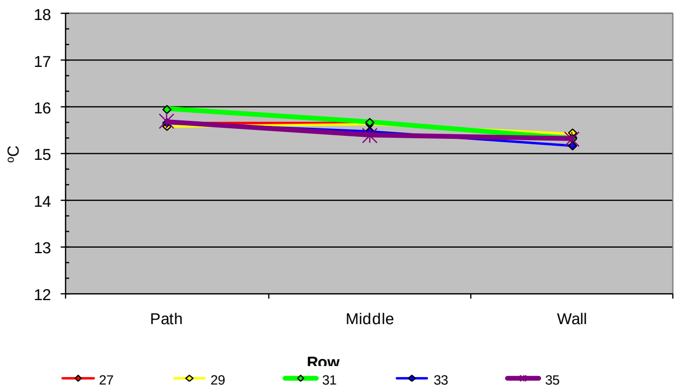

Figure 3. Fan and duct (CMP12)

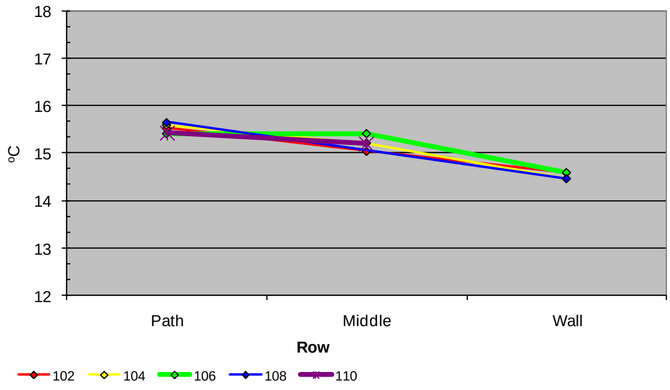

Figure 4. Conventionally heated (CMP14)

This was achieved by:

- Ensuring that the air exited the outlets at 90o to the axis of the duct.
- Blowing a small amount of air back towards the greenhouse wall to solve what were previously dead-spots between adjacent air handling units.

Greenhouse environment

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

Temperature

Temperature control was the most important environmental 'tool' for manipulation of plant growth and condition. The greatest differences in temperature control strategies between compartments occurred between weeks 4 and 12. The same 'rules' of growing (warm day, cold night for a generative effect etc.) were applied in both compartments.

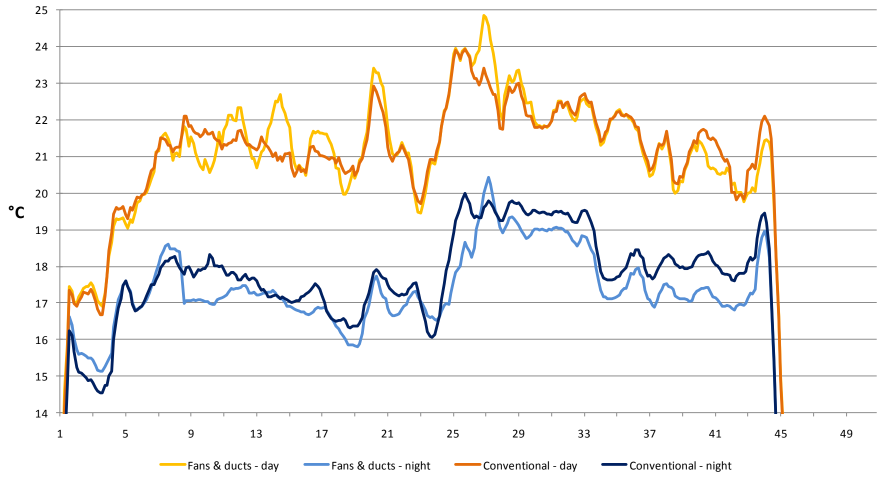

Figure 5. Weekly average temperature at the top of the crop

The greatest difference between temperature treatments in the compartments occurred during the night time. Between weeks 9-12 this was a result of different heating temperature set points. During the summer months it was largely due to lower energy inputs for humidity control.

Humidity

At low humidity deficits (HDs), the grower felt that the environment in the fan and duct compartment was better than in the conventional compartment even when the measured HD was almost the same. This provided the confidence to experiment with lower HDs in the fan and duct compartment. As a result the target HD in the fan and duct compartment was typically 0.3-0.5g/m^3 lower than in the conventional compartment. Figure 6 shows the average HD measured at the top of the crop.

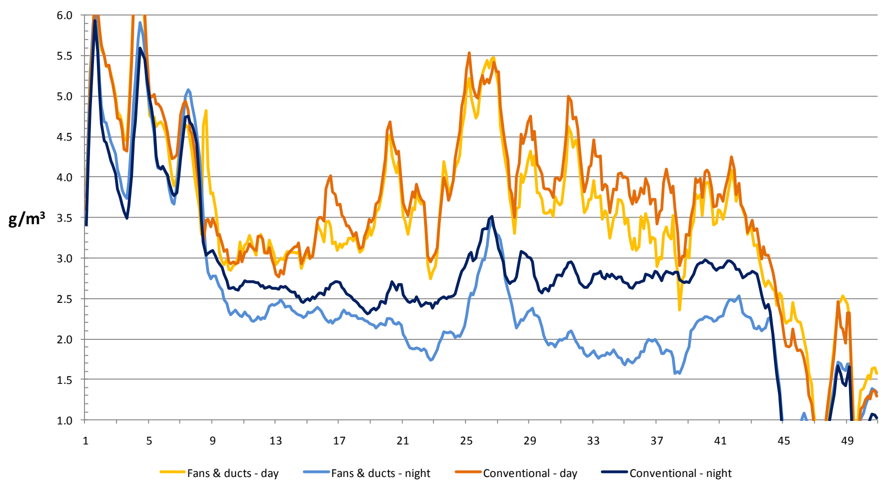

Figure 6. Average humidity deficit measured at the top of the crop

The difference between treatments during the night time is most obvious between weeks 30-40. The difference in daytime HD is most notable between weeks 35-39 when the weather was poor. In addition to energy saving, accepting lower HD's during the daytime meant there was less venting and consequently higher CO_2 levels in the fan and duct compartment.

CO_2

Both compartments are served by a single CO_2 enrichment system controlled according to the higher of the two measurements taken in either of the compartments.

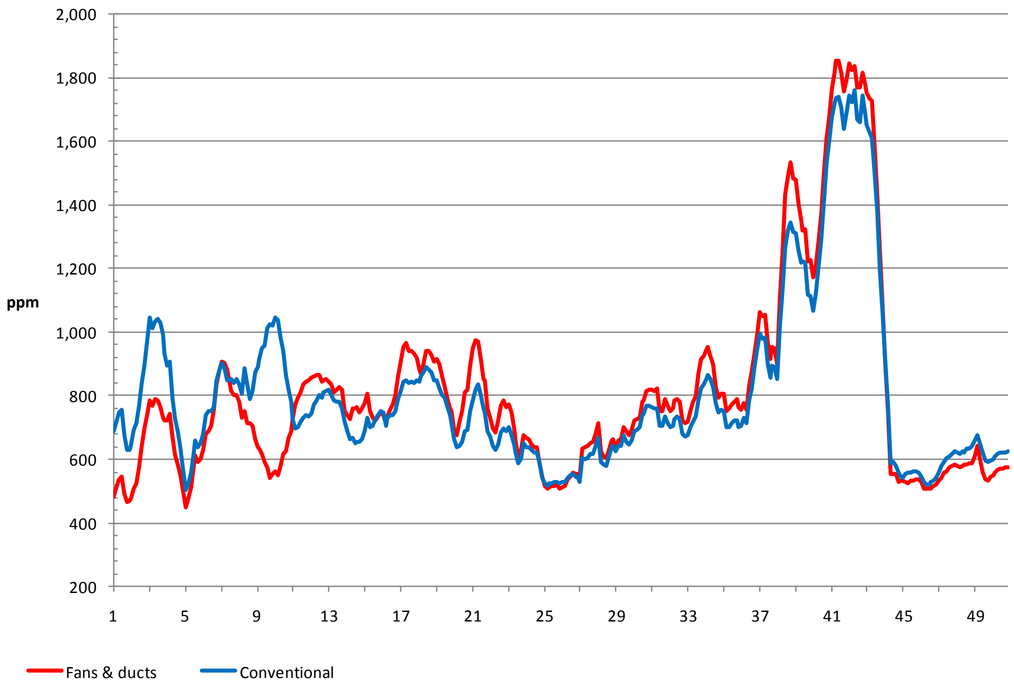

Figure 7. Daytime CO_2 concentration

Data up to week 10 are erroneous due to a fault with the Priva climate control computer. However, as there was no venting at all during this period so it is reasonable to assume that the CO_2 concentrations were broadly the same in both compartments.

With lower humidity in the fan and duct compartment, less venting and therefore higher CO_2 levels were achieved. In 2009, CO_2 concentration was limited to 450ppm because of delivery constraints. In 2010, 800ppm was nearer the norm. The high levels shown around week 42 are correct and were due to problems with the CO_2 enrichment system.

Crop data

Growing strategy / crop management

The grower and crop consultant felt that the increased air movement from the fan and duct system resulted in better transpiration at lower HDs, compared with that which would be achieved in a conventional growing environment at similar HD levels. Normally, increased transpiration is only achieved by increasing HD through greater (and more expensive) use of heat and ventilation. During the early part of the cropping year when the HD was equally good in both treatments more generative growth took place in the fans and ducts compartment. Generally, this can be regarded as beneficial or undesirable depending on the particular stage of development of the crop. If it is felt to be undesirable, some modification of the environmental control parameters is required to “overcome” this generative effect. These modifications are no different to those used for a crop grown with a conventional heating system. They might include:

- Increasing irrigation to produce a more vegetative growth and use night watering to prevent the slab moisture content dropping too low - this should only be carried out where accurate moisture content readings are available as increased irrigation can reduce slab electro-conductivity (EC) etc.
- Reducing the day night heating temperature differential.

Yield

Figure shows the total yield.

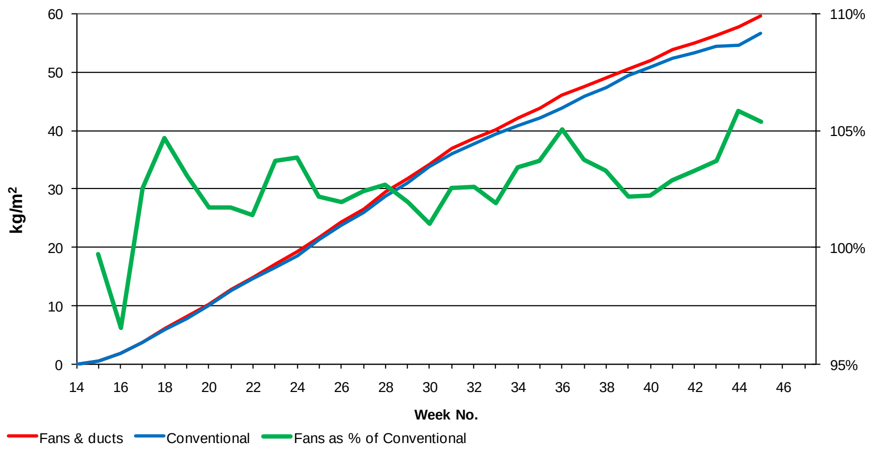

Figure 8. Total yield

Picking of the first fruit in the fan and duct compartment started 2-3 days later than in the conventional compartment. Prior to the installation of fans and ducts this picking delay was sometimes up to 7 days, so this delay was felt to be intrinsic to the performance of compartment rather than to the fans and duct system. Total yield was not affected by this issue.

Higher yields were evident in the fans and duct compartment from week 30 onwards. This was also seen in the 2009 season. This coincided with higher CO_2 levels in the fan and duct block. Table 1 compares the final yield in 2009 and 2010.

Table 1. Yield 2009 and 2010

	2009 Total yield kg/m^2	2010 Total yield kg/m^2
Conventional compartment	48.73	56.61
Fan and duct compartment	52.41	59.63
Difference	3.68kg/m^2 (+7.6%)	3.02kg/m^2 (+5.3%)

2010 yield was higher for both treatments than those recorded in 2009. This was due to higher availability of CO_2 from the nursery's CHP installation in 2010. The smaller difference in yields between the two treatments in 2010 is probably linked to the wholesale increase in CO_2 levels from 2009 to 2010. As overall CO_2 levels rise, the extra yield for each additional 100ppm reduces. Therefore, in 2010 the 'head room' for yield improvements between the two treatments was less than in 2009.

Disease

Disease assessments carried out by Dr Tim O'Neil (ADAS UK Ltd) showed that there was no difference in disease levels in 2010. This compares to a slight reduction in disease in 2009.

It is reasonable to conclude that the reduced energy use and lower HD's, which occurred with the fan and duct installation, did not result in higher disease levels.

Energy

Heat

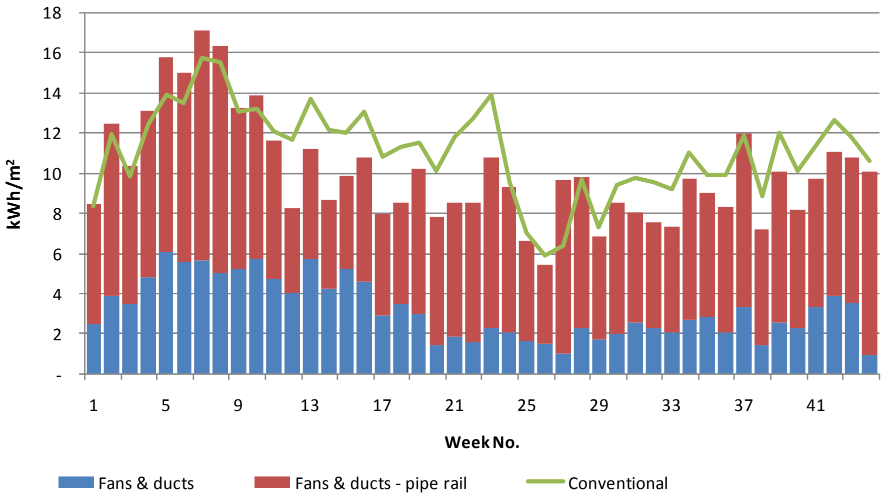

Figure 9. Weekly heat use (as boiler gas)

Up to week 10 (2010), the fan and duct compartment tended to use more heat than the conventional compartment. During this period no venting was required for humidity control, the thermal screen set points were the same and similar greenhouse temperatures were achieved. It could be argued that increased air movement due to the fans increases heat loss. However, the airflow delivered is relatively low and in 2009 energy use during this period was almost identical. One possible explanation could be a change in the prevailing wind direction. Although it was not possible to validate this theory, we are confident that the difference was not caused by the fan and duct installation.

As the difference up to week 10 is not expected to be due to the fan and duct installation the figures in the table below exclude it.

Table 2. Heat usage in 2009 and 2010

	2009 Total kWh/m^2	2010 Total kWh/m^2
Conventional	458	488
Fan & duct	399	436
Saving kWh/m^2	59 (12.8%)	52 (10.7%)

The slightly lower saving in 2010 is due largely to the period between weeks 27-28 when an alternative (but unsuccessful) control strategy was used.

Further analysis of the data showed that 95% of the heat used in the fan and duct compartment was from water of 50^{o}C or less. In the conventional compartment this proportion was only 60%. Furthermore, 40^{o}C water satisfied 60% of the heat required in the fan and duct compartment compared to only 13% in the conventional compartment. This is of particular interest when considering the use of low temperature heating systems such as heat pumps or waste heat sources.

Electricity

In 2010 a simple control regime was employed to reduce fan running hours and therefore electricity consumption when the greenhouse conditions were favourable. The regime was as follows:

Turn the fans off during daylight hours when:
The HD was >4.5g/m^3
AND
The lee side vents were >15% open

Although the fans were turned off for significant periods, especially during the day in summer, only a slight reduction in electricity was recorded over the whole year – 10.7kWh/m^2 compared to 11.0kWh/m^2 in 2009.

One major issue which resulted in the relatively small difference in running costs between the years was associated with a change of filter type in the air handling units. The newer filters allowed a higher airflow delivery and this increased the energy requirement of the fans. Had the airflow remained the same, electricity consumption is estimated to have been 8.1kWh/m^2.

Electricity use remains a major factor affecting the cost effectiveness of the fans and ducts systems.

Financial Benefits

Energy

Heat

The amount of heat energy saved through the use of the fans and ducts system compared to the conventional system in 2010 was 44.2kWh/m^2.

The value of this saving depends on the fuel and system used for heating. At Mill Nurseries Ltd heating water comes from a CHP system. However, the majority of growers still rely on mains gas fuelled boilers. Assuming the latter, and allowing for boiler and system losses, 44.2kWh/m^2 of heat would be associated with the use of 52kWh/m^2 of gas. The value of this depends on the cost of gas. Based on a gas price of 2.4p/kWh (typical projected price for 2012) this would be worth £1.25/m^2.

Electricity

The recorded electricity use of the fans was 10.7kWh/m^2 but a fairer future projection allowing for efficiencies realised by the filter system might be nearer 8.1kWh/m^2. At current mains electricity prices this would cost about £0.69m^2.

This leaves a net energy cost saving of £0.56/m^2 (£0.50/m^2 in 2009).

Maintenance

Since initial teething problems were resolved in 2008, the fan and duct installation has been reliable. To date, maintenance costs have been almost exclusively associated with the fans. Three required replacement bearings which, due to their construction, were relatively easy to fit and cost around £50/fan. Two fan motors burnt out and required re-winding, costing £350 each.

The only ongoing maintenance items to date have been the replacement of air filters in the air handling units. Alternative filter media has been identified which cost £1/fan unit (18 in total). Filters are replaced every six months.

Crop

A yield increase of 3.0kg/m^2 was achieved. This occurred from week 27 onwards and as such coincides with typically lower prices for the fruit. As the crop was of 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, this would provide the opportunity to produce more vines by increasing the crop density or to reduce levels of CO_2 enrichment and associated energy use.

Assuming a value of £0.50/kg, the extra yield would be worth £1.50/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. There have been several similar products brought to the market since the installation of the system in March 2008. As a result, growers who are interested in this technology are 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) has been worth £2.06/m^2. This gives a simple payback on investment of 7.7 years.

Conclusions

- Yield - the average increase achieved over 2-years attributable to the use of a fan and duct system was 3.4kg/m^2 (6.5%). This was largely as a result of the achievement of higher CO^2 levels from reduced venting for humidity control.
- Disease – reducing energy use and accepting a lower humidity deficit with fans and ducts did not result in higher incidence of disease levels.
- The average heat energy (from gas) saving over the 2-year project was 56kWh/m^2 (11.8%).
- The lowest electricity consumption to date was 10.7kWh/m^2. However, lower airflows which are expected to be possible could reduce energy use by 50% without reducing the heat energy saving.

- Low temperature / waste heat sources – the existing installation satisfied 95% of the total greenhouse heat demand with water that was 50ºC or less compared to only 60% with a conventional heating system.
- Reliability – since early teething problems were resolved the installation has been very reliable. Total repair costs after 3-years of operation have been £900.
- The interaction between fan-based air movement systems and natural air movement patterns in large scale commercial greenhouses is complex. Simply 'adding a few fans' can just as easily make temperature uniformity worse as make it better.
- Further investigation to reduce capital/operational costs and of lower airflow systems is required.

Action points for growers

The fans and ducts technique has greatest immediate potential where it can enable lower grade heat sources to be utilised.

Growers with a potential source of low grade heat 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. There were at least six exhibiting at the Hortifair 2010.
- Continue to track progress of this project in 2011 for further results.
- Growers who do not have access to lower cost heat sources should continue to track progress of this project through 2011 as the simpler (lower cost) installation being trialled may have benefits for them.