Growth Chamber Maintenance Costs and Factors Influencing Equipment Longevity, Reliability and Operating Quality

Mark Romer, Claire Cooney, Frank Scopelleti, Glenn Orr
McGill University Phytotron, Montreal, Canada

Introduction

The McGill University Phytotron was inaugurated in March 1988 and has now been operating for 20 years. The facility was designed to provide research users with a diverse collection of controlled environment equipment for experimentation under precise and repeatable environmental conditions. To sustain this objective over the long term, a core staff of specialists was hired to operate the facility and support research users. Maintenance protocols were developed to care for the equipment and service records were kept. An overview of protocols and maintenance costs for selected growth chambers is presented here.

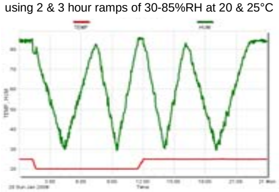
Maintenance Protocols

At the McGill University Phytotron, growth chambers undergo routine verification, calibration and service before experiments are initiated, and periodically throughout the year. All chamber maintenance is initiated with a thorough cleaning. Particular attention is paid to floors, sub-floors, drains and machine compartments where plant debris and soils accumulate. We have discovered that clogged floors and drains reduce air circulation in the growing zone, create problems with humidity and temperature control, elevate canopy leaf temperatures and increase stress on refrigeration and dehumidification systems. After cleaning, each environmental subsystem is verified, sensors are calibrated and equipment is adjusted or replaced as necessary. Lighting systems require particular attention in our facility. In early trials, we established that our VHO fluorescent tubes had a usable life of approximately 5,000 hours and also exhibited a rapid decline in output intensity over the first 1,500 hours of service. We developed a maintenance protocol which involves replacing one third of the lamp canopy every 1,500 hours. Tube operating hours are recorded at each light level by our chamber controllers. Table 1 demonstrates a typical light history record over several months. This balanced light canopy has a more gradual light decay and requires less adjustment than one which is equipped with 100% new tubes. Following maintenance, test programs are run to verify that specification benchmarks can be attained and to assess the accuracy of control during ramping modes. Figure 1 illustrates such a test program where RH% ramps of 2 and 3 hour duration are run at two temperatures. Once experiments are underway, continuous logging of environmental parameters and periodic inspections allow us to verify that systems are functioning correctly.

Table 1 – Typical growth chamber light history record demonstrating an age-balanced light canopy. One third of the canopy is replaced every 1500 hours.

Light Level	Jan 16		April 16		July 20	
	Before	After	Before	After	Before	After
Level 1	4500	0	1500	1500	3000	3000
Level 2	3000	3000	4500	0	1500	1500
Level 3	1500	1500	3000	3000	4500	0
Level 4	4500	0	1500	1500	3000	3000
Level 5	3000	3000	4500	0	1500	1500
Level 6	1500	1500	3000	3000	4500	0

Figure 1 – Humidity control system test program using 2 & 3 hour ramps of 30-85%RH at 20 & 25°C



Results

Tables 2 & 3 summarize the costs of replacement parts for 15 Conviron growth chambers originally installed in 1988. The system components for these chambers are described below:

System	Walk-In Chambers	Reach-In Chambers
Temp	Typical DX refrigeration system with water-cooled condensers, magnetic proportional valves & electric heaters	
Humidity (+)	Vaisala Humicap dry RH% sensors, atomizing spray nozzles & R/O water unit.	
Humidity (-)	Bypass-dehumidification	NA
Light	High lighting option 44 x F96" & 8 x F48" VHO Fluorescent	Standard light 16 x F72" & 4 x F24" VHO Fluorescent
CO_2	Horiba IRGA	NA
Controls	Conviron cmp3000 series controllers & associated hardware	

Table 2 - Average costs of replacement parts for 10 Conviron walk-in growth chambers recorded over 20 years of operation .

Conviron PGW36	$/chamber	$/year	% total
Lighting tubes	1,820	91	29%
Ballasts	1,080	54	17%
RH% Components	787	39	13%
Controls & Electrical	863	43	14%
Refrigeration	1,660	83	27%
	6,210	310	

Table 3 - Average costs of replacement parts for 5 Conviron reach-in growth chambers recorded over 20 years of operation **.**

Conviron E15	$/chamber	$/year	% total
Lighting tubes	624	31	23%
Ballasts	100	5	4%
RH% Components	613	31	23%
Controls & Electrical	584	29	22%
Refrigeration	781	39	29%
	2702	135	

Discussion

Replacement parts for walk-in chambers averaged $ 6,210 over 20 years or $ 310/year. Smaller reach-in chambers averaged $ 2,702 over 20 years or $ 135/year. A breakdown by subsystem reveals that lighting components represent the most significant cost in high-light, walk-in chambers (46%) and refrigeration components in the smaller reach-in chambers (29%). Labour costs are typically the largest component of any growth chamber service budget. At the McGill Phytotron, only refrigeration services were contracted out and these costs averaged $ 1,431/walk-in chamber and $ 1,616/reach-in chamber over 20 years of operation.

Temperature Control - All chambers have performed accurately and continue to exceed temperature specifications in performance trials. The thermistor sensors have been very reliable and only one outright failure has occurred in 20 years. Refrigeration system problems began occurring in the second decade of operation and were eventually linked to plugged and fouled condensers following a decade of irregular chemical treatment of the cooling tower water. In 2004, we replaced and increased the capacity of the cooling tower and pumps, installed an automated chemical treatment plant and acid-washed all growth chamber condensers. The inclusion of temperature sensors at the condenser inlet and outlet and pressure sensors on the refrigeration lines would have been valuable monitoring tools in our situation and are highly recommended for new chamber purchases. Significant parts replaced include 6 compressors, 10 thermal expansion (TX) valves, 2 receivers & 5 ventilation fan motors.

Humidity Control -The maintenance and replacement of additive humidity components (solenoids & atomizing nozzles) represented the most common service intervention in the first decade of facility operation. Leaking valves and plugged nozzles were serviced 3-6 times a year in most chambers. This problem was eventually linked to an incompatibility between the Reverse Osmosis water source and brass components installed within the system. In 2001, we gradually converted all our humidity components to PVC or 100% stainless steel. These parts cost significantly more to install but have been virtually free of service (only very occasional cleaning of nozzle internals is required). Our Vaisala Humicap dry humidity sensors have performed reliably and only 2 of 15 sensors have required replacement.

Lighting Control - As expected, standard VHO fluorescent tubes represent a significant percentage of the total cost of replacement parts (29%/23%). In an effort to improve costs and time spent on light management, we have incorporated 2 alternate lighting technologies in recent years. Phillips ALTO tubes (F96T12/241U/VHO/ALTO) are used as "drop-in" replacements for standard VHO tubes. These provide 20% more output, have a less significant decay rate and last approximately 3 times longer than standard VHO tubes (12,000 hrs). Phillips T8 tubes (F96T8/HO/TL841) have also performed well when tested at operating temperatures above 15°C. A walk-in chamber retrofit with T8 tubes and ballasts produced a lower initial output (20% less than VHO over the first 2000 hours) but has been burning over 25,000 hours with a consistent lighting intensity of over 600 µmol m-2 s-1 (measured at 50 cm). A total of 33% of original fluorescent ballasts have also been replaced primarily in walk-in chambers. In order to establish a management strategy for our aging ballasts, we compared the output of VHO tubes under ballasts of various ages (100 – 55,000 hrs) and found no significant differences in light output or ballast operating amperages. We did discover that different models of VHO ballasts produced differences in output of up to 6%. (eg. Magnatek 930 K-TC-P was 6% > Magnatek 931-LH-TC-P).

CO_2 Control - Our CO_2 analyzers required the most frequent verification and calibration of all our chamber sensors. We have gradually upgraded many of our sensors to Vaisala & PPSystems models which are more stable.

Controllers - Our study chambers are controlled using Conviron cmp3000 series microprocessors and electronic boards which were first developed in 1984. We find these components to be quite reliable and sturdy. Significant replacements included 11 chamber controllers, 6 analog input boards, 2 distribution boards, 19 switching triacs and 4 transformers. In 50% of the cases, the need for controller replacement was linked to problems with the incorporated communications board and not chamber control functions per se. (all Phytotron chambers are linked to Central Host Computers). Components for this control system are now in limited supply and we are preparing to retrofit the chambers using a more current product.

PGW36 Walk-In Chamber Machine Compartment

Conclusions

It is difficult to compare cost of replacement parts incurred at our Phytotron to costs at other facilities. We were unable to find any literature to compare values or experiences.

It would seem reasonable to conclude that routine maintenance contributed significantly to the low annual expense of chamber repairs. The refinement and implementation of quality assurance standards for controlled environment facilities would further improve equipment performance and resulting research products. Some general recommendations for CE facilities:

Facility design - Considerable attention should be put into the design of the overall structure and mechanical systems which will house the individual growth chambers and work rooms. The designation of a dedicated mechanical room for major HVAC components minimizes service disruptions and permits careful monitoring by facility staff. Ventilation systems should be scaled to ensure high fresh air intake and turnover rates, moderating localized heat and CO_2 buildup from users and chambers. Ambient facility temperature and humidity levels should be precisely controlled to optimize equipment performance and appropriate filtration should be incorporated to maintain cleanliness.

Maintenance - A core group of support staff are essential to overseeing and executing the myriad tasks involved in maintaining a facility in top working order. In our experience, the investment in support staff has greatly contributed to equipment longevity and higher productivity from research users. The facility should have clearly-defined and effective procedures for maintaining equipment and incorporate a user fee structure to fund replacement parts and necessary upgrades. A good relationship with facilities management personnel will contribute to ensuring correct maintenance of major mechanical equipment. Similarly, a strong relationship with the CE equipment manufacturer is valuable to deal with issues that arise throughout the lifetime of the equipment.

Improvement - A periodic assessment of equipment function and implementation of modifications and upgrades are key components to maintaining a highly-functional facility. We have found that additional financial resources have periodically been required to upgrade and repair larger facility components and systems.

Poster presented at the 2008 International Meeting on Controlled Environment Agriculture
"Advances in Research and Design in CEA Facilities"
Kennedy Space Center, Florida, March 8-12, 2008.
Correspondence to mark.romer@mcgill.ca
Photos by Guy l'Heureux, June 2008
McGill Biology Image Centre