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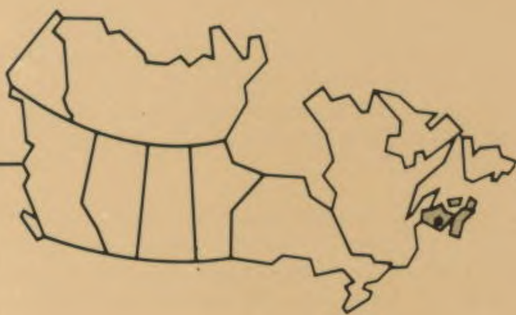
Techniques for upgrading forestry greenhouse facilities: the history of greenhouse development at the Acadia Forest Experiment Station

S.I. Cameron



Information Report M-X-173
Forestry Canada - Maritimes

Forestry Canada

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The Department is a decentralized organization with six regional forestry centres, two national research institutes, and seven regional sub-offices located across Canada. Headquarters is located in the national capital region, in Hull, Quebec.

In support of its mandate, Forestry Canada carries out the following activities:

- Administers forest development agreements negotiated with the provinces
- Undertakes and supports research, development, and technology transfer in forest management and utilization.
- Compiles, analyzes, and disseminates information about national and international forest resources and related matters.
- Monitors disease and insect pests in Canada's forests.
- Provides information, analyses, and policy advice on economics, industry, markets, and trade related to the forest sector.
- Promotes employment, education, and training opportunities in the forest sector.
- Promotes public awareness of all aspects of the forest sector.

The Department interacts regularly with provincial and territorial governments, industry, labor, universities, conservationists, and the public, through such bodies as the Canadian Council of Forest Ministers, the Forest Sector Advisory Council, the Forestry Research Advisory Council of Canada, the Canadian Forest Inventory Committee, the Canadian Committee on Forest Fire Management, the Canadian Interagency Forest Fire Centre, and regional consultative committees. The Department is also active in international forestry agencies such as the International Union of Forest Research Organizations and the Food and Agriculture Organization, as well as in technical and trade missions.

Forêts Canada

Forêts Canada est l'organisme principal en matière de foresterie à l'intérieur du gouvernement fédéral. Chef de file sur le plan national, il assure la préparation, la coordination et la mise en oeuvre des politiques et programmes fédéraux dans le but d'améliorer les avantages économiques, sociaux et environnementaux à long terme offerts aux Canadiens par le secteur forestier.

Le ministère est une organisation décentralisée: six centres de foresterie régionaux, deux instituts de recherche nationaux ainsi qui sept sous-bureaux régionaux sont répartis dans tout le Canada. Le siège social est établi dans la région de la Capitale nationale, à Hull (Québec).

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- il administre les accords de développement forestier conclus avec les provinces
- il entreprend et appuie la recherche, la mise au point et le transfert technologique dans le domaine de la gestion et de l'utilisation des forêts
- il rassemble, analyse et diffuse de l'information sur les ressources forestières nationales et internationales et les domaines connexes
- il fait des relevés des maladies et des insectes ravageurs des forêts canadiennes
- il fournit de l'information, des analyses et des conseils (quant aux politiques) concernant l'économie, l'industrie, les marchés et le commerce reliés au secteur forestier
- il favorise les occasions d'emploi et de formation universitaire et technique dans le secteur forestier
- il encourage les Canadiens à prendre conscience de tous les aspects du secteur forestier.

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TECHNIQUES FOR UPGRADING FORESTRY GREENHOUSE FACILITIES: THE HISTORY OF GREENHOUSE DEVELOPMENT AT THE ACADIA FOREST EXPERIMENT STATION

by

S.I. Cameron

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ABSTRACT

This is an account of modifications made in 1984 to the greenhouse facilities at the Acadia Forest Experiment Station (AFES). The older facility was inadequate for research in state-of-the-art cultural practices. Although many new techniques and products have come on the market, the principles used in this retrofit of climate control computers and energy conservation are still applicable, only there is more to choose from in the market today.

The modifications were carried out in eight areas. A dedicated greenhouse computer system was installed primarily to control greenhouse environment and for data logging. Zone interface cabinets were constructed to connect all electrical devices to one central switch panel to simplify troubleshooting and use by staff. The heating system was upgraded to replace worn out boilers, provide backup, be suitable for minimum and maximum heating loads, and be efficient. Insulation of side- and endwalls and subsoil perimeter was done with methods and materials adaptable to operational greenhouses. Because 90% of greenhouse heat is lost through coverings, thermal curtains were installed which would reduce winter operating costs. Four new greenhouses were constructed in as similar a manner as possible to allow replication of experiments with greenhouse environment or cultural practices. All greenhouse zones have VHO florescent units mounted on the irrigation boom to provide photoperiodic lighting, and most zones also have HID lights. The four research zones were equipped with infrared gas analysers to monitor and control CO_2 levels.

RESUME

Dans ce qui suit, on explique les modifications apportées en 1984 aux serres de la station d'expérimentation forestière Acadia (SEFA). Les anciennes installations ne convenaient plus pour la recherche sur les nouvelles méthodes de culture. Bien que les nouvelles techniques et les nouveaux produits soient nombreux, les principes mis en jeu dans les installations modernisées de contrôle climatique informatisé et de conservation de l'énergie s'appliquent toujours, sauf que le marché offre plus de choix de nos jours.

On a fait huit types de modifications. On a installé un ordinateur qui sert principalement à contrôler les conditions du milieu dans les serres et à enregistrer des données. On a construit des armoires pour raccorder toutes les installations électriques à un tableau central afin de simplifier les réparations et l'utilisation. On a modernisé les installations de chauffage et remplacé les chaudières vétustes pour que le système soit économique, qu'il fournisse un chauffage d'appoint et s'adapte aux demandes maximale et minimale. On a réalisé l'isolation des murs et du périmètre du sous-sol en ayant recours à des méthodes et à des matériaux qui conviennent aux opérations menées dans des serres. Etant donné que 90 % de la chaleur des serres se perd par les couvertures, on a installé des écrans thermiques afin de réduire les frais d'exploitation en hiver. On a construit quatre nouvelles serres aussi semblables que possible de façon à pouvoir reproduire les expériences sur les conditions du milieu ou sur les procédés de culture. Des lampes fluorescentes à décharge de très haute

Following modernization of the Acadia complex, the decision was made to construct new greenhouse facilities at Forestry Canada - Maritimes' new centre in the Hugh John Flemming Forestry Complex in Fredericton. While the renovations done at Acadia in 1984 had many flaws, the purpose was achieved for both research use and development of knowledge of state-of-the-art technologies. The computer knowledge and energy conservation techniques developed at Acadia have been used effectively by other agencies constructing or modifying facilities in the Maritimes.

intensité montées sur le dispositif d'irrigation de chacune des zones permettent de créer un éclairage photopériodique; il y a aussi des lampes à décharge de haute intensité dans presque toutes les zones. Dans les quatre zones de recherche, on a installé un analyseur de gaz à l'infrarouge qui surveille et ajuste la concentration de CO_2.

Après la modernisation du complexe Acadia, il a été décidé de construire de nouvelles serres au nouveau centre de Forêts Canada dans les Maritimes, au complexe de foresterie Hugh John Flemming à Fredericton. Bien que les rénovations réalisées à la station Acadia en 1984 aient présenté de nombreux défauts, on a néanmoins atteint l'objectif fixé quant à la recherche et au développement des connaissances sur les nouvelles techniques. Les connaissances acquises à la station Acadia dans le domaine de l'informatique et de la conservation de l'énergie ont servi à d'autres organismes dans la construction et la modernisation d'installations dans les Maritimes.

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INTRODUCTION

This account of the greenhouse modifications at the Acadia Forest Experiment Station (AFES) is an example of how existing facilities can be upgraded to increase greenhouse performance and versatility. Computer control of greenhouses is a rapidly developing technology and this report deals with the state-of-the-art as of 1987. The reader can expect future changes and refinements in technology but the principles of energy conservation and the extent of automatic controls required should be pertinent to today's expectations. The AFES facilities, built in the late 1960s, had in recent years lagged far behind state-of-the-art facilities of other research and commercial nurseries and were inadequate for modern cultural practices. To provide sufficient replication for scientific evaluation of ongoing research, growing zones were upgraded and increased from four to eight. Some of the features of the renovated complex are described below.

DESIGN GOALS

The complex was designed to meet the following objectives:

1. Expand the facility to meet space requirements over the next five years. This expansion reflects an increasing interest in container seedling production in the Maritimes and the rapid expansion within the industry.

2. Be flexible enough to accommodate both research into greenhouse seedling growth and routine production of quality seedlings, with the goal of minimizing conflicts between the two user groups for a limited amount of growing space.

3. Make the greenhouses into a demonstration centre, showing new technologies for culturing tree seedlings. Past experience shows that industry will more readily implement technology that is already in place and has been tested operationally.

4. Be a research facility capable of duplicating current greenhouse production practices on a small scale, but with enough flexibility and advanced control functions to incorporate both applied and fundamental studies. Forest nurseries are years behind the state-of-the-art production techniques practised by other segments (flower and vegetable growers) of the greenhouse industry.

5. Reduce future operation and maintenance costs, primarily by instituting energy conservation measures, but also through modernization of the obsolete and worn-out equipment of a 15-year-old facility.

6. Purchase modern equipment to make the day-to-day operations of the nursery run more smoothly and efficiently. This is essential to manage an expanded, complex (high-tech) facility with a large clientele and few employees.

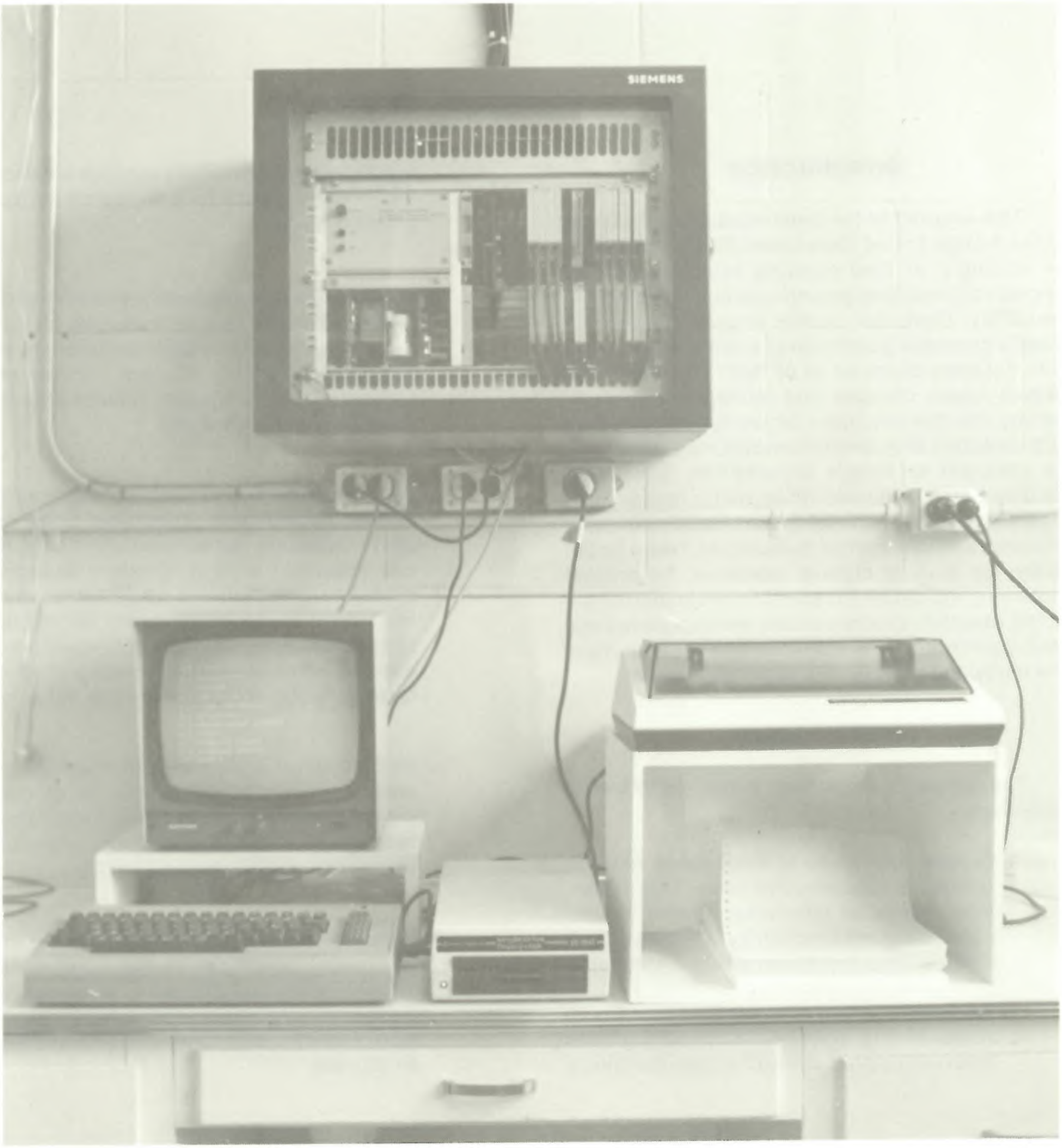


Figure 1. Dedicated greenhouse climate control computer.

COMPUTER SYSTEM

A dedicated greenhouse computer system was purchased from funds received from the Department of Energy, Mines, and Resources to upgrade energy conservation. The computer system performs several important functions:

1. In each of the eight greenhouse zones, it measures and controls temperature (heating and multistage coolings), humidity, photoperiod (using thermal curtains and night-break lighting), high intensity growth lighting, and carbon dioxide levels. The computer can perform other functions, not currently implemented, such as irrigation, fertilization, and monitoring of soil temperature.

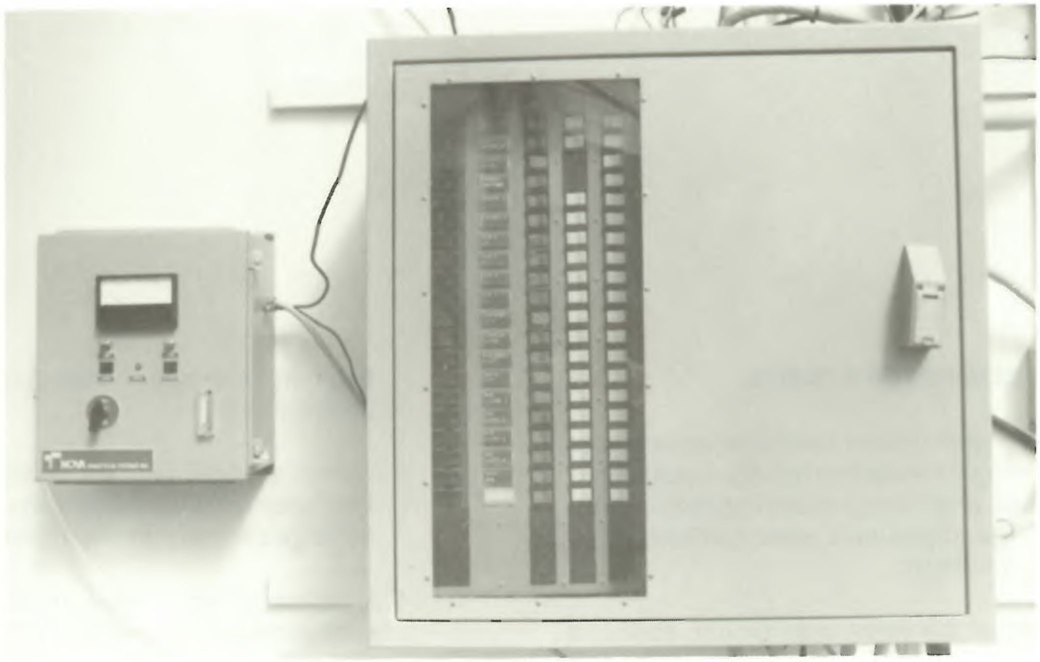
2. A weather station is connected to the computer to measure outside temperature, light intensity and total radiant energy, windspeed and direction, humidity, and precipitation (rain or snow).

3. Heating plant measurement/control is also possible, though not yet implemented, with modulation of boiler firing and aquastat setpoint temperature based on the outdoor temperature.

4. Alarm signals can be routed to station residences and recorded if any of the control settings exceed specified limits.

5. Weather station, greenhouse, and heating data averaged at specified intervals (hourly, daily, etc.) are logged and stored on diskette. Sufficient memory is present for long-term (monthly) storage.

For research, the flexibility and power of the software are important. However, equal attention was given to the ease with which the computer can be programmed, and "user-friendly" software is mandatory for greenhouse staff untrained in computer programming. The software in the AFES computer requires that only single letters, punctuation marks, and numbers be input - no command strings or complex programs are needed. The software, which consists of a series of menus, appears to have been well tested, having been operated, revised, and updated over the past 10 years in European commercial greenhouses.



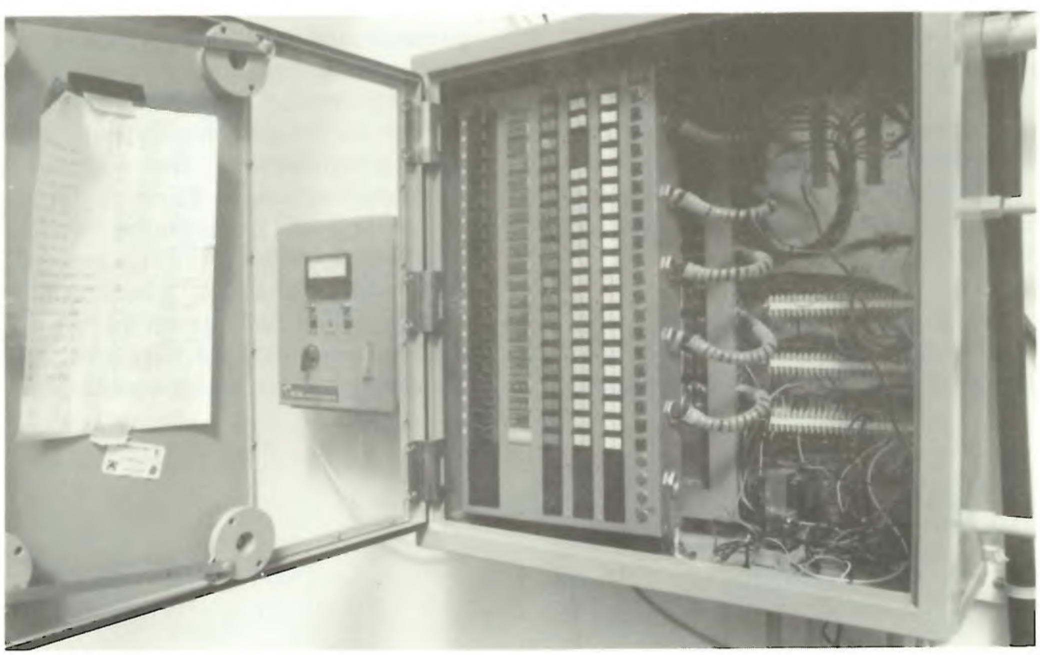


Figure 2. Zone interface cabinets for each greenhouse with a) door closed and CO_2 analyser/controller also visible to the left, and b) door open.

ZONE INTERFACE CABINETS

The many additions and alterations to the greenhouse/headerhouse electrical system during the past 15 years produced a chaotic wiring system. Therefore, one objective was to upgrade the electrical service within each greenhouse by rewiring, where necessary, and connecting all electrical devices to one central switch panel, preferably within the greenhouse, to simplify troubleshooting and modification. A central panel was considered especially important for diagnosing problems when the greenhouse is controlled from a remote source (the central computer).

A suitable switch panel was not commercially available; therefore, we designed and built interface cabinets for the eight zones based on the following requirements:

1. All electrical connections from the various devices in the greenhouse to power, local control (e.g., thermostats, timeclocks, etc.) and computer must be made within the cabinet.

2. The cabinet should be a diagnostic tool for troubleshooting, capable of isolating the source of a malfunction as either the device, a local controller, or the computer, yet simple enough for staff with neither computer nor electrical training to use.

3. Staff must be able to switch every device in the greenhouse from mode to mode (manual, local, or computer) to allow backup control over all greenhouse functions, especially in the event of computer malfunction.

4. The cabinet must be suitably constructed for installation within the greenhouse, an area of high humidity and wide temperature fluctuations, permitting staff to visually check device functioning while switching from mode to mode.

5. Lights within the cabinet should indicate: (a) if there is power to the device; (b) which mode of control (manual, local, or computer) is in use; and (c) whether or not the device is currently energized.

6. The cabinet circuits and format must be standardized throughout all eight zones, even though the devices differ in many of the zones, to facilitate rewiring and modification. Extra circuits must be built-in to allow future expansion as required.

Each cabinet is a small (1 x 1 m), moisture-resistant enclosure with a clear acrylic window to permit viewing of a switch panel within. The panel consists of a small enclosure with four vertical columns of switches (illuminated when 'on') and one column of indicator lamps. Each device in a zone has a dedicated horizontal row (four switches plus an indicator lamp) for power, the three modes of operations (manual, local, or computer control) and a device-active indicator. Spare switches and blank slots for adding further switches are available for future expansion. All interconnections are made within the panel box containing the switches, which swings forward for access to the backplate of the large cabinet, where the busses, wireways, and relays are located. Modular wiring busses have been used to make wiring or rewiring easy, and all connections to both the computer and the devices are made on these busses in predetermined standard locations. For computer control, each device has a solid-state power relay (to avoid possible failure due to humidity), one side of which is connected to an incoming low voltage signal from the computer.

The zone interface cabinets appear to be useful in all eight zones despite the differing patterns of greenhouse use. Design flaws have been found in specific components such as switches, indicator lamps, etc. These will be altered if a subsequent version of the prototype cabinet is built.

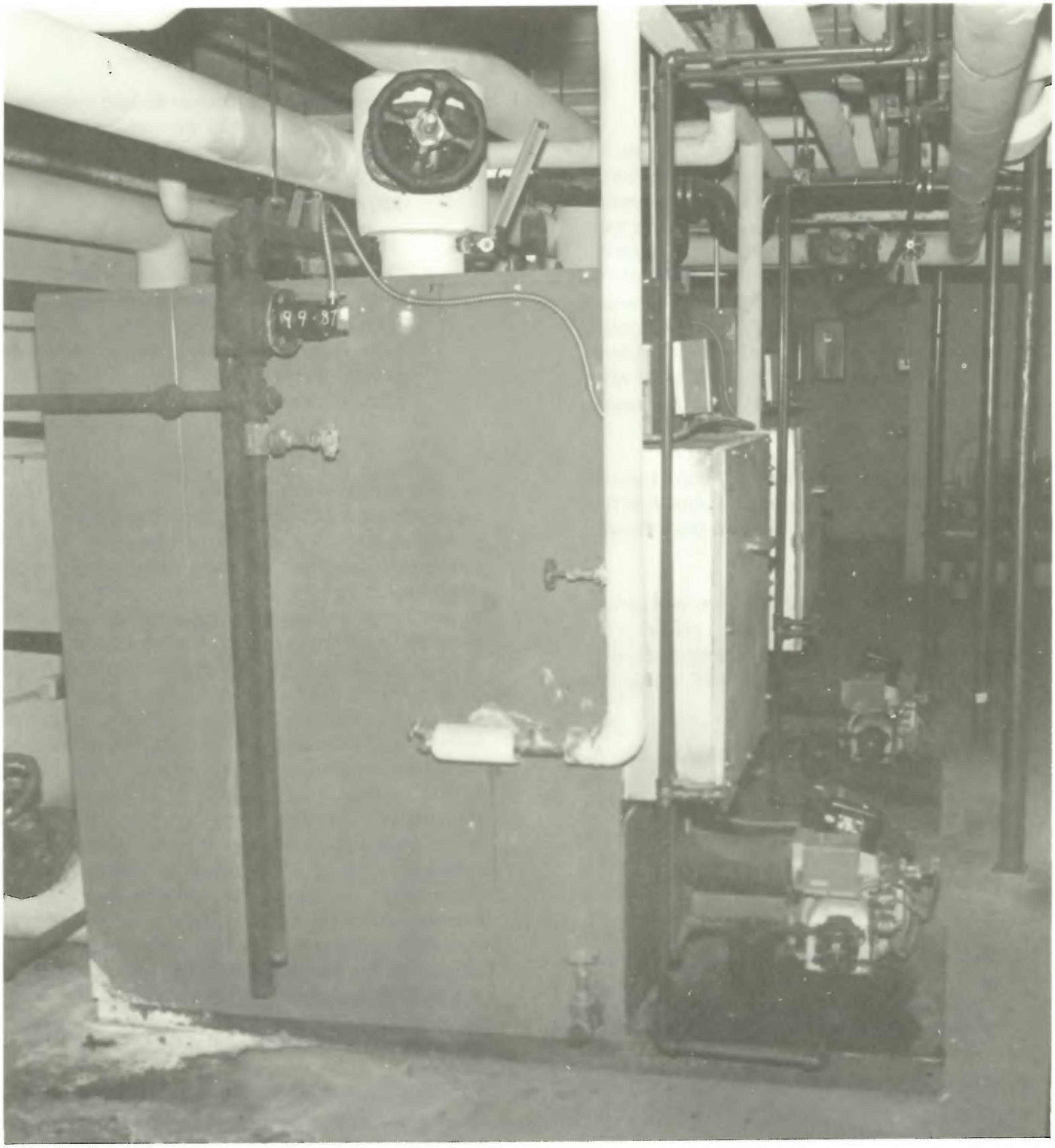


Figure 3. Boiler system.

HEATING SYSTEM

The heating plant was improved by adding two new 30 HP hot water boilers to replace one of two obsolete 20 HP units. (The other boiler is retained as a backup unit and to provide minimal heating during the warm seasons.)

To conserve energy at the heating plant two systems are used. An aquastat temperature setpoint controller was installed to modulate hot water temperature according to outdoor temperature. An automatic boiler firing controller, which can fire one, two, or three of the boilers, depending on outdoor temperature, was also added. These two systems are intended to minimize standby heat losses at the boilers by providing hot water at the minimum temperature necessary to meet greenhouse heating demands, yet using the minimum number of boilers to do so. One unit firing nearly 100% of the time is more energy efficient than two units with a 50% duty cycle.

Heat loss through long runs of bare pipe is significant in a greenhouse, making environmental control difficult in warm weather and increasing fuel consumption in cold weather. Therefore, the hot water piping was insulated and buried to accommodate thermal curtains and in anticipation of using the greenhouses for future experiments in energy conservation. (In such experiments, standby heat losses even from insulated pipes would complicate the calculation of energy consumption within the greenhouses.) The buried system is, to our knowledge, unique in that:

1. the pipe insulation is sufficiently moisture-resistant for greenhouse use and can be installed easily by a nurseryman on site;
2. the insulated pipe can be buried in PVC sewer pipe which protects the heating pipe from corrosion and the insulation from mechanical damage;
3. drain tile was installed beneath the pipe to lower the soil moisture, because dry soil is a better insulator than wet soil; and
4. the buried pipe system is protected from frost damage, so the heating system can be shut down without being drained.

Figure 4. Stages in the installation of sidewall insulation.

INSULATION

Sidewall, endwall, and subsoil perimeter insulation was added to all greenhouses. Each location required different materials and application methods because of the high moisture/humidity environment. Materials and techniques that would be adaptable to operational greenhouses were used.

The insulation in the studded greenhouse endwalls was similar to that used in standard house construction. A vapor barrier was installed on the warm side of the insulation, using an inexpensive grade of polystyrene insulation (EPS type 1, or "beadboard"). EPS type 1 was chosen because of its low cost and because it can be easily cut with hand tools to fit into irregularly-shaped endwall cavities. It has a high R-value (R 3.5/in), producing a composite endwall R-value of about R 10. However, although it is not structurally degraded by moisture, it can absorb a significant amount of water in the absence of a vapour barrier and this lessens its R-value. Therefore, interior sheathing was added to protect the insulation; this was painted white to reflect light onto the crop surface.

Effectively sealing the edges of the sidewall insulation around the reinforced trusses was difficult. To solve this problem, a method of insulating between the trusses was devised using two forms of EPS insulation with a vapor barrier along the edges. The layer of insulation exposed to high humidity is extruded EPS (EPS type 4, or "SM" insulation) which is moisture impermeable. By using a thin layer of the EPS type 4 material, the moisture-sensitive EPS type 1 insulation is effectively protected from the high humidity. The surface of the insulation facing the greenhouse interior could remain exposed in a production facility if it is painted to prevent deterioration from exposure to sunlight. At AFES, white-painted plywood sheathing was added to prevent mechanical damage along the walkways adjacent to the sidewalls.

Subsoil perimeter insulation was applied to all double poly-covered zones. (Addition to the glasshouse was not considered feasible without installing a more energy conservative glazing.) Insulation was installed according to recommendations for residential buildings. Two-inch-thick extruded EPS was placed vertically on the exterior of the footing course extending two feet below ground. Calculations indicate that this thickness and depth are near the optimum for greenhouse use. Galvanized flashing was placed over the top edge to prevent mechanical damage and deterioration from exposure to sunlight. Cement walkways, butted against the sidewall interior, and subsurface drain tile were intended to increase the effectiveness of the insulation by keeping the soil next to the side- and endwalls relatively dry. In addition to energy conservation, perimeter insulation increases soil temperatures adjacent to the periphery, which improves the quality of stock grown in flats or potted stock grown directly on the greenhouse floor.

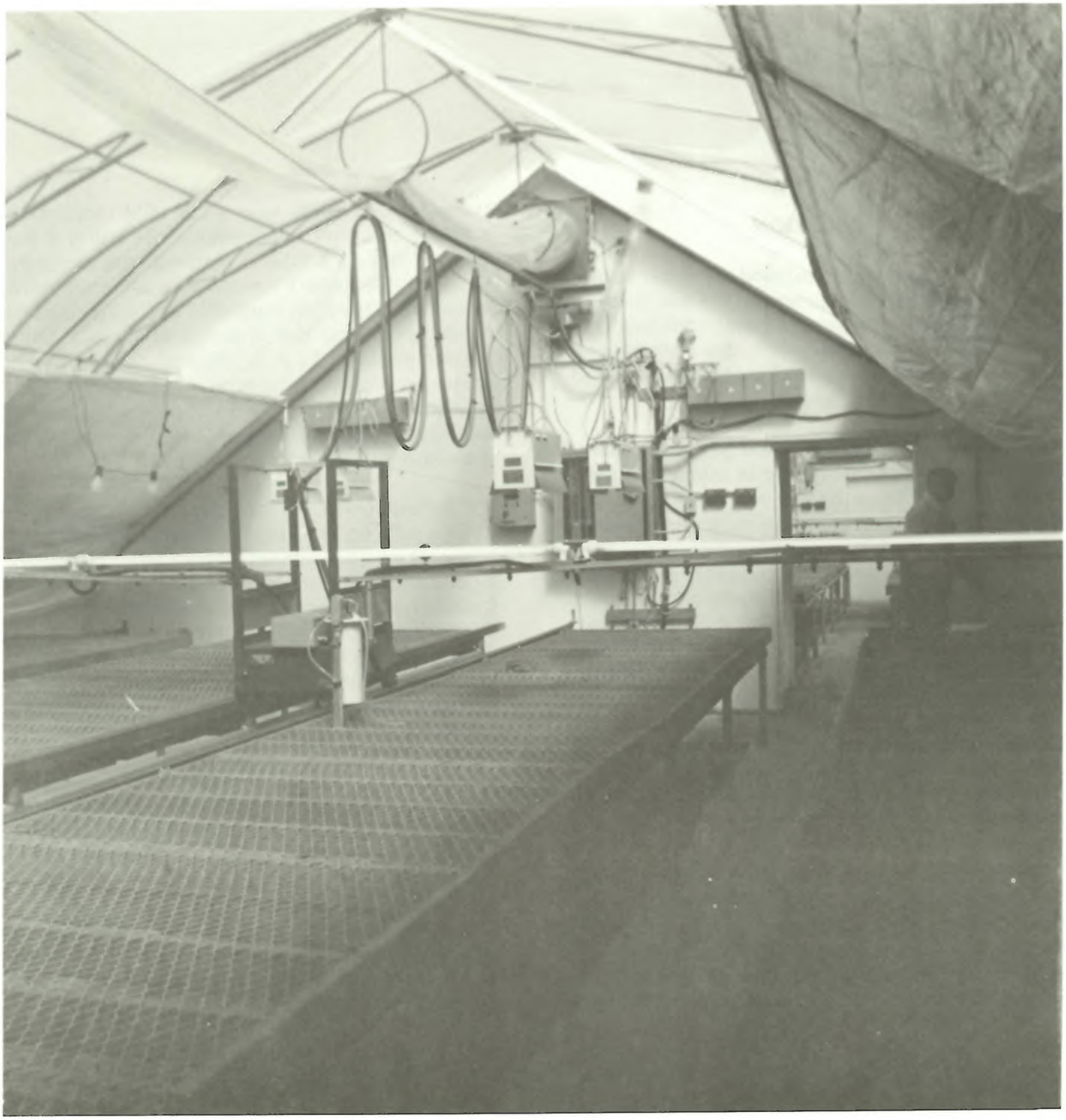


Figure 5. Thermal curtain system partially closed. Also visible are two types of lighting: fluorescent fixtures mounted on the irrigation cart for photoperiodic lighting, and HID lighting fixtures hanging from the structure for growth lighting.

THERMAL CURTAINS

Fuel oil consumption prior to upgrading averaged about 15,000 gal/yr for greenhouse heating. In excess of 90% of the greenhouse heat was lost through the single glass and double poly covers. Therefore, thermal curtains were necessary to reduce winter operating costs. A single-layer thermal curtain (R 1.5-2) was originally specified, but advances in technology in the interval between specification and purchase led to the acquisition of a more highly insulating (R 5-6), multiple-layer curtain, which, though more costly, would save three times the fuel. Calculations indicate that the net effect of curtain installation is that, although the growing area has been expanded by 45%, fuel consumption should stay the same or decrease slightly.

The curtain is composed of three layers of aluminized porous fabric. When the curtain is extended, air spaces form between the layers because the layers of cloth are sewn together to allow each layer to sag appreciably more than the one above it. This gives the curtain several advantages:

1. It is lightweight, permitting the use of a correspondingly light deployment system.
2. The porosity allows moisture to migrate through the layers, minimizing excessive humidity at crop level without sacrificing insulating value due to convective air movement - a problem in some single-layer systems.
3. The aluminized surface reflects a high percentage of infrared radiation onto the crop.
4. When stored, the curtain uses no more space than a single-layer material; earlier high R-value designs were excessively bulky.

The thermal curtain can also be used for other purposes. During the summer, partial deployment has been used to shade crops and reduce the heat load, which is excessive in summer-operated double-poly greenhouses. Because the material is opaque, it can also be used to shorten the photoperiod. The greenhouse computer is capable of controlling curtain deployment for shading and photoperiod control, as well as energy conservation.

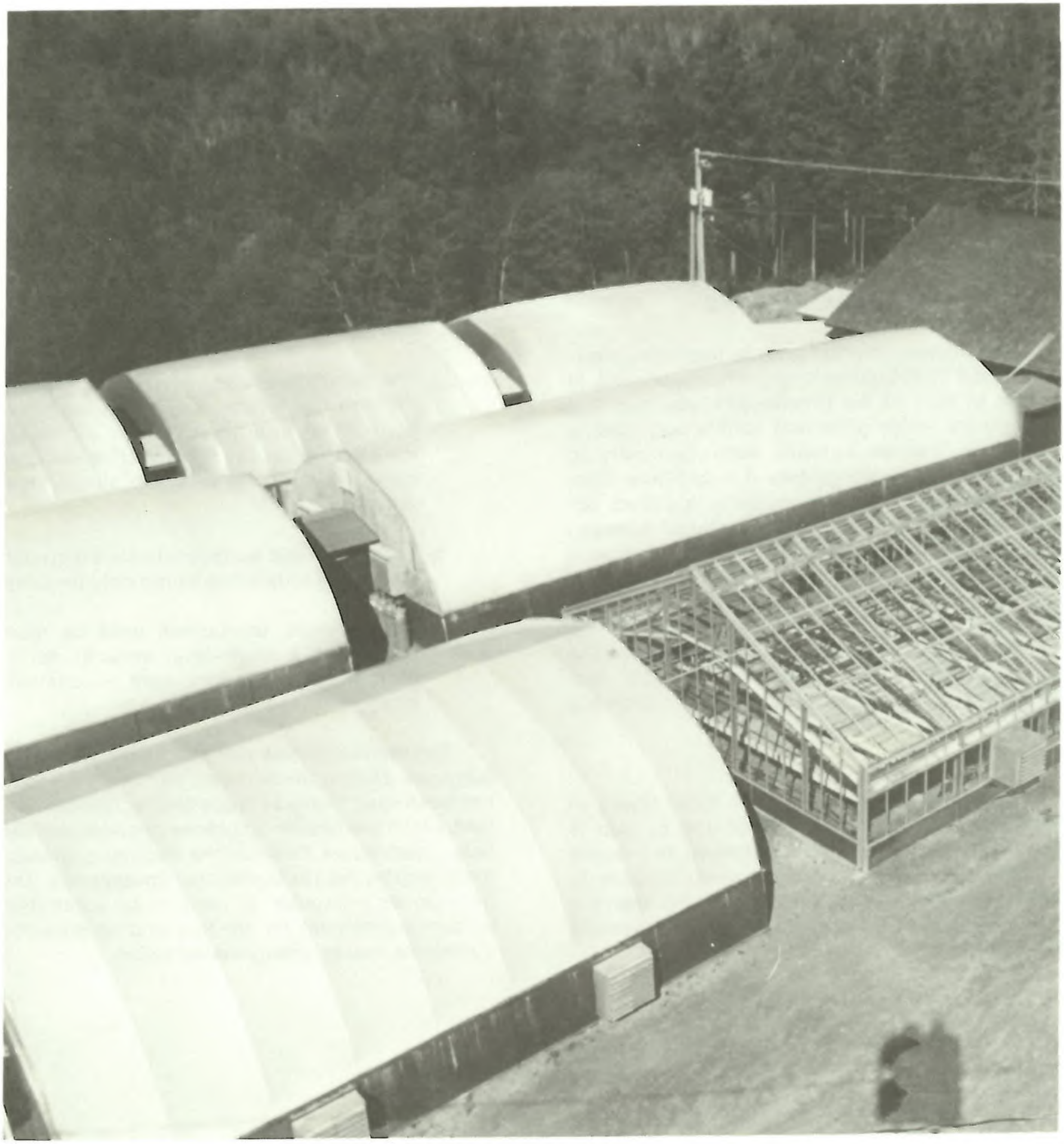


Figure 6. View of new poly-greenhouses: three on the left, with a fourth to the front of the original glasshouse.

NEW GREENHOUSES

To meet the increased needs for research and production, 430 m^2 of additional area was constructed adjacent to the existing greenhouses. Four 9 x 10 m sections were smaller versions of the double poly production greenhouses used throughout the Maritimes Region. Considerable effort was made to situate, construct, and equip the four sections as similarily as possible. The new sections are intended to allow simultaneous replication of experiments performed on greenhouse environmental/cultural parameters, such as differing CO_2 concentrations, temperature regimes, or humidity levels. These experiments are difficult to set up within the same greenhouse. The refinements in the heating system facilitate the study of energy conservation/seedling culture interaction, useful in assessing cost-benefit ratio between energy savings and growth loss through deploying the thermal curtains at differing daylight levels. The use of small greenhouses, such as growth cabinets, should be emphasized. Year-to-year and season-to-season climatic variation is a significant confounding factor in the comparison of research replicated sequentially to provide a range of experimental treatments. Experimental greenhouses enable staff to perform simultaneous experiments in which variation in weather conditions can either be (a) considered constant to all treatments (analogous to growth chamber studies) or (b) considered as an experimental variable whose interaction with different cultural treatments can be quantified through records supplied by the computer weather station.

Within each of the four zones, further compartmentalization for experimental or production growing is possible. Various irrigation/fertilization treatments can be investigated in different zones of the greenhouse using a motorized boom irrigation system like that used in production nurseries. Computer-assisted automation of the procedure is possible, although it is not yet implemented. Each zone is divided into lighting quadrants, two of which have HID lighting. The remaining two are control sections supplied with photoperiodic lighting only. Roller benching has been used in the experimental greenhouses to minimize the possibility of having to restrict replicate size and (or) number in highly nested experiments. This has increased bench space by about 25%.

Lighting

All zones have supplementary illumination and, except for the large, production-oriented zones, most have both photoperiodic and growth lighting. The HID lights have been standardized to one type of 400W fixture (Philips) chosen for its size, which allows placement close to the crop and below the thermal curtains without creating excessive local shading. Two types of HID lamps were purchased: high pressure sodium (HPS) and multivapor (SON/T).

The mounting system for both types of lamps consists of 3 mm diameter stainless steel cable attached to both endwalls and tensioned using turnbuckles. To minimize the weight on the cables, the ballasts have been removed from all lamps and are mounted on the greenhouse endwalls. The remaining part of the lamps is suspended from the cables by chains, which allows adjustment of the light levels by changing the mounting height.

The photoperiodic lighting system in all greenhouses is a mobile VHO fluorescent unit mounted on an irrigation cart, designed at Forestry Canada. Field testing at AFES and elsewhere has shown that this type of lighting fulfills photoperiodic requirements at an estimated one-tenth of the running cost of permanently mounted overhead incandescent lamps.

Supplemental carbon dioxide

Only the four small research zones are equipped for elevated CO_2 level control. Each of the zones has a small, moderately accurate infrared gas analyser to monitor and control CO_2 from ambient levels (250-350 ppm) to 3000 ppm. Both data logging and gas injection can be put under computer control.

Carbon dioxide gas is currently supplied from mini-bulk tanks, rather than by combustion, to allow higher concentrations of CO_2 to be maintained. (Because of small quantities of sulphur-containing compounds in propane, SO_2 is also generated during combustion and can reach phytotoxic levels if burning periods are lengthened to attain high CO_2 concentrations.) A simple, low-cost distribution system using small micrometer valves, solenoids, and soft copper pipe provides gas to the greenhouses. The system has been in use for only one season and it has been noted that gas consumption is higher than was initially predicted using standard calculation methods. The high consumption is thought to result from the large number of unsealed openings (fan louvres, side vents, etc.) in a relatively small area. Consideration has been given, therefore, to installing propane burners when further CO_2 experiments are performed.

SUMMARY

The overall objective in modernizing the AFES complex was to produce a highly integrated state-of-the-art facility. Considerable care was taken in specifying various components of the design and some of the elements are unique. The upgrading and expansion are successful largely because, in designing specific elements, close attention was given to their impact on other design goals, as opposed to the *ad hoc* modifications carried out in previous years.

The Acadia greenhouse complex is to be relocated to Fredericton, N.B., adjacent to the Hugh John Flemming Forestry Complex. The advantage of this relocation is that the many person-days spent travelling each year will be eliminated; also, by placing the new greenhouses in a central location, their value as demonstration units will be enhanced. Additionally and perhaps most importantly, the first renovations had many flaws. Many of the shortcomings apparent after these original modifications will be eliminated in the new facilities. Furthermore, innovations and changes in nursery practice which have come into being since the first renovation will be incorporated. The modern technology used throughout the structures will reflect the way that production greenhouses function in the Maritimes Region and will make the complex a powerful research tool - one of the few in forestry in Canada - as well as an excellent small production facility.