conduction, because the side walls of each cell are heavily insulated. In the black plastic tray with thin walls for each cell, the same absorption of radiant energy occurs, but more heat is lost to the surroundings via conduction through the walls and so the soil does not heat up as much. This difference is also noticed when radiant heat from direct sunlight causes the polystyrene cells to heat up more than plastic trays, and also during a clear cold night when the radiant heat loss of the soil is lower in a polystyrene tray than in a thin-walled plastic tray.

Another heating system for propagating plants uses heated beds or mats, providing heat from below via conduction. Heat passes upwards from the base to the top of the pot. The air is not heated. A 150-mm pot on a heated mat (set at 25C) was monitored and the thermal environment varied dramatically on two successive nights. On a mild cloudy night where little radiant heat loss occurred, conditions inside the pot remained nearly constant at 20 to 22C. On the following cloudless night, significant radiant heat loss occurred from the top of the pots resulting in pot temperatures falling to 12C whilst the mat temperature rose to 35C in an attempt to provide more heat. This under-pot heating system did not maintain a good pot microclimate under the colder conditions

CONCLUSION

Thermal imaging techniques and electronic monitoring equipment have been successfully used to monitor variations in greenhouse macro- and microenvironments under different thermal conditions.

LITERATURE CITED

Garzoli, K. 1988. Greenhouses: Handbook for nurserymen, horticulturists and gardeners. AGPS Press, Canberra, Australia.

Design and Construction of a Controlled Environment for Propagation of Ornamental Plants

Clive Larkman

Larkman Nurseries P/L, PO Box 567, Lilydale, VIC 3140

A controlled environment is one where all climatic variables are controlled and set by the grower.

DESIGN CONSTRAINTS

We were using in-bed electrical cables which were proving inefficient and expensive to run. Determined to reduce the heating costs by at least 40% for our 60 m^2 of heated propagation beds which were costing us approximately $800 per winter month to run, the first decision was which irrigation system to use? Fog, mist, or high pressure mist? The second was to determine which method of heating and therefore what fuel type to use. We were working with an existing tall tunnel, 18.5 m × 6.2 m × 3.4 m (l×w×h) which was used to house stock plants.

IRRIGATION SYSTEM

In the early nineties the buzz word in the propagation world was fogging. It seemed that it was the way of the future; the answer to all those hard-to-strike plants. The theory behind fogging made sense and the general feeling at the time was that it improved strike rates and times. The only negative aspect to fog appeared to be the cost. It was suggested that we use a single row of nozzles down the tunnel centre. However we chose to go with two rows. This reduced the chance of damage from a blocked nozzle, it also meant quicker fogging.

HEATING SYSTEM

This is where the greatest headache arose. If we had wanted to heat the whole tunnel there was no problem, as hydronics heating is used in many areas. As we were only going to heat the root zone in one tunnel, we wanted to install a system that would allow for Melbourne's cold winter days but also make efficient use of energy. The only energy consumption figure for hot beds available was obtained from Queensland, 2.7 kW m^{-2}. After some investigation into average mean temperatures, average minimum temperatures, and actual minimum temperatures, I decided that we were about 10% colder, thus we would require 2.97 kW. At that time there was work being done in Canberra and by private companies on energy efficient tunnels and heating systems. Much of this work was centred around phase-change systems. These involved using principles similar to that used by the common refrigerator. Basically, when a chemical changes from one phase to another it requires an energy transfer. This energy transfer either comes from or goes to the environment around the equipment. A Sydney-based company had developed commercial units for domestic usage. They had two systems, one for heating the water and one for direct heating the relevant area. The first unit was prohibitive in its capital cost. The second was not able to withstand the chemicals used in a nursery situation. Being environmentally conscious we also looked at solar power. The capital cost of solar cells capable of generating sufficient energy were large and extremely expensive. Also the back-up system required for winter usage would still be quite large.

As we had 80 m^2 we decided to use 3 kW m^{-2} (as it made the calculations much easier). This meant that 240 kW of power per day was required. At $0.20 per kWh during the day and $0.041 off peak we would have had a hefty power bill. We were back where we started. Off peak rates are substantially cheaper but to use them we had to generate and store 240 kW of power in 8 h. In other words we needed a 30 kW heater. The heating companies told me this was quite plausible. After visiting some places with wood/coal burners, we felt that our system was too small to justify the boiler size needed to make it efficient. Diesel was too expensive, plus it was likely to go up with government taxes being predicted to rise. Another option was waste oil burners. We felt that these would be too dirty and that it wouldn't be too long before they started charging for the oil (remember that LPG was originally a waste product of petrol production that was burnt). This left gas boilers. Direct comparisons between electricity and gas consumption were nigh on impossible as gas consumption is calculated in kilojoules whilst electricity is calculated in kilowatts. It seemed that at a quoted price of $0.25 per litre of LPG it would cost $10 per day, compared with $9.84 with off-peak electricity. This gas rate involved using a large tank at more than $1 per day rental. This left us with one further problem; how much water would be necessary to store 240 kW of energy? After a fair bit of arithmetic and many phone calls we decided on 5000 litres.

HEAT BEDS

I have always questioned the efficiency of raising propagation beds off the ground. We accepted that it was not ideal to place the beds directly on the ground for both hygiene and work practice reasons. Dr. Garzoli's work showed that rocks and alike are good heat sinks. So we decided to build beds with approximately 300 mm high walls using hollow concrete blocks. The beds were then back filled with volcanic scoria, as it is largely filled with air it was light to carry and shovel into the beds. It also acted as an excellent heat sink, and insulator. We then put a layer of 25-mm polystyrene foam on top of the scoria. This was then covered with aluminum foil to further reduce downward heat loss and to stop the sand from falling through into the scoria.

TUNNEL COVERING

We looked at double skinning as this has been proven to greatly reduce heating costs. As we wanted to create two separate compartments, a fixed 65% shade screen was our original choice (currently we had 10% shade). This was instead of double skinning. The fixed screen acted as a heat transfer barrier, reducing upward heat loss during winter and excess heat build up during summer. The volume of air that needed to be maintained at a set humidity level was greatly reduced. The installation of a large exhaust fan at one end of the tunnel above the fixed screen allowed the exchange of hot air with cooler air from outside without affecting the main growing area.

HINDSIGHT

Having the beds at 300 mm high has proven a bonus in heat reduction during summer. It may be 40C at head height, but is still only 25C at bed height. We use a looping system which created some flow problems as well as uneven heat at the ends, a manifold system is much easier to install and gives better flow rates. The tank we chose was large enough but not the ideal shape. We found that the original solenoids failed after about 2 years, due to corrosion of the centre pins. This was due to the grade of stainless steel used which was not corrosion resistant in very hot water. The fixed screens work well as heat barriers. The down side is that the screens support algal growth and thus light transmission after 2 to 3 years is greatly reduced. We, like many people, assumed that if we were to maintain a high humidity then the tunnel must be made fairly airtight. However we soon started leaving the doors open to allow the tunnel to dry out. This has not caused any significant stress to the plants, but has significantly reduced fungal outbreaks. We have recently installed a large fan that is constantly running and changes the air every 10 min.