2008 International Meeting on Controlled Environment Agriculture

Organized by the North American Committee on Controlled Environment Technology and Use (NCERA-101)

MARCH 2008

REPORTS ON THE CONFERENCE BY RECIPIENTS OF BURSARY AWARDS FROM THE UK CEUG FOR ATTENDANCE AT THIS INTERNATIONAL CONFERENCE

Please note that the full programme of papers and posters, which are reported on below, is available as abstracts or presentations at the NCERA-101 web site with URL:

http://www.lssc.nasa.gov/als/ncera/NCERA%20101%202008%20Meeting%20Program%20with%20Presentations.pdf

or

http://tinyurl.com/6ku6k5

or

http://preview.tinyurl.com/6ku6k5

Sunday, March 9

Session A: New Approaches for Control and Monitoring Environmental Conditions
Moderator: Tony Agostino

1. Changing the way light is delivered to plants in controlled environments: Novel practices with LED lighting	G.D. Massa*, C.M. Bourget, R.C. Morrow, C.A.Mitchell
2. Comparing photoperiodic lighting strategies in controlled greenhouse environments	S. Padhye, E. Runkle*
3. Transmission and distribution of photosynthetically active radiation (PAR) from solar and electric light sources for crop production	T. Nakamura*, A.D. Van Pelt, D.C. Rossi, B.K. Smith, N.C. Yorio, A.E. Drysdale, R.M. Wheeler, J.C. Sager
4. Effect of light quality on production of bioprotective compounds in red leaf lettuce	G.W. Stutte*, I. Eraso, P. Bisbee, C. Ledeker , T. Skerritt
5. Integrated light and CO_2 control to optimize commercial greenhouse plant growth and energy efficiency	T.J. Shelford*, L.D. Albright, D.S. de Villiers
6. Plant performance monitoring via non- invasive image acquisition and processing	F. Gilmer*, A. Walter, A. Ulbrich
7. ENVIRONET®: the next advancement in control technology	H. Imberti*, D. Kiekhaefer
8. Six highly specialized walk-in chambers with atmospheric gas composition control. A discussion of the challenges and possibilities of multiple atmospheric gas control in walk-in chambers	R. Quiring

* Denotes presenter

Reporter: Richard Natt (Central Science Laboratory, Sand Hutton, York YO41 1LZ, UK)

We started the conference with 4 talks showing different ways that light can be used.

Paper 1. Changing the way light is delivered to plants in controlled environments: Novel practices with LED lighting. Speaker: Gioia D Massa

First we looked at the advancement of LEDs. Arrays of LEDs with 16 blue, 64 red, 32 green and 2 photodiodes were made. Twenty of these arrays were then mounted along a hollow linear support with cooling fans mounted at one end to draw cool air out of the top thus removing the generated heat. The trials show that placing these vertically within the plants made more efficient use of the light when compared with similar lighting from above. The arrays are configured to light from the bottom up so that the light can be switched on with the change of plant height. Plants adapted to the change of light direction. The LEDs are current controlled with the colours controlled separately, and both the red-blue ratio and intensity can be adjusted.

Paper 2. Comparing photoperiodic lighting strategies in controlled greenhouse environments. Speaker: Sonali Padhye

Improving plant performance by selective light: While night break and day extension lighting has been used in commercial horticulture for a long time, more pressure is on growers to cut costs and improve plant performance. This paper discusses how by selecting the correct lights, plants can be manipulated to flower earlier/later and grow shorter (high red) and more compact or taller (low red). When using a combination of incandescent and compact fluorescents together flowering was more standard under all night break lighting regimes and individual light sources. Very little difference was seen with free branching between all light and time regimes. Effects will differ with lights from different manufactures due to the wave spectrum variations. This needs to be considered when carrying out any light related work with lights from different sources. This work is aimed primary at commercial plant and flower production, however the benefits could be used when trying to induce flowering or growth in certain crops in growth facilities.

Paper 3. Transmissions and distribution of photosynthetically active radiation (PAR) from solar and electric light source for crop production. Speaker: Takashi Nakamura

Collecting and using free solar power for plant growth: We were shown a solar power concentrator whereby light is collected by the reflector optical fibres. A selective beam splitter rejects non-PAR light minimizing the heat transferred. This allows cool light to be transmitted to the plant growth cabinet and be distributed evenly by the optical fibres placed around the cabinet. While this is a viable and efficient concept for space there is potential for use in other growth facilities where ample free solar radiation is available or during high light long days in the summer to provide free cool light. This would reduce high-energy inputs and the cost of cooling these facilities. The limiting factor at present is the cost of the fibre optic cable; light transmission along a longer cable is not seen as a problem.

Paper 4. Effect of light quality on production of bio protective compounds in red leaf lettuce. Speaker: G W Stutte

How can the production of anthocyanins in food (red lettuce) be increased? Anthocyanin helps to increase the resistance to damage the astronauts may suffer in space travel, it was found that by using LEDs as a lighting source 50% more was produced.

Increasing the anti-oxidants in food helps to increase the resistance to damage the astronauts may suffer in space travel. They require a continuous food supply so increasing the amount of anti-oxidants that are available in plants is a good way of supplying this. Supplying blue light increases anthocyanin but red light is still required to maintain a compact plant, blue light tends to produce long leaves, while white light only produces plants of a smaller size.

> ***Question)*** Why use 23 °C to grow the plant? ***Answer)*** This is the optimum temperature for the cabin, the shorter more compact plants produced more biomass than taller plants.

Paper 5. Integrated light and CO_2 control to optimize commercial greenhouse plant growth and energy efficiency. Speaker: T J Shelford

This is system of glasshouse control using parameters and forecast to control the environmental conditions within the glasshouse. In my opinion very similar environmental control programmes are commercially available, and used widely in commercial glasshouses and some scientific establishments.

Paper 6. Plant performance monitoring via non-invasive acquisition and processing. Speaker: Frank Gilmer

Using photographic systems in measuring and monitoring plant growth is a fast, up and coming area. These systems remove the variability of the human assessment to give accurate consistent results. Examples of how the system works were shown with single leaves, trays of seedlings and whole plants. Examples of differing growth rates were shown for plants grown under different conditions; this showed how accurate the system was for measuring small differences. It is possible to automate the system enabling growth rate to be measured continually in growth rooms. Using this type of equipment it is possible to monitor and identify nutrition deficiency and diseases.

The comparison of night and day measurements of a leaf was questioned as this showed an unusual pattern of faster leaf growth at night. After some discussion it was thought possible that it could be the stomatal elasticity component of the leaves, this shows how accurate some of the measurements are with these systems.

Paper 7. Advancement in control technology. Speaker: Daniel Kiekhaefer

New developments in growth chamber controls: While we grow plants in controlled environments these conditions are far from the normal environmental conditions you would find some of these plants growing in. We use what is a very controlled environment for these experiments. Now we can start to mimic actual weather conditions (excluding wind, CO_2 is simulated) light is total light and not PAR for any location and select dates, which are repeatable. With this software, actual weather conditions from any location in the world can be programmed in and then replicated, allowing the effects of the natural weather to be monitored and be replicated if required. Data can be used from meteorological stations around the world, start dates of past or present, real time can be used, and random factors can also be included. Data is pulled from any meteorological station every hour using average profiles of over 30 years. This is a great advancement in plant science enabling plants to be grown in changing climatic conditions in a controlled and replicated manner.

> ***Question)*** Why is relative humidity used and not vapour moisture deficit? ***Answer)*** Because existing control systems are based on relative humidity sensors.

Paper 8. Six highly specialized walk-in chambers with atmospheric gas composition control. A discussion of the challenges and possibilities of multiple atmospheric gas control in walk-in chambers. Speaker: Reg Quiring

A talk was about supplying six specialist growth rooms with exacting specifications and the problems associated with them. These cabinets were required to replicate conditions from 200 million years ago. High specification lighting was from metal halide lamps producing up to 1100 μmol $m^{-2}s^{-1}$ @ 1 m with dimming and deviation less than 10% Temperature specification was 4 °C to 40 °C and 10 °C to 40 °C with lights on. Air leakage was down to

1 air change per hour. This showed how advanced the technology and the construction of environmental growth facilities has become and is open to more possibilities in the future.

Session B: New Responses / Research Results from Experiments in CEA
Moderator: Erik Runkle

1. Plant growth and flavonoid content in a red-pigmented Lactuca sativa variety as affected by different light conditions	A. Ulbrich*, H. Behn, C. Wieland, S. Tittmann, F. Gilmer
2. Supplemental UV radiation differentially increases phenolic acid esters and flavonoids in cultivars of greenhouse-grown red and green leaf lettuce (*Lactuca sativa*)	C. Caldwell, S. Britz*, R. Mirecki, J. Slusser, W. Gao
3. Changes in the concentration of some secondary metabolites after treatment with ultra-violet light on St. John's wort, *Hypericum perforatum*	M.L. Brechner*, L.D. Albright
4. Enhancing nutritional value of fresh tomato under controlled environments: a summary of collaborative research effort	C. Kubota*, C.A. Thomson
5. Photosynthetic characteristics and growth of rice plants under red light with or without supplemental blue light	R. Matsuda*, K. Ohashi-Kaneko, K. Fujiwara, K. Kurata
6. Effects of duration of temperature perturbations during flowering on tomato fruit	A.J. Both*, L.S. Logendra, D.L. Ward, T. Gianfagna, H.W. Janes, T-C. Lee
7. Grapevine physiology in controlled environments	D. Greer
8. Hypobaria, hypoxia and ethylene influence growth and gas exchange of lettuce plants	F.T. Davies*, C. He, R.E. Lacey
Session B General Discussion	E. Runkle

* Denotes presenter.

Reporter: Laurence Benjamin (Rothamsted Research, TSS Section, West Common, Harpenden AL5 2JQ, UK)

The theme of the eight papers of this session was split between investigations into the effects of spectral quality on secondary metabolite production and investigations into the effects of stresses on primary production and secondary metabolites. The interest in secondary metabolites lay in their human nutrition and medicinal value, especially the production of anti-oxidants. The relevance to space flights was stressed, with emphasis on ensuring that plants produced for food in space have high nutrition value. Also the limitations for space flight was a driver for the experiments, with concerns about investigating the effects of interruptions in power supply and use of low air pressures on plants (to minimise amounts of gases to be transported to space and to reduce leakages).

Some of the experiments gave interesting and unexpected insights to the physiology of plants. Caldwell[2] *et al*. reported that there was an interaction between the relationship between relative increase in flavonoids and absolute increases in phenolic esters for red and green varieties of lettuce in response to increased UV light. They speculated that this interaction could be explained by grouping of enzymes involved in secondary metabolism on cell membranes, causing a 'metabolic channelling' within plants.

Another unexpected finding was that whereas a single dose of UV light causes a three fold increase in a secondary metabolite (hyperforin), but constant or increased daily doses had little further effect[3]. A physiological basis for this pattern of responses could not be provided.

Blue light was reported by Matsuda[5] *et al.* to increase plant growth via enhanced leaf protein and rubisco content. This paper used red and blue LEDs as treatments and there was a discussion on how to balance the red and blue light levels so that light quality treatment was not confounded with total light flux.

For some of the papers, some additional measurements would have greatly enhanced their general relevance. For example, high or low temperature interruptions produced blossom end rot in tomatoes in some treatments[6]. Supplementary measurements of water use, relative humidity or calcium content were not made, but these would have given a better understanding of the underlying responses of the tomato plants to the treatments. Similarly, it was reported that sporadic high temperature episodes caused browning in grapes[7] but the internal grape temperature had not been recorded. It was pointed out in the discussion that without this information, it was difficult to deduce what internal mechanisms were responsible for the browning response.

In the general discussion, the difficulty of measuring UVB was highlighted. For example, the LI-COR 1800 measures radiation in the range 300-850 nm, but UVB is in the range 280-315 nm.

Two outstanding issues were identified (1), the action spectrum for the production of secondary metabolites is not known and (2) the effect of cultivar and underlying genetics on the response of plants to UVB is still to be determined.

Session C: Non-traditional Applications in Controlled Environments
Moderator: L.D. Incoll

1. Guidelines for measuring and reporting environmental parameters in controlled environments used for plant tissue culture experiments	M.P. Fuller*, S. Millam, L.D. Incoll
2. Biopharmaceutical production under controlled environments: photosynthetic rate, soluble protein concentration and growth of transgenic tomato plants expressing a *Yersinia pestis* F1-V antigen fusion protein	R. Matsuda*, C. Kubota, L.M. Alvarez, J. Gamboa, G.A. Cardineau
3. Plant-made pharmaceuticals: scaling up production	J.H. Norikane
4. Waste-energy-leveraged CEA for year-round specialty-crop and bio-fuel feedstock production in temperate climates	C.A. Mitchell*, G.D. Massa, C. Alexander, R. Turco, J. Dennis, A. Murphy, S. Weller, B. Bordelon, R. Lopez
5. Commercial aeroponic farming of baby leafy greens	E.D. Harwood
6. Climate change and controlled environments	M. Stenning
Session F General Discussion	L.D. Incoll

* Denotes presenter.

Reporter: George Waimann (Rothamsted Research, TSS Section, West Common, Harpenden AL5 2JQ, UK)

This section contained a variety of papers reflecting the ‘catch all’ nature of this session. From the initial presentation on the tissue culture guidelines to the final presentation on climate change research in controlled environments, a wide variety of uses for controlled environments were presented.

Although the discussion and question& answer session was at the end of the set of papers, the questions and answers are here placed after the paper to which they referred.

Paper 1: Guidelines for measuring and reporting environmental parameters in controlled environments used for plant tissue culture experiments. Speaker: M.P. Fuller

Mick Fuller gave an overview of plant tissue culture, noting its extensive use in horticulture. He noted the need by the ‘industry’ to have consistent reproducible conditions and the fact there existed no standard set of reporting conditions. Indeed he noted how poor in some instances monitoring of conditions was. The sheer size of tissue culture facilities was impressive with over 45 million plants alone grown annually in Holland, and 75% of the Scottish seed potato crop, from tissue cultured plants. He reinforced the necessity to disseminate this information and to promote the posters.

> A statement was made from the floor: People often know what works in tissue culture facilities but do not wish to share such information as it can be commercially valuable.

> ***Question)*** Where do you get a small poster? ***Answer)*** When members of the UK CEUG, NCERA-101 and ACEWG have received copies from their group's committees, the small poster (and the tissue culture guidelines leaflet) will be made available for downloading from the NCERA-101 web site.
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> ***Question)*** Why not put explants in a plant growth medium such as peat rather than Agar? ***Answer)***. Agar gel is the best medium for transmission and uptake of soluble material taken up by tissue culture cells because, at a concentration of less than 1%, agar gel is almost 100% water.
>
> ***Statement)*** It is important to use same lot number of agar per phenotype. ***Reply)*** It is, but not to report it because a particular lot number is unlikely to be available to different research groups. There is a lot of variation between agars, so we specified type, manufacturer and most importantly the pH of the medium. Co-author Lynton Incoll observed, in response to the idea that such detail as lot number should be in the tissue culture guidelines leaflet, that there is only so much information that will fit on an A4 or letter-sized sheet of paper.

Paper 2: Biopharmaceutical production under controlled environments: photosynthetic rate, soluble protein concentration and growth of transgenic tomato plants expressing a *Yersinia pestis* F1-V antigen fusion protein. Speaker: R. Matsuda

Ryo Matsuda presented a paper outlining a facility, large greenhouse, used for growing plants expressing an antigen that could be used as a vaccine. The facility itself was a large glasshouse with wet pad fan cooling and overhead heating system. The facility was used to study the growth response of tomato plants carrying the vaccine protein versus control tomatoes. The biochemistry was complex for an engineer and more on the facility would have been interesting. Possible containment issues as well the requirements for pharmaceutical production would have useful.

> ***Question)*** Have you tried vacuum infiltrating seeds? ***Answer)*** No, I have not.

Paper 3: Plant-made pharmaceuticals: scaling up production. Speaker: J.H. Norikane

J. Norikane gave a good presentation on a production system, using *Nicotiana* to produce novel proteins in their leaves. The process of using agrobacterium in leaves to produce novel proteins that could be used as vaccines was complex., however the potential to produce vaccines in as little as 12 weeks showed great promise. The leaves of five to six week old *Nicotiana* plants were vacuum infiltrated by the agrobacterium and then allowed to grow a further few days before extraction. The conditions of light and temperature were not exacting but were required to be reproducible. The need to grow in a contained environment, aseptically were challenging, especially if harvesting by hand was required.

Paper 4: Waste-energy-leveraged CEA for year-round specialty-crop and bio-fuel feedstock production in temperate climates. Speaker: C.A. Mitchell

Cary Mitchell presented details of a facility using waste heat for plant production. The potential to extend growing seasons using waste heat in polytunnels was explored and the problems highlighted. It was recognised that light was an issue. The use of this facility to grow and produce feedstock (biomass) for the power station producing the waste heat was discussed as was the production of speciality crops. This is a concept that could be readily developed on district heating schemes, especially those utilising CHP, large thermal storage systems or geo-thermal energy.

> ***Question)*** You are now talking about a Green House rather than a polytunnel! ***Answer)*** Tunnel, Green House, etc, it does not matter, a high tunnel can be easily installed at a waste heat plant, it's all about economics!
>
> ***Question)*** What are you going to do with the plants? *Answer)* Go back 50-60 years and grow locally to meet local demand, rather than transporting from Mexico.
>
> ***Question)*** You are using the heat in the winter months what do you plan to do in the summer? ***Answer)*** In summer there is more cooling water from the towers (heat), the heat could be stored in thermal storage. The temperature in the region provides only one growth season, thermal storage and the utilisation of waste heat will enable the extension of growth seasons.

Paper 5: Commercial aeroponic farming of baby leafy greens. Speaker: E.D. Harwood

Edward Harwood presented a system for growing baby leaf greens effectively in a growth room. I was impressed that this was being developed as a commercial system. The system consisted of plants growing through a polyester cloth, the roots being sprayed with a nutrient solution. Lighting was supplied by 400 W high pressure sodium lamps. Temperature control was provided fans using heat from lit areas to heat unlit areas. An economic breakdown was given of costs and potential sales. Although an impressive system sales were key to making the system viable, however the system enabled the ability to produce year-round mixed salad to a consistent quality required by the retailers.

> ***Question)*** Is the cloth scrapped after each production run? ***Answer)*** The roots are scraped off and the cloth is put in the washing machine, "my wife was horrified".
>
> ***Question)*** With reference to the water sprays, are you using solenoids and mains water pressure? ***Answer)*** No pumps, the power to drive the pumps is not a lot compared to the power required for lighting.
>
> ***Question)*** Are you growing red leaf lettuce? ***Answer)*** No, but I will, following this meeting.

Paper 6: Climate change and controlled environments. Speaker: M. Stenning

Martyn Stenning provided a compelling overview of climate change and where controlled environments could be used to study these changes in quite complex ecosystems. The value of controlled environments was shown to be in the ability to change single environmental factors in quite complex ecosystems. The extension of work on single species to groups of plants in an ecosystem as well as herbivores such as birds was interesting. The environmental impact of the use of controlled environment facilities was also discussed Martyn showed us a slide of the ECOTRON facilty in the UK, which unfortunately is still under threat of closure in spite of its potential to effectively carryout this type of research. The use of recovered heat, and more energy efficient light sources was highlighted.

SESSION D

Monday, March 10

Session D: Novel Instrumentation, Sensors, and/or Analysis Approaches
Moderator: Bruce Bugbee

1.	Estimating carbon use efficiency, growth respiration, and maintenance respiration from canopy gas exchange measurements	M.W. van Iersel
2.	Hands-off sensors: applications of spectral devices to controlled environment agriculture	G.L. Ritchie*, J. Frantz, C. Bednarz, B. Bugbee
3.	Evaluation of two new net radiometers	J. M. Blonquist Jr.*, B Tanner, B. Bugbee
4.	Effect of atmospheric pressure on wet bulb depression	R.M. Wheeler*, M.A. Stasiak, J.Lawson, C.A. P. Wehkamp, M.A. Dixon
5.	Large high-output LED arrays for plant growth	R.C. Morrow*, C.M. Bourget
6.	Probing responses of plants by chlorophyll fluorescence under controlled environments	H.M. Kalaji
7.	Automatic and 3-dimensional phenotyping of complete plants in greenhouses	J. Vandenhirtz*, M. Eberius, D. Vandenhirtz, H.G. Luigs, G. Kreyerhoff, U. Bonger, M. Radermacher, H. Lasinger, R. Schunk
8.	Uniformity in soil plant atmosphere chambers	D.H. Fleisher*, D.J. Timlin, V.R. Reddy
9.	Real-time measurement of whole plant transpiration and stomatal conductance using electronic balances and infrared sensors	B. Bugbee*, J. Chard
10.	Monitoring and controlling substrate water content in controlled environments	M.W. van Iersel

* Denotes presenter

Reporter: Mick Fuller (The Graduate School, University of Plymouth, Plymouth PL4 8AA, UK)

Paper 1. Estimating carbon use efficiency, growth respiration and maintenance respiration from canopy gas exchange measurements. Speaker: Marc W. van Iersel

Marc reviewed the concept of chamber gas exchange as a measure of net photosynthesis and estimating carbon use efficiency and respiration. Carbon use efficiency was defined as net amount of carbon fixed divided by the gross amount fixed and showed that this is about 60% i.e. respiration counts for 40%. The respiration component is made up of both respiration during the dark period and respiration during the light period and respiration in the light period have two components the “true” respiration and “photorespiration” but that photorespiration has to be assumed to be included in the net growth measurements. He also

discussed the paradigm of Growth + Maintenance, a description frequently used in animal studies but little in plant studies.
After reviewing some concepts and data he concluded that whole plant i.e. chamber measured photosynthesis is much more useful than measurements of leaf photosynthesis. His approach would be the same for either C3 or C4 plants.

Using his approach he was able to demonstrate when small changes occurred in CE chamber efficiency e.g. a variation in temperature or a drop in the output of chamber lights.

Paper 2. Hands-off sensors: applications of spectral devices to controlled environment agriculture. Speaker: Jonathan Frantz.

Sub-titled- The Dark side of electric lights

Reflectance sensors designed for detecting health of the canopy and stress are made for the field and therefore need correcting if used in controlled environments. Incandescent lights have as similar spectrum to sunlight and therefore are good for CE reflectance measurements. Reflectance noise from a canopy can be cleaned up by measuring reflectance from a white background first and then subtracting it from the reflectance of a canopy to get an NDVI (normalised digital vegetation index) can be used to pick up stress in the plants.

Fluorescent and HPS lamps have very peaked spectra and even in glasshouses with supplementary lighting can pose some problems and it is easy to pick up light contamination from neighbouring glasshouses with supplementary lights even when there is little or no detectable extra PAR.

One can use remote sensing in glasshouses to detect stress but it's only reliable in natural sunlight. In CE's its difficult because most stress is measuring in the NIR waveband and there is not a lot of signal in this waveband with artificial lights.

Paper 3. Evaluation of two new net radiometers. Speaker: J. Mark Blonquist

Mark presented data which evaluated two new net radiometers (CNR2 and REBS Q7.1)) and compared them to existing models. The CNR2 has two sensors, a net SW (short wave) sensor and a net LW (long wave) sensor. The REBS Q7.1 has one sensor which measured SWi-SWr + Lei-LWe.

Sensors were compared to two standard CNR1 sensors. All SW sensors were calibrated to a reference standard Quantum Sensor and all were within 1%. For LW measurements and Infrared camera was used and all sensors were within 2%.

All systems matched up reasonably well on instantaneous measurements but when integrated over time showed up some differences:

1. CNR1 was the most accurate
2. NR01 had outlier data points
3. CNR2 was accurate but SW measurements mismatched
4. NR-Lite had offsetting errors
5. Q7.1 had offsetting errors

For CE measurements of LWR the CNR1 was best because it has the four sensors and these can be logged separately.

Paper 4. Effect of atmospheric pressure on wet bulb depression. Speaker: Ray Wheeler

The literature reports that transpiration increases at low atmospheric pressure, but water vapour does not act as an ideal gas and has a 1-3% error.

He measured wet bulb temperature at five pressures and three %rhs in hyperbaric chambers and found that measurements matched the modelled equations. At low pressures evaporation rates were higher and leaves therefore would be cooler than expected.

Paper 5. Large output LED arrays for plant growth. Speaker: Bob Morrow

Demonstrated large LED arrays 3-10 ft x 15 ft (1-3 m x 5 m) in CEs comprised of blue 458 nm and red 640 nm. As LEDs get warmer their output drops and so cooling is necessary – they use distilled water cooling. At max output the LED array uses 52 amps and 9120 watts.

At 1 cm distance from the array leaf temperature rises by 2 0 °C but no effect if more than 10 cm away.

In-situ efficiency for LEDs giving 1000 µmol m^{-2} s^{-1} at the canopy surface comparing LEDs with conventional light sources is:

Light Source	*In situ* efficiency / µmol per J (radiant energy)
LEDs	1.231
HP/MH	0.285
HPS	0.417

Can add a bit of green LED to make a white light for human comfort but the blue+red are the most efficient for plant growth.

We still need development of:

- More wavelengths
- Higher outputs
- More electrical efficiency
- Lenses
- Cheaper designs

Paper 6. Probing the responses of plants by chlorophyll fluorescence under controlled environments. Hazem Kalaji (This paper was not presented because the speaker had failed to gain a US visa in time to attend the conference)

Paper 7. Automatic and 3-dimensional phenotyping of complete plants in greenhouses. Speaker: Joerg Vandenhirtz

Joerg presented the 3D analyser of LemnaTec. Standard systems measure only in 2D. This system takes a picture at two angles and can be used with a conveyor belt, irrigation and spray actions via robotics. The system takes its pictures and the plant image is skeletonised and analysed as a set of vectors and can be reconstructed as an image but with data that can be analysed. Data can be projected to give a theoretical biomass accumulation over time.

System can detect flowering time, characterise compactness, detect disease lesions, colour differences and even used for phenotyping of cereal varieties. With the use of other sensors e.g. fluorescence and NIR then can classify water content and give information on root performance using a plastic pot/tube and measuring roots on the tube surface. Infrared imaging is also possible.

The system was recommended for high throughput applications e.g. in plant breeding.

Paper 8. Uniformity in soil plant atmosphere chambers. Speaker: Dave Fleischer

Dave described the SPAR chambers (SPAR = soil, plant, atmosphere research). They have 18 chambers in total. In these chambers which are naturally lit they can measure soil moisture using TDR, net photosynthesis by gas exchange and evapotranspiration. The main use of the chambers is to produce models of plant growth and development.

Chambers were assessed in a uniformity trial using the Apogee dwarf wheat cultivar which is fast growing.

Control achieved was ± 0.4 °C of set temp; ± 50 ppm of set CO_2 but got some variation of relative humidity between chambers. There were some differences in leaf appearance rate and he queried if this would impact on the modelling. Some effects in stem elongation rates too. Found that variability was greater within a chamber than between chambers. Despite the variations in %rh there was no relationship with crop response. They will use covariate adjustments in future experiments.

Paper 9. Real-time measurement of whole plant transpiration and stomatal conductance using electronic balances and infrared sensors. Speaker: Bruce Bugbee

Bruce presented a paper based on the use of electronic balances. This was currently justified because of the reduced cost of balances and this makes them a viable technique for studying water relations in CEs. Balances were constantly logged into a datalogger and intital concerns were load cell fatique when constantly challenged but this did not prove to be a problem. Basically, a plant in a pot on a balance which is logged every minute can give accurate and good measurements of transpiration. Evaporation can be minimised by enclosing the pot in a plastic bag.

He tested the system with cotton plants and found that plants could transpire 6g water per minute. He investigated whether MCP inhibits transpiration *per se* (as reported in the literature) and found no effect of MCP by this method.

He was able to calculate stomatal conductance by dividing the transpiration by the VPD and this gave an easy calculation of stomatal conductance.

They investigated two types of balance costing US$300 and US$750. The only difference was that the cheaper balances were not temperature compensated so if used in constant temperatures they were OK or if averaged over 10 to 15 min you could take out the error of the temperature cycling in the CE.

Paper 10. Monitoring and controlling substrate water content in controlled environments. Speaker: Marc van Irsel.

Marc reviewed soil moisture sensors. He made the point that soil moisture measurement is not in the Minimum Guidelines but if not paid attention to then it will severely affect plant performance and he considered that substrate water content was the most overlooked variable in CEs. Even at 5% substrate water content, plants often don't look as if they are drought stressed. At substrate water contents of 37%, plants are generally unaffected by variation.

Capacitance sensors have the same principle as TDRs and measurements are simplified and sensors are inexpensive.

Decagon probes (EC5s, 10s, 20s and the TE) need to be left *in situ*.

Delta T thetaprobe, W.E.T. sensor, and SM200 are good for moving about and occasional use.

Campbell Scientific CS616 + CS62S are OK. Electrical conductivity (EC) of soil water can affect these.

All soil water content probes must be calibrated with the substrate you use – DO NOT BELIEVE the manufacturers calibration curves. And calibration changes with compaction (bulk density) and with high soil EC but the Echo probes are least affected by EC.

The Echo 10 is very sensitive to temperature but the others are not sensitive to temp.

There have been big advances in recent years. Decagon offer remote logging using wireless communication to a computer.

Delta T and Dynamax offer a constant measure which will remotely switch on/off the irrigation based on two sensors and can be used for efficient watering.

Nemali and Irsel 2006 (via a paper from the website) show that it is possible to maintain a setpoint water content in a pot using an irrigation controller with a 15 s pulse irrigator and a 2-4 L h^{-1} dripper nozzle.

Session E: Design and Development of New Facilities
Moderator: Alex Turkewitsch

1.	Engineering in sustainability and innovative development of controlled environments: a UK perspective on refrigerants, achieving efficient systems and energy management	G. M. Waimann
2.	Description, operation and production of the South Pole Food Growth Chamber (SPFGC)	R.L. Patterson*, G.A. Giacomelli, P. Sadler
3.	New Bioscience Complex at University of Maryland	G. F. Deitzer
Session E Short Discussion		A. Turkewitsch
4.	The Biotron and Guelph's plant productivity model	E.D. Leonardos, M.J. Iqbal, A. Singh, N. Hüner, B. Grodzinski*
5.	Containment level 3 facility for growing genetically modified plants and plant pathogens	J. Franklin*, R. Taberer
6.	The Australian Plant Phenomics Facility	T. Agostino
Session E Short Discussion		A. Turkewitsch
7.	***(An addition to the published programme)*** Kooland – a Chinese company manufacturing 'CE'	Qian Xioafeng, Ke Gang

* Denotes presenter.

Reporter: Graham Pitkin (Scottish Crop Research Institute, Estate Department, Invergowrie, Dundee DD2 5DA, UK)

Paper 1: Engineering in Sustainability. A UK Perspective on Refrigerants, Achieving Efficient Systems and Energy Management. Speaker: G. Waimann

George Waimann's presentation gave a very thought provoking overview of the efficiencies / inefficiencies of current CE, answering many half – formed questions that facility managers have about the best way to run CEs. UK and EU legislation on refrigerant gasses changes yearly, and the UK faces problems now that US will not face until 2030 (use of HCFC). There are other gases with far lower GWP and TEWI e.g. NH_3 and CO_2. Designers of new facilities should consider the use of these and of free cooling such as ground source, heat recovery, thermal storage, and by attending to detail such as using correctly sized exchangers and compressors. Sophisticated modelling programs exist and should be used. Typical costs during the life time of a CE unit are 20% installation, 20% maintenance and 60% energy consumption. There are many ways to reduce energy consumption during use, including the use of invertors to control pump speed – running pumps more slowly saves energy by cubic function.

Interestingly there were no questions from the floor. (The UK contingent asked many questions at George's last presentation on this subject at Aberystwyth in September 2007 (see http://www.ceug.ac.uk/documents/proceedings-06-acro_003.pdf). This reflects the difference in relative energy costs and the immediacy of the problem of finding new refrigerants in the

UK / Europe compared to the USA. These issues appear to be taken less seriously in the USA, although Cary Mitchell's paper showed that some in the US are taking sustainability seriously.)

Paper 2: Description of the Operation of the South Pole Food Growth Chamber. Speaker: R.L. Patterson

A 55 m^3 area within the Amundsen – Scott South Pole station is given over to the hydroponic production of salad crops and vegetables. Half of this area is a CE growth room, the rest being engineering plant, and preparation space. The water cooled HPS lights provide a heat source for the station and relief for the personnel from the six months of darkness. The lighting is sufficient to produce 4.6 kg fresh food per day (500 calories). The hydroponics growth chamber is run at 24/18 °C 60%rh and 1000 ppm CO_2. This consumes an average of 281 kWh per day from fuel oil fired generators. There are a total of 42 sensors monitoring the growing facility. An IPM programme controls pests, but there is algal contamination of the nutrient solution.

This interesting talk provoked questions mostly about the recycling or disposal of waste from the Station.

Food waste is flown to McMurdo Base and shipped out to Australia once a year!

Paper 3: New Bioscience Complex at University of Maryland. Speaker: G.E. Deitzer

Gerald F Deitzer described the new facility that was opened in September 2007. The abstract describes it in detail. Some innovations in their CE include the use of quantum sensors to maintain the light set points in their Percival chambers. They had measured the spectral distribution of different lamps and recommend plotting a logarithmic graph to emphasise the differences between light sources.

We were shown photographs of the successful production of orchids in the facility.

Paper 4: The Biotron and Guelph's Plant Productivity Module. Speaker: A Turkewitsch
This research facility is based at the University of Western Ontario and University of Guelph (Canada). B. Grodzinski described that the concept was to bring together environmental biology, agriculture and medicine, in a facility that could address a number of ecological issues. Climate control chambers capable of handling 10,000 kg of soil, and six containment level 3 rooms enable entomologists, soil and plant scientists to work together.

Paper 5: Containment level 3 facility for growing genetically modified plants and plant pathogens. Speaker: B. Grodinski

Julian Franklin described the newly opened facility at Rothamsted Research, Harpenden, UK. The efficient use of energy was a theme running through the facility from its design, build and ongoing maintenance costs. The 2009 meeting of the UK CEUG is scheduled to meet here, and members should get an opportunity to see this facility for themselves. Most interest from the floor, as with the Antarctic Station, was concerned with the handling of waste from the facility, particularly treatment of waste water – chemical methods versus UV irradiation. Containment of insect cultures was a problem familiar to some. The effectiveness of the air shower was discussed (its effectiveness has yet to be fully established).

Paper 6: The Australian Plant Phenomics Facility. Speaker: T. Agostino

A large amount of funding has been made available to create this facility, sited at Adelaide and Canberra. The Canberra Phytotron, visited by some UK delegates to the 2004 International Meeting on Controlled Environments, is to be redeveloped at a cost of A$18m over 5 years. The facility will incorporate non-destructive whole plant analysis and allow technologies to be transferred to the field. Those of us that saw the Phytotron in 2004 will recall that the structure was in need of some refurbishment!

Paper 7: (an addition to the published programme) Kooland – a Chinese company manufacturing 'CE'. Speaker: Q. Xioafeng

A director of the Kooland company gave a brief description of his companies interests in CE, with some examples. These included a cold seed store; and a zootron animal handling unit, researching animal nutrition. Six chambers with air movement and gas content control had been constructed. The Chinese have yet to enter the US or European markets with this type of equipment.

SESSION F

Tuesday, March 11	
Session F: Reliability and Quality Control for CEA Facilities *Moderator: Mark Romer*	
1. Quality standards in CE; implications for the user	L. Benjamin
2. Performance verification of new research greenhouse facilities	A. Turkewitsch*, D. Brault, B. Faucher
3. Energy efficiency and green technologies in environmental chambers	D. Kiekhaefer*, H. Imberti
4. Supervisory control – implications for environmental control systems	A. Mackenzie
General Discussion	D.H. Fleisher

* Denotes presenter

Reporter: Julian Franklin (Rothamsted Research, TSS Section, West Common, Harpenden AL5 2JQ, UK)

The session consisted of four talks, all quite different, both in their content and approach, although addressing the theme of the session.

The first talk by Laurence Benjamin on 'Quality Standards in CE; Implications for the user'[1] addressed the need for accuracy and reliability in the measurement of environmental parameters as defined by the International Committee for Controlled Environment Guidelines. Laurence demonstrated via the use of several models for plant growth and development, the effect of just a deviation of 2°C from a set point. Consequences that arose were changes in time to flower by up to ± 5 days over 50 days and yield differences of ± 9%. Such changes it was pointed out masked differences between treatments. As well a 10% increase in the duration of the experiment represented a significant increase in costs to the experimenter. I think Laurence clearly demonstrated the need for accurate measurement of parameters both scientifically and in terms of cost, not an insignificant item when rooms cost up to £15 a square metre a day to run. Reference was also made to quality assurance standards required by funding agencies notably within the UK.

Alex Turkewitsch[2] addressed the requirement to validate the performance of a new containment glasshouse facility at Laval University in Quebec, Canada. Of primary concern was the air exchange performance, (infiltration) of the facility. The builder was required to ensure that the glasshouse achieved less than 0.1 of an air change an hour. Using the data from the greenhouse control systems and looking at CO_2 depletion rates, the authors built up a picture of the effects of temperature and wind direction and speed on the structural integrity of the glasshouses. The response to such changes was apparently not simple, with increasing wind speeds not always resulting in increased leakage. Internal temperature had an effect on leakage rate, as did wind direction, however perhaps not as one would have thought. I found his validation fascinating having had to estimate for leakages from glasshouse structures under varying circumstances myself using similar methods.

Daniel Kiekhaefer from Percival Scientific was on ‘Energy Efficiency and Green Technologies in Environmental Chambers’[3]. The speaker examined a variety of energy efficient changes for one of their latest Model PC-10 chambers. The main saving was the introduction of the T5 lamp over the T12 lamp. Apart from being more energy efficient in terms of light output per watt the lamps also operated at higher temperatures thereby requiring less cooling. Both factors resulted in considerable energy savings of +30%. More efficient lighting required less cooling plant, especially when better insulation was installed. His paper showed what can be done when modern efficient technologies are applied to Controlled Environment chambers. I would hasten to add that most CE suppliers, certainly those from the UK, have already implemented many, if not all the changes made by Percival.

Alec Mackenzie spoke on ‘Supervisory Control - Implications for Environmental Control Systems’[4]. He examined the use of computing software to integrate the best strategies, (environmental parameters) with responses to external conditions as well as models for optimum production. Alex outlined the capabilities of existing computing environmental control systems where basic parameters such as lighting, temperature and humidity are controlled at ‘user defined’ levels. He discussed the integration of strategies such as temperature profiling to meet production dates as well as energy optimisation. He mentioned the need to have ‘guardian’ software to meet extreme external conditions as well as to oversee ‘optimisation’ software, preventing extreme internal conditions. The talk outlined a supervisory system that sat on top of an existing greenhouse control system enabling higher level optimisation but allowing basic functions, including basic ‘guardian’ functions to be carried out by the basic glasshouse control system. This was a good talk for those with an interest in the complexities of computer control systems and their application to improving crop production.

The common message from the four talks was that improved control of controlled environments will reduce their running costs.

Poster Presentations

	Session A: New Approaches for Control and Monitoring Environmental Conditions	
1.	Evaluation of a humidity insensitive sorbent-based air sampling system	A. Flanagan*, D. Braithwaite, T.S. Topham, G.E. Bingham, O. Monje
2.	Predicting night-time low temperatures in unheated high tunnels	A. Ogden*, M. Van Iersel
	*Session B: New Responses / Research Results from Experiments in CE*A	
3.	Development of a production system for basil on the International Space Station	A.R. Beaman*, R.J. Gladon
4.	Harvest index of 'Rocky' cucumber plants (*Cucumis sativus* L.) grown in elevated CO2 is not different from 'Rocky' cucumber grown in ambient CO_2	L. Crosby*, E. Peffley, L. Thompson
5.	Modified field environments for high latitude crop production	M. Karlsson*, J. Werner
6.	The potential for autotoxicity of root exudates in commercial hydroponic lettuce (*Lactuca sativa*) production	N.S. Mattson*, L.D. Albright, M.L. Brechner
7.	Research plants in controlled environments – does green waste compost make a reliable alternative substrate to peat?	G. Pitkin*, R. McHutchon
8.	Effect of light quality on growth of *Salvia miltiorrhizr* Bunge	Q. Li*, Z.-S. Liang
9.	Effects of a new cyclical lighting system on flower induction in long-day plants: a preliminary investigation	M.G. Blanchard, E.S. Runkle*
	Session C: Non-traditional Applications in Controlled Environments	
10.	Isotopic labeling of red cabbage anthocyanins with atmospheric $^{13}CO_2$ in closed environments	C. Charron, S. Britz*, R. Mirecki, D. Harrison, B. Clevidence, J. Novotny
11	Effect of elevated CO_2 and harvest schedule on *Allium* biomass and sensory quality of *Allium fistulosum*	A. Broome*, E. Peffley, L. Thompson, D. Wester
12.	How to measure and report growing conditions for experiments in plant tissue culture facilities	ICCEG
	Session D: Novel Instrumentation, Sensors, and/or Analysis Approaches	
13.	Maintaining and quantifying drought stress in containers	J. Chard, B.Bugbee*
	Session E: Design and Development of New Facilities	
14.	Energy saving measures in controlled environments at Rothamsted Research	I. Pearman, J. Franklin*, G. Waimann
	Session F: Reliability and Quality Control for CEA Facilities	
15.	Containment of quarantined insects	R. Natt

16.	Growth chamber maintenance costs and factors influencing equipment longevity, reliability and operating quality	M. Romer*, C. Cooney, F. Scopelleti, G. Orr
17.	A risk analysis of the production of hydroponic babyleaf spinach with respect to *Pythium aphanidermatum*	T.J. Shelford*, L.D. Albright

* Denotes presenter.

Reporter: Martyn Stenning, School of Life Sciences, University of Sussex, Brighton BN1 9QG, UK

The 17 posters presented were about as diverse as they could be for a conference on controlled environment agriculture. Perhaps the most important one was that presented by our own Professor Mick Fuller[12] on behalf of the International Committee for Controlled Environment Guidelines. It was concerned with the protocol for measuring and reporting growing conditions for experiments in plant tissue culture. Very soon, all our institutions will be able to have a supply of these guidelines in the form of leaflets and posters. This follows on from the excellent leaflets and posters arising from the ICCEG setting out the guidelines for measuring and reporting environmental parameters for experiments on plants in growth rooms and chambers. This information is a must for any institution concerned with these techniques.

The remaining 16 posters were reporting experiments and research using controlled environments in divers and novel ways. I was interested to see how the frontiers were being pushed back in food production[2, 3, 4, 5], and pest control[15, 17] as the planet moves into a food deficit phase requiring a huge increase in production. I was also interested in the emphasis placed on energy saving techniques[2, 3, 7, 14, 16], sampling[1] and measuring[13] systems.

Perhaps the most engaging poster was presented by Angela Beaman[3] who was working on growing sweet basil (*Ocimum basilicum*) with a view to cultivating it on the International Space Station. The poster focussed on the most energy efficient methods for doing this, not to necessarily minimise its carbon footprint, but to conserve energy on the space station. Here is another example of how space technology can have terrestrial applications! The research compared several cultivars and scored them for biomass and fecundity under several light regimes.

Another fascinating poster was presented by Aisling Flanagan[1] another internee at NASA assigned to evaluate a humidity insensitive sorbent–based air sampling system. High humidity is often best for growing plants, however, it can be a problem when sampling air. This research concluded that heating the adsorbent tube while sampling reduces the sampling volume required to accurately measure the atmospheric volatile organic compound concentration.

In our health conscious modern world, the idea of producing blueberries out of season seems attractive. This was the subject of a poster presented by Andrew Ogden[2] the research found that temperature inside polytunnels often dropped below ambient, and heating them was expensive. Frost blankets could be used to save fuel, but by making detailed recordings using data loggers, it was possible to produce a model that could predict night-time lows sufficiently to actively minimise fuel and labour costs.

It has often been said that not enough negative results are published, because a negative result is still a result, and therefore useful for future reference. Crosby *et al*.[4] found that although some parameters of cucumber plants grown in elevated CO_2 were significantly different from controls, harvest indices of plants grown in elevated CO_2 were not significant from controls. Continuing the fruit and vegetable theme, Karlsson & Werner[5] tested high tunnel materials using raspberries and found that a material called K50 IR/AC produced the best results. This may be useful for future reference. The Cornell group (Shelford *et al*.) presented a poster[17] on disease control when growing hydroponic spinach. It was informative about the disease (*Pythium aphanidermatum*) and the methods using a clever use of the risk assessment process, but was only preliminary, and had no results to present.

Plants killing other plants (allelopathy) is an interesting area of plant science. However, lettuces killing or inhibiting other lettuces is a novel idea[6] presented by Mattsen *et al*. The poster presented discussion on the potential for these autotoxic compounds to limit production in containers.

The importance of light quality (spectrum) to plant production has been often tested. A Chinese group[8] presented their results using Dan Shen or red sage (*Salvia militorrhiza*). This herb is credited with properties that help heart disease. While this poster reported differences in growth patterns under different wavelengths, I think it added very little to the understanding of the plant or controlled environments. In contrast, the poster presented by Matthew Blanchard & Erik Runkle[9] introduced something genuinely new, namely an oscillating parabolic reflector that provides an intermittent beam of light over a large growing area from one high pressure sodium lamp during the night from 2200 hours to 0200 hours to control flowering in long-day plants. Unfortunately the system malfunctioned, and the results were not conclusive, but indicative that this system works, and may be used as an energy saving measure.

I spent some time talking with Stephen Britz about his poster[10] on isotopic labelling of red cabbage anthocyanins with atmospheric $^{13}CO_2$ in closed environments. I had done some experiments with anthocyanins in the past, and am still fascinated by these important pigments. I was also interested in the design of the closed environment, particularly the use of a “cold finger” to condense the water vapour to water the plants. The group were able to identify a total of 37 anthocyanin compounds from red cabbage. In follow up correspondence with S Britz, he said something that may be of interest to other members of the group, namely: “… another project we have is to investigate CO_2 x temperature x drought interactions on tocopherols (i.e. vitamin E) and isoflavones in developing soybean seeds? I think it's a good example of the use of controlled environments for global change research. It would be difficult, or at least expensive, to vary temperature systematically in free air CO_2 enrichments (FACE). I would add that it's important to validate controlled environment work with field experiments, if possible. We see the same results in soybeans from stressed conditions in the field as we do in the growth chambers.”

Graham Pitkin (SCRI) presented an interesting poster[7] on the use of green waste compost (GWC) as an alternative to peat. As responsible environmentalists, we should all seek to avoid using moss peat in our growth media as it destroys ancient raised mire habitats that take millions of years to develop. So recycling green waste is an obvious good practice alternative. The results suggest that GWC may not be quite as good as peat, but that the growing environment caused greater differences in growth than the type of compost.

Allium spp. (onions and garlic) are important components of a healthy diet. The CO_2 concentration of global atmosphere is increasing. Broome *et al.*[11] presented an excellent poster, crammed with maybe too much information, and found that Allium spp. grown in elevated CO_2 showed few differences and actually seemed to taste less good than those grown in ambient CO_2.

As usual, Bruce Bugbee's group[13] produced a poster packed with controlled environment information. This time they were addressing the topic of drought stress in containers. They used soil columns and soil-less media in pots. The poster described the methods of measuring soil water potential using Watermark sensors. Gravimetric measurement of transpiration was done using balances. On a larger scale, solving the problem of expensive high energy use in controlled environments was addressed by Pearman *et al*. This was an excellent poster[14] showing how addressing energy wastage by replacing old inefficient kit with new energy efficient units can both save money and help to save the planet. Continuing the 'how to' theme, Richard Natt's poster[15] showed us how to contain insect pests in controlled environments. This poster would provide a good starting point for anyone wishing to begin research on insect pests; I certainly intend to keep a copy for future reference as I often have to work with insects.

Finally, Mark Romer presented an excellent poster[16] summarizing a huge amount of information about the McGill Phytotron. This was an excellent example of a well run facility, and could be used as a bench mark for the rest of us university managers of CE units.

EDITOR: L.D. Incoll
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